ISSN: 0974-5823 Vol. 7 No. 11 November, 2022

International Journal of Mechanical Engineering

Modelling & Parametric Optimization of AISI 1045 Tool Steel Using Response Surface Methodology of Die Sinking EDM

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Acceptance Date: 13th September, 2022

Publication Date: 25th September, 2022

Abstract:

Electrically conductive materials are machined using Electrical Discharge Machining (EDM), a non-conventional machining technique that uses a precisely regulated spark that forms between an electrode and a work piece in the presence of a dielectric fluid. The current study illustrates that Response Surface Methodology is used to optimize the material removal rate (MRR) of electrical discharge machining (EDM). AISI 1045 tool steel was used as the work piece and copper as a tool. The EDM control parameters were the pulse current (I), pulse on time (Ton), and pulse off time (Toff). Since the Taguchi approach is the most popular experimental design for simulating a second-order response surface, it was utilized to create the experiment. The process has been effectively modeled through the application of response surface methodology (RSM)and optimized with Taguchi, using Minitab software is utilized for model adequacy testing.

Keywords: Electric discharge machine, response surface methodology, MRR.

Introduction:

Aeronautics, automotive, nuclear reactor, missile, turbine, and other technologically advanced sectors require materials like high strength temperature resistant alloys with greater strength, corrosion resistance, toughness, and other diversified features. The need for cutting tool materials and procedures that can safely and conveniently machine these novel materials has arisen due to the materials industry's rapid development [1], [2] . Electric discharge machining is one of the non-conventional processes which provide high accuracy, adaptability and continuous output in machining of newly developed high strength materials. Owing to this unique capability, EDM has been widely used in the modern manufacturing sector to produce intricate tasks in dies and molds that are challenging to produce using traditional machining in recent years [3], [4]. Its special ability to machine electrically conductive parts utilizing heat energy independent of their hardness has been a key benefit for the production of surgical components [5]. Utilizing the Orthogonal Array L27 Taguchi, M. Sangeetha et al. prepared the experimental design using Minitab software, taking into account the following material parameters: base material type (Al5052, Al6082, Al7075), reinforcement material type (FlyAsh, SiC, Al2O3), percentage of reinforcement (2. 5, 5%, 10%), and machining parameters (current (Ip), pulse on time (Ton), pulse off time (Toff), and tool lifting time (TL) [6]. Response surface methodology is used to optimize the process parameters for surface roughness for AISI D2 Steel [7]. E. Uhlmann optimized process parameters of the die-sinking EDM-technology for the fabrication of turbine components [8]. B. Vinod Kumar deals with the optimization model to investigate the effect of Voltage and Duty Cycle on MRR in Die-Sinking EDM [9].

Experimental Procedure:

The workpiece material for the research project is AISI 1045 tool steel, which was chosen due to its expanding range of applications in the field of mold industries. A number of experiments were conducted to study the effects of various machining parameters on EDM process. These studies were carried out on JOEMARS AZ 50 JM-322 die sinking machine using positive polarity. The flushing pressure was 0.5 Kg/cm2. Die-electric fluid-92 (DEF-92) was used as die electric fluid, and copper with a diameter of 15 mm was used as a tool electrode. The workpiece before and after experimentation are seen in fig. 1.

Fig. 1: Workpiece before and after machining

The volume of metal removed in a unit of time is known as the metal removal rate. In order to compare the output of various machines or electrode materials, it can alternatively be expressed as the volume of metal removed per unit time per ampere.

$$MRR = \frac{W_{tb} - W_{ta}}{D \times t}$$

Where,

W_{tb} = Weight before machining of w/p in gm,

W_{ta} = Weight after machining of w/p in gm,

D = Density of work piece material in gm/mm3,

t = Time consumed for machining in minute.

Response surface methodology:

RSM is a set of statistical and mathematical methods that are helpful for modeling and analyzing situations where the goal is to optimize a response that is influenced by multiple variables [10]. The link between the three operating variables current, pulse on-time, and pulse off-time was to be determined using the Taguchi design. Mathematical models of the second order polynomial response surface can be created in order to investigate the impact of the EDM parameters on the machining criteria. The response surface is described by an equation listed below [11], [12].

$$Y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i<j=2}^{k} b_{ij} x_i x_j + \varepsilon_r$$

Where, Y is the estimated response, b's are the coefficients and xi's are the independent variables.

The various variables and their respective levels utilized in EDM machining are displayed in Table no.1. Current, pulse on time, and pulse off time are the variables that are being employed here. The Taguchi technique is used to arrange experiments for the development of second-order nonlinear polynomials. Table no. 2 contains the optimized L 27 runs based on the Taguchi technique. The output parameters is MRR.

Table: 1 Different variable and their levels

		Levels		
Parameter		1	2	3
Current (amp)	I	13	17	21
Pulse on time (µs)	T_{on}	40	50	60
Pulse off time (µs)	T_{off}	30	40	50

Table: 2 Experimentation design as per Taguchi L 27 Orthogonal Array

SR.	Current	Pulse on time	Pulse off time	MRR

1	13	40	30	12.6426
2	13	40	40	9.2649
3	13	40	50	6.1698
4	13	50	30	14.3777
5	13	50	40	12.0887
6	13	50	50	9.3270
7	13	60	30	14.2725
8	13	60	40	12.4651
9	13	60	50	11.4056
10	17	40	30	17.9037
11	17	40	40	13.3942
12	17	40	50	8.9341
13	17	50	30	21.2662
14	17	50	40	17.2902
15	17	50	50	13.8162
16	17	60	30	23.9430
17	17	60	40	21.8327
18	17	60	50	17.6476
19	21	40	30	22.9797
20	21	40	40	16.2560
21	21	40	50	11.3853
22	21	50	30	28.9189
23	21	50	40	24.1191
24	21	50	50	18.0304
25	21	60	30	32.9670
26	21	60	40	27.7655
27	21	60	50	23.6641

Results and discussion:

Response table and response diagram for MRR using taguchi:

The response of signal to noise ratio and means for MRR calculated based on larger is better. The data of signal to noise ratio and means depicted on the Table no. 3 & 4. The most significant parameters are Current and T_{off}. The least significant parameter is T_{on}.

Table 3: Response Table for Signal to Noise Ratios (Larger is better)

Level	I (amp)	Ton (µs)	Toff (µs)
1	20.84	21.82	26.03
2	24.45	24.48	24.19
3	26.81	25.80	21.87
Delta	5.97	3.98	4.16
Rank	1	3	2

Table 4: Response Table for Means

Level	I (amp)	Ton (µs)	Toff (µs)
1	11.33	13.21	21.03
2	17.34	17.69	17.16
3	22.90	20.66	13.38
Delta	11.56	7.45	7.65
Rank	1	3	2

The interaction plot for S/N ratio of MRR is depicted in figure 2. The optimized parameters for Higher MRR is 21 amp current, 60 µs pulse on time and 60 µs pulse off time. The figure is also suggest the effect of various process parameters for higher MRR.

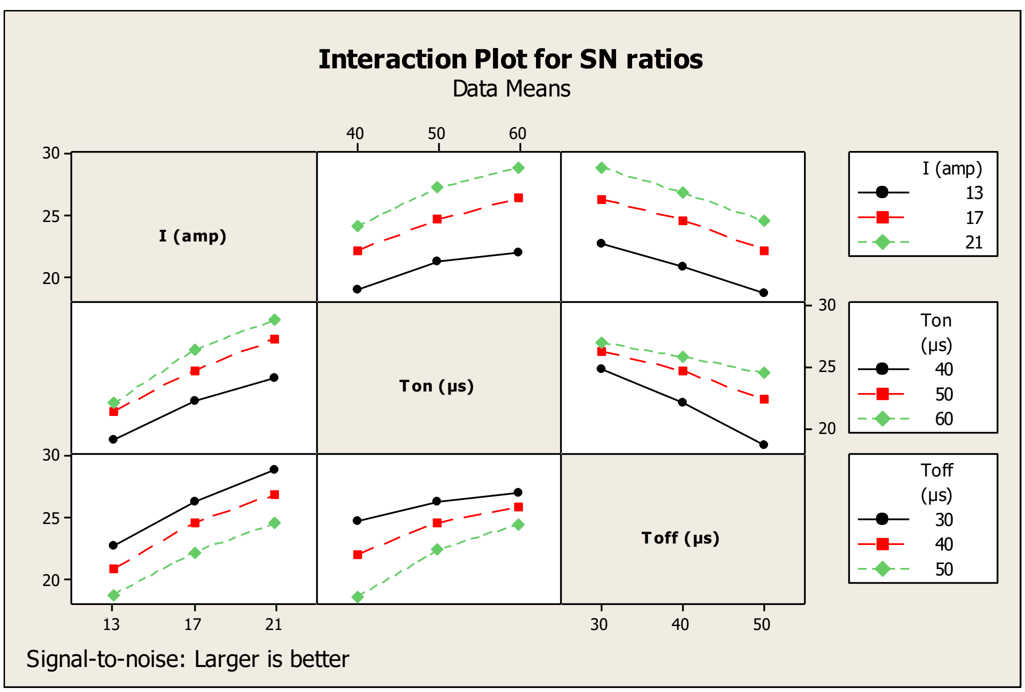

Fig. 2 Interaction Plot for SN ration of MRR

Table 5: Analysis of Variance for MRR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
I (amp)	2	602.01	602.01	301.01	73.64	0.000
Ton (µs)	2	253.05	253.05	126.52	30.95	0.000
Toff (µs)	2	263.68	263.68	131.84	32.26	0.000
Error	20	81.75	81.75	4.09		
Total	26	1200.48				
S = 2.02172 R-Sq = 93.19% R-Sq(adj) = 91.15%						

It is important to check the adequacy of the fitted model, because an incorrect or under-specified model can lead to misleading conclusions. By checking the fit of the model one can check whether the model is under specified. The Analysis of variance for MRR is calculated based on 95% confidence level depicted in Table no. 5. The P value indicated the good adoptability of the model. The R^2 value for the fitted model is 93.19%. The normal probably plot as shown in figure no. 3 the all the points on plot come close to form a straight line, it implies that the data are normal.

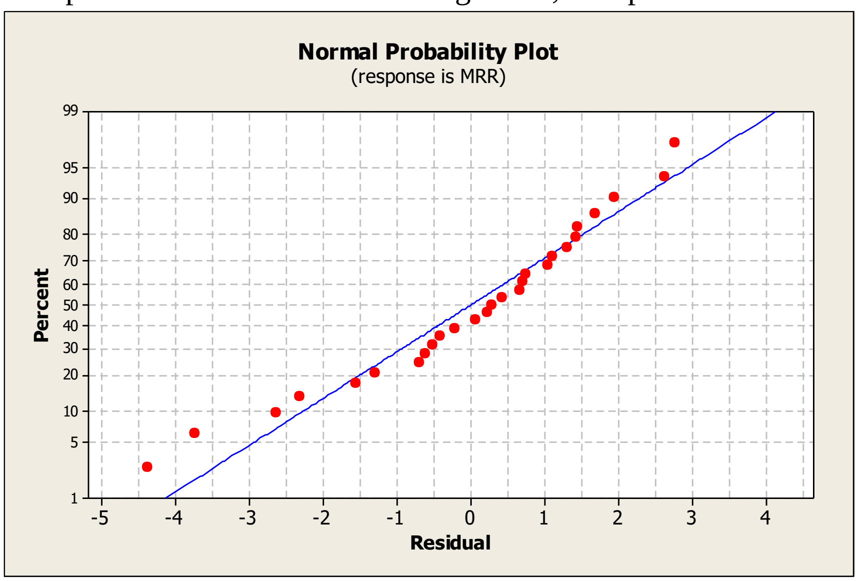

Fig. 3 Normal Probability Plot for MRR

Estimation of coefficient of MRR:

The unknown coefficients are computed using the experimental data that are displayed in Tables 5. A tabulation of the standard errors on the coefficient estimations may be seen in the "SE coef" column. The following is the formulation of the material removal rate non linear regression equations. The significance of how much of the variation in the response is described by the model is shown by the coefficient of determination (R^2), which is at 99.70% for MRR. A higher R2 value suggests that the model fits the data more accurately.

Table: 5 Estimated Regression Coefficients for MRR

Term	Coef	SE Coef	T	P
Constant	17.8134	0.2331	76.434	0.000
I (amp)	5.7818	0.1079	53.593	0.000
Ton (µs)	3.724	0.1079	34.519	0.000
Toff (µs)	-3.8273	0.1079	-35.476	0.000
I (amp)*I (amp)	-0.2198	0.1869	-1.176	0.256
Ton (µs)*Ton (µs)	-0.7542	0.1869	-4.036	0.001
Toff (µs)*Toff (µs)	0.0388	0.1869	0.208	0.838
I (amp)*Ton (µs)	1.9758	0.1321	14.954	0.000
I (amp)*Toff (µs)	-1.4496	0.1321	-10.971	0.000
Ton (µs)*Toff (µs)	0.7143	0.1321	5.406	0.000
S = 0.457712 PRESS = 7.78864 R-Sq = 99.70% R-Sq(pred) = 99.35% R-Sq(adj) = 99.55%				

$$MRR = 17.81 + 5.78 \times I + 3.72 \times T_{on} - 3.82 \times T_{off} - 0.21 \times I \times I - 0.75 \times T_{on} \times T_{on} + 0.03 \times T_{off} \times T_{off} + 1.97 \times I \times T_{on} - 1.44 \times I \times T_{off} + 0.7143 \times T_{on} \times T_{off}$$

Effect of various parameters on MRR:

The contour plot (Figure 4) for MRR depicts that I and Ton have significant impact. MRR is increasing nonlinearly with the increase in current and T_{on}. This is obvious, as the I increases, the pulse energy increases, and thus more heat is produced in the work piece interface that leads to increase the melting and evaporation. One can interpret that I (Current) has a significant and direct impact on MRR. It is observed that the MRR values are high when T_{on} is higher with lower T_{off}. From the analysis it is said that the interaction of T_{on} and T_{off} is significant. Although the influence of this two parameter is very less when compared with the effect of current on MRR.

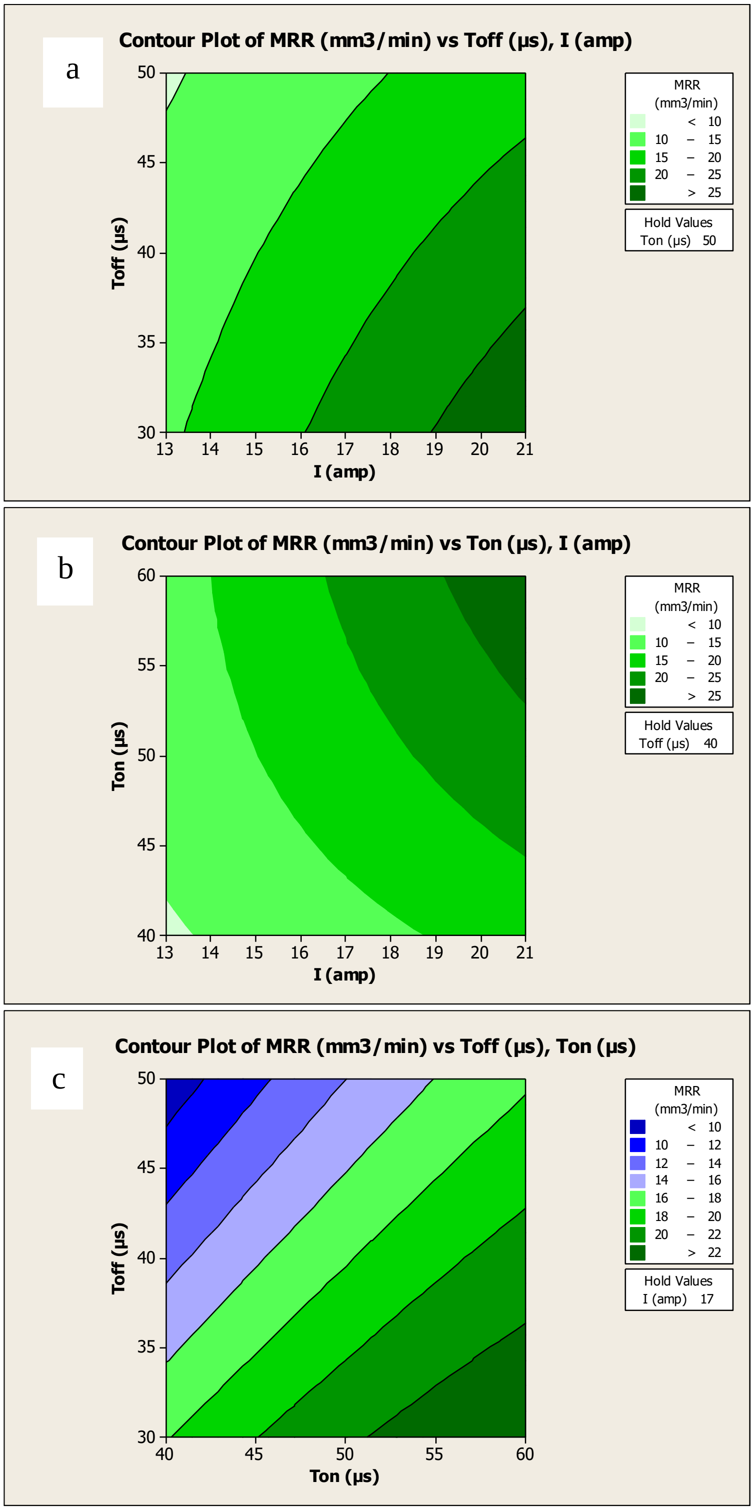

Fig. 4: Contour plot for MRR for various parameters a) T_{off} vs I b) T_{on} vs I c) T_{off} vs T_{on}

Conclusion:

RSM was used in the current investigation to identify the process parameters that had a substantial impact on MRR. The significance of parameters are in ascending order of current, pulse off time and pulse on time as per Taguchi optimization. This paper also describes the creation of a thorough mathematical model using response surface methodology (RSM) to correlate the interactive and higher order influences of different electrical discharge machining parameters. Relevant experimental data collected through experimentation is used in this process. the coefficient of determination (R^2), which is at 99.70% for MRR. A higher R^2 value suggests that the model fits the data more accurately. In order to achieve the highest possible EDM efficiency when machining AISI 1045 tool steel, the research findings of this study, which are based on RSM models, can be applied successfully.

References:

[1] Dr. N. M. Kumar and Mr. P. C. Rao, "Optimization of EDM Process Parameters using Response Surface Methodology for AISI D3 Steel," *International Journal of Trend in Scientific Research and Development*, vol. Volume-3, no. Issue-3, pp. 1651–1656, Apr. 2019, doi: 10.31142/ijtsrd23535.

[2] G. K. Bose, P. Pain, and S. Mukhopadhyay, "Multi-Objective Optimization of Die-Sinking EDM Process on AISI P-20 Tool Steel Using Cuckoo Search and Genetic Algorithm," 2017, pp. 111–129. doi: 10.4018/978-1-5225-1639-2.ch006.

[3] K. H. Ho and S. T. Newman, "State of the art electrical discharge machining (EDM)," *Int J Mach Tools Manuf*, vol. 43, no. 13, pp. 1287–1300, Oct. 2003, doi: 10.1016/S0890-6955(03)00162-7.

[4] M. Tanjilul and A. S. Kumar, "Die-sinking of super dielectric based electrical discharge machining using 3D printed electrodes," *Procedia CIRP*, vol. 95, pp. 471–475, 2020, doi: 10.1016/j.procir.2020.02.324.

[5] K. Ponappa, S. Aravindan, P. V. Rao, J. Ramkumar, and M. Gupta, "The effect of process parameters on machining of magnesium nano alumina composites through EDM," *The International Journal of Advanced Manufacturing Technology*, vol. 46, no. 9–12, pp. 1035–1042, Feb. 2010, doi: 10.1007/s00170-009-2158-9.

[6] A. S. R. G. V. K. M. Sangeetha, "Optimization of Die-Sinking EDM Process Parameters in Machining OF AMMC-Desirability Approach," *Mechanics, Materials Science & Engineering*, Dec. 2016.

[7] K. B. R. B B PATEL, "Multi-Parameter Analysis and Modeling of Surface Roughness in Electro Discharge Machining of AISI D2 Steel," *Int J Sci Eng Res*, vol. 3, no. 6, Jun. 2012.

[8] E. Uhlmann and D. C. Domingos, “Development and Optimization of the Die-Sinking EDM-Technology for Machining the Nickel-based Alloy MAR-M247 for Turbine Components,” *Procedia CIRP*, vol. 6, pp. 180–185, 2013, doi: 10.1016/j.procir.2013.03.102.

[9] B. Vinod Kumar And D.J. Jyothsna Devi, “Optimization of Die-Sinking EDM Process Parameters with Steel Electrodes Using ANOVA,” *International Journal of Computational Engineering Research (IJCER)*, vol. 8, no. 6, pp. 60–66, Jan. 2018.

[10] S. Kumar, A. K. Dhingra, and S. Kumar, “Parametric optimization of powder mixed electrical discharge machining for nickel-based superalloy inconel-800 using response surface methodology,” *Mech Adv Mater Mod Process*, vol. 3, no. 1, p. 7, Dec. 2017, doi: 10.1186/s40759-017-0022-4.

[11] S. J. M. Breig and K. J. K. Luti, “Response surface methodology: A review on its applications and challenges in microbial cultures,” *Mater Today Proc*, vol. 42, pp. 2277–2284, 2021, doi: 10.1016/j.matpr.2020.12.316.

[12] S. K. Behera, H. Meena, S. Chakraborty, and B. C. Meikap, “Application of response surface methodology (RSM) for optimization of leaching parameters for ash reduction from low-grade coal,” *Int J Min Sci Technol*, vol. 28, no. 4, pp. 621–629, Jul. 2018, doi: 0.1016/j.ijmst.2018.04.014.