Mechanics and Mechanical Engineering
Vol. 21, No. 1 (2017) 57–66

Optimization of Surface Roughness for Duplex Brass Alloy in EDM Using Response Surface Methodology

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Received (21 October 2016)
Revised (6 November 2016)
Accepted (11 December 2016)

In recent scenario, Duplex brass alloy have drawn many attention of researchers due to the properties such as excellent corrosive resistance, machinability, ductile and easy of fabrication. In present work, the alloy is fabricated by stir casting technique and the machinability was studied during Electric Discharge Machining. In this experiment the control parameters such as current, voltage, pulse on time and flushing pressure were considered to study the effect on Surface roughness (Ra). Response surface methodology (RSM) was used to design the experiment using Box - Behnken design (BBD). An attempt has been made to investigate find out the best optimal parameter for the machining the alloy. The response model has been validated with analysis of variance (ANOVA). Peak current was identified as the significant factor affecting the surface roughness during machining.

Keywords: Electrical Discharge Machining (EDM), duplex brass, Response Surface Methodology (RSM), MRR, EWR.

1. Introduction

EDM was the most unconventional machining process in current trend due to their advantages like good surface finish, chip less process, high accuracy, machining complicated shapes and drilling fine holes. The controlled application of high frequency electrical discharges makes the work piece material to melt in a specific area. EDM is selected for machining the electrical conductive materials in the presence of a dielectric fluid. The basic principle of EDM is transformation of electrical energy into thermal energy through a series of discrete electrical discharges between the electrode and work piece. Combined effect of controlled pulse of direct current forms electric discharge. EDM has a high capability of machining the precise cavities of dies and moulds. However, the surface quality aspect of electro discharge machined component is important to meet the requirements of component performance, longevity and reliability. In order to increase the machining efficiency, the surface roughness must be minimized in the EDM process. Therefore, in EDM, it is necessary to minimize the surface roughness by optimizing the process. RSM has been proposed to minimize the surface in EDM process. A mathematical model was established to predict the relationship among the process parameter of EDM and response Ra by using RSM. As a consequence, optimal parameters that are required under various operational conditions of EDM were acquired. D Kanagarajan et al. [1] developed models for the MRR and SR over the most influencing process parameters in EDM of WC/30% Co composites. The RSM methodology is used to identify the most influential parameters for maximizing metal removal rate and for minimizing the surface roughness. Zhang et al. [2] have investigated the effects on material removal rate, surface roughness and diameter of discharge points in electro-discharge machining (EDM) on ceramics. From the experimental results, they have shown that the material removal rate, surface roughness and the diameter of discharge point all increase with increasing pulse-on time and discharge current. Tsai and Wang [3] have established a semi-empirical model of surface finish on work for various materials (three different grades of steel) in electrical discharge machining and the parameters of the model viz. peak current, pulse duration, electric polarity and properties of materials have been fitted based on the experimental data using Taguchi method. It is seen that the developed model is dependent on work and tool materials. Routara et al. [4] developed the roughness models of EDM process for three different roughness parameters using response surface method. Study shows that the machining parameters, pulse current and pulse on time, have the maximum influence on the roughness parameters while pulse of time has no significant effect on roughness parameters. Bhattachrya et al. [5] implemented Response Surface Methodology (RSM) to develop a mathematical model for correlating the process parameter with the responses. Zarepour et al [6] investigated the effect of machining parameters of the EDM process, including on-time, current, voltage, the engaging time between workpiece and electrode, and pre–EDM roughing on electrode wear were experimentally investigated. Kao et al. [7] optimized the EDM parameters, for EWR, MRR and surface roughness as the performance characteristics of the EDM machining of Ti6Al4V alloy. Pradhan et. al. [8] established quite a few surface models based on various RSM models taking the effects of a number of parameters under consideration. They later developed a regression model, it was noted that the model produces a lot of reliable surface roughness prediction for a given work under different process conditions. D. C. Montgomery, [9] The response surface methodology approach is the procedure for determining the relationship between various process parameters with various machining criteria. In this work also RSM is used to determine the relationship between the input process parameters of EDM with surface roughness [9]. The response surface methodology approach is the procedure for determining the relationship between various process parameters with various machining criteria. In this work also RSM is used to determine the relationship between the input process parameters of EDM with surface roughness. M. R. Shabgard et al. [10] suggested mathematical models for relating the Material Removal Rate (MRR), Tool Wear Ratio (TWR) and Surface Roughness (SR) to machining parameters. Response Surface Methodology (RSM) approach is used to determine the relationship between various process parameters and machining criteria of FW4 welded steel. Asif Iqbal et al. [11] used Response surface methodology to investigate the relationships and parametric interactions between three controllable variables on the MRR, EWR and Ra in EDM milling of AISI 304 steel. Developed models can be used to get the desired responses within the experimental range. El-Taweel T. A. [12] investigated the relationship of process parameters in EDM of CK45 steel with electrode of composite material such as Al-Cu-Si-TiC. The RSM was employed for developing models of MRR and TWR and found that experimental and predicted values are in good agreement. The objective of this paper is to study the influence of machining parameters of EDM on Duplex brass alloy and minimizing Surface roughness characteristics. The second order mathematical models in terms of machining parameters are developed for Surface roughness prediction using response surface methodology (RSM) on the basis of experimental results.

2. Experimental details

2.1. *Material and methods*

In this experimental work, Duplex brass alloy was selected as the work piece material. Stir casting have the advantages of simplicity, flexibility and applicability to large quantity production with homogeneous distribution of reinforcement in the matrix as it has a strong impact on the properties and the quality of the material. A stirring system has been developed by the motor with regulator and a cast stirrer. To ensure the proper mixing of melts, all the melting was carried out in a graphite crucible in an open hearth furnace. Billet of tin is melted at temperature 240^{o}C followed by addition of Copper at temperature 1100^{o}C. The mixture is stirred continuously. Then the billet of zinc is introduced in to the graphite crucible. The mixture is stirred well so that the added metals to be distributed uniformly throughout the composition. The alloy slurry was poured in a sand mould designed to get standard specimens of size 100 x 50 x 8.5 mm. The composition of alloy shown in the Tab. 2. The drilled operation was made in the cast material using Electrical Discharge Machine and the details of level of parameters are given in Tab. 1. Fig. 1 shows the EDM setup. Roughness of a surface (R_a) is a measure of the texture of a surface. It is counted by the vertical nonconformities of the real surface from the perfect surface. If this deviation is large, the surface is said to be rough and if they are minor, the surface is smooth. Roughness measurement is measured using the Mitutoyo Talysurf (SJ-201). Tab. 2 shows the experimental results of output parameters.

Figure 1 EDM used for machining

Table 1 Level of parameters

Parametrs	Low level	Medium level	High level
Current [A]	10	12.5	15
Voltage [V]	30	40	50
Pulse on time [μs]	70	85	100
Flushing pressure [Kgf/cm^2]	0.10	0.15	0.20

Table 2 Composition of duplex brass alloy

Elements	Weight [%]
Copper	55.56
Zinc	37.01
Oxygen	2.96
Lead	1.47
Tin	1.93
Iron	1.08

3. Results and discussion

3.1. *Design of experiments*

The design of experiments (DOE) is the design of any task that aims to describe or explain the variation of information under conditions that are hypothesized to reflect the variation. These strategies were originally developed for the model fitting of physical experiments, but can also be applied to numerical experiments. The objective of DOE is the selection of the points where the response should be evaluated. The main idea of RSM is to use a sequence of designed experiments to obtain an optimal response. Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. The objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response. In this work, response surface modelling (RSM) is utilized for determining the relations between the various EDM process parameters with the various machining criteria and exploring the effect of these process parameters on the response, i.e. surface roughness (Ra). Box–Behnken designs are experimental designs for response surface methodology, to achieve the following goals:

1. Each factor, or independent variable, is placed at one of three equally spaced values, usually coded as -1, 0, +1. (At least three levels are needed for the following goal).

2. The design should be sufficient to fit a quadratic model, that is, one containing squared terms and products of two factors.

3. The ratio of the number of experimental points to the number of coefficients in the quadratic model should be reasonable (in fact, their designs kept it in the range of 1.5 to 2.6).

4. The estimation variance should more or less depend only on the distance from the centre (this is achieved exactly for the designs with 4 and 7 factors), and should not vary too much inside the smallest (hyper) cube containing the experimental points.

From Tab. 3, the model F-value of 11.21 implies the model is significant. There is only a 0.01% chance that an F–value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, AC, A∧2 are significant model terms. The "Pred R-Squared" of 0.6748 is in reasonable agreement with the "Adj R–Squared" of 0.8362; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Adeq Precision ratio of 13.753 indicates an adequate signal. This model can be used to navigate the design space.

3.2. *Mathematical modeling for surface roughness (Ra)*

A proposed mathematical model between surface roughness (Ra) and the independent variables such as current, voltage, pulse on time and flushing pressure. This is

Table 3 Experimental results for machining of duplex brass alloy using EDM

S. No.	Current [A]	Voltage [V]	Pulse on time [μs]	Flushing pressure [Kgf/cm^2]	Surface roughness [μm]
1	10	50	85	0.15	3.5
2	10	40	70	0.15	3.1
3	12.5	30	85	0.1	3.75
4	12.5	30	100	0.15	3.8
5	12.5	50	100	0.15	4.1
6	10	40	85	0.2	3.11
7	12.5	40	85	0.15	3.9
8	15	40	70	0.15	4.5
9	12.5	30	85	0.2	3.9
10	12.5	30	70	0.15	4.78
11	15	40	85	0.1	7
12	12.5	40	85	0.15	3.57
13	12.5	50	85	0.1	3.21
14	10	30	85	0.15	2.01
15	12.5	40	85	0.15	4.06
16	10	40	85	0.1	2.111
17	12.5	50	85	0.2	2.99
18	12.5	50	70	0.15	3.011
19	10	40	100	0.15	2.032
20	12.5	40	100	0.1	2.56
21	12.5	40	70	0.2	2.99
22	15	50	85	0.15	7.11
23	15	30	85	0.15	6.99
24	12.5	40	100	0.2	3.8
25	12.5	40	70	0.1	3
26	12.5	40	85	0.15	3.102
27	15	40	100	0.15	8.6
28	12.5	40	85	0.15	5.34
29	15	40	85	0.2	6.8

the final equation in terms of actual factors.

$$
\begin{aligned}
\text{Surface roughness (Ra)} \quad = \quad & 43.74469 - 5.16663A - 0.13056B - 0.36390C \\
& +60.34233D - 0.013700AB + 0.034453AC \\
& -2.39800AD + 3.44833E - 033BC - 0.18500BD \\
& +0.41667CD + 0.15935A^2 + 3.19250E - 004B^2 \\
& -1.45700E - 003C^2 - 183.73000D^2
\end{aligned}
$$

The above equation can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for

Table 4 ANOVA for response surface quadratic model

Source	Sum of square	df	Mean squares	F value	p value Prob>F	
Model	73.58	14	5.26	11.21	< 0.0001	significant
A-Current	52.66	1	52.66	112.27	< 0.0001	
B-Voltage	0.14	1	0.14	0.30	0.5898	
C-Pulse on time	1.03	1	1.03	2.19	0.1610	
D-Flushing pressure	0.32	1	0.32	0.68	0.4228	
AB	0.47	1	0.47	1.00	0.3342	
AC	6.68	1	6.68	14.24	0.0021	
AD	0.36	1	0.36	0.77	0.3961	
BC	1.07	1	1.07	2.28	0.1531	
BD	0.034	1	0.034	0.073	0.7910	
CD	0.39	1	0.39	0.83	0.3769	
A^2	6.43	1	6.43	13.72	0.0024	
B^2	$6.611 \cdot 10^{-3}$	1	$6.611 \cdot 10^{-3}$	0.014	0.9072	
C^2	0.70	1	0.70	1.49	0.2429	
D^2	1.37	1	1.37	2.92	0.1097	
Residual	6.57	14	0.47			
Lack of fit	3.77	10	0.38	0.54	0.8057	
Pure error	2.80	4	0.70			
Cor total	80.15	28				

each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

The following is the final equation in terms of coded factors

$$
\begin{aligned}
\text{Surface roughness (Ra)} \quad = \quad & 3.99 + 2.09A - 0.11B + 0.29C + 0.16D - 0.34AB \\
& +1.29AC - 0.30AC - 0.30AD + 0.52BC - 0.092BD \\
& +0.31CD + 1.00A^2 + 0.032B^2 - 0.33C^2 - 0.46D^2
\end{aligned}
$$

The above equation can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low level of the factors are coded as -1.This equation is useful for identifying the relative impact of the factors by comparing the factor coefficient.

3.3. *Control parameters influence on the surface roughness*

The surface roughness model has been tested through the analysis of variance. The results of the analysis justify the closeness of fit of the mathematical model. From Fig. 2a, it is to be noted that SR increases with increase in Current and Voltage respectively. At the lower value of current and Voltage, SR Value is less. From Fig.

2b, the SR does not vary linearly with increase in current and pulse on time. At the higher level of current and pulse on time, SR value is high. From Fig. 2c It is clearly shown that SR is increasing linearly with increase in current and flushing pressure. From Fig. 3a shows that surface roughness slightly increase with increase of pulse on time and voltage. From Fig. 3b shows that pulse on time and voltage slightly affect the surface roughness. From Fig. 3c shows that middle level of flushing pressure, pulse on time have higher value surface roughness with compared to starting and ending level of flushing pressure, pulse on time.

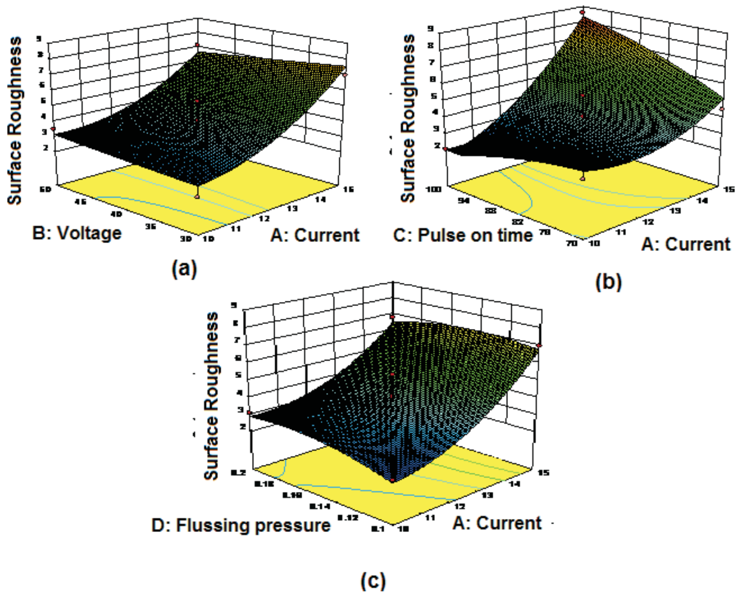

Figure 2 Effect of: a) voltage and current, b) pulse on time and current, c) flushing pressure and current on surface roughness

From Fig. 4a shows that all the points fall near the straight line,the reasonable normality, normal errors distributed are adequate and the developed model is fitted with the observed values. From Fig. 4b predicted and actual responses lies on a straight line which implies that the model adequate without any violation.

3.4. *Optimal parameters*

For the purpose of achieving controlled electro–discharge machining, optimal combination of the various process–variable effects with the Ra values, can be analyzed based on the developed mathematical models. Tab. 4 shows the optimal solutions. The optimal search was formulated for the various process variable conditions based on minimizing the Ra values.

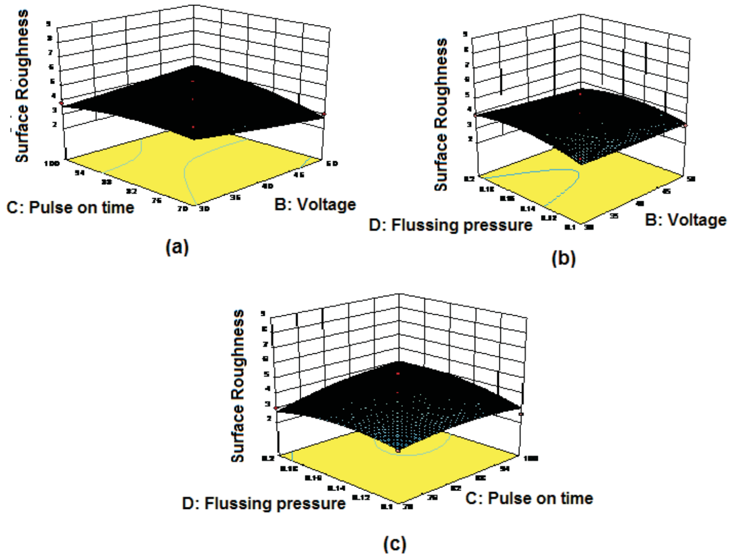

Figure 3 Effect of: a) voltage and pulse on time, b) voltage and flushing pressure, c) flushing pressure and pulse on time on surface roughness

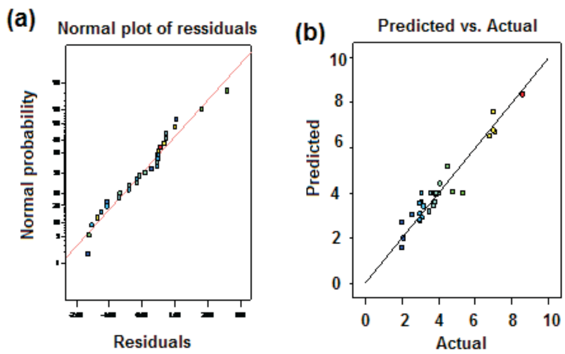

Figure 4 a) Normal probability plot Vs residual for Ra, b) Predicted Vs actual for Ra

Table 5 Optimal solutions

Current	Voltage	Pulse on time	Flushing pressure	Surface roughness
12.500	39.561	71.271	0.196	2.989

4. Conclusion

The analysis of the experimental observations highlights that the surface roughness in electrical discharge machining are greatly influenced by the various dominant process parameters considered. The mathematical models have been developed by utilizing the data from practical observable conditions of the electrical discharge machining of alloy on the basis of RSM. From ANOVA analysis peak current is the significant factor affecting the surface roughness of the machined surface.

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