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EXPERIMENTALLY INVESTIGATION THE MATERIAL REMOVAL RATE IN POWDER MIXED ELECTRIC DISCHARGE MACHINING PROCESS ON HIGH SPEED STEEL

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ABSTRACT

Powder Mixed Electric Discharge Machining is capable of machining geometrically complex shapes and hard material components that are difficult to machine such as ceramics, carbides, heat treated tool steels, composites, super alloys, heat resistant steels etc. These hard material components are widely used in tool, die and mold making industries, automotive, aeronautics, nuclear industries and construction industries. For any manufacturing and fabrication process, particularly related to Electric Discharge Machining process the correct selection of machining parameters is one of the most important aspects to be considered.

This experimental work investigates the effect of dielectric fluid on the material removal rate. Further, the machining parameters like pulse on time, current and pulse off time are also investigated to improve the material removal rate. The experiment has been conducted on high speed steel work piece using square shaped copper electrode having cross-section 8mm×8mm. For this experimental work, kerosene oil and copper powder mixed kerosene oil are used as a dielectric medium. The layout of design of experiment is based on Taguchi L9 orthogonal array and the analysis of variance is used to analyze the results and to determine the most significance machining parameter. From the results obtained, it is concluded that copper powder mixed kerosene oil as a dielectric fluid provides more material removal rate as compared to the simple kerosene oil. From the main effect plots, it is found that pulse on time and current are the most influencing parameters for material removal rate and pulse off time has the least effect. As the pulse on time and current increases, the material removal rate also increases (i.e. material removal rate varies directly with pulse on time and current). The optimal values of machining parameters like pulse on time, current and pulse off time are 150 µs, 12 Amp and 10 µs respectively.

Powder Mixed Electric Discharge machining(PMEDM)

The word PMEDM is stands for Powder mixed electric discharge machining. This method of machining is to be different to simple EDM. In PMEDM process metal powder is mixed with dielectric fluid for achieving good machining characteristics and better surface quality. Mainly copper, aluminium, magnesium, titanium, tungsten and graphite powder are used for the machining in PMEDM process.

Principle of PMEDM

The PMEDM process is based on the conversion of the electrical energy into heat energy by producing a series of continuous spark between the tool and work piece. Both the tool and work piece are electrical conductive and submerged in dielectric fluid separated by a small gap. In PMEDM process, the metal in powder form is mixed into the dielectric fluid. When a voltage is applied to the tool and work piece, an electric field is generated. The spark gap is filled up with additive particles of metal powder, and the distance between the tool and work piece increases from 30 µm to 50 µm to many times larger. The powder particles get energized and move in a zigzag way between the machining areas. Under the sparking area, the particles come close to each other and get together in clusters. After this the powder particles arrange themselves in the form of chains at different places under the machining area. This chain formation helps in bridging the gap between the tool and the work piece. Due to this bridging effect, the spark gap voltage and insulating strength of the dielectric fluid becomes less and an easy short circuit takes place between the tool and electrode, which causes erosion of material in the spark gap.

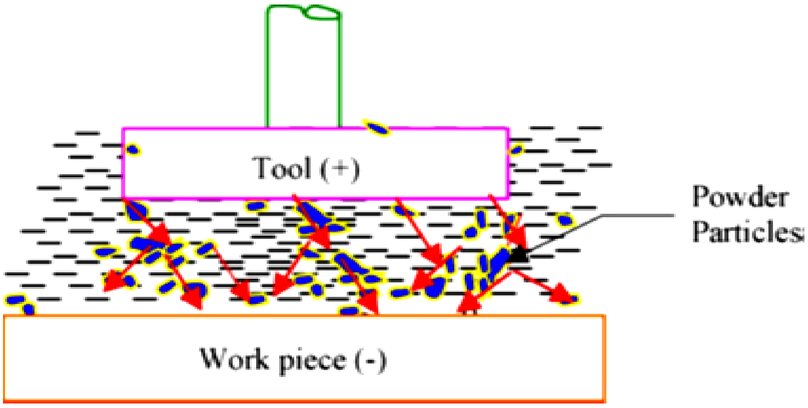

Fig: 1.4 Principle of PMEDM [3]

In PMEDM, the erosion process due to a single spark is generally passes through following five phases:

1. Pre-Breakdown Phase
2. Breakdown Phase
3. Discharge Phase
4. End Discharge Phase
5. Post Discharge Phase

1. Pre-Breakdown Phase: In this phase, the tool move close to the work piece and a small spark gap is maintained with the help of servo mechanism system. A high potential difference is applied between the tool and work piece and move towards the next phase (breakdown phase).

2. Breakdown Phase: The breakdown of dielectric medium is initiated by applying the voltage which crosses the boundary limit of strength of the dielectric medium used in the machining process. The breakdown point is normally present between the nearest surface of tool and work piece. Raise in intensity of current is occurred during the breakdown phase. A plasma channel is formed between the tool and work piece by the ionization of the dielectric medium, which further leads to discharge phase.

3. Discharge Phase: In discharge phase, incessantly attack of ions and electrons on the electrode is done by maintaining the flow of current at constant level which causes to a strong heating of work piece surface under sparking zone. By this action temperature is raised at a range of 8000 ºC to 12000 ºC, this begins to start a small molten metal pool at the surface of work piece. The radius of molten metal pool is increased with time as the plasma channel gets expend. The spark gap is an important parameter throughout the discharge phase.

4. End Discharge Phase: In this phase, cut-off of voltage is occurred therefore under the surrounding pressure in-force by the dielectric plasma channel get collapse.

5. Post Discharge Phase: In this phase, the plasma channel is ended and small metal is removed from the surface of work piece. Due to the cooling and collapsing of plasma channel, a thin layer known as white layer is deposited on the surface from charter on the surface of work piece

Machining Parameters of Powder Mixed Electric Discharge Machine

Machining parameters are variables within the process which affects the performance characteristics. If we want to an efficient machine performance we should have to identify the important machining parameters. These are generally controllable machining input variables that find the conditions in which machining operation is carried out. The various machining parameters of PMEDM are:

a. Pulse on Time
b. Pulse off Time
c. Duty Cycle
d. Discharge Current
e. Voltage
f. Spark Gap
g. Polarity
h. Dielectric Fluid
i. Flushing Pressure

a. Pulse on Time (T_{ON}): It is the time duration in microseconds under which actual machining is to be taken placed. It is the duration of time during which the current is allowed to flow through the circuit. In an Powder Mixed Electric Discharge Machining process, the material removal is directly proportional to applied energy during the pulse on time, so longer is the pulse duration, crater produced by the current is wider and deeper. Both the discharge current and the ignition length are depends on gap size. With the discharge current, the amount of heat energy generated during single discharge is set by the pulse on time. When discharges with small pulse on times are used, the removal of material from the work piece surface is less or vice versa. Whereas the surface finish is inversely proportional to the pulse on time i.e. as the pulse on time increases, the surface finish decreases or vice versa.

b. Pulse off Time (T_{OFF}): It is the time duration in microseconds between the two consecutive sparks. The pulse off time allows solidifying the molten metal and washing out this solidified metal from the machining area by using accurate flushing method. The material removal rate is inversely proportional to the pulse off time i.e. as the pulse off time increases, the material removal rate decreases. On the other hand, the surface quality increases with increase in pulse off time.

c. **Duty Cycle (τ):** It is defined as the ratio of pulse on time to the total cycle time. It is measured in percentage. With higher percentage of duty cycle, the machine gives higher efficiency, if current is applied for the long duration of the pulse on time. The material removal rate is directly proportional to the duty factor. The mathematical expression for duty cycle are as:

$$\tau = \frac{\mathrm{Ton}}{\mathrm{Ton+Toff}} * 100 \quad \text{.....................} \ (1.1)$$

Where,

τ = Duty Cycle

T_{ON} = Pulse on time

T_{OFF} = Pulse off Time

d. **Discharge Current (I)**: Discharge current is the pre-set value of the current. It is the amount of electrical energy in ampere is supplied per cycle. In an electrical discharge the discharge current is directly related to the power intensity. This parameter determines the consumption of power during machining process, so it is an important machining parameter to be considered while machining. As the intensity of current of current is increase, the material removal rate also increases.

e. **Voltage (V):** It is the potential difference applied across the circuit. The electrical discharge influences by the spark energy is specified by the open circuit voltage. It is measured in volt. De-ionization of dielectric medium depends upon the strength of dielectric fluid used and the spark gap set voltage between tool and work piece.

f. **Spark Gap:** The spark gap also known as arc gap or inter electrode gap. It is the distance measured in mm between the tool and work piece. During an Powder Mixed Electric Discharge Machining process, for the proper flushing and stability of spark it is the most important to set a constant spark gap. A servo controlled mechanism is used to maintain a constant spark gap. The value of spark gap generally varies from 0.01 mm to 0.5 mm.

g. **Polarity:** The potential of both the electrodes is specified through the polarity. It is either positive or negative for tool/work piece depends on application. In general the metal like titanium and carbide are cut with negative polarity of electrode.

h. **Dielectric Fluid:** In an Powder Mixed Electric Discharge Machining process dielectric fluid is used as an electric insulator. Its function is to concentrate the electrical discharges to a narrow region, cooling the tool and work piece and flush away the debris from the machining area. Generally EDM oil, kerosene oil, de-ionized water, paraffin oil and transformer oil are used a dielectric fluid.

i. **Flushing Pressure (F_P):** In an Powder Mixed Electric Discharge Machining process, for the supply of clean and filtered dielectric fluid into machining area, the flushing taken as an important consideration. If flushing is insufficient, it may cause to uncontrolled arcing and may create unwanted cavities which can also damage the work piece. In an Electric Discharge Machining process, generally pressure flushing, suction flushing and injection flushing are used to introduce the dielectric fluid through the spark gap.

Response Parameters

The response parameters are also known as performance parameters or output characteristics of machining process. In an Powder mixed Electric Discharge Machining process, the various response parameters are as:

a. Material Removal Rate
b. Tool Wear Rate
c. Heat Affected Zone
d. Over Cut
e. Surface Roughness

a. **Material Removal Rate (MRR):** It is the ratio amount of material removed from the surface of work piece to the machining time. It is measured in gram per minute. The material removal rate is large at anode with the shorter pulse duration, while material removal is larger at cathode with the large pulse duration. In an Powder Mixed Electric Discharge Machining process, if the value of material removal rate is higher, it will take as better response characteristics.

$$MRR\ (g/min) = \frac{\mathrm{Wwb} - \mathrm{Wwa}}{\mathrm{T}} \ldots \ldots\ldots\ldots\ldots\ldots \quad (1.2)$$

Where,

Wwb = Weight of work piece before machining

Wwa = Weight of work piece after machining

T = Machining Time

b. **Tool Wear Rate (TWR):** It is associated with the wearing of tool during machining process. It is the ratio of the material removed from the tool to the total machining time. In an Powder Mixed Electric Discharge Machining process, lower the value of tool wear rate better will be the response characteristics. Therefore, tool wear rate is the lower-the-better response characteristics. It is mathematically expressed as:

$$TWR\ (g/min) = \frac{\mathrm{Wtb} - \mathrm{Wta}}{\mathrm{T}} \quad \text{.......................} \ (1.3)$$

Where,

Wtb = Weight of tool before machining

Wta = Weight of work piece after machining

T = Machining Time

c. **Heat Affected Zone (HAZ):** Heat affected zone or heat affected area specified the area of the work piece that did not melt during electric discharges but has experienced a transformation or change of phase similar to heat treatment process under the high temperature of electric discharges.

d. **Over Cut (OC):** The over cut is the half of difference between the diameter of hole produced and electrode diameter. It is measured in mm. Smaller the value of over cut, better the response characteristics. Hence, over cut is the smaller the better performance parameter. It can be expressed mathematically as:

$$OC\ (mm) = \frac{\text{Dia.of hole produced} - \text{Dia.of Tool}}{2} \quad \text{.........} \ (1.4)$$

e. **Surface Roughness (SR):** It is the vertical deviations on the surface of work piece. It is generally measured in µm. The surface roughness is measured with the help of a profile-meter. R_a is the average value of surface roughness which mostly used as a surface roughness parameter. Smaller the value of surface roughness results in better response characteristics. Hence, surface roughness is the smaller the better performance parameter.

Benefits of Powder Mixed Electric Discharge Machining Process

1. Since there is no physical contact between the tool and work piece, there is no mechanical deformation due to mechanical stresses during the machining process as occurred in conventional machining process.
2. The Powder Mixed Electric Discharge Machining process is free from mechanical stresses and vibrations, because there is no direct contact between the tool and the work piece.
3. In an Powder Mixed Electric Discharge Machining process, properties of work piece material like hardness, toughness and microstructure produce has no barrier to its application.
4. Slender and fragile work piece can also machine with this process.
5. Parts or components can produce with a high degree of accuracy and surface quality.
6. The surface produced through Electric Discharge Machining process consist multitude of small crater; which helps in retention of oil and better lubricating property.
7. Micro components and intricate shapes can also machine through this process with high degree of precession.

Methodology

For the present experimental work, three machining parameters namely pulse on time, current and pulse off time are selected. The design of experiment is based on Taguchi L_9 orthogonal array. Taguchi design approach is one of the most suitable statistical tools for designing high quality design process at low cost. Taguchi design approach uses a special design of orthogonal array to analyze the machining parameter with a less number of experiments.

In Taguchi design approach, Signal to Noise ratio is the measure of quality characteristics and Signal to Noise ratio (S/N ratio) for material removal rate is calculated as “higher is better” criterion and Signal to Noise ratio (S/N ratio) for tool wear rate and surface roughness is determined as “smaller is better” criterion. Further, Analysis of Variance is used to analyze the results obtained from Taguchi design approach.

Conduct of Experiment

The design variables for this experimental work are shown in tableA.1.

Table A.1 Design Variables for Experiment

Design Variables			
Machining Parameters	**Constant Parameters**	**Fluid Used**	**Response Parameter**
• Pulse on Time • Current • Pulse off Time	• Voltage • Duty Factor • Polarity • Flushing Pressure • Spark Gap • Experiment Time	• Kerosene Oil • Copper Powder Mixed Kerosene Oil	• MRR

ELEKTRA EMS 5535 Die Sinker type of EDM machine is used to conduct the experiments on high speed steel work piece by using square shaped copper electrodes having cross-section 8mm × 8mm respectively. Kerosene oil and kerosene oil mixed with copper powder is used as a dielectric fluid. The grain size of powder particles of copper is 8 µm. External pressure flushing is used to flush the dielectric fluid between the spark gap. Experiments are conducted with positive polarity of work piece. In this experiment voltage, duty factor, flushing pressure, spark gap and experiment time are kept constant 50V, 8%, 0.28 kgf/cm^2, 0.07 mm and 30min respectively. The copper powder is mixed with kerosene oil in the ratio of 9:1 i.e. 9g/l. The layout of experiment is based on Taguchi L_9 orthogonal array. Total eighteen number of experiments are conducted (nine experiments are conducted by using kerosene oil and the remaining nine experiments are conducted by using copper powder mixed kerosene oil as dielectric medium). An electronic weighing machine is used to weigh the work piece before and after experiment. The capacity of weighing machine is 800 gram and accuracy is 0.002 gram. The observed weight of high speed steel work piece after each experiment is shown in table A.2 as:

Table A.2 Observation Table

Run	Ton	I	Toff	Weight of Work Piece (gm) for Kerosene Oil		Weight of Work Piece (gm) for Powder Mixed Kerosene Oil	
				Before Run	After Run	Before Run	After Run
1	50	9	6	378.646	378.537	376.865	376.749
2	50	12	8	378.537	378.391	376.749	376.599
3	50	15	10	378.391	378.207	376.599	376.408
4	100	9	8	378.207	378.058	376.408	376.254
5	100	12	10	378.058	377.866	376.254	376.056
6	100	15	6	377.866	377.617	376.056	375.800
7	150	9	10	377.617	377.410	375.800	375.589
8	150	12	6	377.410	377.155	375.589	375.328
9	150	15	8	377.155	376.865	375.328	375.031

Calculation of MRR

The material removal rate for kerosene oil and copper powder mixed kerosene oil are calculated by using the equation given below as:

$$MRR\ (g/min) = \frac{\mathrm{Wwb} - \mathrm{Wwa}}{\mathrm{T}} \ldots \ldots\ldots\ldots\ldots\ldots \quad (4.1)$$

The calculated values of material removal rate are shown in table1.1 as:

Table 1.1 Material Removal Rate

Run	Ton	I	Toff	Material Removal Rate (g/min)	
				Kerosene Oil	Powder Mixed Kerosene Oil
1	50	9	6	0.00366	0.00387
2	50	12	8	0.00487	0.00501
3	50	15	10	0.00615	0.00638
4	100	9	8	0.00498	0.00514
5	100	12	10	0.00641	0.00663
6	100	15	6	0.00833	0.00856
7	150	9	10	0.00693	0.00706
8	150	12	6	0.00852	0.00872
9	150	15	8	0.00968	0.00992

From the above table, it is evident that the machining with copper powder mixed kerosene oil as a dielectric fluid gives more material removal rate as compared to kerosene oil. The reason behind that, the particles of copper powder form a chain with the effect of electric forces at different regions in the sparking area. This chain helps in bridging the gap between the electrode and work piece which further weakens the strength of dielectric fluid and an easy short circuit takes place, which results early explosion in the arc gap. Due to this, the process became more stable, which results in improving material removal rate. The comparison graph shows the material removal rate for kerosene oil and powder mixed kerosene oil is shown in fig. 4.1 as:

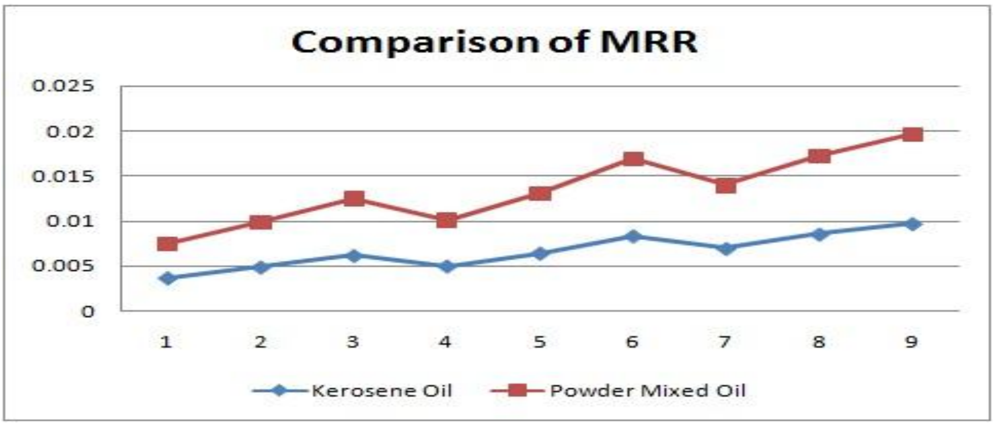

Fig: 1.1 MRR Comparisons

Signal to Noise Ratio for MRR

The signal to noise ratios for material removal rate is calculated as given in equation 4.2. Taguchi technique is used to find the result of response of machining parameter for higher is better criteria.

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

Where, i= Experiment number

u= Trial number

Ni= Number of trials for ith experiment

y= Response (Output)

Table 1.2 S/N Ratio for MRR

Run	Ton	I	Toff	S/N Ratio	
				Kerosene Oil	Powder Mixed Kerosene Oil
1	50	9	6	-48.7304	-48.2458
2	50	12	8	-46.2494	-46.0032
3	50	15	10	-44.2225	-43.9036
4	100	9	8	-46.0554	-45.7807
5	100	12	10	-43.8628	-43.5697
6	100	15	6	-41.5871	-41.3505
7	150	9	10	-43.1853	-43.0239
8	150	12	6	-41.3912	-41.1897
9	150	15	8	-40.2825	-40.0698

Response Tables and Main Effect Plots

The response tables for S/N ratios by using kerosene oil and powder mixed kerosene oil as a dielectric fluid are shown in table 1.3 and table 1.4 respectively. The response table shows the importance of each machining parameter for material removal rate. The delta values and rank for pulse on time, current and pulse off time are 4.78, 3.96, 0.44 and 1, 2 and 3 respectively, as shown in table 1.3 for kerosene oil.

Table 1.3 Response Table for S/N Ratio with Kerosene Oil

Level	Ton	I	Toff
1	-46.40	-45.99	-43.90
2	-43.84	-43.83	-44.20
3	-41.62	-42.03	-43.76
Delta	4.78	3.96	0.44
Rank	1	2	3

Similarly from response table for powder mixed kerosene oil shown in table 1.4, the delta values and rank for machining parameters are 4.62, 3.91, 0.45 and 1, 2 and 3 respectively.

Table 1.4 Response Table for S/N Ratio with Powder Mixed Kerosene Oil

Level	Ton	I	Toff
1	-46.05	-45.68	-43.60
2	-43.57	-43.59	-43.95
3	-41.43	-41.77	-43.50
Delta	4.62	3.91	0.45
Rank	1	2	3

The response shows that the machining parameter gets highest rank whose delta value is highest. From the table 1.3 and 1.4, it is clears that the pulse on time gets rank 1 followed by current and pulse off time. The rank shows the relative importance of each machining parameter to the material removal rate. From these tables it is clears that the pulse on time significantly affects the material removal rate followed by the current and pulse off time.

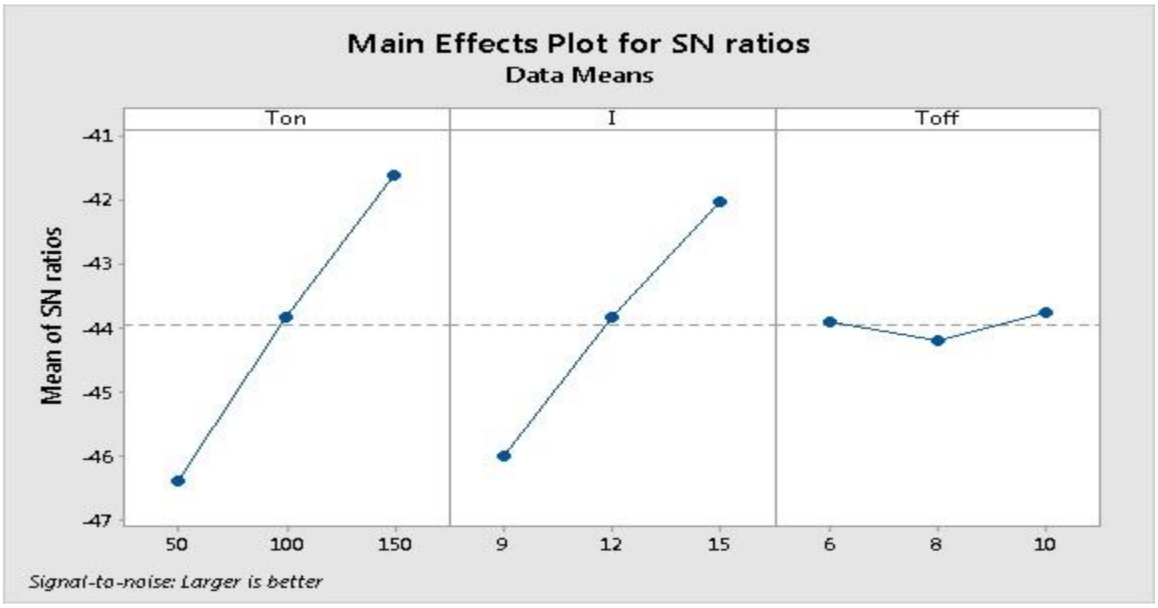

Fig. 1.2 Main Effects plot for S/N Ratio with Kerosene Oil

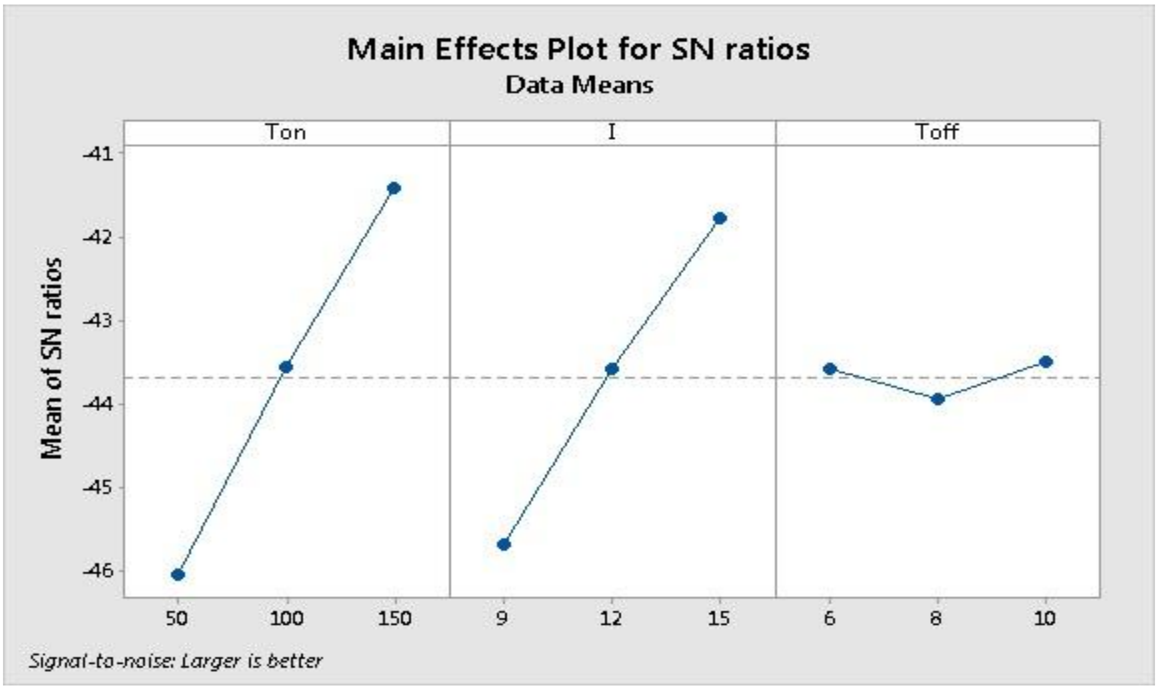

Fig: 1.3 Main Effects plot for S/N Ratio with Powder Mixed Kerosene Oil

The main effect plot for S/N with kerosene oil and powder mixed kerosene oil are shown in fig. 1.2 and 1.3 respectively. From these plots it is clears that the pulse on time and current are the most significant parameters for material removal rate, whereas the pulse off time has the least effect on material removal rate. As the pulse on time and current increases, the material removal rate also increases. This is due to the fact that at the starting of electric discharge machining process, the plasma channel occurred with small diameter, and lightweight electrons move towards the positive ions under the influence of electric field. And with the increase of intensity of current, the plasma channel expands and more positive ions move towards the cathode which helps in to remove the material from the work piece at higher rate.

Analysis of Variance

The analysis of variance is done to determine the significance of each machining parameters over the response i.e. material removal rate. The analysis of variance tables for S/N ratio of material removal rate are shown in table 1.5 and 1.6 respectively.

Table 1.5 Analysis of Variance for S/N Ratio with Kerosene Oil

Source	DF	Seq SS	Adj MS	F-Value	P-Value	% Contribution
Ton	2	34.3495	17.1748	58.20	0.017	58.40
I	2	23.5806	11.7903	39.96	0.024	40.49
Toff	2	0.2997	0.1499	0.51	0.663	0.51
Error	2	0.5902	0.2951			
Total	8	58.8200				
DF= Degree of Freedom, Seq SS= Sequential sum of squares, Adj MS= Adjusted mean squares (variance), F= Ratio of variance of source to variance of error, P ≤ 0.05 determines significance parameter at 95% confidence level						

Table 1.6 Analysis of Variance for S/N Ratio with Powder Mixed Kerosene Oil

Source	DF	Seq SS	Adj MS	F-Value	P-Value	% Contribution
Ton	2	32.1188	16.0594	81.61	0.012	57.55
I	2	22.9587	11.4793	58.34	0.017	41.14
Toff	2	0.3404	0.1702	0.86	0.536	0.61
Error	2	0.3935	0.1968			
Total	8	55.8115				

In an analysis of variance table, the P value determines the most significant machining parameter. The machining parameter having highest F value gets smallest P value. The machining parameter whose P value is less than 0.05 will be most significant machining parameter for the response. The above table's revels that pulse on time are the most influential parameter for material removal rate followed by current and pulse off time. The analysis of variance tables also shows that the pulse off time is not important for influencing material removal rate.

Conclusions

The following conclusions have been drawn from this experimental work:-

1. Copper powder mixed kerosene oil provides more material removal rate as compare to simple kerosene oil.
2. The copper powder mixed dielectric fluid provides better machining characteristics over the simple kerosene oil.
3. The most influencing machining parameter for material removal rate is pulse on time followed by current and last one is pulse off time.
4. The material removal rate is directly proportional to the pulse on time and current and inversely proportional to the pulse off time.
5. As the pulse on time and current increases, the material removal rate also increases.
6. Pulse off time has negligible effect on material removal rate.

Scope for Future Work

Some of the problems which can be investigated in future are as:

1. The use of graphite, brass and aluminium electrodes and carbides and composites as a work piece material could be taken as future study.
2. The experimental investigation of tool wear rate, surface finish and overcut by using copper tool in electric discharge machining process could also be taken as future work.
3. The experimental observe the effect of machining parameters like voltage, flushing pressure, and duty cycle could also be investigated.
4. The other design of experiment technique like response surface methodology and central composite design could be used to design the layout of experiment for future work.

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