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Optimization of Surface Roughness, Material Removal Rate and Tool Wear Rate in EDM using Taguchi Method

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ABSTRACT

In the present manufacturing scenario, EDM is the widely used non-traditional machining process which is used to machine hard materials such as alloys or composites. In the last few decades, there are lots of advancements in EDM which makes EDM more popular. There is a wide range of application of EDM in the aerospace, die-making and some other manufacturing sectors which require high precision. EDM is also called as high precision machining which can be used in the batch production where the traditional machining processes fail. In the last few years the developments in the new tool material, optimization techniques, and conductive ceramics have made some new research scopes in EDM. The aim of present study is to investigate the effect of input parameters like current, voltage and pulse-on-time on the Al-SiC (reinforced with 10% wt. of SiC). The output parameters for the process are MRR, TWR and surface roughness. It is found that the selection of input parameters plays an important role in the performance of the EDM.

Keywords: *EDM, Al-SiC Composites, Optimization, Taguchi.*

1. INTRODUCTION

EDM is one of the most widely used non-traditional machining processes in the present manufacturing scenario. In the last few decades competition in global market and development in the materials made new research scopes in the EDM. EDM stands for the Electro discharge machining process. EDM used to machine those materials which are difficult to machine by conventional machining processes. Electro-discharge machining is a thermoelectric process which utilizes the heat energy generated by a spark to remove the material from the surface of work-piece. The only limitation in the EDM is that the work-piece and the tool material both should be electrically conductive. The electrical energy converted into the thermal energy by series of the electric discharge that occurred between the work-piece and tool which are immersed in the dielectric fluid. The plasma channel is generated by thermal energy between anode and cathode. The plasma channel is generated at a temperature range of 8000-1200°C. Sometimes it is nearly about 20,000°C which is too high and can machine any material. The location of electric spark which is generated by heat energy is determined by the narrowest gap between the tool and work-piece. Duration of each spark is very short. The frequency of each spark is high as thousands of sparks per second. However, spark radius is very small and the temperature in the spark zone is very high. This temperature of spark is capable of partially vaporize and melting the material from both the work-piece and tool material. The volume of material removal per discharge from the work-piece depends upon the specific applications and it is ranging from 10^{-6}-10^{-4} mm^3. The material removed from the surface of work-piece is in the form of craters which is all overspread on the work-piece. Craters sizes are highly influenced by the value of current. Previous studies show that the size of the crater is increase with an increase in discharge current.

2. LITERATURE REVIEW

In the past few decades, lots of studies have been done in the optimization of process parameters and EDM process development. [1] conducted an experiment on mild steel 1018 and optimized MRR, TWR, and Surface roughness with the input parameters pulse on time, voltage and current and found that MRR is increased with increase in voltage and current. However large values of current and voltage affect the surface finish. [2] conducted an experiment to find the effect of input parameters on responses on mild steel IS-2026. It was found that at lower values of current and voltages gives the better surface finish. [3] conducted an experiment to investigate the Magnesium Nano-composite. It was concluded that crater size increases with increase in the Current values and this is a major factor which also affects the surface finish of the material. [4] investigated the effect of both electrical and non-electrical parameters which affects the responses of EDM. It was found that non-electrical parameters are responsible in most of the cases to achieve the high surface finish rates. [5] investigated that non-electrical parameter like flushing pressure, rotation of tool material or work-piece provides a high surface finish to the final product and it was also found that dielectric fluid also affects the surface texture of the material. [6] found that EDM is widely used non-traditional machining process and it has made new research scopes in the machining area. The input parameters like voltage, current, pulse on time, pulse off time and flushing pressure of EDM dielectric fluid majorly affects the output parameters of the process. [7] conducted an experiment to optimize the output parameters and found that current plays major role in the MRR and Surface finish. It also optimizes the Tool wear rate. Less tool wear rates can be achieved at low values of current. [8] concluded that lower values of current give the optimum values for tool wear rate and material removal rate. However, the surface finish starts decreasing when we increase the value of discharge current. [9,10] conclude in his study that increasing the values of a pulse on time increases the MRR for some time but after that, it starts damaging the surface texture of material which results in the increase in the surface roughness of the material. [11,12] conducted an experiment to investigate the effect of input parameters on the output parameters and found that surface finish increases with a decrease in the pulse on time. [13,14] concluded in his experiment that long pulse off time decreases the cutting speed of EDM which lowers the MRR in the process.

3. EXPERIMENTAL DETAILS

Commercially available EDM was used for the experiments. The dielectric fluid used was Kerosene oil. All the experiments were conducted with the positive polarity of tool material.

3.1 Tool Material Selection for the Process

The copper material of diameter 2.5mm and density 8.96g/cm^3 was used as tool material for the EDM process. It is found that copper tool materials having the less tool wear rates than the other available tool materials like brass and aluminum. And moreover, the copper tool is capable to machine advanced materials i.e. composites, which are very hard in nature and difficult to machine by tool materials like aluminum, zinc, and brass.

3.2 Work-Piece Selection for the Experiment

For the experiment, Al-SiC (10% SiC reinforcement by wt.%) was used. Al-SiC metal matrix composites having a wide range of applications in the present time. With their advanced properties, these composites are widely used in the automotive industries.

3.3 Selection of Process Parameters

In some studies, it is found that both electrical and non-electrical parameters of EDM affect the output characteristics of the EDM process. For present work input parameters selected are voltage, current, and pulse-on-time. The response parameters are Material removal rate (MRR), Tool wear rate (TWR) and Surface roughness.

3.4 Experiment Setup

The three input parameters vary at three levels. Taguchi L9 orthogonal array is used in the experiment. The design matrix is constructed with the help of Minitab. The input parameters at three levels for the present work is shown in the table below:

Table-1: Input Parameters at Different Levels

Level	Discharge Current	Voltage	Pulse on Time
1	7	30	50
2	9	40	150
3	11	50	200

The design matrix for the present work is shown in the table below:

Table- 2: Design Matrix for the Experiments

Experiment No.	Voltage	Pulse-on-time	Discharge Current
1	30	50	7
2	30	150	9
3	30	200	11
4	40	50	9
5	40	150	11
6	40	200	7
7	50	50	11
8	50	150	7
9	50	200	9

3.4.1 Material Removal Rate

Material removal rate may be defined as the volume of material removed from the surface of a workpiece within a specific time. It is calculated by:

$$MRR = Intial\ weight\ of\ workpiece - Final\ weight\ of\ workpiece \div Density\ of\ workpiece \times Machining\ time$$

3.4.2 Tool Wear Rate

Tool wear rate may be defined as the volume of material removed from the surface of tool material during the machining process. It is calculated by:

$$TWR = Initial\ weight\ of\ tool - Final\ weight\ of\ tool \div Density\ of\ tool \times machining\ time$$

3.4.3 Surface Roughness

Surface roughness is a measure of surface texture of final shape obtained after the machining process. The surface roughness test is done by stylus type profilometer.

4. RESPONSE TABLES

Responses for the EDM process is shown in the table below:

Table-3: Response Table for MRR, TWR and Surface Roughness

SNo	Voltage	Pulse-on-time	Discharge Current	M/C time (in mins)	Change in Wt. Workpiece	MRR	TWR	Surface roughness
1	30	50	7	10	1	36.36364	0.112727	3.2648
2	30	150	9	10	1.03	37.45455	0.163636	6.12065
3	30	200	11	10	1.38	50.18182	0.207273	6.98145
4	40	50	9	10	1.99	72.36364	0.149091	4.02361
5	40	150	11	10	1.48	53.81818	0.196364	7.62346
6	40	200	7	10	1.47	53.45455	0.141818	6.46127
7	50	50	11	10	2.61	94.90909	0.174545	5.99214
8	50	150	7	10	1.05	38.18182	0.149091	6.94815
9	50	200	9	10	1.37	49.81818	0.167273	8.76482

4.1 Means Values for Single Response Table

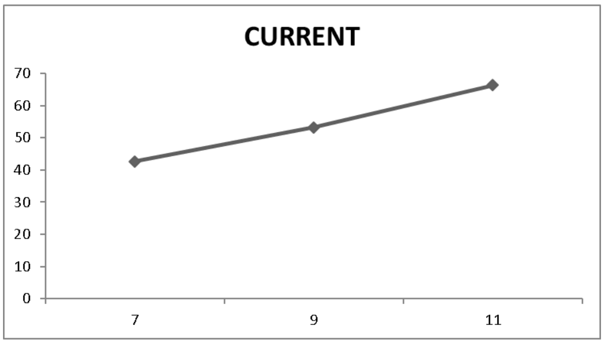
The optimal settings and the optimal values for output characteristics such as MRR, Ra & TWR are determined individually by Taguchi’s approach. The table shows these individual optimal values of all output parameters:

Table-4: Means of MRR, TWR, and Surface Roughness at Different Levels

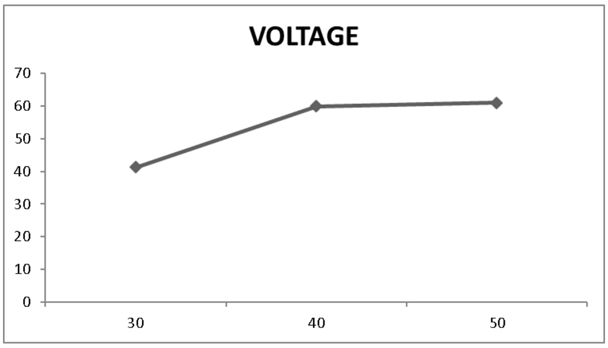
Single Response								
MRR			TWR			Surface roughness		
VOLTAGE	PULSE ON TIME	CURRENT	VOLTAGE	PULSE ON TIME	CURRENT	VOLTAGE	PULSE ON TIME	CURRENT
41.33333	67.87879	42.66667	5.63133	4.36993	5.6073	0.161212	0.145455	0.134545
59.87879	43.15152	53.21212	5.8113	6.9007	6.2153	0.162424	0.169697	0.16
60.9697	51.15152	66.30303	7.28273	7.45473	6.90276	0.163636	0.172121	0.192727

4.2 Interpretation of plots for Material Removal Rate

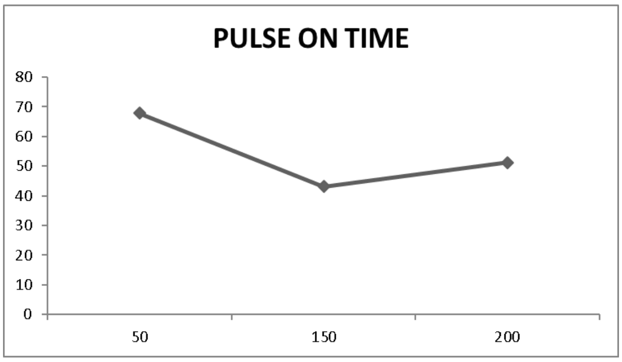
The data is collected through the number of experiments. There are three graphs which shows the optimal values for the MRR based on the voltage, discharge current, and pulse-on-time.



Graph-1: Response Graph of Current for MRR



Graph-2: Response Graph of Voltage for MRR

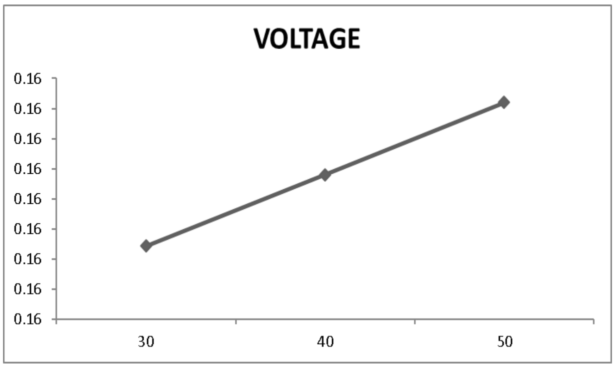


Graph-3: Response Graph of Pulse on Time for MRR

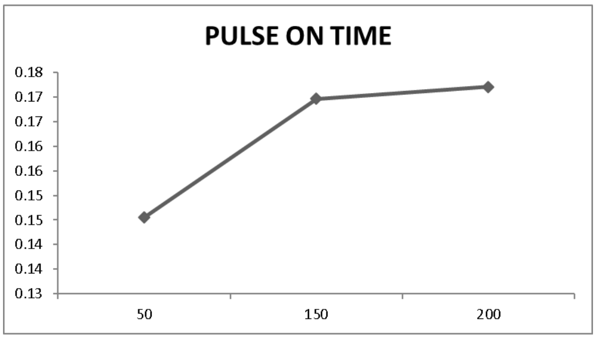
It is found in the study that with an increase in the voltage material removal rate is also increases. It is found that initially, the MRR is low when the value of voltage is low but as we increase the value of voltage, MRR starts increasing. Maximum MRR is found at 50volts. Pulse-on-time also affects the MRR in the EDM process. Initially, the MRR is high but soon when values of pulse-on-time increases it affects the MRR. MRR slows down with an increase in the Pulse-on-time for the AMC's. Whereas, with an increase in the value of current MRR starts increasing. At the low values of current MRR is lower but as there is an increase in the value of current, MRR is faster. Increase in the value of current increases the MRR.

4.3 Interpretation of plots for Tool Wear Rate

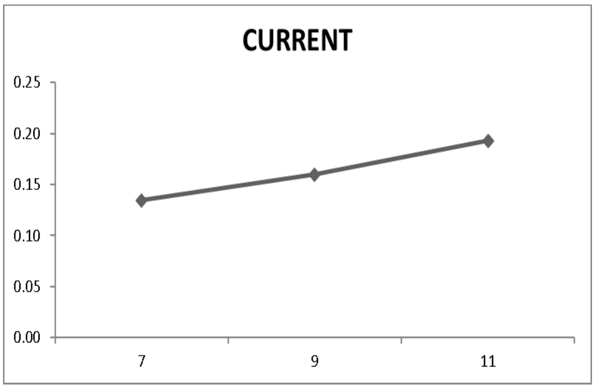
The optimal values of voltage, pulse-on-time and discharge current for the tool wear rate is shown in the graphs below:



Graph-4: Response Graph of Voltage for TWR



Graph-5: Response Graph of Pulse on Time for TWR

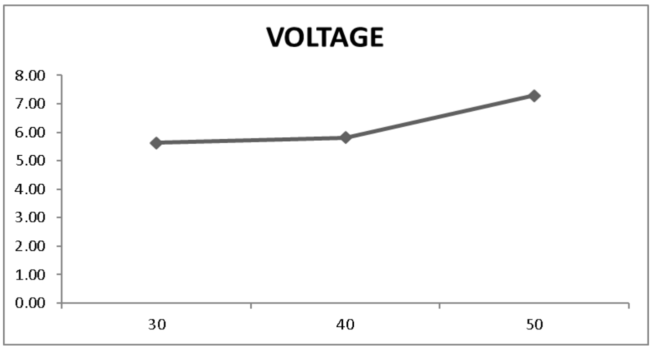


Graph-6: Response Graph of Current for TWR

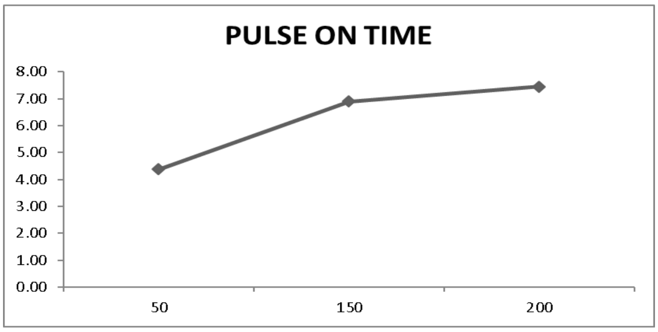
It is found that voltage affects the tool wear rate of the tool. The low tool wear rate is found at low values of voltage. Increase in the values of voltage increases the tool wear rate. For the pulse-on-time, the low tool wear rate is found at low values of pulse-on-time. The tool wear rate starts increases with increase in the pulse on-time. Current is the main parameter which affects the tool wear rate. There is an increase in the value of tool wear rate as the value of current increases.

4.4 Interpretation of plots for the Surface Roughness

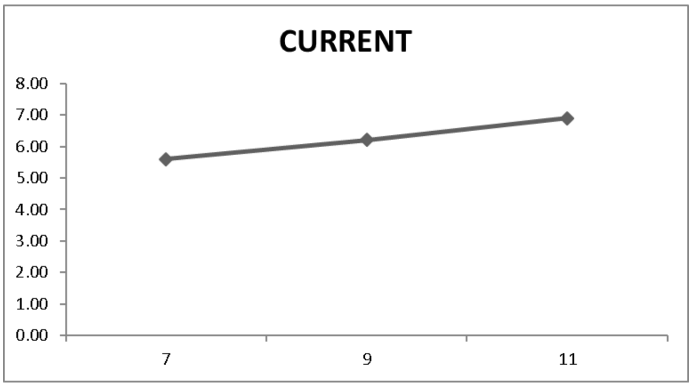
Surface quality is the main output parameter in the EDM process. The optimum values for the voltage, pulse-on-time, and current is shown the graphs below:



Graph-7: Response Graph of Voltage for Surface Roughness



Graph-8: Response Graph of Pulse on Time for Surface Roughness



Graph-9: Response Graph of Current for Surface Roughness

It is found that increase in the voltage increases the surface roughness which affects the surface quality of the material. At the lower values of voltage low surface roughness is achieved. Pulse-on-time also affects the surface quality of the product. Higher values of pulse-on-time lead to higher surface roughness and increase in the current also increases the surface roughness which damages the surface quality of the product.

5. ANALYSIS OF MULTI-RESPONSE STAGE

The Signal to Noise ratio considers both the mean and the variability in the data. In the present work, a multi-response methodology based on Taguchi technique and Utility concept is used for optimizing MRR, Ra & TWR. Taguchi proposed many different possible S/N ratios to obtain the optimal process efficiency. Two of them are selected for the present work. Those are,

- Larger the better S/N ratio for MRR

$$n1 = -10log10\{\frac{1}{MRR^2}\}$$

- Smaller the better for Surface Roughness

$$n2 = -10log10Ra^2$$

- Smaller the better for tool wear rate

$$n3 = -10log10TWR^2$$

From the utility concept, the multi-response S/N ratio of the overall utility value is given by:

$$nobs = W1n1 + W2n2 + W3n3$$

Where W1, W2 & W3 are the weights assigned to the Material Removal Rate, Surface roughness, and Tool Wear Rate. All Weights are defined according to the importance and customer requirements. Weights values taken for W1, W2 & W3 are as follows: W1=0.40, W2=0.40 and W3=0.20

The best combination for input process parameters for simultaneous optimization of Material removal rate (MRR), Surface roughness (Ra), &Tool Wear Rate (TWR) is obtained by the mean values of the multi-response S/N ratio shown in the following Table:

Table-5: Design Matrix with Multi-Response Signal to Noise Ratio

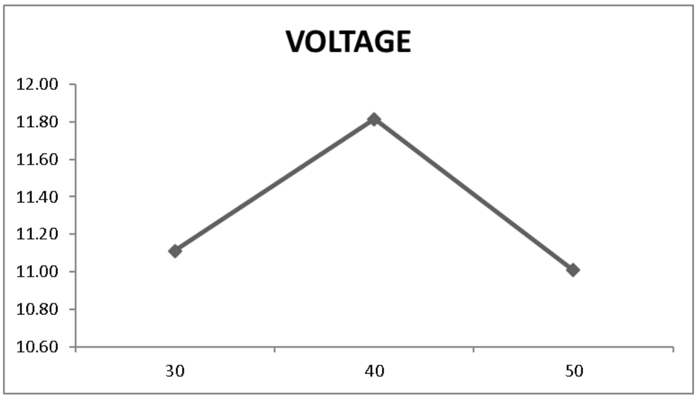
Experiment No.	VOLTAGE	PULSE ON TIME	CURRENT	n1for MRR	n2 for Ra	n3for TWR	nobs
1	30	50	7	31.21335	-10.2771	18.95942	13.0155
2	30	150	9	31.47009	-15.736	15.7224	10.22367
3	30	200	11	34.01093	-16.8789	13.66916	10.09695
4	40	50	9	37.19041	-12.0923	16.53098	13.74362
5	40	150	11	34.61858	-17.643	14.13878	10.18307
6	40	200	7	34.55969	-16.2064	16.96536	11.51328
7	50	50	11	39.54616	-15.5516	15.16183	12.94663
8	50	150	7	31.63713	-16.8374	16.53098	10.1392
9	50	200	9	33.94776	-18.8549	15.5315	9.941963

6. MEAN VALUES OF HOBS AT DIFFERENT LEVELS

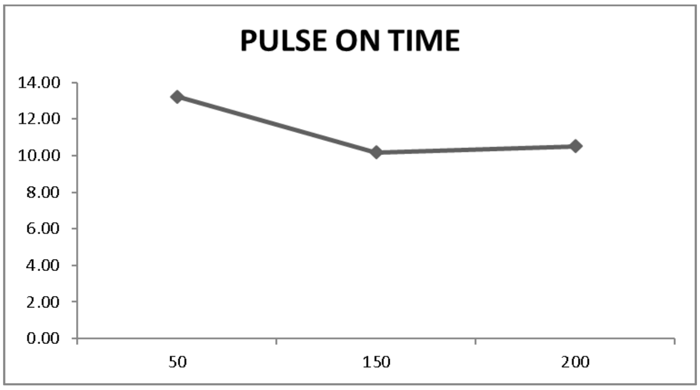
Table-6: Mean Values of ηobs at the Different Levels

MULTI RESPONSE		
ηobs		
VOLTAGE	PULSE ON TIME	CURRENT
11.11204	13.23525	11.55599
11.81332	10.18198	11.30309
11.00927	10.5174	11.07555

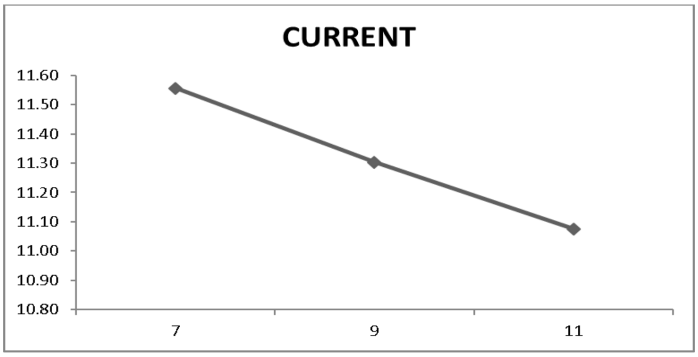
The optimal values for the MRR, TWR and surface roughness at the different levels is found and interpreted in the graphs. It is found that MRR is increased with the increase in the value of voltage. For the MRR voltage is the significant parameter but it also increases the tool wear rate and leads to more tool wear when we increase the value of the voltage to higher levels. Surface roughness also increases with increases as voltage increases which affects the surface quality of the product. For the processes where the surface finish is primary aim voltage is the main parameter. The optimal value of voltage for the combined MRR, TWR and surface roughness is 40 volts which give the optimal results during the EDM process. Pulse-on-time is also the important parameter in the EDM process. It is found that at higher pulse-on-time increases the MRR and TWR but it damages the surface quality. The optimal value of pulse-on-time for the MRR, TWR and Surface roughness is at lower pulse-on-time which is 50µm.TWR increases with increases in current whereas it also damages the surface quality. MRR is also increased with increases in the value of discharge current. The optimal value of MRR, TWR and surface roughness is found at a lower value of current which is 7 amps.



Graph-10: Multi-Response Signal to Noise Ratio Graph of Voltage



Graph-11: Multi-Response Signal to Noise Ratio Graph of Pulse on Time



Graph-12: Multi-Response Signal to Noise Ratio Graph of Current

7. CONCLUSION

A set of experiments done on the Al-SiC composite using the copper tool material. It is found that both the electrical and non-electrical parameters are important for the EDM process. Non-electrical parameters are the important factors which affect the surface quality. The input parameters used for the study are Voltage, pulse-on-time and discharge current for the output parameters surface roughness, tool wear rate, and material removal rate. It is found that proper selection of input parameters affects the performance of the EDM process. Based on the observations it is concluded that:

1. MRR is increased with increase in the Pulse-on-time, current and voltage.
2. TWR is found at the lower values of current, voltage and pulse-on-time.
3. Higher the value of pulse-on-time, current and voltage increase the surface roughness which damages the surface quality of the material.
4. The optimal values for the MRR, TWR and surface roughness are found at low current, low pulse-on-time, and low voltage, Although the value of voltage can be increased up to a certain level at very high voltages it starts damaging the surface quality of the material.

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