

Machining Parameter Optimization in Electrical Discharge Machining by Using Grey Relational Analysis and ANOVA

Mary George¹, Amjith.T.R²P.G. Student, Department of Mechanical Engineering, Sree Buddha College Engineering, Pattoor, Kerala, India¹Assistant Professor, Department of Mechanical Engineering, Sree Buddha College Engineering, Pattoor, Kerala, India²

ABSTRACT: Optimization of machining parameters in the Electric Discharge Machining (EDM) process on Stainless Steel 304 using Grey Relational Analysis and ANOVA has been proposed to evaluate and estimate the effect of machining parameters on the response. The experiments are carried out using three electrodes they are Cu, WCu, and Graphite. The major response selected for this analysis is Surface Roughness. The corresponding machining parameters considered for this study are current, voltage and spark gap. The design of experiments is carried out using L9 orthogonal array, which is being done with the help of Minitab. The results were analyzed using Grey Relational Analysis and ANOVA. In which Grey Relational Grade (GRG) calculated based on GRA, to optimize the EDM process. ANOVA is also performed to identify the Statistical significance of parameters. These results provide useful information on how to control the machining parameters and corresponding Surface finish to obtain high productivity and better accuracy of the EDM process.

KEYWORDS: EDM, Surfaceroughness, Grey relational analysis, ANOVA, Optimization

I. INTRODUCTION

In which machining parameter such as surface roughness has been incorporated to enhance the effectiveness of the machining parameter of SS304 material in Electrical Discharge Machining using Cu, WCu and Graphite. Electrical Discharge Machining is generally an electrical energy based processes, electrical energy is used to cut the material to get the final shape and size. It is also known as spark erosion machining or electro-erosion machining. EDM has found ready application in the machining of hard metals or alloys which cannot be machined by conventional methods. Alloys used in aeronautics industry. This process capable of machining complicated Component. Effective movement through EDM makes it more commonly offered and also beneficial above outdated machining procedures. In this process the metal is removed by intense heat of electric spark. The spark discharges (flow of a stream of electrons) are created by maintaining sufficient potential difference between tool and work piece, separated by a dielectric in a very small gap. A large number of electrons emitted from tool (cathode) impinges on work material (anode) and thus develop a very high temperature (20000°C). This temperature is sufficient to melt and even vaporize a part of a metal. Then the metal removal from the work piece takes place.

In this work, an experimental study is carried out for the simultaneous optimization of surface roughness and to study the effects of machining parameters. The study is carried out while machining SS304 material in Electrical Discharge machining (EDM) using three electrode materials (Cu, WCu and Graphite). The effect of machining parameters such as Voltage, Current and Spark gap on the surface Roughness of machined work piece were inspected and optimized using the technique called Grey Relational analysis (GRA). The predictions of regression model for the surface roughness were developed. ANOVA is used to check the satisfactoriness of the regression models and to find out the contribution percentage of each parameter on surface roughness. Improvement in machining parameters is obtained by conducting a confirmation experiment on optimized parameter combination.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

II. WORK PIECE AND ELECTRODE MATERIAL

Among the difficult-to-cut materials, stainless steel (SS 304) is the material extensively used in manufacturing because of its excellent wear and corrosion resistance. It has high strength, high ductility, and high work hardening tendency of stainless steels which make its machinability difficult. In addition, during the investigation on the machinability of SS 304 in conventional machining it has been observed that problems such as poor surface finish and high tool wear are common. So it bonds very strongly to the cutting tool during cutting and when the chip is broken it may bring a fragment of the tool with it, particularly when cutting with cemented carbide tools [7]. Table 1 shows the composition of SS304 and Table 2 shows the properties of SS304.

Carbon (C)	Manganese (Mn)	Phosphorus	Sulfur (S)	Silicon (Si)	Chromium (Cr)	Nickel (Ni)	Nitrogen (N)	Iron (Fe)
0.08%	2.00%	0.045%	0.030%	0.75%	18-20%	8-12%	0.10%	66.345-74 %

Table 1 Composition of SS304

Properties	SS304
Density (g/cm ³)	8.03
Melting point (°c)	1400 – 1455
Electrical resistivity (μΩcm)	72
Hardness	HB 123

Table2 Properties of SS304

EDM electrode materials and components consist of highly conductive and arc erosion-resistant materials such as Copper, Tungsten-Copper and Graphite. EDM is the process that uses an electrical spark to erode metal. When it is impinged by positive ions tool material should be such that it would not undergo much tool wear. EDM electrodes are manufactured in variety of forms such as tube shaped, or bar stock, depending on the EDM electrode materials used and the application. Table 3 shows comparison of electrode materials properties.

Properties	Graphite	Copper	Copper Tungsten
Composition	100%	99.9%	75% Tungsten, 25% copper
Density (g/cm ³)	1.811	8.96	15.2
Melting point (°c)	3675	1084	3410
Electrical resistivity (μΩcm)	14	9	5.5
Hardness	HB 10	HB 100	HB200

Table 3 comparison of electrode materials properties

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

III. EXPERIMENTAL METHOD AND ANALYSIS

By using Taguchi plan of experiment and by using the procedures explained in the previous chapters, Total 27 number of experiments by using 3 electrodes was conducted on SS304 material in Electrical Discharge Machining. Table 4 shows the machining conditions and fig 1 shows CNC EDM machine used for the experiment.

Machine	CNC EDM (MAKINO EDGE2) X 300, Y 250, Z 250 mm Table Size 500x300
Tool	1. Cu (ø12 mm) 2. WCu (ø12 mm) 3. Graphite (ø12 mm)
Workpiece	SS304 (100 x 70 x 10mm)
Dielectric Fluid	Castrol SE 180

Table 4 Machining Conditions



Fig 1 CNC EDM

In which voltage, Current and Spark gap is selected as input parameters and its levels considered shown in the table 5

Process Parameter	Unit	Level1	Level 2	Level3
Voltage	V	40.00	57.5	75.00
Current	A	2.85	5.71	8.57
Spark gap	mm	0.1	0.15	0.2

Table 5 EDM process parameters

In which L9 Orthogonal Array design is used to set the control parameters to evaluate the process performance. The design used in this work and the corresponding results of surface roughness are obtained.

IV. OPTIMIZATION STRATEGY AND RESULTS

In this project optimization of machining parameters are done by using two statistical tools. Grey relational analysis and Analysis of variance.

Grey relational analysis (GRA)

The grey relational analysis (GRA) associated with the Taguchi method represents a rather new approach to optimization developed by Deng in 1989. The Grey theory is based on the random uncertainty of small samples which provide an evaluation technique to solve certain problems of system that are complex and incomplete information. The Grey relational analysis (GRA) is an effective soft-tool to analyze performance characteristics.

Normalization of experimental results in GRA

To avoid the effect of adopting different units and minimize the variability then the response data obtained is pre-processed. It is the process of transferring the original sequence to a comparable sequence. So the experimental results are first normalized in the range between zero and one. Surface roughness values should be minimized to 0. Smaller the better equation for normalizing the Ra value.

$$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)}$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

Where, $x_i^*(k)$ is the generating value of Grey relational analysis; $\min x_i^o(k)$ is the minimum value of $x_i^o(k)$; $\max x_i^o(k)$ is the maximum value of $x_i^o(k)$.

Grey Relational Coefficient (GRC)

For the data pre-processing then a grey relational coefficient (GRC or φ) is calculated to show the relationship between the ideal and actual experimental results which are normalized. The grey relational coefficient can be expressed as follows

$$\varphi_i(k) = \frac{\Delta_{min} + \delta\Delta_{max}}{\Delta_{oi}(k) + \delta\Delta_{max}}$$

Where, δ is the weightage coefficient or is distinguishing or identification coefficient ($\delta \in [0, 1]$) and is taken as 0.5

Grey Relational Grade

After obtaining the grey relational coefficient, the grey relational grade is calculated by taking the average of grey relational coefficients. The grey relational grade is defined as follows.

$$\gamma_i = \frac{1}{n} \sum_{k=1}^n \varphi_i(k)$$

where, γ_i = Grey Relational Grade, n = Number of response factors

The calculation of first grey relational grade is given below as an example. All other grades are calculated similarly. Table 6(a), 6(b), 6(c) shows the design matrix and the corresponding experimental values and the result obtained from the GRA for the Grey Relational Grade are shown.

Exp No:	Parameter Combinations			Surface Roughness Ra (μm)	Normalized Values	GRG	
	Voltage (V)	Current (A)	Spark gap (mm)			Surface roughness	Grey Grade
1	40.00	2.85	0.1	1.38	0.7891	0.7033	3
2	40.00	5.71	0.15	1.56	0.7236	0.6439	5
3	40.00	8.57	0.2	2.68	0.3164	0.4224	7
4	57.5	2.85	0.15	0.92	0.9564	0.9198	2
5	57.5	5.71	0.2	2.55	0.3636	0.4399	6
6	57.5	8.57	0.1	3.55	0	0.3333	9
7	75.00	2.85	0.2	0.8	1	1	1
8	75.00	5.71	0.1	1.52	0.7382	0.6563	4
9	75.00	8.57	0.15	3.32	0.0836	0.3530	8

Table 6(a) experimental result and Grey Relational Grade (GRG) of Cu

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

Exp No:	Parameter Combinations			Surface Roughness Ra (μm)	Normalized Values	GRG	
	Voltage (V)	Current (A)	Spark gap (mm)		Surface roughness	Grey Grade	Rank
1	40.00	2.85	0.1	2.30	0.7529	0.6693	3
2	40.00	5.71	0.15	2.50	0.6353	0.5782	5
3	40.00	8.57	0.2	3.02	0.3294	0.4271	8
4	57.5	2.85	0.15	2.12	0.8588	0.7798	2
5	57.5	5.71	0.2	2.72	0.5059	0.5029	7
6	57.5	8.57	0.1	3.58	0	0.3333	9
7	75.00	2.85	0.2	1.88	1	1	1
8	75.00	5.71	0.1	2.52	0.6235	0.5705	6
9	75.00	8.57	0.15	2.44	0.6706	0.6028	4

Table 6(b) experimental result and Grey Relational Grade (GRG) of WCu

Exp No:	Parameter Combinations			Surface Roughness Ra (μm)	Normalized Values	GRG	
	Voltage (V)	Current (A)	Spark gap (mm)		Surface roughness	Grey Grade	Rank
1	40.00	2.85	0.1	1.68	0.9163	0.8566	3
2	40.00	5.71	0.15	2.56	0.7225	0.6431	5
3	40.00	8.57	0.2	4.96	0.1938	0.3828	8
4	57.5	2.85	0.15	1.40	0.9779	0.9577	2
5	57.5	5.71	0.2	3.60	0.4934	0.4967	6
6	57.5	8.57	0.1	5.84	0	0.3333	9
7	75.00	2.85	0.2	1.30	1	1	1
8	75.00	5.71	0.1	1.94	0.8590	0.7800	4
9	75.00	8.57	0.15	4.86	0.2159	0.3894	7

Table 6(c) experimental result and Grey Relational Grade (GRG) of Gr

Analysis of variance (ANOVA)

Analysis of Variance (ANOVA) is to investigate which of the process parameters seriously affect the performance characteristics. This is obtained by dividing the total variability of the grey relational grades. This is measured by the sum of the squared deviation from the grey relational grade total mean into contributions by each machining parameter and the error. The results of the ANOVA are shown in table 7. The F-test is used to determine which process parameters have a significant effect on the process response, when the F-value is large the change of process parameters has a significant effect on the process response. The results of the ANOVA shows that the current is the

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

significant process parameter and voltage, spark gap are the insignificant process parameters effecting the process response. Hence the optimal machining parameters are voltage at level 3, current at level 1, spark gap at level 2. Shown in the Table 7(a), 7(b), 7(c)

PROCESS PARAMETERS	GREY RELATIONAL GRADE				
	LEVEL 1	LEVEL 2	LEVEL 3	MAX-MIN	RANK
Voltage	0.5899	0.5643	0.6698*	0.1055	2
Current	0.8744*	0.5800	0.3696	0.5048	1
Spark gap	0.5643	0.6389*	0.6208	0.0746	3
Total mean value of grey grade = 0.6079					
*Optimum levels					

Table 7(a) Response table for grey relational grade

PROCESS PARAMETERS	GREY RELATIONAL GRADE				
	LEVEL 1	LEVEL 2	LEVEL 3	MAX-MIN	RANK
Voltage	0.5582	0.5387	0.7244*	0.1857	2
Current	0.8164*	0.5505	0.4544	0.362	1
Spark gap	0.5244	0.6536*	0.6433	0.1292	3
Total mean value of grey grade = 0.6071					
*Optimum levels					

Table 7(b) Response table for grey relational grade

PROCESS PARAMETERS	GREY RELATIONAL GRADE				
	LEVEL 1	LEVEL 2	LEVEL 3	MAX-MIN	RANK
Voltage	0.6275	0.5959	0.7231*	0.1272	2
Current	0.9381*	0.6399	0.3685	0.5696	1
Spark gap	0.6566	0.6634*	0.6265	0.0369	3
Total mean value of grey grade = 0.6488					
*Optimum levels					

Table 7(c) Response table for grey relational grade

From the results it state that current is the most significant process parameter in machining SS304 material. Table 8(a), 8(b), 8(c) shows contribution of each parameter.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

Source	DOF	SS	MS	F	% Contribution
Voltage	2	0.0182	0.0091	0.3383	3.8973
Current	2	0.3858	0.1929	7.1710	82.61
Spark gap	2	0.0091	0.0046	0.1710	1.9699
Error	2	0.0537	0.0269	1	11.5203
Total	8	0.4668		8.6803	100

Table 8(a) Results of ANOVA using Cu electrode in SS304

Source	DOF	SS	MS	F	% Contribution
Voltage	2	0.0625	0.0312	14.8571	20.2203
Current	2	0.2109	0.1055	50.2381	68.3734
Spark gap	2	0.0309	0.155	7.3809	10.0453
Error	2	0.0042	0.0021	1	1.3609
Total	8	0.3085		73.4761	100

Table 8(b) Results of ANOVA using WCu electrode in SS304

Source	DOF	SS	MS	F	% Contribution
Voltage	2	0.0263	0.01315	1.0779	4.8696
Current	2	0.4870	0.2435	19.9590	90.1682
Spark gap	2	0.0023	0.0012	0.0984	0.4445
Error	2	0.0243	0.0122	1	4.5177
Total	8	0.5399		22.1353	100

Table 8(c) Results of ANOVA using Gr electrode in SS304

Confirmation experiment

After evaluating the parameter settings the next step is to predict and verify enhancement of the quality characteristics using the optimized parametric combination. The estimated grey relational grade

$$\gamma' = \gamma_m + \sum (\gamma_i - \gamma_m)$$

where, γ_m = Total mean grey relational grade, γ_i = Mean grey relational grade at the optimum level

Finally the confirmation tests are conducted using the optimal EDM process parameters combination or Cu, WCu and Gr. The minimum surface roughness obtained from the confirmation experiments are 0.59% reduction, 0.44% reduction, 0.67% reduction respectively.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

	Initial machining parameter	Optimal machining parameters	
		Prediction	Experiment
Setting level	V₁I₁SG₁	V₃I₁SG₂	V₃I₁SG₂
Surface Roughness	1.38	0.956	0.79
Grey grade	0.7033	0.9673	
Improvement in GRG	0.264		

Table 9(a) Results of Confirmation experiment using Cu electrode in SS304

	Initial machining parameter	Optimal machining parameters	
		Prediction	Experiment
Setting level	V₁I₁SG₁	V₃I₁SG₂	V₃I₁SG₂
Surface Roughness	2.30	1.94	1.86
Grey grade	0.6693	0.9802	
Improvement in GRG	0.3109		

Table 9(b) Results of Confirmation experiment using WCu electrode in SS304

	Initial machining parameter	Optimal machining parameters	
		Prediction	Experiment
Setting level	V₁I₁SG₁	V₃I₁SG₂	V₃I₁SG₂
Surface Roughness	1.68	1.06	1.01
Grey grade	0.8566	1.027	
Improvement in GRG	0.1704		

Table 9(c) Results of Confirmation experiment using Gr electrode in SS304

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 9, September 2016

The table 9(a), 9(b), 9(c) shows the comparison of process responses for initial and optimal machining parameters. In Cu, WCu, Gr electrodes Ra value reduced from 1.38 microns to 0.79 microns i.e. 0.59% reduction. 2.30 microns to 1.86 microns is obtained i.e. 0.44 % reduction. 1.68 microns to 1.01 microns i.e. 0.67 % reduction respectively.

V. CONCLUSION

An experimental study to analyze the effects of Electrical Discharge Machining parameters such as Voltage, Current and Spark Gap on response parameters such as Surface roughness during machining SS04 using three electrodes Cu, WCu and Graphite are conducted and optimized using Grey Relational Analysis (GRA) and ANOVA.

1. Optimum Surface finish for SS304 using three electrode materials are found using GRA and the values are obtained as Voltage 75.00V (level 3), Current 2.85A (level 1) and Spark gap 0.15mm (level 2).
2. The contribution of each parameter is obtained as Voltage is 3.89 %, Current is 82.61% and Spark gap is 1.97 %. From the study, Current is the most significant process parameter in machining SS304 material using Cu electrode in EDM.
3. The contribution of each parameter is obtained as Voltage is 20.22 %, Current is 68.37 % and Spark gap is 10.04 %. From the study, Current is the most significant process parameter in machining SS304 material using WCu electrode in EDM.
4. The contribution of each parameter is obtained as Voltage is 4.87 %, Current is 90.17 % and Spark gap is 0.44 %. From the study, Current is the most significant process parameter in machining SS304 material using Gr electrode in EDM.
5. Mathematical models which join the input parameters and output responses using regression analysis using MINITAB17 software is obtained.
6. Comparing initial experiment and confirmation experiment, using Cu electrode it is found that surface roughness reduces from 1.38 microns to 0.79 microns i.e. 0.59% reduction.
7. Comparing initial experiment and confirmation experiment, using WCu electrode then the reduction of surface roughness from 2.30 microns to 1.86 microns is obtained i.e. 0.44 % reduction.
8. Comparing initial experiment and confirmation experiment, using Gr electrode it is found that surface roughness reduces from 1.68 microns to 1.01 microns i.e. 0.67 % reduction.

The study can be extended by considering more number of parameters. Responses in machining of other materials with similar machining characteristics can be calculated and can find most suitable optimum parameter combination; it can be used as future reference for machining performance improvement factor in machining operation.

REFERENCES

- [1] Jong Hyuk Jung and Won Tae Kwon, "Optimization of EDM process for multiple performance characteristics using Taguchi method and Grey relational analysis". *J. Mechanical Science and Technol.* 1083-1090, 2010.
- [2] Rajmohan.T, Prabu R., et al., "Optimization of machining parameters in electrical discharge machining (edm) of 304 stainless steel". *Procedia Engineering* 38 .1030 – 1036, 2012.
- [3] K. H. Ho and S. T. Newman., "State of the art electrical discharge machining (EDM)", *Int. J. Mach. Tools Manuf.* 43.1287-1300, 2003.
- [4] G. Krishna MohanaRao., et al., "Development of hybrid model and optimization of surface roughness in electric discharge machining using artificial neural networks and genetic algorithm" *J. Mater. Process Technol.* 1512–1520, 2009.
- [5] N. Natarajan, R.M.Arunachalam., et al., "Experimental study and analysis of micro holes machining in EDM of SS 304". *Int. J. Machining and Machinability of Materials*, Vol. 13, No., 2013.
- [6] Vishnu D Asal., et al., "Optimization Of Process Parameters Of EDM Using ANOVA Method". *Int. J. Engineering Research and Applications*. Vol. 3, Issue 2, pp.1119-1125, 2013.
- [7] Jahan, M.P., Rahman M., et al., "A comparative experimental investigation of deep-hole micro-EDM drilling capability for cemented carbide (WC-Co) against austenitic stainless steel". *Int. J. Advanced Manufacturing Technol.* Vol. 46, No. 9, pp.1145–1160, 2010.
- [8] H. S. Lim, Y. S. Wong, M. Rahman and M. K. Edwin Lee., "A study on the machining of high-aspect ratio microstructure using micro-EDM". *J. Mater. Process. Technol.* 140 318-325, 2003.