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Study of PMEDM Efficiency on HCHCr Steel using Silicon Powder in Dielectric Fluid

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Abstract – In this present work, study has been made to optimize the process parameters of powder mixed electrical discharge machining (PMEDM). Addition of optimal amount of powder in dielectric fluid of EDM influence the Material Removal Rate and lower the Tool Wear Rate of workpiece. Current, pulse on, pulse off and powder concentration were chosen variable to study the process performance.Taguchi Orthogonal Array L9 has been used as a DOE (Design of Experiment) method to plan and analyses the experiments. 5 gm/l and 10 gm/l of Silicon powder (200 mesh size) has been used in EDM oil. It has been investigated that current, pulse on time and powder concentration are the most significant factor that influence the output response MRR and TWR. Increase in powder concentration improves process parameter but higher amount of concentration results in arcing which gives undesirable machining results. High-Carbon High-Chromium (HCHCr) steel has been selected as workpiece material and Tungsten Copper is used as electrode.

Index Terms: EDM parameters, HCHCr workpiece, Tungsten Copper electrode, EDM oil dielectric fluid.

1. INTRODUCTION

EDM is used in the machining of hardened material, or even ultra-hardened material to fabricate tools or moulds, is regarded as one of the main technologies in today's tooling field. In this process electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. Materials are conductive work piece and by applying high-frequency pulsed, electrical current to it via a solid shaped electrode. There is no physical contact between the electrode and work piece but instead discharges its current through an insulating dielectric fluid (water or oil) across a very small spark gap (0.025-0.050 mm), this discharge leads to the generation of extremely high temperature between 8000-12000 ˚C, causing fusion or partial vaporization of the material at the point of discharge[1]. The spark is plasma hot, under extreme high temperature it leads to melting of work piece materials which results in material removal. Due to conversion of electrical energy to thermal energy, high intension vaporization cause the erosion of material removal which infect gives poor surface integrity. To overcome poor surface integrity input parameters like current, pulse on, pulse off time plays vital role. High current and pulse on time induces more material removal rate (MRR) but results in poor surface finish where as high pulse off time generates more time interval to flush away debris from the spark gap and re-ionization of the dielectric take place, which helps in better surface finish. Suspended powders influence the sparking pattern and machining efficiency, these conductive powders enlarge the gap distance and improve the surface finish by reducing the spark energy and dispersing the discharge more randomly throughout the thickness of the recast layer is smaller and micro cracks on surface are improved. Consequently the corrosion resistance of the machined surface is substantially improved.

2. LITERATURE REVIEW

S Kumar *et al.* [1] with tungsten copper electrode, micro hardness of AISI H13 increase by 76 % by migration of tungsten from electrode bodies to the machined surface. Best value of micro hardness was obtained at 6A peak current. Tungsten has a very good potential as an alloying element for deposition during the EDM process. Tungsten and copper were found on surface of work piece material when machined with tungsten copper electrode. **Naveen Kumar** *et al.* [2] they conclude that MRR increased with addition of powder and increase in its concentration. This increase in powder concentration helps to concentrated the discharge energy with more uniformly and increase spark frequency. Whereas TWR reduced, it is because the presence of powder particles absorbed the fraction of heat generated that forms compounds which deposit on the machined surface. This reduces the fraction of heat transferred to the electrode. **Tzeng Y F** *et al.* [3] alloying elements may be added to the tool or suspended in the dielectric in the form of fine metal powders and they may get deposited on the machine surface either in free form or as carbides by combining with carbon from the breakdown of dielectric medium. **Kansal H K** *et al.* [4] addition of powders in dielectric medium influence the machining efficiency and sparking pattern. These powder enlarge the gap distance and improve surface finish by reducing the spark energy and dispersing the discharge more randomly throughout the surface. The thickness of recast layer is smaller and micro cracks on surface is reduced. Corrosion resistance of material surface is also improved. **Dewes R** *et al.* [5] peak current is the most important electrical parameter affecting the phenomenon of material transfer. Low value of pulse on time provoked a certain amount of electrode wear in EDM. **Wong** *et al.* [6] its states that the best surface finish obtained by silicon and graphite powders is with a low concentration of powder (2g/l). **Mohri** *et al.* [7, 8] and **Narumiya** *et al* [9]. They used silicon, graphite and aluminium as powder particles of concentration between 2-40 g/l, and their results shows that the gap distance between electrode and workpiece increases with addition of powder concentration and is larger for Al powder. Whereas the best results for MRR is achieved at higher powder concentrations levels for graphite and silicon powders. **Ming and He** [10] and **Yan and Chen** [11]. According to them, the powder materials contribute in the reduction of surface cracks and it gives the smoothness and homogenisation of the white layer. The proportional balance between the discharge rate and discharge energy is observed for a powder concentration in the range of 2-5 g/l and also lowest surface roughness levels is obtained as well. **Klocke** *et al.* [12] they study the effect of silicon powder of average particles size range of 10 micron and 10 g/l with flushing flow in the thermal influenced zone. The author use the high speed framing camera to capture the process and they found the powder suspended in the dielectric change the thermal material removal mechanism. Silicon particles store heat energy during the discharge. After the discharge process the transfer of this energy to the workpiece is balanced with the rapid cool down of the molten surface. Therefore silicon powder suspended in the dielectric promotes a softer transition from the white layer into the matrix material than the observed with powder free dielectric. **Jeswani** [14] they reported that the powder concentration plays important influence on discharge process. The powder concentration increases the gap distance and the discharge rate. While lower concentration of powder the gap increasing is not enough to promote the discharge stability. **V V Potdar** *et al.* [15]. They study that increase in MRR due to increase in powder concentration is mainly that the conductive particle when added into the dielectric fluid, it lowers the breakdown strength of the dielectric fluid. The powder tries to form the plasma bridge between the discharge gap.This facilitates the dispersion of discharge energy into several uniform area and enhance the MRR.

3. EXPERIMENTAL SETUP

High Carbon High Chromium is selected as a workpiece. The chemical composition of workpiece has been shown in the table 1. Tungsten copper electrode of 20 mm diameter has been used as tool electrode. EDM oil is used as dielectric fluid. To ensure that the suspended powder particles do not clog the filtering system mild steel tank of 9 litre volume capacity has been used for conducting experiment as shown in the figure 1. A motor of 1300 rpm is used in the tank for better mixing of the powder in the dielectric. Silicon powder of 200 mesh size is used as powder in dielectric fluid. MRR is calculated by measuring the loss of weight of the workpiece before and after the machining,

$$\text{MRR}=\frac{(Wi-Wf)}{\rho \text{ x t}}\, x\; 1000\; mm^3/min \quad \textit{equation (i)}$$

Where,

Wi= Initial weight of work piece material (gms)

Wf= Final weight of work piece material (gms)

t= Time period of trails in minutes

ρ= Density of work piece in gms/cc

TWR is calculate by measuring the loss in tool length,

$$\text{TWR}=\frac{A\,xL}{t}\; mm^3/min \qquad \text{equation (ii)}$$

Where A= front area of electrode (mm^3)

L= Loss in length of electrode (mm)

t= time period of trail (minutes)

Table 1. Chemical composition of HCHCr.

Workpiece	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Co	Cu	Ti	W
HCHCr	83.5	1.6	0.5	0.55	0.03	0.03	13.3	0.05	0.07	0.01	0.05	0.02	0.02

Figure 1. HCHCr workpiece before machining.

Figure 2. HCHCr workpiece after machining.

Table 2. Chemical composition of Tungsten copper.

Electrode	W	Cu	Ni	Z	Ti	Pb
Tungsten Copper	79.36	19.462	0.121	0.047	0.014	0.026

Figure 3. Tungsten Copper of 20 mm diameter.

Figure 4. Mild steel tank with 1300 rpm motor.

4. EXPERIMENTAL SETTING

The experiments will be conducted on the Electrical Discharge Machine model D-7120, Die sinking EDM type available at Sharda University Machine design lab. The dielectric fluid i.e. EDM oil is pour into the machining tank. A stirring motor is also used to prevent settling down of the powdered particles. The input parameters like current, pulse on, pulse off and powder concentration are varied during the experiment. And these parameters are selected to study their significance influence to MRR, TWR, Surface roughness and Microhardness. The polarity is positive (tool electrode cathode and workpiece anode) and machining time period each trial is 10 minutes. Electrode diameter is 20 mm and volume of dielectric fluid is 9 liters.

The input parameters, which will be kept constant during the experimentation are given in the table 3.

Table 3. Constant Parameters

S/No	Parameter	Value set as
1	Open circuit voltage	135±5%
2	Polarity	Positive
3	Machining time	10 minutes
4	Dielectric Fluid Volume	9 litres

5. METHODOLOGY

The effect of various input parameters i.e. current, pulse on, pulse off, electrode and powder concentration to output response MRR and TWR were investigated

through the DOE (Design of Experiment) using statistical software MINITAB. Under DOE, Taguchi design helps to create various levels and factors. All the factors were varied at three levels. Orthogonal Array that can be used will be L9 which accommodate a combination of 3 level factors, thus used to conduct of experiments to measure two response values MRR and TWR. After the conduct of the 9 trials, the mean values for MRR and TWR are recorded. For the analysis of the results, Analysis of Variance (ANOVA) was performed.

By applying Analysis of Variance (ANOVA) using Minitab software, significant parameters affecting the machining parameters (MRR) and (TWR) are determined.

Table 4. L9 Orthogonal Array after assigning factors.

S.No	Current (I) (Amp)	Pulse On (T_{on}) (μs)	Pulse Off (T_{off}) (μs)	Powder Concentration (g/l)
1	2	10	38	0
2	2	50	57	5
3	2	100	85	10
4	5	10	57	10
5	5	50	85	0
6	5	100	38	5
7	8	10	85	5
8	8	50	38	10
9	8	100	57	0

6. RESULTS AND DISCUSSIONS

The results of MRR is analyzed by using ANOVA-Analysis of Variance. The results shows that current, pulse on time and concentration contributed significantly to change in MRR. Current has the highest rank, significantly highest contribution to MRR followed by powder concentration and pulse on time.

Table 5. Measured value of Mean and S/N Ratio for MRR

S. No	Current (I) (Amp)	Pulse On (T_{on}) (μs)	Pulse off (T_{off}) (μs)	Powder Concentration (gm/l)	Mean MRR (mm^3/min)	S/N Ratio
1	2	10	38	0	3.11	-13.3917
2	2	50	57	5	5.60	-8.6595
3	2	100	85	10	7.67	-5.8231
4	5	10	57	10	12.45	-5.3924
5	5	50	85	0	8.70	-2.7217
6	5	100	38	5	14.45	0.1036
7	8	10	85	5	8.90	-1.7131
8	8	50	38	10	17.65	-0.2556
9	8	100	57	0	12.67	3.9014

Table 6. Response table for mean MRR

Level	Current (Amp)	Pulse On (μs)	Pulse Off(μs)	Powder Concentration (gm/l)
1	5.460	8.153	11.737	8.160
2	11.867	10.650	10.240	9.650
3	13.073	11.597	8.423	12.590
Delta	7.613	3.443	3.313	4.430
Rank	1	3	4	2

The main effect plots of MRR at each factors are shown in figure 5. From the figure5, it can be seen that increase in current and pulse on time significantly increase the value of MRR. It is also observed that addition of powder particles (10gm/l) and it's concentration in dielectric fluid increase the rate of MRR by 37%. It is due to fact that addition of powder particles in dielectric fluid increase the dielectric strength and discharge energy gets concentrated with more uniform and increases the spark frequency.

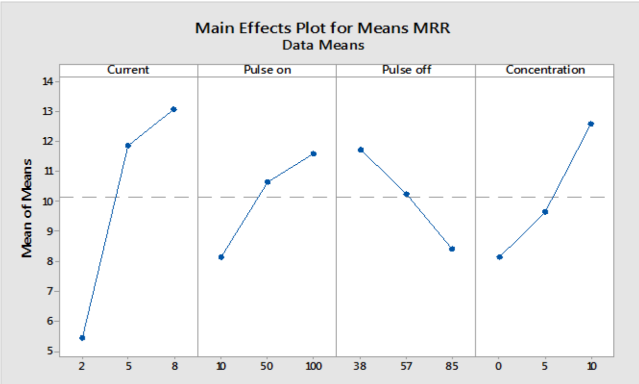

Figure 5. The main effect plots of MRR.

Whereas MRR decrease when pulse off time increase, this is due to reason that during pulse off time there is no spark discharge take places and it's the time when flushing occurs to carry away the debris from the workpiece surface [13]. Hence more pulse off time, less MRR take place.

Table 7. Response table for Signal to Noise Ratio (MRR)

Level	Current (Amp)	Pulse On (μs)	Pulse Off (μs)	Concentration (gm/l)
1	14.17	16.92	19.33	16.90
2	21.30	19.56	19.64	19.05
3	21.99	20.98	18.49	21.51
Delta	7.82	4.07	1.15	4.61
Rank	1	3	4	2

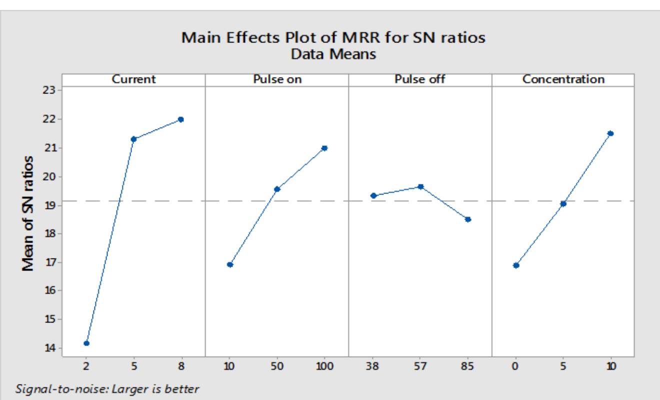

Figure 6. The main effect plot of S/N ratio for MRR

Table 8. Analysis of Variance for Mean, using for F-test (MRR)

Parameter	DOF	Sum of Square	Mean variance	F-ratio	P (% contribution)	Rank
Current	2	100.464	50.2321	*	0.60354	1
Pulse on	2	18.986	9.4930	*	0.11405	3
Pulse off	2	16.518	8.2592	*	0.09923	4
Concentration	2	30.489	15.2443	*	0.18316	2
Residual Error	0	0	0	0	0	
Total	8	166.457	83.2285		100	

Table 9. Analysis of Variance for S/N ratio, using for F-test (MRR)

Parameter	DOF	Sum of Square	Mean variance	F-ratio	P (% contribution)	Rank
Current	2	112.425	56.2127	*	0.65341	1
Pulse on	2	25.570	12.7850	*	0.14861	3
Pulse off	2	2.120	1.0602	*	0.01232	4
Concentration	2	31.941	15.9705	*	0.18564	2
Residual Error	0	0	0	0	0	
Total	8	172.057	86.0285		100	

The response parameter of mean and S/N ratio of MRR are shown in table 6, 7. The F-value and contribution percentage (P) of each factor obtained from ANOVA method are shown in table 8 and 9. From the table it conclude that, based on P value, the significance factor that contributed most are arranged in their ranking manners. Current place the highest rank and powder concentration, pulse on and pulse off respectively.

Table 10. Measured value of Mean and S/N Ratio for TWR is shown in table below.

S/N	Current (I) (Amp)	Pulse On (T_{on}) (µs)	Pulse off (T_{off}) (µs)	Concentration (g/l)	Mean TWR (mm^3/min)	S/N Ratio
1	2	10	38	0	0.2140	13.3917
2	2	50	57	5	0.2077	13.6513
3	2	100	85	10	0.4115	7.7126
4	5	10	57	10	0.2773	11.1410
5	5	50	85	0	0.6470	3.7819
6	5	100	38	5	0.9330	0.6024
7	8	10	85	5	0.6912	3.2079
8	8	50	38	10	0.7441	2.5674
9	8	100	57	0	1.2630	-2.0281

The results of TWR is analyzed by using ANOVA-Analysis of Variance. The results shows that current, pulse on time, pulse off time and concentration contributed significantly to change in TWR. Current has the highest rank, significantly highest contribution to MRR. Whereas Pulse off time has the lowest rank that significantly contributed to TWR. Response table for mean and Signal to Noise Ratio TWR are shown in table 11 and 12 respectively.

Table 11. Response table for mean TWR.

Level	Current (Amp)	Pulse On (µs)	Pulse Off (µs)	Concentration (g/l)
1	0.2777	0.3942	0.6304	0.7080
2	0.6191	0.5329	0.5827	0.6106
3	0.8994	0.8692	0.5832	0.4776
Delta	0.6217	0.4750	0.0477	0.2304
Rank	1	2	4	3

The main effect plots of TWR at each factors are shown in figure 7. As the current and pulse on time increases the TWR also increases. From the figure 7, it can be seen that increase in current and pulse on time significantly increase the value of TWR by 56%. This is due to reason that high current and more pulse on time increase the spark energy leading to higher heat being transferred to electrode and more heat being generated, which eventually leads to more TWR.

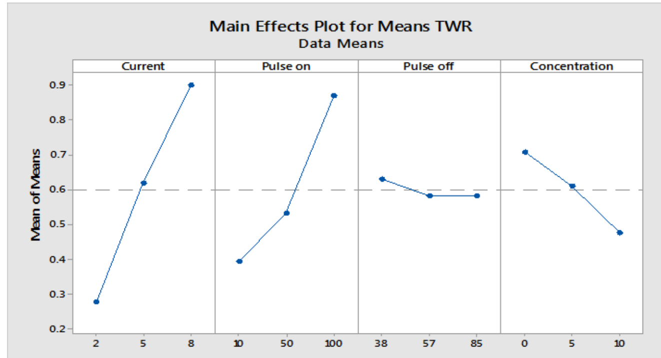

Figure 7. The main effect plots of TWR

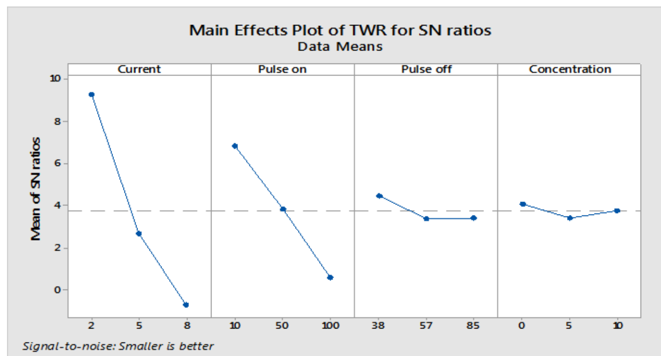

Figure 8. The main effect plot of S/N ratio for TWR

However increase in powder concentration, TWR is reduced. According to **Ajay Batish** *et al* [13] when the powder particles are present in the inter-electrode gap, even if the discharges are concentrated and uniform, a fraction of the heat generated is observed by the powder forming compounds that deposits on the machined surface. This phenomena reduces the fraction of heat transferred to the electrode. But, an increased powder concentration of beyond 10 % may lead to undesirable arcing.

Table 12. Response table for Signal to Noise Ratio (TWR).

Level	Current (Amp)	Pulse On (µs)	Pulse Off (µs)	Concentration (g/l)
1	11.585	9.247	5.520	5.049
2	5.175	6.667	7.588	5.821
3	1.249	2.096	4.901	7.140
Delta	10.336	7.151	2.687	2.092
Rank	1	2	3	4

While it is observed, when pulse off time increase, TWR decrease by 4.38%, this is due to the reason that during pulse off time there is no spark discharge take place.

Table 13. Analysis of Variance for Mean, using F-tests (TWR).

Parameter	DOF	Sum of Square	Mean variance	F-ratio	P (% contribution)	Rank
Current	2	0.58163	0.290814	*	0.56783	1
Pulse on	2	0.35793	0.178967	*	0.34943	2
Pulse off	2	0.00450	0.002249	*	0.004393	4
Concentration	2	0.08024	0.040119	*	0.078336	3
Residual Error	0	0	0	0	0	
Total	8	1.024298	0.512149		100	

The response parameter of mean and S/N ratio of TWR are shown in table 11 and 12. The percentage contribution (P) of each factor for mean and S/N ratio obtained from ANOVA method are shown in table 13 and 14. From the table, it concludes that, based on P value, the significance factor that contributed most are arranged in their ranking manners.

Table 14. Analysis of Variance for S/N Ratio, using F-tests (TWR)

Parameter	DOF	Sum of Square	Mean variance	F-ratio	P (% contribution)	Rank
Current	2	163.338	81.6692	*	0.62671	1
Pulse on	2	78.693	39.3465	*	0.30193	2
Pulse off	2	11.880	5.9401	*	0.04558	3
Concentration	2	6.714	3.3568	*	0.02576	4
Residual Error	0	0	0	0	0	
Total	8	260.625	130.3125		100	

Current place the highest rank and pulse on, powder concentration and pulse off respectively for Mean TWR whereas for S/N ratio of TWR most significant factor that contributed is current with 62.67%, next significant factor is pulse on with 30.19% and the third significant factor is pulse off with 4.558% and the forth significant factor is powder concentration with 2.576%.

7. CONCLUSION

In this study the influence of PMEDM with Tungsten copper electrode and silicon powder in EDM oil dielectric has been investigated. MRR and TWR was analyzed for effects of different input parameters. The following conclusion has been found out from the experiment and results

1. Higher current and higher pulse on time influence most significantly in both MRR and TWR. It has been seen from the results that when pulse on time increases Material Removal Rate of workpiece is increase by 41%.
2. When concentration of silicon powder increases from 0-10 g/l, MRR also increase but TWR decrease as the concentration increases. From the result's observation, it concludes that when powder concentration increases from 0 to 10 g/l, TWR decrease by 35%.
3. While increase in pulse off time, MRR reduced by 32% and TWR by 4.38%.

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