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INVESTIGATION OF MRR OF EDM PROCESS ON MILD STEEL USING COPPER ELECTRODE

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ABSTRACT

Electrical discharge machining is a non conventional process of machining very hard material such as titanium alloys, heat treated tool steels, super alloys, composites, ceramics, heat resistant steels, tungsten carbides etc. These materials are precise and very difficult to machine with conventional way of machining processes like milling, drilling etc. These hard materials are widely used in modern industries (die and mold making industries, medical, aerospace, aeronautics and nuclear industries). Electric discharge machining is a thermal based machining process in which machining is done with the repeatedly reoccurring electric sparks occurs between the tool and work piece. Both the tool and work piece are immersed in dielectric fluid.

This study discusses the influence of machining parameters like current, voltage, pulse on time and pulse off time on the performance parameters such as material removal rate and tool wear rate. These selected machining parameters are varied up to their four levels. The other machining parameters such as duty cycle, polarity, spark gap are kept constant. Since mild steel is an electric conductive material and found applications in various industries for making desirable products, so in this experiment mild steel is used as a work piece material and machining is done with copper electrode having 10 mm in diameter. The layout of design of experiment is based on Taguchi L_{16} orthogonal array and analysis of variance (ANOVA) is used to investigate the results obtained from Taguchi. From results it is concluded that out of four selected machining parameters, current and pulse on time are the most influencing parameter for material removal rate and the other two parameters i.e. voltage and pulse off time have not much effect on performance. As the current and pulse on time increases, the material removal rate also increases. From the response tables for means and S/N ratio for material removal rate , it is found that current is the most impacting parameter followed by pulse on time, voltage and pulse off time.

1.1 Electrical Discharge Machining

The history of Electrical Discharge Machining techniques goes as far back as the 1770s when it was discovered by an English Scientist. However, Electrical Discharge Machining was not fully taken advantage of until 1943 when Russian scientists learned how the erosive effects of the technique could be controlled and used for machining purposes. During research to eliminate erosive effects on electrical contacts, the soviet scientists decided to exploit the destructive effect of an electrical discharge and develop a controlled method of metal machining [3]. In 1943, soviet scientists announced the construction of the first spark erosion machining.Electrical Discharge Machining is a most basic nonconventional machining process, where material is removed from the work piece by thermal energy of repeated sequences of spark occurring between the small gap of an electrode and a work piece. Electrical Discharge Machining is mainly used for machining of electrically conductive hard metals, alloys and composites in aerospace, automotive and dies making industries. Electrical Discharge Machining process removes the undesirable material in the form of debris and produce shape of the tool surface as of a metal portion by means of a recurring electrical sparks stuck between tool and the work piece in the existence of dielectric fluid. Dielectric fluid may be EDM oil, kerosene oil, transformer oil and distilled water. The dielectric liquid acts as a de- ionizing medium between the tool and work piece.

1.2 Electrical Discharge Machining Types

Mainly, there are two kinds of Electrical Discharge Machining process

1.2.1 Sinking Electrical Discharge Machining Process

1.2.2 Wire Electrical Discharge Machining Process

1.2.1 Sinking Electrical Discharge Machining Process

Sinking Electrical Discharge Machining also called cavity type Electrical Discharge Machining, probe Electrical Discharge Machining or volume Electrical Discharge This machining consists of a tool and work piece submerged in a dielectric fluid such as EDM oil, kerosene oil; powder mixed EDM oil and de-ionized water. The tool and work piece are separated by a small gap known as arc gap. The arc gap generally ranges from 0.01mm – 0.5 mm [8].

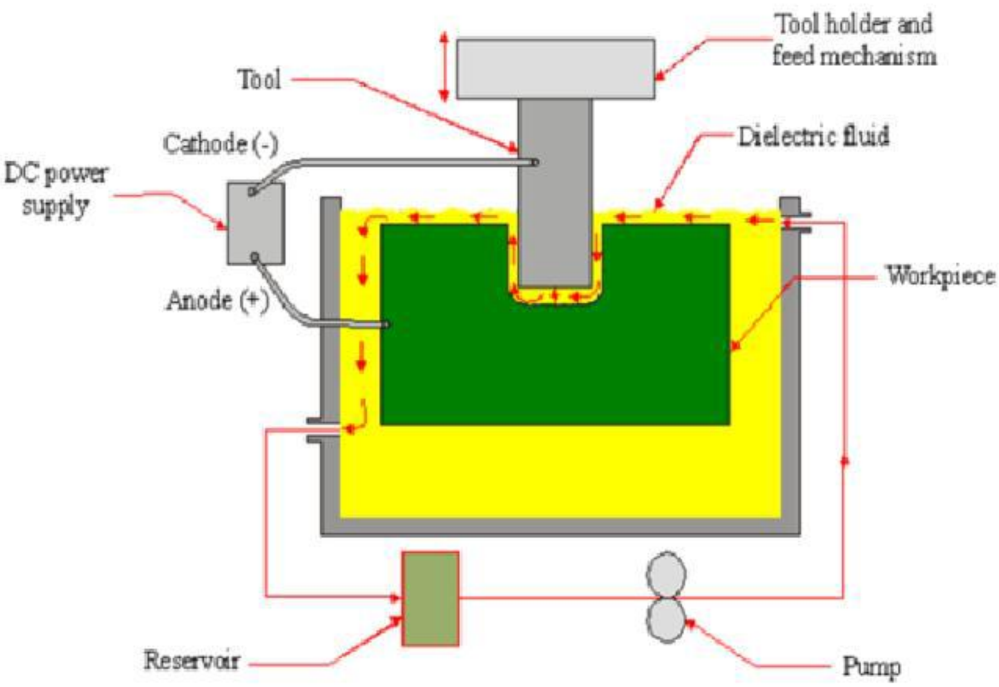

Fig. 1.1 Setup of Sinking Electrical Discharge Machining Process [6]

The dielectric fluid is allowed to flow through this arc gap to remove the debris from the machining surface. The tool and work piece are connected to a suitable power supply. The power supply produces an electrical potential between the tool and work piece. As the tool approaches the work piece, dielectric breakdown occurs in the fluid, forming a plasma channel, and a small spark jumps.

These sparks usually strike one at a time because it is very unlikely that different locations in the inter-electrode space have the identical local electrical characteristics which would enable a spark to occur simultaneously in all such locations. These sparks happen in huge numbers at seemingly random locations between the electrode and the work piece. As the base metal is eroded, and the spark gap subsequently increased, the electrode is lowered automatically by the machine so that the process can continue uninterrupted.

1.2.1.1 Principle of Operation

In this machining process the material is removed from the work piece owed to controlled wearing away action by means of repeatedly reoccurring spark ejection between the tool and work piece. Both the tool and the work piece are immersed in a dielectric fluid and are separated by a small gap known as arc gap. The value of arc gap generally varies from 0.01mm to 0.5mm. The tool is connected to cathode terminal and the work piece is connected to anode terminal.

When the voltage across the spark gap becomes sufficiently high, it discharges through the spark gap in the form of the spark in the interval of about 10 micro seconds. Due to this, the positive ions and electrons get accelerated, producing a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between ions and electrons and creating a channel of plasma. A sudden drop of the electric resistance of the previous channel allows that current density reaches very high values producing an increase of ionization and the creation of a powerful magnetic field.

The spark develops sufficiently high pressure between work and tool as a result of which a very high temperature is reached. This high temperature spark causes sufficiently compressive force developed between the tool and work piece as an outcome that minute amount of metallic particles are liquefied and eroded. Material removal occurs due to instant vaporization of the material as well as due to melting. [3]

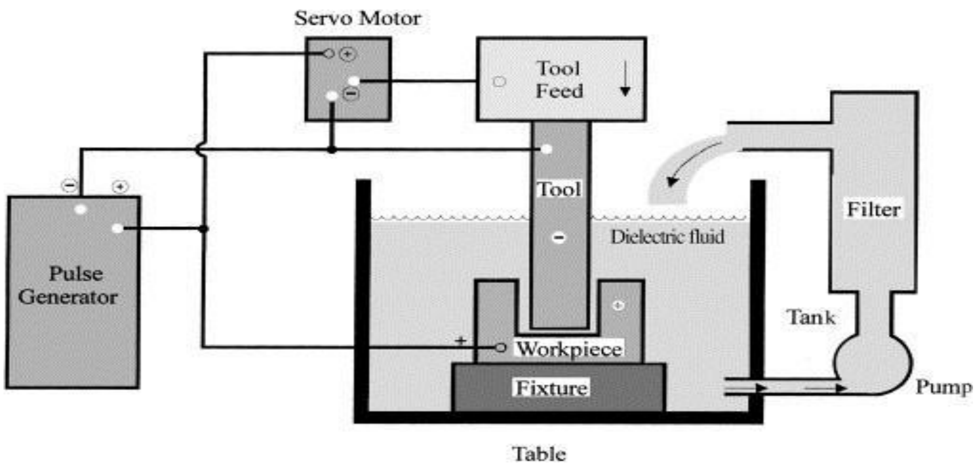

Fig. 1.2 Principle of Operation

1.2.1.2 Mechanism of Material Removal

The mechanism of material removal of Electrical Discharge Machining process is the conversion of electrical energy into heat energy. During machining process the sparks are produced between work piece and electrode. Each spark produces a tiny crater by melting and vaporization, thus eroding the work piece to the shape of the tool. It is well-known by many Electrical Discharge Machining researchers that the mechanism of material removal is the process of transformation of elements of material between the work-piece and electrode. The transformation of material elements are transported in solid, liquid or gaseous state, and then alloyed with the contacting surface by undergoing a solid, liquid or gaseous phase reaction.

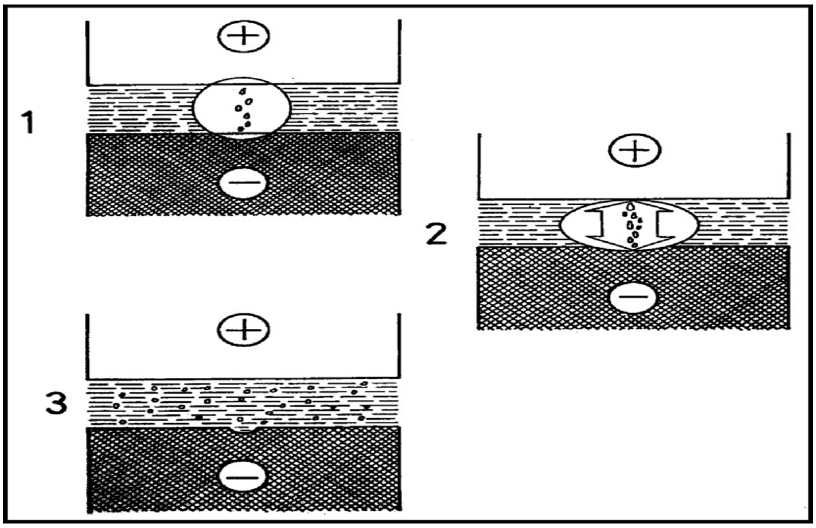

Fig. 1.3 Cycles of Operation [8]

1.2.2 Wire Electrical Discharge Machining Process

Wire-Cut Electrical Discharge Machining also called electrical discharge wire cutting process used for creating two or three dimensional complex shapes using an electro thermal mechanism for eroding the material from a thin single stranded by guide rollers metal wire surrounded by de-ionized water which is used to conduct electricity.

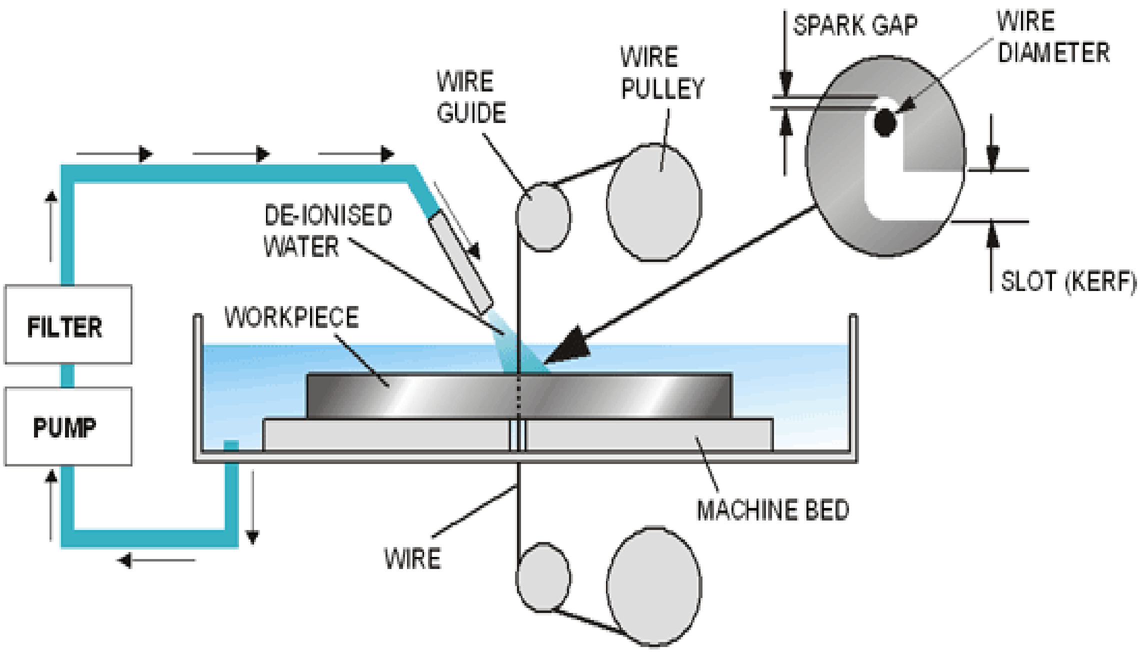

Fig. 1.4 Setup of Wire Electrical Discharge Machining

Any hard material can cut by wire EDM process, but the material should have an electrical conductive properties. The electrode wire is commonly made up of brass or copper material. The diameter of wire is generally varies from 0.25 mm – 0.5 mm. The wire is wound on a two wire spool which is rotated in the same direction to strand the wire. The speed of wire movement is up to 3 m/min. The spark is generated between moving electrode wire and the work piece, thereby removing the material. The dielectric is localized rather than submerging the whole work-piece.

2.2 Literature Review

[1] Goyal S. et. al. (2017), investigated the process parameters of electro discharge machining process. Taguchi's technique was used to design the layout of experiment. Three control parameters named current, pulse on time and pulse off time were chosen and the performance was measured in terms of material removal rate, tool wear rate and surface roughness. AISI 1020 steel was used as a work piece and copper is used as cutting tool material. From the multi response graph, it was concluded that, the material removal rate, tool wear rate and surface roughness is directly proportional to the current and pulse on time and inversely proportional the pulse off time. As the current and pulse on time increases, the material removal rate, tool wear rate and surface roughness also increases whereas with the increase in pulse off time, the material removal rate, tool wear rate and surface roughness decreases.

[2] Mujawar et. al. (2016), optimized that the effect of machining parameter such as pulse on time (Ton), pulse on time (Toff) and discharge current (DC) on the surface roughness (SR) of the workpiece. L_{16} orthogonal array with four level and three parameters was used by author for this experiment. The plots for the roughness were obtained by using Minitab 14 software for the study the importance of parameters in effecting the desired quality characteristics. He keeps smaller the better as the main objective for tool wear rate. Author resulted that the pulse on time, pulse off time and discharge current (DC) has effect on surface roughness (SR). But discharge current has significant effect as compared to another two parameters.

[3] Thomas S. et. al. (2016), optimized the parameters of powder mixed electro discharge machining process using Taguchi's technique. In this study, various control parameters like current, pulse on time and pulse off time were selected to investigate the performance in terms of material removal rate and tool wear rate. The experiments were performed on D2 Die steel using copper electrode. EDM oil mixed with zirconium powder having grain size 46 microns was used as a dielectric fluid. Total nine numbers of experiments were performed taking 10 minutes for each experiment. Taguchi's method was employed to design the experimental layout and analysis of variance was carried out to show the significance of individual input parameter that effect the material removal rate and tool wear rate. Based on the results obtained from the analysis of variance, it was concluded that current was the most significant parameter for material removal rate followed by pulse on time and pulse off time. The similar result was obtained for tool wear rate.

[4] Arya et. al. (2016), optimized that influence of process parameters such as pulse on time, pulse off time, current and concentration of powder on the response parameter as MRR, TWR of Di-sinking powder mixed electric discharge machine (PMEDM). The experiments were performed on stainless steel 304 as work piece by using the 10 mm cylindrical shaped copper rode as electrode and copper powder mixed with EDM oil. The outline of experiment was based on taguchi L_9 array method for experiment design. For analysis of the result ANOVA was used obtained from taguchi experiment design. The result founded by author from electrode wear rate and material removal rate (MRR) signify that current and pulse on time had highest parametric effect on material removal rate (MRR) and electrode wear rate. Also observed that when pulse on time and current increases then material removal rate (MRR) and electrode wear rate also increases. Means material removal rate and electrode wear rate is directly related to the pulse on time and current, is also observed that concentration of powder is inversely related to the tool wear rate.

[5] Gupta V.K et. al. (2016), optimized the material removal rate for sinking EDM using generic algorithm technique. The experiments were performed on titanium alloy Ti 6-4 using copper electrode. Pulse on time, pulse off time and discharge current were the process parameters selected for this study. Material removal rate was selected as a response parameter. Each process parameter was varied up to six levels. The experiments were performed with normal polarity i.e. work piece was taken as cathode and electrode was taken as anode. Analysis of variance and regression analysis was done to optimize the process parameters. Further, generic algorithm was done to create the model. From the results obtained, it was concluded that the discharge current was the most important process parameter that affects the material removal rate followed by pulse on time and pulse off time. It was also concluded that, as the discharge current and pulse on time increases, the material removal rate also increase. On the other hand as the pulse off time increases, the material removal rate decreases.

[6] **Sundaram M.C. et. al. (2016),** observed the effect of tool material on the machining performance characteristics of powder mixed electrical discharge machining of OHNS Die Tool Steel. Copper with titanium carbide and tungsten carbide were used a tool material. The experiments were performed on OHNS Die Tool Steel work piece. Various process parameters namely pulse on time; pulse off time, current and voltage were selected as input parameters. The performance was measured in terms of material removal rate and tool wear rate. Taguchi method was employed to design the layout of experiment. Further, Analysis of variance (ANOVA) was used to find the significant factors affecting the response characteristics. It was observed that, copper with tungsten carbide tool provide more material removal rate and less tool wear rate as compare to copper with titanium carbide tool. Further, it was concluded that as the current and pulse on time increases, the material removal rate also increases. Whereas, the voltage and pulse off time increases, the material removal rate decreases.

[7] Younis M. A. et. al. (2015), studied the effect of electrode material on surface roughness and to avoid residual stresses during electrical discharge machining. For this study two types of electrode material were chosen namely, Dura graphite 11 and Poco graphite EDMC-3. Two grades of tool steels DIN 1.2080 and DIN 1.2379 were chosen as a work piece material. To prepare the specimens for Electrical Discharge Machining process, the base specimens were machined by Electrical Discharge Machining to remove the unwanted material at various machining conditions i.e. rough, medium and soft according to the pulse on time and pulse off time. The scanning of specimen was done by scanning electron microscope (SEM) to study the effect of electrode of material upon the surface roughness and cracks. After that, the X- ray diffraction method was used to measure the residual stresses. From results, it was found that POCO graphite EDMC-3 electrode results higher residual stresses compared with Dura graphite electrode. Also the soft Electrical Discharge Machining exhibited higher residual stresses as a result of higher pulse on time.

[8] Gudur et. al. (2015), investigated the effect of mixing the silicon carbide with dielectric fluid on the machining parameters of EDM. The experiment was conducted on SS 316L work piece material. Machining parameters namely pulse-on time, pulse-off time, peak current, powder concentration, powder grain size and nozzle flushing, duty factor have been optimized. The performance characteristics were calculated in terms of response variables like material removal rate (MRR) and surface roughness (SR). Kerosene is used as dielectric fluid and it mixed with silicon carbide powder was used. The design of experiment was based on Taguchi method for the experiment design. Further, analysis of variance (ANOVA) was performing to decide which process parameter considerably affects the response characteristics of the EDM. In results, the authors founded that silicon carbide powder mixed EDM gives higher material removal rate and better surface finish as compared to conventional EDM.

[9] Banker K. et. al. (2014), investigated the machining parameters of electrical discharge machining of AISI 304 using Taguchi method. The layout of experiment was based on Taguchi L9 orthogonal array. Current, pulse on time and pulse off time were the control parameters selected for this experiment. MRR was selected as a performance parameter. Experiments were conducted on AISI 304L work piece material by using copper tool. Kerosene oil with diluted with water was used as a dielectric fluid. Minitab software was utilized to find the signal to noise ratio and means for the most affective parameters. It was concluded that, pulse on time was the most effective parameter for MRR followed by current and pulse off time. It was also observed that, as the pulse on time and current increases, the material removal rate also increase. On the other hand, as the pulse off time increase, the material removal rate decreases.

[10] Habib S. S. (2014), optimized the electrical discharge machining process by using Taguchi approach. For this study hot work tool steel was chosen as a work piece material and copper and graphite were used as an electrode. The main machining parameters such as pulse on time, pulse off time, discharge current and voltage were chosen to determine Electrical Discharge Machining response parameters such as material removal rate, surface roughness and gap size. In this work L27 orthogonal array based on Taguchi experimental design was utilized to plan the experiment. It was concluded that, pulse on time was the most significant parameter for MRR, SR and gap size. MRR, SR and gap size were slightly affected with voltage for both copper and graphite electrodes. When copper electrode was used for machining, the effect of control parameters can be ranked as follows: pulse on time, current, pulse off time and voltage. For graphite electrode pulse on time was the most significant parameter followed by pulse off time, current and voltage.

[11] Dhakry et. al. (2014), investigated the process parameters in electric discharge machining of tungsten carbide using copper electrode. Pulse on time, current, duty cycle and gap voltage were machining parameters chosen for this experiment. MRR was the response parameter to be optimized. L_8 orthogonal array based on Taguchi design was used to design the layout of experiment. Further, ANOVA was used to analyze the effect of each control parameters on MRR. Eight experiments were performed by variablevalues of control parameters. Experimental work was done on EDM machine model T- 3822 M. Di-ionized water was serves the purpose of dielectric fluid. The authors founded that, peak current and duty cycle were the most valuable control parameters for MRR. Pulse on time and gap voltage has the smallest amount effect on MRR. It was also concluded by the authors that, as the peak current and duty cycle increases, the value of MRR also increase means peak current has directly perposnal relation with material removal rate. Peak current was the most important parameter for MRR followed by duty cycle, pulse on time and gap voltage.

3.1 Objectives of the Present Work

The objectives of this dissertation are as:

1. To experimentally investigate the material removal rate for Sinker EDM on mild steel using copper electrode.
2. To experimentally find out the influence of current, pulse on time, pulse off time and voltage on the material removal rate of Sinker EDM.
3. To find the optimum value of machining influence of current, pulse on time, pulse off time and voltage for higher material removal rate.

3.2 Selection of Machining Parameters

Process parameters are the variables within the process that affects the performance characteristics. Determination of the process parameters which affects the performance is an important task for any design of experiment to achieve better quality characteristics. The machining parameters selected for this experiment are current, pulse on time, pulse off time and voltage.

Table 3.1 Machining Parameters

Machining Parameters	Symbol	Unit	Levels			
			Level 1	Level 2	Level 3	Level 4
Current	I	Amp	8	10	12	14
Voltage	V	Volt	35	40	45	50
Pulse on Time	Ton	µs	50	100	150	200
Pulse off Time	Toff	µs	5	7	9	11

3.3 Response Data

For this experiment the response data are:

1. Material Removal Rate (MRR)

The objective of this experiment is to maximize the material removal rate.

3.4 Calculation of Material Removal Rate

It is the amount of material removed in gram from the work piece per minute. The material removal rate (MRR) is expressed as the difference of weight of the work piece before and after machining to the machining time.

$$MRR\ (g/min) = \frac{\text{Wwb} - \text{Wwa}}{\text{T}} \quad \text{..............................} \ (3.4)$$

Where, Wwb = Weight of the work piece before machining
Wwa = Weight of the work piece after machining
T = machining time

3.5 Selection of Orthogonal Array

The selection of an orthogonal array for an experiment depends upon the following two factors: i.e. number of parameters and number of levels for each parameter. In this experiment four machining parameters namely current, pulse on time, pulse off time and voltage and each at four levels have been selected and hence the L_{16} orthogonal array is chosen. Responses are obtained by running the experiments according to the L_{16} orthogonal array. The L_{16} orthogonal array in terms of actual parameters is shown in table 3.2.

Table 3.2 L16 Orthogonal Array

Column	1	2	3	4	Response Data
Run	**I**	**V**	**Ton**	**Toff**	**MRR**
1	8	35	50	5	-
2	8	40	100	7	-
3	8	45	150	9	-
4	8	50	200	11	-
5	10	35	100	9	-
6	10	40	50	11	-
7	10	45	200	5	-
8	10	50	150	7	-
9	12	35	150	11	-
10	12	40	200	9	-
11	12	45	50	7	-
12	12	50	100	5	-
13	14	35	200	7	-
14	14	40	150	5	-
15	14	45	100	11	-
16	14	50	50	9	-

3.6 Conduct of Experiment

The experiment is done on ELEKTRA EMS 5535 Die-sinking type of EDM machine using copper electrode having 10 mm in diameter and mild steel as a work piece. Commercial grade EDM oil is used as a dielectric fluid with external pressure flushing. Experiments are conducted with negative polarity of electrode. Pressure flushing is used to flush the EDM oil between the spark gap. The design of experiment is based on Taguchi L_{16} orthogonal array. In this experiment flushing pressure, duty cycle and spark gap are kept constant i.e, 0.25 kgf/cm^2, 8% and 0.05 mm respectively. A constant spark gap can be maintained with the help of a servo control system. The total sixteen numbers of experiments are performed on die sinking type electrical discharge machine. The material removal rate is calculated by using equations 3.4. The calculated values of material removal rate is shown in table 3.8 as:

Table 3.8 Calculated Values of MRR

Run	I (Amp)	V (Volt)	Ton (µs)	Toff (µs)	MRR (g/min)
1	8	35	50	5	0.05283
2	8	40	100	7	0.05635
3	8	45	150	9	0.05979
4	8	50	200	11	0.06385
5	10	35	100	9	0.06678
6	10	40	50	11	0.06267
7	10	45	200	5	0.06898
8	10	50	150	7	0.06579
9	12	35	150	11	0.06747
10	12	40	200	9	0.07066
11	12	45	50	7	0.06639
12	12	50	100	5	0.06987
13	14	35	200	7	0.08158
14	14	40	150	5	0.07746
15	14	45	100	11	0.07364
16	14	50	50	9	0.06846

RESULTS AND DISCUSSION

4.1 Signal to Noise Ratio: The signal-to-noise (S/N) ratio indicates how the response characteristics varies relative to the target value under different noise factors. We can choose from different S/N ratios, depending on the objective of experiment. The equations for calculating S/N ratios for larger is better (LB), smaller is better (SB) and nominal is best (NB) are as follows:

1. Larger is Better

$$SN_i = -10\log \frac{1}{N_i} \sum_{u=1}^{N_i} \frac{1}{y^2} \quad \text{……………………………………… (4.1)}$$

2. Smaller is Better

$$SN_i = -10\log \sum_{u=1}^{N_i} \frac{y^2}{N_i} \quad \text{……………………………………………… (4.2)}$$

3. Nominal is Best

$$SN_i = 10 \log \frac{y^2}{s^2} \quad \text{………………………………………………………… (4.3)}$$

Where, i= Experiment number
u= Trial number
N_i= Number of trials for experiment I
S= Variance
y= Performance Parameter

Table 4.1 S/N Ratio for MRR

Run	I (Amp)	V (Volt)	Ton (µs)	Toff (µs)	MRR (g/min)	S/N Ratio
1	8	35	50	5	0.05283	-25.5424
2	8	40	100	7	0.05635	-24.9821
3	8	45	150	9	0.05979	-24.4674
4	8	50	200	11	0.06385	-23.8968
5	10	35	100	9	0.06678	-23.5071
6	10	40	50	11	0.06267	-24.0588
7	10	45	200	5	0.06898	-23.2255
8	10	50	150	7	0.06579	-23.6368
9	12	35	150	11	0.06747	-23.4178
10	12	40	200	9	0.07066	-23.0165
11	12	45	50	7	0.06639	-23.5579
12	12	50	100	5	0.06987	-23.1742
13	14	35	200	7	0.08158	-21.7683
14	14	40	150	5	0.07746	-22.2185
15	14	45	100	11	0.07364	-22.6577
16	14	50	50	9	0.06846	-23.2913

4.2 Influences on MRR

The response tables for means and S/N ratio are shown in table 4.3 and table 4.4 respectively. The resppnse table represents the relative significance of each machining parameter towards the response. These tables show the delta value and rank for each machining parameter. The machining parameter which possesses higher delta value attains first rank and so on. The delta values and ranks for each machining parameter i.e. current (I), voltage (V), pulse on time (Ton) and pulse off time (Toff) are 0.01708, 0.00041, 0.00868 and 0.00111 and 1, 3, 2 and 4 respectively, in response table for means shown in table 4.3. Similarly from response table for S/N ratio shown in table 4.4 the

delta values and ranks for machining parameters are 2.24, 0.09, 1.14 and 0.08 and1, 3, 2 and 4 respectively.
The rank shows the significance of each machining parameter towards the response. From these tables, it is clears that the current gets rank 1 followed by pulse on time, voltage and pulse off time. These tables clearly indicates that the current has the highest impact on material removal rate and pulse off time has the lowest significant machining parameter for the material removal rate.

Table 4.3 Response Table for Means (MRR)

Level	I	V	Ton	Toff
1	0.05821	0.06717	0.06259	0.06729
2	0.06606	0.06679	0.06666	0.06753
3	0.06860	0.06720	0.06763	0.06642
4	0.07528	0.06699	0.07127	0.06691
Delta	0.01708	0.00041	0.00868	0.00111
Rank	1	3	2	4

Table 4.4 Response Table for S/N Ratio (MRR)

Level	I	V	Ton	Toff
1	-24.72	-23.56	-24.11	-23.53
2	-23.61	-23.57	-23.57	-23.49
3	-23.28	-23.48	-23.44	-23.57
4	-22.48	-23.48	-22.98	-23.51
Delta	2.24	0.09	1.14	0.08
Rank	1	3	2	4

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4.3 Main Effect Plot For MRR

The main effect plot for means and S/N ratio are shown in figure 4.1 and 4.2 respectively. These plots indicates the effect of each machining parameters to the response. From these graps, it is clears that, during the electrical discharge machining of mild steel work piece using copper tool, various machining parameter like current, voltage, pulse on time and pulse off time has significant effect on material removal rate. These graphs clearly indicate that the current and pulse on time directly related with material removal rate i.e. as the current and pulse on time increases the value of material removal rate also increases. Further, it is also concluded from these graps that the voltage and pulse off time have the negligible effect on material removal rate.

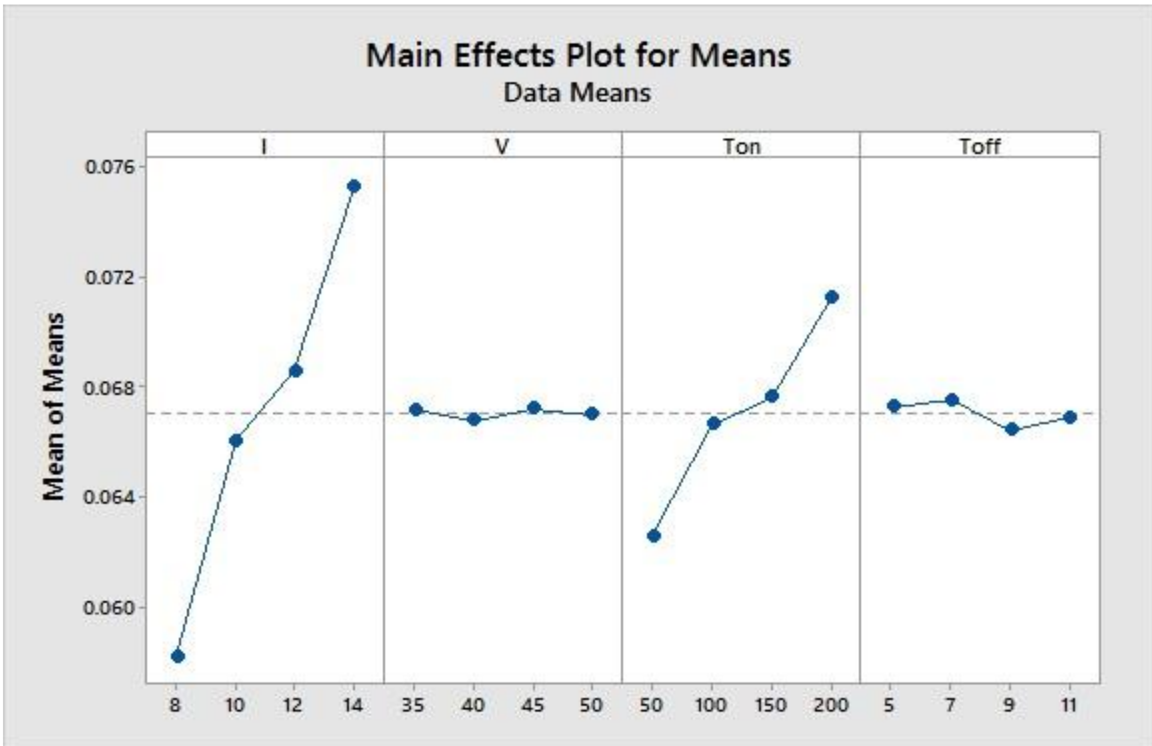

Fig. 4.1 Main Effect Plot for Means (MRR)

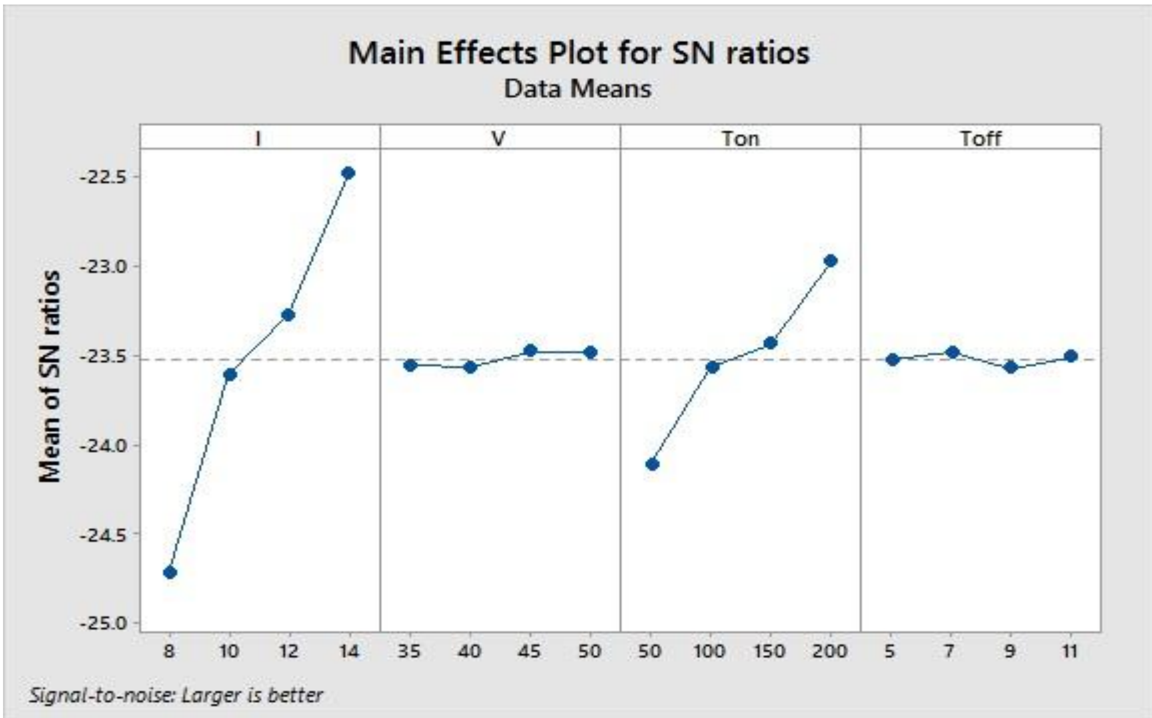

Fig. 4.2 Main Effect Plot for S/N Ratio (MRR)

4.4 Analysis of Variance For MRR

The analysis of variance (ANOVA) for MRR is shown in table 4.5.

Table 4.5 Analysis of Variance for MRR

Source	DF	Seq SS	Adj MS	F	P	% Contribution
I	3	10.3418	3.44726	16.17	0.023	75.78
V	3	0.0279	0.00929	0.04	0.986	0.20
Ton	3	2.6219	0.87397	4.10	0.138	19.21
Toff	3	0.0154	0.00513	0.02	0.994	0.11
Error	3	0.6395	0.21317			
Total	15	13.6465				

In an analysis of variance table, the P value represents the most significant parameter. The parameter whose P value is less than 0.05 will be the most important parameter. The P values for current, voltage, pulse on time and voltage are 0.023, 0.986, 0.138 and 0.994S respectively from table 4.5. From the results of analysis of variance tables, it is clear that out of all the selected machining parameters; current is the most significant machining parameter for MRR followed by pulse on time, voltage and pulse off time.

From results of analysis of variance tables, it is clear that out of all machining parameters, current and pulse on time have most significant effect on tool wear rate. From these results, it is also clears that current is the most effective parameter for tool wear rate followed by pulse on time, voltage and pulse off time.

CONCLUSIONS AND FUTURE SCOPE

5.1 Conclusions

The main aim of this work is to determine the most significant values of different machining parameters like current, voltage, pulse on time and pulse off time to maximize the material removal rate with minimum tool wear rate. For this experiment, the work is done on mild steel work piece by using a cylindrical shaped copper rod is used as a work piece and 8 pieces of cylindrical shaped copper tool having 10 mm in diameter and 6 cm in length each is used as an electrode. The complete work is done by an ELEKTRA- EMS 5535 die-sinking type electric discharge machine. Taguchi L_{16} orthogonal array is employed to design the experimental layout. From the results obtained for this experiment, the following conclusions have been drawn: -

1. The response parameters i.e. material removal rate is significantly influencing by the machining parameters.
2. Current is the most significant parameter for material removal rate followed by pulse on time, voltage and pulse off time.
3. The material removal rate is directly proportional to the current and pulse on time.
4. As the range of current and pulse on time increases, the material removal rate also increases. This is due to that as the current and pulse on time increases, the heat energy also increase which further results of more metal to be melt from work piece.
5. For the response parameter i.e. material removal rate , the voltage and pulse off time have not much effect.
6. For higher material removal rate, the optimal value of machining parameters are current (14 amp), pulse on time (200 µs), voltage (45 volt) and pulse off time (7 µs) respectively.

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