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An Investigation on Material Removal Rate of EDM Process: A Response Surface Methodology Approach

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***Abstract*—**In the present work response surface methodology (RSM) based central composite design (CCD) is used for analyzing the electrical discharge machining (EDM) process. For experimentation, mild steel is selected as work piece and copper is used as electrode. Three machining parameters namely current (I), spark on time (T_{on}) and spark off time (T_{off}) are selected as the input variables. The output or response chosen is material removal rate (MRR) which is to be maximized. To reduce the number of runs face centered central composite design (FCCCD) was used. ANOVA was used to determine the significance of parameter and interactions. The suitability of model is tested using Anderson darling (AD) plot. The results conclude that different parameters considered i.e. current, pulse on and pulse off time; all have dominant effect on the MRR. At last, the optimized parameter setting for maximizing MRR is found through main effect plot analysis.

***Keywords*—**Electrical discharge machining, electrode, MRR, RSM, ANOVA.

I. Introduction

PRESENT manufacturing industries are facing challenges from the advanced materials such as super alloys, ceramics and composites that are hard and difficult to machine using conventional machining methods such as turning, drilling and milling etc., as it demands high accuracy and better surface finish which increases the machining cost [1]. To meet these requirements, advanced machining is highly required. In this regard, EDM is one of the most important processes that have great potential in machining of these advanced materials [2]. It removes electrically conductive material by means of rapid and repetitive spark discharges from a pulsating direct-current power supply with dielectric flow between the work piece and the tool. The shaped tool (electrode) is fed into the work piece under servo control. A spark discharge then breaks down the dielectric fluid. The servo control maintains a constant gap between the tool and the work piece while advancing the electrode into work piece. One of the main advantages of using EDM is that since there is no contact between tool and work piece there is no mechanical force present during machining. The dielectric oil cools and flushes out the vaporised and condensed material [3]. In today's manufacturing scenario, EDM contributes a prime share in the manufacture of complex shaped dies, molds, and critical parts used in automobile, aerospace, and other industrial applications [4]. The important performance measures in EDM process are:

- MRR, measured in mm^3/min.
- Tool wear rate (TWR), measured in mm^3/min and
- Surface roughness (SR) of the eroded cavity, measured in μm.

In addition, surface finish, dimensional accuracy and geometry of the electrode, as well as the material properties, such as thermal conductivity, and wear resistance affect EDM performance measures too. Depending on the MRR, EDM can be characterized as: roughing, semi-roughing and finishing. Because of the nature of the EDM process, optimization of the process parameters is required in order to achieve the desirable performance specifications. For MRR, research work has been focused on material removal mechanism [5]-[7] and methods of improving MRR [8]-[10].

Various researchers have investigated on the effect of process parameters on different responses of EDM. In this direction, Puertas et al. [11] studied the influence of process parameters such as current intensity, pulse-on-time and pulse-off-time on dimensional accuracy and surface quality. Factorial design of experiments combined with regression technique was used. They concluded that current intensity and significant interaction between the current intensity (I) and the pulse on time (T_{on}) are the most significant factors affecting the response considered. They have also recommended working with high intensity values and low pulse on time values. Lajis et al. [12] use Taguchi design methodology to investigate the relationship of process parameters and studied responses in EDM of Tungsten carbide using graphite electrode. MRR, TWR and SR were selected as performance measures and different process parameters studied are peak current, voltage, pulse on time and pulse off time. It was concluded that, the peak current mainly affects the electrode wear rate and SR while MRR is mostly affected by pulse on time. Tomadi et al. [13] investigated on the effect of pulse on time, pulse off time, supply voltage, peak current on MRR and TWR using full factorial design. Tungsten Carbide was used as the work piece material and copper tungsten was selected as electrode. They concluded SR is mostly affected by voltage and then followed by pulse off time and peak current. They also proposed that pulse on time was most significant parameter affecting the MRR. MRR was also influenced by voltage, peak current and pulse off time. Chattopadhyay et.al [14] studied MRR, SR and electrode wear ratio (EWR) by considering three machining parameters viz. peak current,

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pulse on time and rotational speed of the electrode. They have selected (EN-8) as work piece and copper as electrode. Signal-noise ratio was calculated and ANOVA was used to establish the significance of terms. The conclusions was made that main influencing factors affecting metal removal rate and EWR in order of importance were peak current, pulse on time and electrode rotation. However, roughness was mainly influenced by peak current and then followed by electrode rotation and pulse on time. Dewangan et al. [15] investigated the effect of process parameters like pulse on time, discharge current and diameter of electrode on MRR, TWR and over cut. AISI P20 tool steel was selected to work upon with U-shaped copper tool with internal flushing system. The S/N ratios were used for minimizing the TWR and maximizing the MRR and Taguchi method was used for optimization of the process parameters. It was concluded that pulse on time was the most influencing factor for MRR followed by discharge current and the diameter of the tool. TWR is mostly affected by discharge current and least affected by diameter of tool. Rajmohan et al. [16] have carried out optimization of machining parameters in EDM of 304 Stainless Steel using design of experiment. In their work, the effect of EDM input parameters such as voltage, pulse on time, pulse off time, and current on MRR was studied. On the basis of experimental results, calculated S/N ratio, analysis of variance (ANOVA) the current and pulse off time are found to be most significant machining parameter for MRR. George et al. [17] worked on the EDM machining of carbon-carbon composite by using a Taguchi approach. Their objective was to determine the optimal setting of the process parameters on the EDM while machining carbon-carbon composites. It was observed that selecting the optimum machine parameters setting and their levels will provide the improved values of studied performance. Taweel [18] has used RSM to carry out the investigation to establish relationship of process parameters in EDM of CK-45 steel with novel tool electrode material Al-Cu-Si-TiC composite product using powder metallurgy technique. The input parameters considered for investigation are peak current, dielectric flushing pressure and pulse on time whereas response selected for studying are MRR and TWR. It was concluded that the peak current was most important factor effecting both the MRR and TWR while dielectric flushing pressure has little effect on both responses. He recommended that Al-Cu-Si-TiC electrodes were found to be more sensitive to peak current and pulse on time than conventional electrodes. Sohani et al. [19] uses the RSM approach for determining the suitability of different shapes of electrode used in EDM. They have considered four different geometries for their study namely: triangular, square, rectangular and circular. It was observed that circular cross section of electrode provides the highest MRR and lowest TWR. The result is followed by triangular, rectangular and circular cross sections.

Muthukumar et al. [20] worked on mathematical modeling for radial overcut on EDM of Incoloy 800 by RSM. The effect of different parameters like current, pulse on time, pulse off time and voltage were observed on radial overcut. ANOVA result shows that current and voltage are highly significant while pulse on time and pulse off time are not significant parameters for radial overcut. The predicted values match the experimental results reasonably well with the coefficient of determination (R^2) of 0.9699 for radial Overcut. Patel et al. [21] derived quadratic mathematical model to represent the process behaviour of EDM. Experiments have been conducted with four process parameters viz. discharge current, pulse on time, duty cycle and gap voltage to relate them with process response SR. RSM was found efficient for prediction of process response for various combinations of factor setting. Also, the significance of machining parameters selected has been established using ANOVA. The SR prediction model has been optimized using a trust region method. It was concluded that pulse-on time is found to be the dominant parameter influencing SR. Asif et al. [22] developed empirical relations between the chosen machining parameters and studied response using the RSM. The model proposed shows that voltage and rotary motion of electrode are the important parameters affecting the MRR, TWR and surface finish of machined profile. Anish et al. [23] used RSM to develop quadratic models for the machining rate, SR and dimensional deviation. Box behnken design of RSM is used for designing the experiments. It was found that the most significant parameters are pulse on time, pulse off time, peak current and spark gap voltage. They also concluded that machining rate, SR and dimensional deviations were fairly well fitted. Majhi et al. [24] presented a hybrid optimization approach for the determination of the optimal process parameters which will maximize the MRR and minimize SR and TWR. The parameters considered are current, pulse duration and pulse off time. The influences of these parameters have been optimized by multi response analysis. The designed experimental results are used in the gray relational and the weight of the quality characteristics are determined by the entropy measurement method. The effects of the parameters on the responses were evaluated by RSM, which is based on the optimization results. Subrahmanyam et al. [25] derived non-linear mathematical model to represent the process behaviour of wire EDM process. Eight different process parameters are selected for experiment. To determine optimal parameter setting, grey based Taguchi technique has been used. It was concluded that the Grey-Taguchi Method is most ideal and suitable for the parametric optimization of the Wire-Cut EDM process, when using the multiple performance characteristics. Milan et al. [26] studied the application of artificial bee colony (ABC) algorithm for optimization of MRR and SR in EDM of EN31 tool steel. The results obtained match with the experimental values. It was concluded that MRR and SR were influenced by pulse on time and discharge current. Bharti et al. [27] performed multi-objective optimization of electric-discharge machining process using controlled elitist NSGA-II. The average percentage difference between experimental and ANN's predicted value was 4 and 4.67 for MRR and SR respectively.

II. Materials and Methods

For carrying out the experiments, a die-sinking EDM machine by MMC was used. The experiments have been performed using copper electrode as tool and stainless steel as work piece. Commercial kerosene was used as a dielectric fluid. Three process parameters are selected for machining are Current (I), Spark/Pulse On time (T_{on}) and Spark Off time (T_{off}). The performance measure is MRR. The machining was generally carried out for a fixed depth of 4 mm and the amount of metal removed was measured by calculating the volume of metal removed with time. The experimental plan was prepared using CCD RSM. The results of experiments were analyzed by Minitab R 16 software at 95% confidence level. Finally, the optimum parameter setting for increasing the MRR is expressed through the main effect plot.

A. RSM

It is a statistical method that defines the relationship between input variables and output response [28]. In a problem involving two variables for a response, it is defined by:

$$y = f(x1, x2) + e \tag{1}$$

where, x_1 and x_2 are variables and the response y depends on their values, e is experimental error commonly known as noise. If the relationship between response and dependent variables is linear it can be defined by:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + e \tag{2}$$

If curvature is involved then second order response surface can be expressed as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_{11}^2 + \beta_{22} x_{22}^2 + \beta_{12} x_1 x_2 + e \tag{3}$$

RSM is used for the analyzing the MRR. CCD is implemented to estimate a second-degree polynomial model, which is still only an approximation at best.

III. Experimentation

The main objective of experimental design is studying the relations between the various parameter levels affecting the response. Design of experiments (DOE) is a tool which is used to study the effects of individual factors as well as their interactions. It also allows achieving the optimum results with minimum number of experiments [29]. In the present study, to reduce the experimental runs Face-centered central composite design (FCCCD) is used. The Face-centered CCD involves 20 experimental observations at three independent input variables. It includes eight star points and six central points (coded level 0), acts as the midpoint between the high (+) and low (-) levels, with alpha=1. For the experimentation, three important process parameters are selected; Current (I), Spark On time (T_{on}) and Spark Off time (T_{off}). The performance measure is MRR. 20 holes were machined as per experimental design. The depth of hole was fixed as 4 mm. Control factors and their levels selected for experimentation are as given in Table I. Maximum and minimum values of each factor are coded into +1 and -1, respectively. Table II presents the experimental matrix that was adopted in this study in the coded form along with the MRR obtained at different parameters setting.

TABLE I
Control Factors and Their Levels

Factors	Symbol	Units	Levels		
			-1	0	1
Current	A	Ampere	5	10	15
Spark on time (T_{on})	B	Microsecond (μs)	150	300	450
Spark off time (T_{off})	C	Microsecond (μs)	90	50	210

TABLE II
Plan for Central Composite Rotatable Second-Order Design: Different Controlling Parameters and Results

Experiment No.	I (Amperes)	T_{on} (μs)	T_{off} (μs)	MRR (mm^3/min)
1	-1	-1	-1	1.587
2	1	-1	-1	20.685
3	-1	1	-1	1.844
4	1	1	-1	25.052
5	-1	-1	1	1.172
6	1	-1	1	20.260
7	-1	1	1	3.304
8	1	1	1	27.309
9	-1	0	0	2.369
10	1	0	0	24.670
11	0	-1	0	8.058
12	0	1	0	11.652
13	0	0	-1	10.309
14	0	0	1	10.969
15	0	0	0	10.946
16	0	0	0	10.725
17	0	0	0	11.076
18	0	0	0	10.876
19	0	0	0	10.843
20	0	0	0	10.650

IV. Results and Discussion

Analysis of results is made using Minitab R16 software at 95% of confidence level. The significance of terms and their interactions are established by ANOVA table (Table III). If p value is less than 0.05, corresponding term and interaction is significant. For lack of fit, p value must be greater than 0.05. An insignificant lack of fit is desirable because it indicates any term left out of model is not significant and developed model fits well.

From ANOVA Table III, it can be clearly observed that all the linear terms have significant effect on MRR. The interaction of A x B and B x C are significant whereas A x C don't have any impact on MRR. The value of R2 was found to be 99% which shows model is well suited to explain the variation in result of Minitab. MRR is calculated as general form in which the response surface is described as an equation [30]. Thus, after analysis MRR is rewritten according to the three variables used as:

$$MRR = 10.8027 + 10.7700\,A + 1.73990\,B + 0.353700\,C + 2.7913\,A^2 - 0.872773\,B^2 - 0.0887727\,C^2 + 1.12838\,(A \times B) + 0.0983750\,(A \times C) + 0.569625\,(B \times C) \quad (4)$$

where, A, B and C corresponds to I, T_{on} and T_{off}. Typical Response surface plot is shown in Fig. 1. It can be clearly observed from the plot (a) that MRR continues increasing with increase in current. The reason is, as the value of current increases the diameter of plasma increases. Also, the energy of plasma increases which increases the MRR. Also, Fig. 1 (a) explains that as the T_{on} increases the MRR also increases because of formation of larger crater at increased T_{on}. Fig. 1 (b) depicts that MRR increase with T_{on}. Lastly, it can be also observed from Fig. 1 (b) that MRR also increases with T_{off} because increase in spark off time provides sufficient time for removal of formed crater thus enhancing MRR.

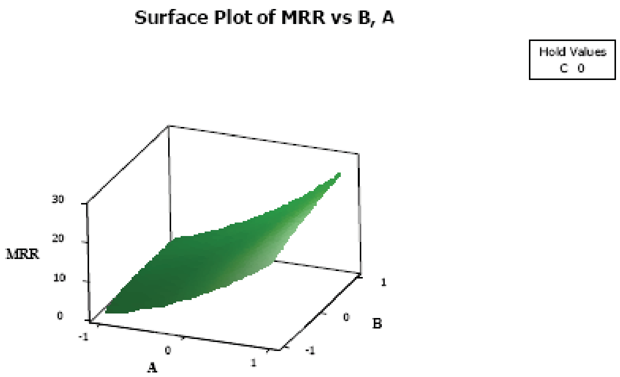
TABLE III
ANOVA TABLE FOR MRR

Source	DOF	MRR in mm³/min			
		SS	MS	F	P
A	1	1159.93	1159.93	18678.82	0.000
B	1	30.27	30.27	487.49	0.001
C	1	1.25	1.25	20.15	0.006
A*A	1	24.53	21.43	345.14	0.000
B*B	1	2.63	2.09	33.73	0.000
C*C	1	0.02	0.02	0.35	0.568
A*B	1	10.19	10.19	164.03	0.000
A*C	1	0.08	0.08	1.25	0.290
B*C	1	2.60	2.60	41.80	0.000
Error	10	0.62	0.06		
Total	19	1232.11			

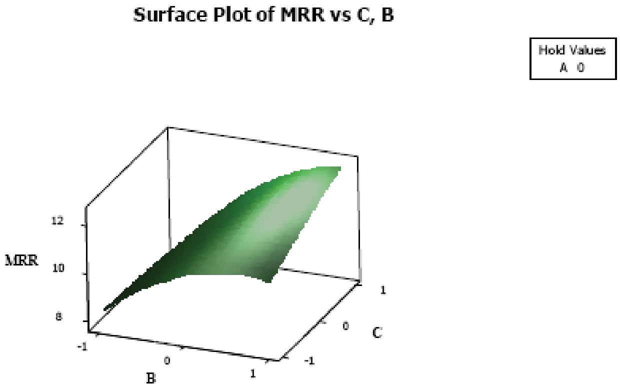
AD plot given in Fig. 2 shows that the residues are normally distributed. Maximum number of points is near the central control line.

Also during the analysis, the value of regression ($R^{2)}$ and R^2 adjusted is 99.91% and 99.82. How well the estimated model fits the data can be measured by the value of R^2. The R^2 lies in the interval [0, 1]. When R^2 is closer to the 1, the better the estimation of regression equation fits the sample data. However, adding a variable to the model always increased R^2, regardless of whether or not that variable statistically significant. Thus, some experimenter rather using adjusted-R^2. When variables are added to the model, the adjusted- R^2 will not necessarily increase. In actual fact, if unnecessary variables are added, the value of adjusted R^2 will often decrease. Both of $R^2$and adjusted- R^2 are statistically significant for the response variables RSE and Yield.

The optimum parameter setting for maximum MRR during EDM of mild steel using copper electrode is presented through the mean effect plot as shown in Fig. 3. It is found that first level of current (A_1), first level of pulse on duration, T_{on} (B_1) and second level of pulse off duration, T_{off} (C_2) results minimum value of MRR while machining of mild steel in EDM process. However, third level of current (A_3), third level of pulse on duration, T_{on} (B_3) and third level of pulse off duration, T_{off} (C_3) results in maximum MRR. Thus, as per the requirement (maximum MRR) the optimum parameter setting for maximizing MRR is found as 15 amperes current, 450 µm spark on time (T_{on}) and 210 µm spark off time (T_{off}).



(a)



(b)

Fig. 1 Response surface plots of MRR for significant interactions (a). IxT_{on} (b) T_{on} xT_{off}

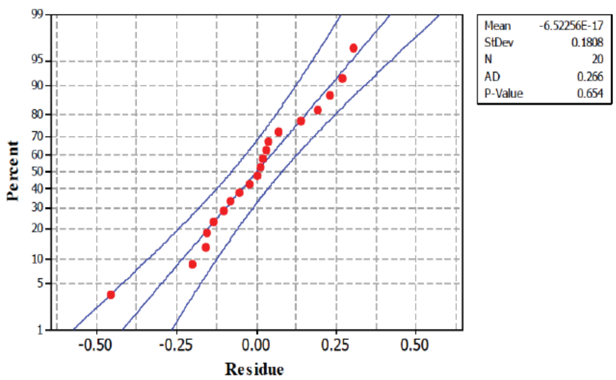


Fig. 2 AD plot for MRR

V. CONCLUSION

RSM was adopted to study the effect of different process parameters (I, T_{on}, T_{off}) on the MRR. In accordance with response surface design matrix, 20 different holes were machined to analyze the MRR. The depth of hole was fixed at

4mm. The analysis of the experimental observations highlights that the metal removal rate in EDM is greatly influenced by the various process parameters (I, T_{on} and T_{off}) considered in the present study. The metal removal rate increases with an increase of peak current (I), and pulse off time (T_{off}). However, it is maximum at least and highest value of pulse on time (T_{on}). The mathematical models have been developed utilizing the data from practical observation. In accordance with the value of R^2, the model can be used to predict the results parameters not considered in the present study.

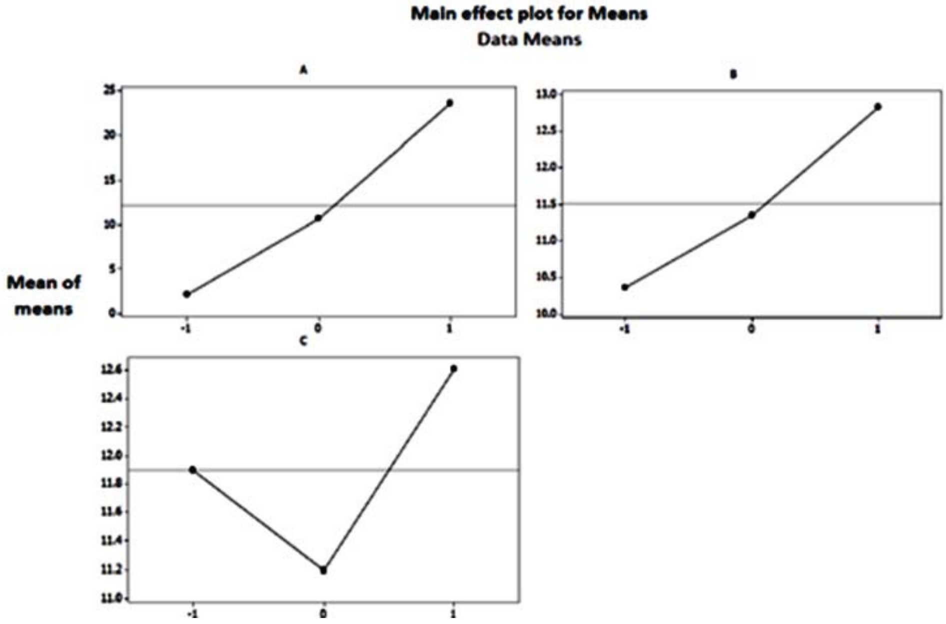


Fig. 3 Main effect plot for MRR

REFERENCES

[1] J. Kozak, and K.P. Rajurkar, "Hybrid machining processes: Evaluation and development," *Proceedings of 2nd International Conference on Machining and measurement of sculptured surfaces,* Krakow, 2001, p. 501-536.

[2] H. Ramasawmy, and L. Blunt, "Effect of EDM process parameters on 3D surface topography," *Journal of Materials Processing Technology*, vol. 148, pp. 155-164, 2004.

[3] R. Williams, "Machining Hard Materials. Dearborn, MI: Machining Data Handbook" 3rd ed. vol. 2, Society of Manufacturing Engineers: 1980.

[4] K. Ho, and S. Newman, "State of the art electrical discharge machining (EDM)," *International Journal of Machine Tools & Manufacture*, vol. 43, pp. 1287-1300, 2000.

[5] J. Soni, and G. Chakraverti, "Experimental investigation on migration of material during EDM of T 215 Cr12 die steel," *Journal of Materials Processing Technology*, vol. 56, pp. 439-451, 1996.

[6] F. Roethel, L. Kosec, and V. Garbajs, "Contributions to the micro-analysis of spark eroded surfaces," *Annals of the CIRP*, vol. 25, no. 1, pp. 135-140, 1976.

[7] A. Erden, "Effect of materials on the mechanism of electric discharge machining (EDM)," *Journal of Engineering and Material Technology*, vol. 105, pp. 132-138, 1983.

[8] M. Bayramoglu, and A. W. Duffill, "Manufacturing linear and circular contours using CNC EDM and frame type tools," *International Journal of Machine Tools and Manufacture,*1995; vol. 35, no. 8, pp. 1125-1136, 1995.

[9] M. Bayramoglu, and A. W. Duffill, "Production of three dimensional shapes using computational electrical discharge machining," *In Proc. Int. M.T.D.R.,* pp. 107-112, 1992.

[10] K. Saito, T. Kishinami, H. Konno, M. Sato, and H. Takeyama, "Development of numerical contouring control electrical discharge machining (NCC-EDM)," *Ann. CIRP,* vol. 35, no. 1, pp. 117-120, 1986.

[11] I. Puertas, and C.J. Lusis, "A study on the machining parameters optimization of electrical discharge machining," *Journal of materials processing technology*, vol. 143-144, pp. 521-526, 2003.

[12] M. A. Lajis, H.C.D. Mohd Radzi, and A. K. M. Nurul Amin, "The Implementation of Taguchi Method on EDM Process of Tungsten Carbide," *European Journal of Scientific Research*, vol. 36, no. 4, pp. 609-617, 2009.

[13] S. H. Tomadi, M. A. Hassan, and Z. Hamedon, "Analysis of the Influence of EDM Parameters on Surface Quality, Material Removal Rate and Electrode Wear of Tungsten Carbide," *International Multi Conference of Engineers and Computer Scientists*: 2, 2009.

[14] K. D. Chattopadhyay, S. Verma, P. S. Satsangi, and P. C. Sharma, "Development of empirical model for different process parameters during rotary electrical discharge machining of copper–steel (EN-8) system‖," *Journal of materials processing technology,* vol. 20, no. 9, pp. 1454-1465, 2008.

[15] S. Dewangan, and C. K. Biswas, "Experiment Investigation of Machining Parameters for EDM Using U- shaped Electrode of AISI P20 Tool Steel," *International conference on emerging trends in mechanical engineering* :1-6, 2011.

[16] T, Rajmohan, R., Prabhu, G., Subba Rao, and K., Palanikumar, "Optimization of Machining Parameters in Electrical Discharge Machining (EDM) of (304) stainless steel," *International Conference on Modeling, Optimization and Computing (ICMOC):* 103-1036, 2012.

[17] P. M. George, B. K.Raghunath, L. M. Manocha, and A. M. Warrier, "EDM machining of carbon-carbon composite- a taguchi approach," *Journal of Materials Processing Technology*, vol. 145, no. 1, pp. 66-71, 2003.

[18] T. A. El-Taweel, "Multi-response Optimization of EDM with Al-Cu-Si-TiC P/M Composite Electrode," *International Journal of Advance Manufacturing Technology*, vol. 44, pp. 100-113, 2009.

[19] M. S. Sohani, V. N. Gaitonde, B. Siddeswarappa, and A. S. Deshpande, "Investigations into the Effect of Tool Shapes with Size Factor consideration in Sink Electrical Discharge Machining (EDM) Process," *International Journal of Advance Manufacturing Technology*, vol. 45, pp. 1131-1145, 2009.

[20] V. Muthukumar, N. Rajesh, R. Venkatasamy, A. Sureshbabu, and N. Senthilkumar, "Mathematical Modelling for Radial Overcut on Electrical Discharge Machining of Incoloy 800 by Response Surface Methodology," *Procedia material science*, vol. 6, pp. 1674-1682, 2014.

[21] K. M. Patel, P. M. Panday, and P. V. Rao, "Determination of an Optimum Parametric Combination Using a Surface Roughness Prediction Model for EDM of Al2O3/SiCw/TiC Ceramic Composite‖," *Journal of Materials and Manufacturing Processes*, vol. 24, pp. 675-682, 2009.

[22] Asif Iqbal, A. K. M., Khan, and Ahsan Ali, "Modeling and Analysis of MRR, EWR and Surface Roughness in EDM Milling through Response Surface Methodology‖," *American Journal of Engineering and Applied Sciences,* vol. 3, no. 4, pp. 611-619, 2010.

[23] A. Kumar, V. Kumar, and J. Kumar, "Prediction of Surface Roughness in Wire Electric Discharge Machining (WEDM) Process based on Response Surface Methodology," *International Journal of Engineering & Technology*, vol. 2, no. 4, pp. 708-719, 2014.

[24] S. K. Majhi, M.K Pradhan, and Hargovind Soni, "Optimization of EDM parameters using RSM, GRA and Entropy method," *International Journal of Applied Research in Mechanical Engineering*, vol. 3, no. 1, pp. 82-87, 2013.

[25] S. V. Subrahmanyam, and M. M M. Sarcar, "Evaluation of Optimal Parameters for machining with Wire cut EDM Using Grey-Taguchi Method," *International Journal of Scientific and Research Publications*, vol. 3, no. 3, pp. 1-9, 2013.

[26] Milan Kumar Das, Kaushik Kumar, Tapan Kr. Barman,and Prasanta Sahoo, "Application of Artificial bee Colony Algorithm Optimization of MRR and Surface Roughness in EDM of EN31 tool steel," *Procedia material science*, vol. 6, pp. 741-751, 2014.

[27] P. S. Bharti, S. Maheshwari, and C. Sharma, "Mmulti-objective optimization of electric-discharge machining process using controlled elitist NSGA-II. *Journal of mechanical science and technology*, vol. 26, no. 6, pp. 1875-1883, 2012.

[28] C. Montgomery, "Design and Analysis of Experiments," Response surface method and designs. John Wiley and Sons, Inc., New Jersey, 2005.

[29] A.N. Armstrong, "Pharmaceutical Experimental Design and Interpretation," New York. Taylor & Francis group, 2006.

[30] M. Fattouh, M. Elkhabeery, and A.H. Fayed, "Modelling of some response parameters in EDM," *In: AME Fourth Conference Military Technical College*, Cairo, Egypt.1990.

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