Parametric Optimization of Process Parameters of EDM for SS304 by Using Design of Experiments Method

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Abstract: ***EDM has become an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. It is widely used in the process of making moulds and dies and sections of complex geometry and intricate shapes. The work-piece material has been selected for this experiment is AISI304 Stainless steel taking into account its wide usage in industrial applications. In today's world 304 Stainless steel contributes to almost half of the world's production and consumption for industrial purposes. The input variable parameters are discharge current, pulse on time and pulse off time. Taguchi method is applied to create an L18 orthogonal array of input variables using the Design of Experiments (DOE). The effect of the variable parameters mentioned above upon machining characteristics such as Material Removal Rate (MRR), will be carried out for optimization and investigation. The tool material will be chosen as copper electrode whose shape and size is cylindrical bar of 10 mm diameter. And the work-piece material is 5mm thick 304 stainless steel plate.***

Keywords: Taguchi method, MRR, electrically conductive materials etc.

1. Introduction

Electrical Discharge Machining, commonly known as EDM is a non-conventional machining method used to remove material by a number of repetitive electrical discharges of small duration and high current density between the work piece and the tool. EDM is an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. In EDM, since there is no direct contact between the work piece and the electrode, hence there are no mechanical forces existing between them. Any type of conductive material can be machined using EDM irrespective of the hardness or toughness of the material.

In this process the material is removed from the work piece due to erosion caused by rapidly recurring electrical spark discharge between the work piece and the tool electrode. There is a small gap between the tool and the work piece. The work piece and tool both are submerged in dielectric fluid, commonly used are EDM oil, de-ionized water, and kerosene.

Basically there are two types of EDM: Die-sinking EDM and Wire-cut EDM

1.1. Die-sinking EDM

Die-sinking EDM, also known as Volume EDM or cavity type EDM consists of an electrode and a work piece which is submerged in an insulating fluid such as oil or other dielectric fluids.

1.2. Wire-cut EDM

Wire-cut EDM, also known as Spark EDM is mostly used when low residual stresses are required, as it does not needs high cutting forces for removal of material.

2. Methodology Used

For fabricating arrayed structures, the output response such as MRR was measured. The measurement approach of these output response was discussed as below:

2.1. MRR is defined as the ratio of the difference of weight of the work piece before and after machining to the machining time and density of the material as shown in below:

MRR = $\frac{Wi-Wf}{D*t}$ mm^3/min.

Where,
Wi = weight before machining (gm),
Wf = weight after machining (gm),
D = density of work piece material (gm/mm^3)
t = time consumed for machining (min.).

2.2. Performance evaluation using Taguchi's S/N ratio

Taguchi method uses a statistical tool to measure performance characteristics known as signal-to-noise (S/N) ratio to find out the optimum settings for the design parameters and it (S/N ratio) consists of both the mean and the variability of performance characteristics. This method tries to select the design parameter in order to maximize the S/N ratio because higher the S/N ratio the more balanced the adoptable is the performance quality. There are three criterions of signal-to-noise ratios which are lower-the-better (LTB), the higher-the-better (HTB), and nominal-the-best (NTB). In present work one response is considered material removal rate (MRR). Material removal rate is need to be maximize. So, for calculating S/N ratio of material removal rate HTB criterion should be selected. The equation for aforesaid two criterions is given below:

- **Lower-is-Better (LTB) criterion:**

$$\text{S/N ratio} = -10\log\left(\frac{1}{n}\sum y^2\right)$$

- **Higher-is-Better (HTB) criterion:**

$$\text{S/N ratio} = -10\log\left(\frac{1}{n}\sum \frac{1}{y^2}\right)$$

Here, y is average of all observed value and n is number of observations. So this method is useful only for optimization of a single performance characteristic. Optimization of design parameters with more than one performance characteristics are still an area of research.

3. Experimentation

3.1 Copper Electrode Properties

Copper and copper alloys have better EDM wear resistance than brass, but are more difficult to machine than either brass or graphite. It is also more expensive than graphite. Copper is, however, a common base material because it is highly conductive and strong. It is useful in the EDM machining of tungsten carbide, or in applications requiring a fine finish.

Copper tungsten materials are composites of tungsten and copper. They are produced using powder metallurgy processes. Copper tungsten is very expensive compared to other electrode materials, but is useful for making deep slots under poor flushing conditions and in the EDM machining of tungsten carbide. Copper tungsten materials are also used in resistance welding electrodes and some circuit breaker applications.

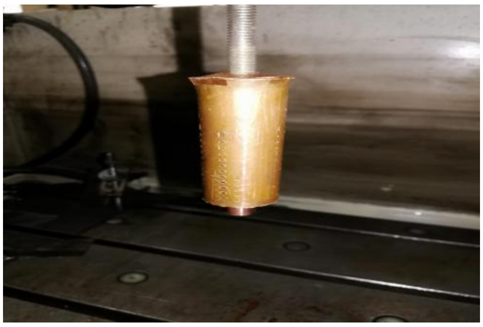

Figure 1: Copper Electrode used in experiment

3.2 Chosen Work-piece Material

AISI304 Stainless Steel is still sometimes referred to by its old name 18/8 which is derived from the nominal composition of type 304 being 18% chromium and 8% nickel. Stainless steel 304 has excellent corrosion resistance in a wide variety of environments and when in contact with different corrosive media. Pitting and crevice corrosion can occur in environments containing chlorides. Stress corrosion cracking can occur at temperatures over 60°C.

Stainless steel 304 has good resistance to oxidation in intermittent service up to 870°C and in continuous service to 925°C. However, continuous use at 425-860°C is not recommended if corrosion resistance in water is required. In this instance 304L is recommended due to its resistance to carbide precipitation.

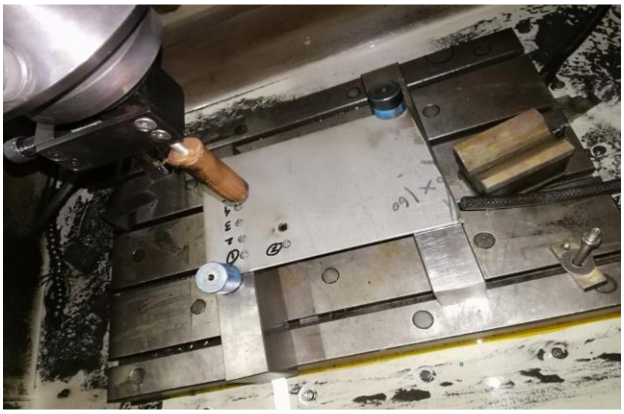

Figure 2: Experimental setup of Copper tool and Work-piece

Figure 3: Display Panel of EDM for taken readings

The above display panel is associated with the control of CNC operated EDM where the values are feed at allocated parameters. And after machining the readings are noted down.

In the current study, the machining was done by choosing discharge current (Ip), pulse-on time (Ton) and pulse-off time (Toff) as input parameters and the other parameters such as duty factor (τau) equal to 80 % and gap voltage of 50 V are kept constant throughout the experiment.

Table 1: Allocated Values of EDM parameters and their levels

Parameters		Units	Level 1	Level 2	Level 3
A	Discharge current (I_p)	Amps.	10	6	3
B	Pulse on time (T_{on})	μs	400	200	100
C	Pulse off time (T_{off})	μs	32	20	10

4. Results and Discussion

Based on the above limitation of EDM the designed experiment is performed and calculation is done. And found that which combination of machined parameters is best suited for industry application to get higher material removal rate over the work-piece.

Table 2: Calculation table by DoE (Design of experiment) Matrix of L18 Orthogonal array (OA)

Sl. No.	Current (I_p) (Amperes)	T_{on} (micro seconds)	T_{off} (micro seconds)	Calculation of MRR (mm^3/Min.)
1	10	400	32	0.0156
2	10	200	20	0.0105
3	**10**	**100**	**10**	**0.0625**
4	6	400	32	0.0084
5	6	200	20	0.0083
6	6	100	10	0.0028
7	3	400	20	0.0027
8	3	200	10	0.0018
9	3	100	32	0.0015
10	10	100	10	0.0133
11	10	200	32	0.0041
12	10	400	20	0.0189
13	6	100	20	0.0027
14	6	200	10	0.0055
15	6	400	32	0.0067
16	3	100	10	0.0008
17	3	200	32	0.0004
18	3	400	20	0.0047

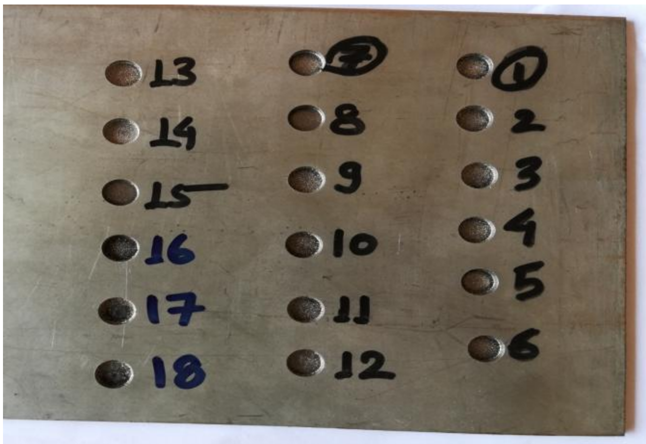

Figure 4: Image of work-piece after L18 experiment in EDM

4.1 Influences on MRR

The S/N ratios for MRR are calculated as given in Equation. Taguchi method is used to analysis the result of response of machining parameter for larger is better criteria.

4.2 Model Analysis of MRR

The coefficients of model for S/N ratios for MRR are shown in Table 4.4. The parameter R-Sq describes the amount of variation observed in MRR is explained by the input factors. R-Sq = 64.7 % indicate that the model is able to predict the response with high accuracy. R-Sq(sdj) is a modified R-Sq that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R-Sq can be artificially high, but R-Sq(sdj) = 38.2 %. may get smaller. The standard deviation of errors in the modeling, S= 0.007752 . Comparing the p-value to a commonly used α-level = 0.05, it is found that if the p-value is less than or equal to α, it can be concluded that the effect is significant (shown in bold), otherwise it is not significant.

Table 3: Coefficients of model for S/N ratios

A	B	C	MRR	SNRA1
10	400	32	0.0156	-36.1375
10	200	20	0.0105	-39.5762
10	100	10	0.0625	-34.705
6	400	32	0.0084	-42.6066
6	200	20	0.0083	-41.6184
6	100	10	0.0028	-51.0568
3	400	20	0.0027	-49.601
3	200	10	0.0018	-54.8945
3	100	32	0.0015	-56.4782
10	100	10	0.0133	
10	200	32	0.0041	-47.7443
10	400	20	0.0189	-34.4708
6	100	20	0.0027	-51.3727
6	200	10	0.0055	-45.1927
6	400	32	0.0067	
3	100	10	0.0008	-61.9382
3	200	32	0.0004	-67.9588
3	400	20	0.0047	

S = 0.007752 R-Sq = 64.7% R-Sq(adj) = 38.2%

From the Analysis of variance studied for the effect of factors on MRR is indicating in Table 4 which obviously shows that the discharge current is the most significant factor while machining of AISI 304 SS with copper tool. After that pulse off time is an important parameter and pulse on time is significant factor during machining. Figure shows that the main effects of S/N ratios on MRR by the factor. For this case "higher is better" is chosen.

Table 4: ANOVA Table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	0.000678	0.000706	0.000353	5.87	**0.027**
B	2	0.0001	0.000096	0.000048	0.8	0.484
C	2	0.000103	0.000103	0.000051	0.85	0.461
Residual Error	8	0.000481	0.000481	0.00006		
Total	14	0.001362				

The residual plot of MRR is shown in Fig 5. This design is helpful to determine whether the model meets the assumptions of the analysis. The residual plots in the graph and the interpretation of each residual plot indicate below:

a) Normal probability plot indicates the data are usually distributed and the variables are influencing the response. Outliers don't exist in the data, because standardized residues are between -0.01 and 0.01.
b) Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists.
c) Histogram proves the data are not skewed.
d) Residuals versus order of the data indicate that there are systematic effects in the data due to time or data collection order.

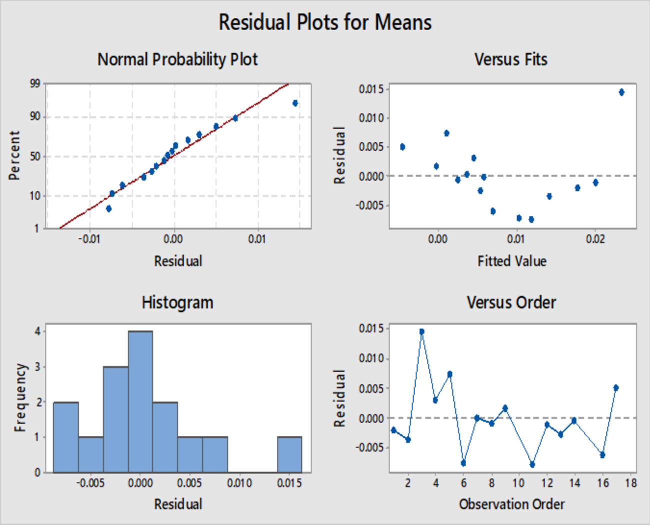

Figure 5: Residual plot of MRR

During the process of Electrical discharge machining, the influence of various machining parameter like Ip, Ton and Toff has significant effect on MRR, as shown in main effect plot for S/N ratio of MRR in Fig 6. The discharge current (Ip) is directly proportional to MRR in the range of 3A to 10A. This is expected because an increase in pulse current produces strong spark, which produces the higher temperature, causing more material to melt and erode from the work piece. Besides, it is clearly evident that the other factor does not influence much as compared to Ip. But, with increase in discharge current from 3A to 10A MRR increases slightly. However, MRR decreases monotonically with the increase in pulse off time.

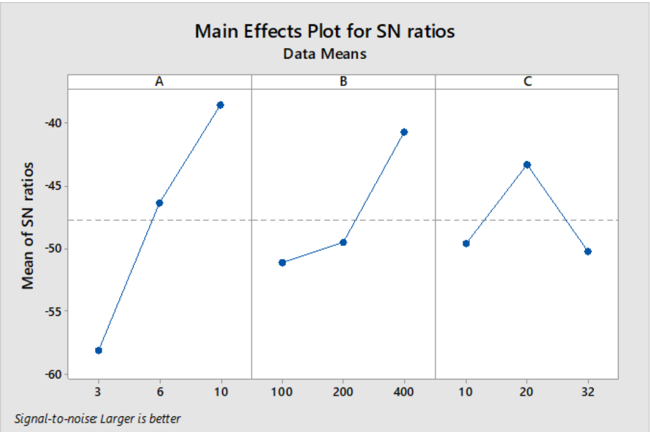

Figure 6: Main effects plot on S/N ratio on MRR by the factor

5. Conclusions

In the current study on the outcome of machining response of MRR of the AISI grade 304 stainless steel plate by means of the cylindrical formed copper tool with external flush system tool has been experimented for EDM process. The experiments were conducted under various parameter set of Discharge Current (Ip), Pulse On-Time (Ton), and Pulse Off-Time (Toff) of the tool. L-18 OA based on Taguchi design was performed for Minitab software was used for examination the result and this response was partially validated experimentally.

1) Finding the result of MRR discharge current is most influencing factor and then pulse duration time. MRR increased with the discharge current (Ip). As the pulse duration extended, the MRR decreases monotonically.
2) The experiment of run number 3 gives the higher material removal rate based on the combination of controlled parameters of discharge current 10 amperes, pulse on time is 100 micro-seconds and pulse off time is 10 micro-seconds.

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Author Profile

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