

## Optimization of MRR and SR for AISI 316 Stainless steel material by using RSM Technique in EDM machining

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### ABSTRACT:

In present days non-conventional machining like electrical discharge machining (EDM) is used to withstand the competition and to meet the demands in the industry. EDM is one where electrical sparks are generated by creating voltage difference between the electrode and work piece. The eroding of material takes place. To machine the materials which are difficult to machine in traditional machining and for temperature resistant high strength alloys EDM is applicable. The practical applications include dies in watches, mould cavity with deeper and narrow slots, mould cavity for the injection molding.

The theme of this project is to optimize the machining parameters in die sinking electrical discharge machining in order to able the best parameter to get the high MRR and low SR. In present the work pieces is AISI 316 stainless steel materials and Copper electrode with 9. are used to conduct the experiments by varying the control factors such as Discharge current ( $I_p$ ), Pulse on time ( $T_{on}$ ) and Duty cycle (%). Process responses such as material removal rate (MRR) and surface roughness (SR) are determined for every experimental run. With a minimum amount of experimentation Taguchi's L9 orthogonal array (OA) is used to study the response of control factors with varying levels in commercial tool MINITAB 17. To get the optimized results individually for process responses, Taguchi single objective optimization is used. And finally, a mathematical and statistical technique called Response surface methodology (RSM) has been used for the analysis and modeling of the MRR and SR by using the commercial tool Design expert 9.0.3.1.

**Key words:** EDM, AISI, SS316, L9 OA, Taguchi, RSM, MRR and SR

### Introduction of EDM

Electro Discharge Machining (sometimes also referred to as spark machining, spark eroding, die sinking) (EDM) is an electro-thermal non-traditional machining Process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark [3]. EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. In this machining process work piece is called the anode because it is connected with positive terminal and electrode is connected with

negative terminal i.e. called cathode. Dielectric fluid may be kerosene, transformer oil, distilled water, etc [4]. The layout of EDM is shown in below figure 1.1.

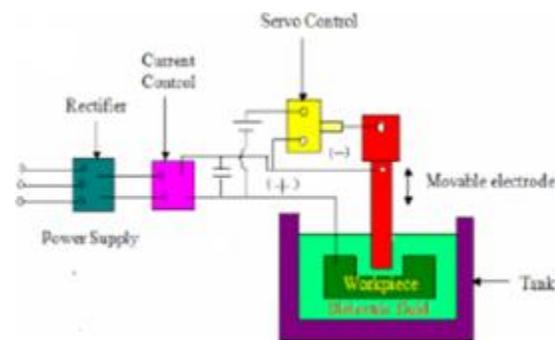


Figure 1.1: Schematic of EDM process

The machining process is carried out within the dielectric fluid which creates path for discharge. When potential difference is applied between the two surfaces of work piece and tool, the dielectric gets ionized and electric sparks/discharges are generated across the two terminals. The application of focused heat of the tool raises the temperature of work piece in that region, which consequently melts and evaporates the metal. In this way small volumes of work piece material are removed by the mechanism of melting and vaporization during a discharge. In a single spark volume of material removed is very small in the range of  $10^{-6}$  to  $10^{-4}$  mm<sup>3</sup>, but this basic process is continuous around 10,000 times per second [5]. The erosion process consists of five phases, namely pre breakdown, breakdown, discharge, end of discharge and post discharge which are shown in figure 1.2. Plasma channel is created between the electrode and work piece with the help of electro thermal energy and temperature ranges are 8000°C to 12000°C. With this high temperature of plasma state eroding occurs.

**a) Pre-breakdown:** During this phase the tool moves closer to the work piece and voltage (V) is applied between the electrodes.

**b) Breakdown:** As the applied voltage cross the boundary limit of dielectric strength of dielectric fluid, this initiates the breakdown of the dielectric. Usually the dielectric breaks near the closest point between the tool and work piece, but it also depend on conductive particles present between the gaps [6].

**c) Discharge:** During this phase the discharge current is maintained at a constant level for a continuous bombardment of ions and electrons on the electrodes. Due to which there is strong heating of the work piece (and also on the electrode), One of the important parameter in the discharge phase is the Inter

Electrode Gap (IEG) which is estimated to be around 10 to 100 micrometers and is directly proportional to discharge current.

**d) End of the discharge:** At the end of the discharge phase the current and the voltage supply stops. The plasma collapses as there is no spark and also due to the pressure enforced by the surrounding dielectric.

**e) Post-discharge:** As during the end of discharge phase the plasma extinguishes. Here a small portion of metal will be removed and a thin layer of metal will recast on the surface of work piece due to the cooling and collapsing of plasma. The thickness of the layer is around 20 to 100 microns and is known as white layer.

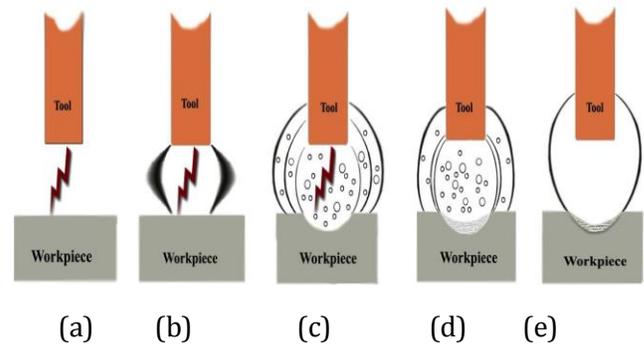


Figure 1.2: (a) Pre-breakdown phase (b) Breakdown phase (c) Discharge phase (d) End of the discharge and (e) Post-discharge phase.

## 1. Experimental Setup:

The fig shows EDM machine experimental



setup



Fig: 3.1 EDM

Fig: 3.2 Spark

produced between tool and work piece during machining

## 2. Selection of Tool and Work piece Material

4.1 Work piece Material: a. AISI 316 Stainless



steel

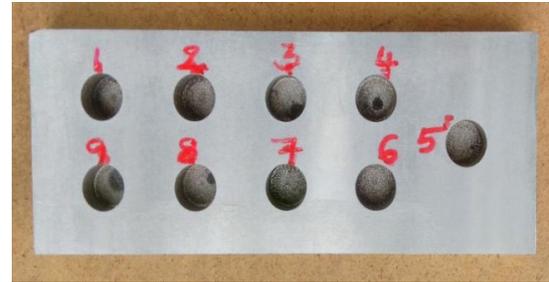


Fig: 4.1.1 Before machining of AISI 316ss Fig: 4.1.2 After machining of AISI 316 ss

The dimensions of the work piece were 316 SS size 150mm × 58mm × 12mm plate. Grade of SS 316 is a high chromium (16% to 18%) steel alloy with high degree of corrosion resistance, hardness, strength and possesses magnetic property.

## 4.2 Tool Material:

b. Copper electrode



Fig: 4.2 copper electrode

While selecting tool material, it should not undergo much tool wear when it is impinged by positive ions. For machining of complex shapes, the tool should be easily workable.

## 5. Taguchi Technique:

The Taguchi technique was able to determine the levels and control variables. L9 orthogonal array by using design of experiments.

Ru n No.	Dischar ge current(D)	Pulse-on time(E)	Duty cycle(F)	MRR	SR
1	6	100	10	0.18 45	3.6 05
2	6	150	11	0.19 14	3.8 75
3	6	200	12	0.30 76	4.4
4	8	100	11	0.19 85	5.3
5	8	150	12	0.45 98	5.2
6	8	200	10	0.37 45	5.2 5
7	10	100	12	0.53 24	6.1
8	10	150	10	0.41 85	6.5 3
9	10	200	11	0.68 32	6.8 1

S.NO	Design Factors	Symbol	Units	Levels		
				1	2	3
1	Discharge current(I <sub>p</sub> )	D	Amp	6	8	10
2	Pulse on time(T <sub>on</sub> )	E	Micro Sec(μsec)	100	150	200
3	Duty cycle(τ)	F	Percentage (%)	10	11	12

**Table: 5.1** Levels of process parameters

### 5.1 Material Removal Rate

It is the ratio of weight loss of the work piece plate before and after machining to machining time.

$$MRR = \frac{\text{weight loss}}{\text{machining time}} = \left( \frac{W_i - W_f}{t} \right) \text{ gm/min}$$

Where  $W_i$  = initial weight before machining

$W_f$  = final weight after machining

$t$  = machining time

### 5.2 Surface Roughness

Mitutoyo Talysurf electronic device is used to calculate surface roughness (Ra) values.



**Fig:5.2** Mituyo Talysurf Equipment

### 5.3 The experimental results of SS316 plate

**Table:5.2** SS316 experimental results for MRR and SR

### 6. Response surface Method

RSM is a group of mathematical and statistical methods that are suitable for applications such as modeling and analysis. An optimal response was obtained by choosing a proper choice of design and operating conditions on a set of controllable variables. Here output is influenced by the number of input factors.

#### 6.1 Procedure:

RSM comprises the following steps

- Prepare a set of trials for sufficient and consistent extent of the output.
- Progress an empirical model of the 2<sup>nd</sup> order response surface with the suitable sets.
- Identify the efficient set of trial variables that gives a maximum and minimum response values.

- Characterize the direct and the collaborative effects of variables through 2D and 3D graphs.

**6.2 Analysis of variance (ANOVA)**

ANOVA is conducted for the experimental results to find out the effect of process parameters on process responses. The ANOVA for material removal rate (MRR) and surface roughness (SR) are given in the Table 6.1 and Table 6.2 respectively.

Source	Sum of Squares	d. f.	Mean Square	F-Value	Prob > F
Model	0.20	3	0.067	10.24	0.0142
D	0.15	1	0.15	22.95	0.0049
E	0.034	1	0.034	5.14	0.0727
F	0.017	1	0.017	2.64	0.1653
Residual	0.033	5	6.563E-003		
Total	0.23	8			
Std. Dev.	0.081		R <sup>2</sup>	0.8600	
Mean	0.37		Adj. R <sup>2</sup>	0.7761	
			Pred. R <sup>2</sup>	0.4437	

Table 6.1 ANOVA for MRR

Multiple regression coefficient (R<sup>2</sup>) is used, to check whether the fitted models actually describe the experimental data or not. From the table 6.1, R<sup>2</sup> value for MRR is found to be 0.8600. This shows that the linear model can explain the variation in MRR up to the extent of 86.00%. And adjusted R<sup>2</sup> and Pred. R<sup>2</sup> for MRR are found to be 0.7761, 0.4437. It can be observed that the values of pred. R<sup>2</sup> and adjusted R<sup>2</sup> are closer to each other which is difference is 0.3. This means that the developed model can represent the process adequately.

From the Table 6.2, R<sup>2</sup> value for SR is found to be 0.9782. This shows that the linear model can explain the variation in SR up to the extent of 97.82%. And adjusted R<sup>2</sup> and Pred.

R<sup>2</sup> values for SR are found to be 0.9652, 0.9233. It can be observed that the values of pred. R<sup>2</sup> and adjusted R<sup>2</sup> are closer to each other which is difference is 0.04. This means that the developed model can represent the process adequately.

Source	Sum of Squares	d. f.	Mean Square	F-Value	Prob > F
Model	9.89	3	3.30	74.94	0.0001
D	9.53	1	9.53	216.42	<0.0001
E	0.35	1	0.35	8.02	0.0366
F	0.017	1	0.017	0.38	0.5667
Residual	0.22	5	0.044		
Total	10.12	8			
Std. Dev.	0.21		R <sup>2</sup>	0.9782	
Mean	5.23		Adj. R <sup>2</sup>	0.9652	
			Pred. R <sup>2</sup>	0.9233	
			R <sup>2</sup>	3	

table 6.2: ANOVA for SR

**7. Normal plots for MRR and SR**

The normal probability plots indicates whether residual follow a normal distribution or not. The plots are shown in figures 7.1 & 7.2. From the plots it can be perceived that residuals are located on a straight line, which means that errors are distributed normally.

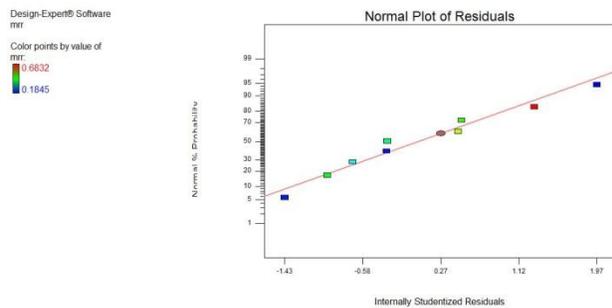


Figure 7.1: Normal probability plot of residuals for MRR

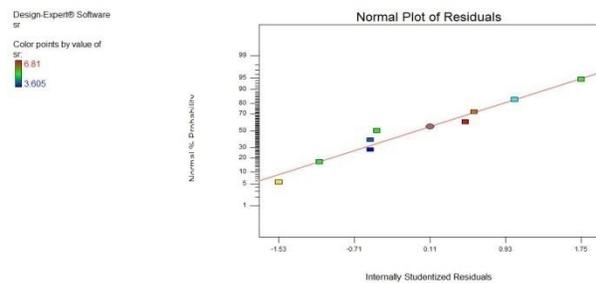


Figure 7.2: Normal probability plot of residuals for SR.

### 8. EFFECTS OF PROCESS PARAMETERS

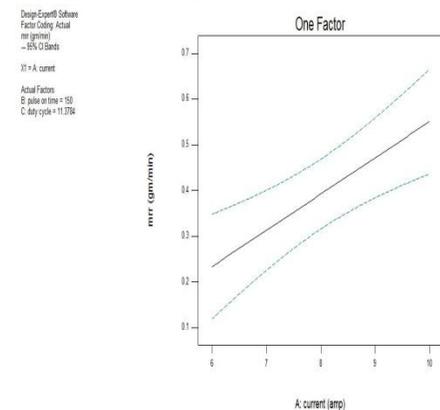


Figure 8.1: Graph between discharge current and MRR.

The individual effect of Discharge current on MRR is shown in figure 8.1. From the graph, it can be observed that, the MRR increases rapidly with increase of Discharge current. This is due to when Discharge current increases more heat is supplied to the work

material so that material melts easily. And rate of production increases.

From 8.2 figures, the individual effect of Pulse on time on MRR is shown in above figure. From the graph, it can be observed that MRR increases with increase of Pulse on time and it shows less effect than Discharge current. Reason here for increasing of MRR is that, when Pulse on time increases the sparking width increases, which cause big craters on the work material which results higher MRR.

From 8.3 figures, the individual effect of Duty cycle on MRR is shown in above figure. From the graph, it can be observed that with increase of Duty cycle, MRR increases slightly. From this it is clear that, Duty cycle has less effect on MRR compared to the Discharge current and Pulse on time.

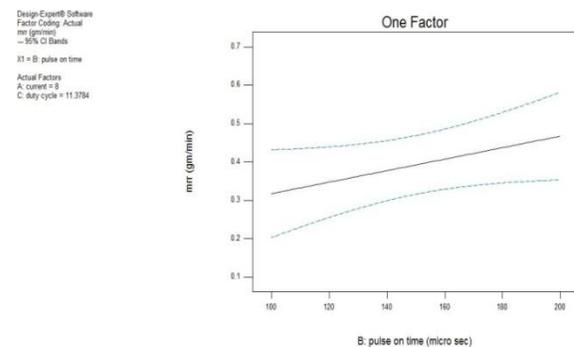


Figure 8.2: Graph between Pulse on time and MRR

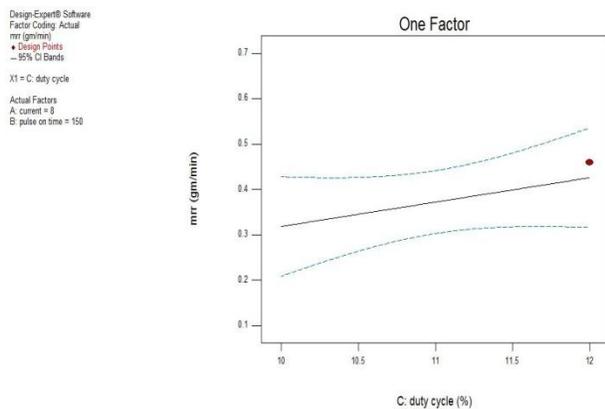


Figure 8.3: Graph between Duty cycle and MRR

**EFFECTS OF PROCESS PARAMETERS ON SR**

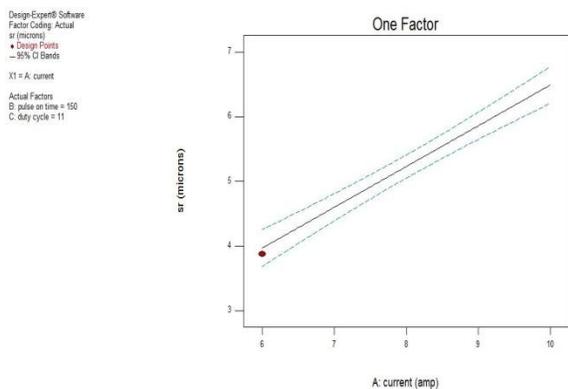


Figure 9.1: Graph between discharge current and SR

The individual effect of Discharge current on SR is shown in above figure. From the graph, it can be observed that with increase of Discharge current SR increases. The reason for this is, when the Discharge current increases sparking energy increases. This causes big craters on the work surface.

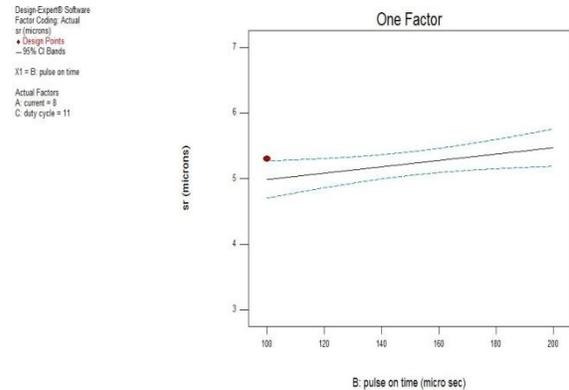


Figure 9.2: Graph between Pulse on time and SR

The individual effect of Pulse on time on SR is shown in above figure. From the graph, it can be observed that with increase of Pulse on time the SR increases. The reason for this is with the increase of pulse on time; pulse width increases and forms the big crater on the work surface i.e. surface irregularities increases. But Pulse on time shows less effect on SR when compared with Discharge current.

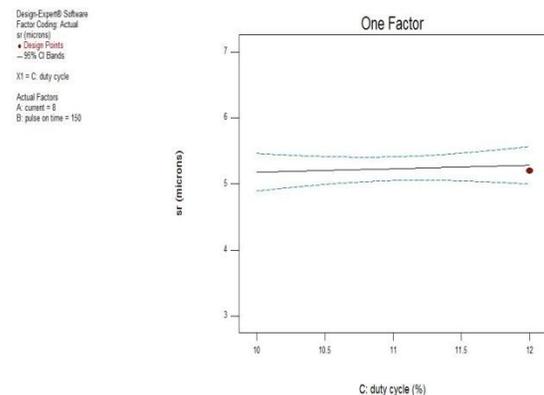


Figure 9.3: Graph between Duty cycle and SR

The individual effect of Duty cycle on SR is shown in above figure. From the graph, it can be observed that with increase of Duty cycle the SR increases slowly. It shows less effect compared to the Discharge current and Pulse on time on SR.

## CONCLUSION:

In the earlier chapters, the consequences of process parameters on process responses of the discharge machining (EDM) method are mentioned and additionally best setting of method parameters has been obtained for max MRR and minimum SR individually at the same time. The vital conclusions from this work square measure summarized as follows:

- The optimum set of method parameters are known for achieving most MRR and minimum SR using Taguchi technique is as follows:

Response surface method linear model individually in MRR and SR in terms of multiple regressions co-efficient ( $R^2$ ) is up to the extent of 86.00% and 97.82% respectively for the material of SS330.

- It was also observed that the Discharge current is the most significant design variable influencing the MRR and SR for machining for SS330 material.

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