Regression model for surface roughness on EDM using Al6061 + SiC, Copper and Brass Tools

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ABSTRACT

Keywords:
Discharge Current(I_P), Pulse On Time (T_{ON}), Pulse Off Time (T_{OFF}), Surface Roughness, EDM.

Electrical Discharge Machining (EDM) is one of the electrical energy based Modern Machining Technique. where electrical energy is directly used to remove or cut the metals. In the present work experiments are conducted on EDM using Al6061+SiC(3%,6%,9%), Copper and Brass materials as electrodes and EN8 steel as work material. Discharge current (I_P), pulse on time (T_{ON}), pulse off time (T_{OFF}) are selected as process parameters, Surface Roughness (S_R), Tool Wear Rate (TWR) as response. Taguchi design of experiment is used to find the influence of process parameters on response and a mathematical model is developed. Percentage contribution of each factor is determined.

1. Introduction

Electrical Discharge Machining (EDM) process involves a controlled erosion of electrically conductive materials by initiation of rapid and repetitive spark discharge between electrode tool and work piece, separated by a small gap of about 0.01 to 0.05mm known a spark gap. This is either flooded or immersed under dielectric fluid. The controlled pulsing of direct current produces the spark discharge between the work piece and tool. Each spark produces enough heat to melt and vaporize a tiny volume of the work piece material leaving a small crater on its surface. The energy contained in each spark is discrete and it can be controlled so that material removal rate, surface finish and tolerance can be produced. EDM is most widely used machining process among the non-traditional machining methods. Its chief applications are in the manufacture and reconditioning of press tools and forging dies as well as moulds for injection moulding. It is successfully employed for producing intricate and irregular shape profiles common in tool rooms.

2. Objectives & Methodology

A Mathematical model is developed to optimize the input parameters for each tool used for machining by Design of Experiments. In design of experiments, numbers of trails to be conducted are determined by Taguchi DoE and design matrix is constructed for both Al6061 + SiC (3%,6% & 9%),Copper and Brass electrodes used. Experiments are carried out as per the design matrix. After getting the design matrix, regression coefficients are calculated. Adequacy of model is tested by fisher test at 5% significance level. Student's t-test is done for each regression coefficient to check the significance. The final mathematical model is formed after removing non significant coefficients. Finally Analysis of Variance (ANOVA) is done to find out the percentage contribution of each factor to the Surface Roughness.

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Taguchi DoE

Taguchi has envisaged a new method of conducting the design of experiments which are based on well defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting minimal number of experiments which could give the full information of all the factors that affects the performance parameters. There are many standard orthogonal arrays available, each of the arrays is meant for a specific number of independent design variables and levels. For example, if one wants to conduct an experiment to understand the influence of

4 different independent variables with each variable having 3 set values (level values), then an L9 orthogonal array might be the right choice. The L9 orthogonal array is meant for understanding the effect of 4 independent factors each having 3 factor level values. This array assumes that there is no interaction between any two factors. While in many cases, no interaction model assumption is valid, there are some cases where there is clear evidence of interaction. A typical case of interaction would be the interaction between the material properties and temperature.

Postulation of Mathematical Model

The regression equation is an algebraic representation of the regression line and describes the relationship between the response and predictor variables. The regression equation takes the form of:

Response = constant + coefficient * predictor + ... + coefficient * predictor
or $y = b_o + b_1X_1 + b_2X_2 + ... + b_kX_k$

Where:

- Response (Y) is the value of the response.
- Constant (b_o) is the value of the response variable when the predictor variable(s) is zero. The constant is also called the intercept because it determines where the regression line intercepts (meets) the Y-axis.
- Predictor(s) (X) is the value of the predictor variable(s). The predictor can be a polynomial term.
- Coefficients (b_1, b_2, ... ,b_k) represent the estimated change in mean response for each unit change in the predictor value. In other words, it is the change in Y that occurs when X increases by one unit.

Table 1
EDM Factors and Levels.

Process parameter	Units	Level 1	Level 2	Level 3
Pulse on time(T_{ON})	µs	200	500	900
Pulse off time(T_{OFF})	A	100	200	500
Voltage(V)	V	30	40	45
Current(I)	µs	6	8	10

The EDM process variables (factors) are identified to develop the mathematical model to predict the MRR and SR. These include pulse on time (T_{ON}), pulse off time (T_{OFF}) and pulse current (Ip), Voltage (V). The first order model is assumed with two and three four interactions which can be expressed as

Regression

Regression investigates and models the relationship between a response (Y) and Predictors (X). The response must be continuous, but you can have both continuous and categorical predictors. You can model both linear and polynomial relationships.

In particular, regression analysis is often used to determine how the response variable changes as a particular predictor variable change. Minitab stores the last regression model that you fit for each response variable. You can use stored models to quickly generate predictions, contour plots, surface plots, overlaid contour plots, and optimized responses. For analyses that can use multiple responses, you will need to fit a model for each response.

3. Experimentation

The experimentation is carried out on Electrical Discharge Machine which is classified as (die-sinking type) SYCNC PC-60 whose polarization on the electrode be located as negative whereas that of work piece be located as positive. The dielectric liquid recycled was EDM oil having specific gravity 0.763. (Ref. Fig. 1 & 2)

Fig. 1. Machining with different types of tools.

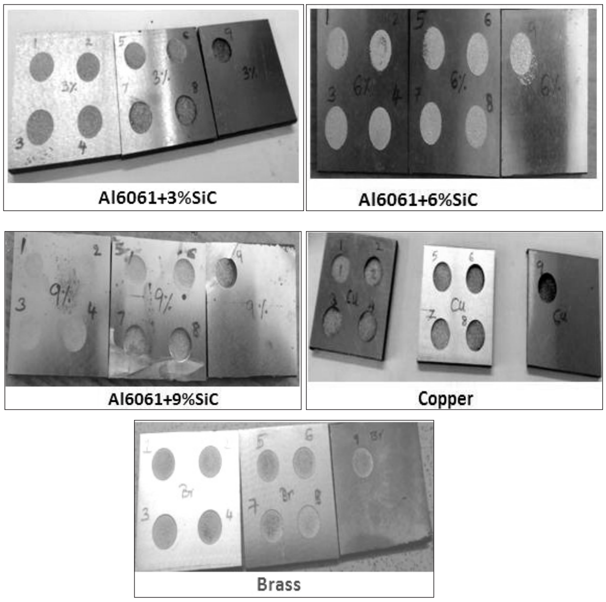

Fig. 2. Work pieces.

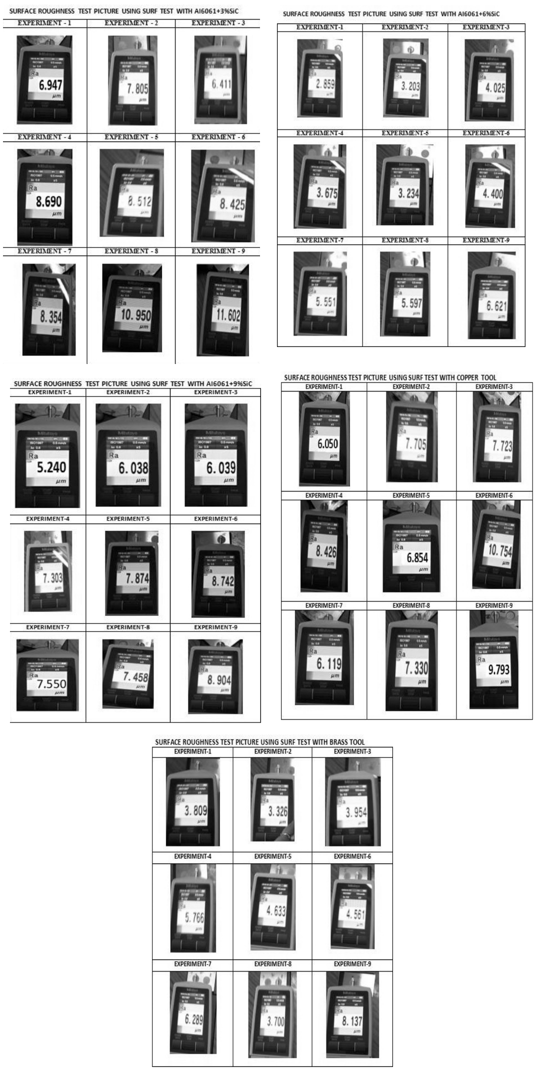

Fig. 3. Surface Roughness Test Pictures Using Surf Test.

Table 2

Calculated S_R for Al6061+SiC(3%,6%,9%), Copper & Brass Electrodes.

S.NO	T_{ON} (µs)	I_P (A)	V (V)	T_{OFF} (µs)	SR (µm)				
					Al6061+ 3%SiC	Al6061+ 6%SiC	Al6061+ 9%SiC	COPPER	BRASS
1	200	6	30	100	6.947	2.859	5.24	6.05	3.809
2	200	8	40	200	7.805	3.203	6.038	7.705	3.326
3	200	10	45	500	6.411	4.025	6.039	7.723	3.954
4	500	6	30	500	8.69	3.675	7.303	8.426	5.766
5	500	8	40	100	8.512	3.234	7.874	6.854	4.633
6	500	10	45	200	8.425	4.4	8.742	10.754	4.561
7	900	6	30	200	8.354	5.551	7.55	6.119	6.289
8	900	8	40	500	10.95	5.597	7.458	7.33	3.700
9	900	10	45	100	11.602	6.621	8.904	9.793	8.137

Table 3

Calculation of Regression coefficients for SR.

Regression Coefficients	Al6061+3% SiC	Al6061+6% SiC	Al6061+9% SiC	Copper	Brass
Constant	3.21	1.97	-1.13	-2.19	6.05
T_{ON}	0.00259	0.003751	-0.00063	-0.00009	0.00332
I	2.26	1.013	5.648	2.94	-1.55
V	-0.365	-0.204	-0.945	-0.339	0.172
T_{OFF}	0.0005	0.00041	0.02584	0.0293	0.01077
$I*T_{OFF}$	-0.01158		-0.003826	-0.00365	
$V*T_{OFF}$	0.0024				
$T_{ON}*I$			-0.00763	-0.000102	0.00364
$T_{ON}*V$			0.001643		-0.00062
$T_{ON}*T_{OFF}$					-0.00002

The value of the surface roughness of the machined surface is found using a Surf Test.

The following images shows the roughness values in microns for the trials conducted. (Ref. Fig.3)

The adequacy of the model was then tested by Fisher test. As per this technique, F-ratio of the model developed does not exceed the standard tabulated value of f-ratio for a 95% confidence level. Hence the model was adequate. The significance of the coefficients was checked by using student's t-test and only the significant coefficients were used to develop final mathematical model. The final models in coded form for the SR for Al6061 + SiC(3%, 6%, 9%), Copper and Brass tool are given below.

Regression Equation For Surface Roughness

$$SR\ (Al6061+3\%\ SiC) = 3.21 + 0.00259\ T_{ON} + 2.26\ I - 0.365\ V + 0.0005\ T_{OFF} - 0.01158\ I*T_{OFF} + 0.00240\ V*T_{OFF}$$

$$SR\ (Al6061+6\%\ SiC) = 1.97 + 0.003751\ T_{ON} + 1.013\ I - 0.204\ V + 0.00041\ T_{OFF}$$

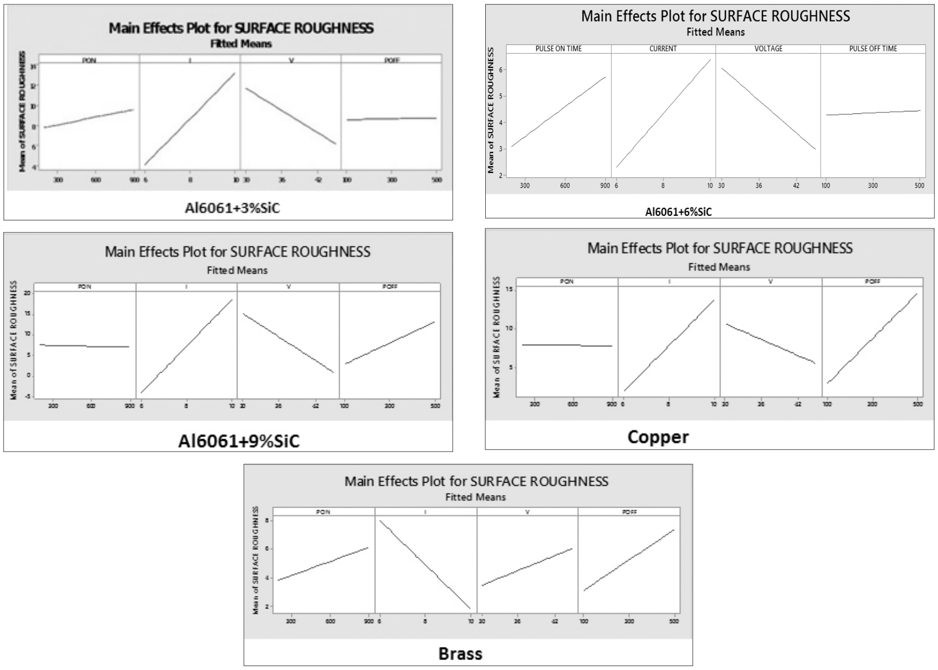

Fig. 4. Main effects of surface roughness

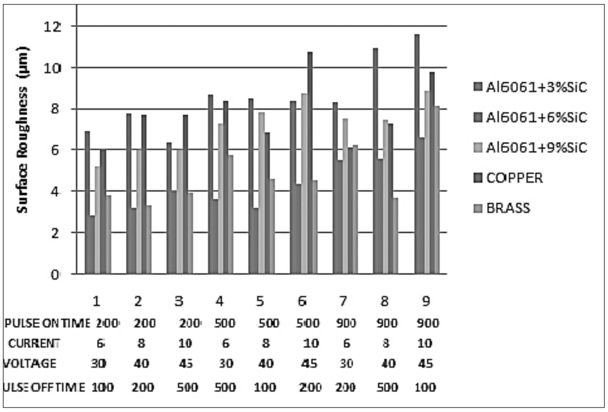

Fig. 5. SR Vs input parameters

$$SR\ (Al6061+9\%\ SiC) = -1.13 - 0.00063\ T_{ON} + 5.648\ I - 0.945\ V + 0.02584\ T_{OFF} - 0.00763\ T_{ON} * I + 0.001643\ T_{ON} * V - 0.003826\ I * T_{OFF}$$

$$SR\ (Copper) = -2.19 - 0.00009\ T_{ON} + 2.94\ I - 0.339\ V + 0.02930\ T_{OFF} - 0.00365\ I * T_{OFF} - 0.000102\ T_{ON} * I$$

$$SR\ (Brass) = 6.05 + 0.00332\ T_{ON} - 1.55\ I + 0.172\ V + 0.01077\ T_{OFF} + 0.00364\ T_{ON} * I - 0.000620\ T_{ON} * V - 0.000020\ T_{ON} * T_{OFF}$$

4. Results & Conclusions

The experiments were conducted as per design matrix by Taguchi methodology. The following conclusions are made from the work carried out.

- Al6061 + SiC (with SiC of 3%) tool had a minimum metal Surface Roughness of 6.411μm for a combination of input variables Pulse on time: 200μs, Current: 10A, Voltage: 45V, Pulse off time: 500μs.
- Al6061 + SiC (with SiC of 6%) tool had a minimum metal Surface Roughness of 2.859μm for a combination of input variables Pulse on time: 200μs, Current: 6A, Voltage: 30V, Pulse off time: 100μs
- Al6061 + SiC (with SiC of 9%) tool had a minimum metal Surface Roughness of 5.24μm for a combination of input variables Pulse on time: 200μs, Current: 6A, Voltage: 30V, Pulse off time: 100μs
- Copper tool had a minimum metal Surface Roughness of 6.05μm for a combination of input variables Pulse on time: 200μs, Current: 6A, Voltage: 30V, Pulse off time: 100μs
- Brass tool had a minimum metal Surface Roughness of 3.326μm for a combination of input variables Pulse on time: 200μs, Current: 8A, Voltage: 40V, Pulse off time: 200μs
- From the above Observation (Table 2) the minimum surface roughness is 2.859μm for the tool Al6061+ SiC (with SiC of 6%)

5. References

1. Sushil Kumar Choudhary: Current Advanced Research Development of Electric Discharge

Machining (EDM), 'International Journal of Research in Advent Technology', vol. 2, no. 3 (E-ISSN: 2321-9637), 2014, 273-274

2. Ho, KH; Newman, ST: State of the art electrical discharge machining (EDM), 'International Journal of Machine Tools & Manufacture', 43, 2003, 1287-1300.
3. Rao, P Srinivasa; Reddy, Sidda B; Kumar, JS and Reddy, KVK: Fuzzy modelling for electrical discharge machining of AISI 304 stainless steel, 'Journal of Applied Sciences Research', 6 (11), 2010, 1687-1700.
4. Tomadi, SH; Hassan, MA; Hamedon, Z; Daud, R; Khalid, AG: Analysis of the influence of EDM parameters on surface quality, material removal rate and electrode wear of tungsten carbide. In Proceedings of the International Multi Conference of Engineers and Computer Scientists, 2009, Mar 18, vol. 2, 18-20.
5. Wansheng, Zhao; Zhenlong, Wang; Shichun, Di; Guanxin, Chi; Hongyu, Wei: Ultrasonic and electric discharge machining to deep and small hole on titanium alloy, 'Journal of Materials Processing Technology', 120, 2002, 101-106.
6. Çaydas, Ulas & Hasçalik, Ahmet: Modeling and analysis of electrode wear and white layer thickness in die-sinking EDM process through response surface methodology, 'Int J Adv Manuf Technol', 2008, 38:1148–1156.
7. Yu, ZY; Rajurkar, KP and Shen, H: High Aspect Ratio and Complex Shaped Blind Micro Holes by Micro EDM, University of Nebraska-Lincoln, USA, 2002.
8. Appa Rao, G; Mahendra Kumar, Srinivas, M; Sarma, DS: Effect of standard heat treatment on the microstructure and mechanical, 2003.
9. Kuppan, P & Rajadurai, A & Narayanan, S: Influence of EDM process parameters in deep hole drilling of Inconel 718, 'Int J Adv Manuf Technol', 2008, 38:74–84. properties of hot isostatically pressed superalloy inconel 718. 'Materials Science and Engineering A355', 2003, 114/125.
10. Spedding, TA and Wang, ZQ: Study on modeling of wire EDM process, 'Journal of Materials Processing Technology', 69, 1997, 8- 28
11. Salonitis, K; Stournaras, A; Stavropoulos, P & Chryssolouris, G: Thermal modelling of the material removal rate and surface roughness for die-sinking EDM, 'Int J Adv Manuf Technol', 2009, 40:316-323.
12. Ankur Srivastava; Kumar Abhishek; Surav Datta; Chandramani Upadhyaya; Siba Sankar Mahapatra: Effect of variation of electrode material on machining performance of Al 6061 during EDM operation, Department of Mechanical Engineering FST, IFHE, Hyderabad, INDIA Department of Mechanical Engineering National Institute of Technology, Rourkela, Odisha, India.
13. Arunkumar, N; Shareef, H; Rawoof, Abdur and Vivek, R: Investigation on the Effect of Process Parameters for Machining of EN31 (Air Hardened Steel) By EDM, International Journal of Engineering Research and Applications (IJERA), ISSN: 2248-9622, vol. 2, no. 4, July-August 2012, 1111-1121.
14. Patel, VD; Patel, CP; Patel, UJ: Analysis of Different Tool Material on MRR and Surface Roughness of Mild Steel In EDM, 'International Journal of Engineering Research and Applications (IJERA)', ISSN:2248-9622, vol. 1, no. 3, 394-397.
15. Manish Vishwakarma; Khare, VK; Parashar, Vishal: Response Surface approach for optimization of Sinker EDM process parameters on AISI 4140 alloy steel, 'International Journal of Engineering Research and Applications (IJERA)', vol. 2, no. 4, July-August 2012.
16. Sandeep: Metal Removal Rate Optimization in Electric Discharge Machining Process, 'International Journal of Enhanced Research in Science Technology & amp; Engineering', ISSN: 2319-7463, vol. 3, no. 10, October 2014.
17. Prashant Yadava; Dixit, Avdesh Chandra; Jitendra Kumar Verma: Optimization of EDM Parameter of High Carbon-High Chromium Steel (AISI D3) by using Brass Electrode, 'International Journal of Engineering Trends and Technology (IJETT)', vol. 34, no. 3, April 2016 .
18. Shankar, P; Boopathi, R and Prabu, M: Investigating the Effect of Brass Electrode on Inconel 718 on Electrical Discharge Machine, 'IJISET - International Journal of Innovative Science, Engineering & Technology', vol. 2, no. 4, April 2015.
19. Sandeep Kumar; Ramola, Ishwar Chand; Ranjeet Kumar: Analysis of Surface Roughness and Material Removal Rate for High Carbon High Chromium Steel on Die Sinking EDM using Taguchi Technique, 'International Journal of Mechanical Engineering (SSRG-IJME) – EFES' April 2015.
20. Nayan Patel: Review on Importance of Electrodes in Electrical Discharge Machining Process, International 'Journal of Research in Aeronautical and Mechanical Engineering'.
21. Samruddhi Rao; Pragati Samant; Athira Kadampatta; Reshma Shenoy: An Overview Of Taguchi Method: Evolution, Concept and Interdisciplinary Applications, 'International Journal of Scientific and Engineering Research', 2013.
22. Bolboaca, Sorana D and Jantschi, Lorentz: Design of Experiments: Useful Orthogonal Arrays for Number of Experiments from 4 to 6, 'Entropy',

vol. 9, 2007, 198-232.

23. Ojha, Kuldeep; Garg, RK; Singh, KK: 'Journal of Minerals & Materials Characterization & Engineering', vol. 9, no. 8, 709-739, 2010, jmmce.org.
24. Arun Kumar; RP Swamy: Evaluation of mechanical properties of Al6061, flyash and E-glass fiber reinforced hybrid metal matrix composites, 2011/5ARPN 'Journal Of Engineering and Applied Sciences', vol. 6, no. 5, 40-44 .
25. Ashwani Kharola: Analysis of Various machining parameters of EDM on Hard Steel using copper and Aluminium electrodes (March 2015) have studied the process parameters on EDM using Copper, Aluminium electrodes and EN8 work material 2015/3/1, JEM, vol. 5, 1-14 .
26. Laxman, J; Gururaj, K: Modeling and Analysis of EDM process parameters using Taguchi technique and Fuzzy based modeling, 'International Journal of Advanced Mechanical Engineering', ISSN 2250-3234, vol. 4, no. 5, 2014, 473-480.
27. Jeevamalar, J; Ramabalan, DS: Experimental Investigations into the Effect of Process Parameters on Performance Measures of Sink EDM Process: A Review Year 2011 To 2015 and Future Work, 'IJERT', ISSN: 2278-0181, IJERTV5IS010213, vol. 5, no. 01, January-2016 .
28. Mathalai Sundaram, C; Sivasubramanian, R; Sivakumar, M: An Experimental Investigation on Machining Parameters of Electrical Discharge Machining of OHNS Steel, 'IJERT', vol. 2, no. 12, December 2013.
29. Pandey, Ved Prakash; Mall, RN: Analysis of material removal rate of AlSi 304 SS in EDM process, 'IJSRD, vol. 2, no. 07, 2014, ISSN (online): 2321-0613.
30. Mehta, Mehul G; Patel, Nikul K: Temperature and thermal stress analysis of EDM, (Jan-2014), vol. 03, no. 01, Published (First Online): 23-01-2014 ISSN: 2278-0181 Publisher Name: IJERT

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