EXPERIMENTAL STUDIES ON THE INFLUENCE OF ADDITIVES IN DIELECTRIC MEDIUM ON CERTAIN QUALITY CHARACTERISTICS OF ELECTRIC DISCHARGE MACHINED COMPONENTS

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Abstract: Electrical discharge machining (EDM) is one of the non-traditional machining processes used to remove material based on the development of thermal sparks occurring between the tool and workpiece in the presence of dielectric fluid. Many researchers have already attempted to study the influence of adding single additive in dielectric fluid on the quality characteristics of EDMed parts. In order to achieve higher production rate significant attention has to be paid towards improving the quality and performance of dielectric fluid. In this work, the influence of adding graphite and aluminium powders with the dielectric liquid on surface roughness and material removal rate (MRR) of the EDMed componentswere studied by conducting experiments. The experiments were conducted with and without additives in the dielectric and the influence of additives were studied by comparing these results.

Index Terms: Electrical discharge machining, dielectric, additives, surface roughness, material removal rate, Taguchi's design of experiments.

1. Introduction

Electrical discharge machining is a die-sinking process used for stock removal. Presently, EDM is employed in manufacturing field to make dies and moulds, aerospace, automotive and biomedical components. The outstanding capabilities of this technique include the ability to machine conductive materials with high hardness and produce complex geometrical shapes without any mechanical stress. Despite the advantages, tool wear, relatively low material removal rate (MRR) and its adverse effects on surface quality limit its applications. Addition of powdered additives like graphite with dielectric is considered as an effective means of enhancing the performance of EDM.The dielectric fluid is a primary factor that affects material removal rate and surface finish. The essential tasks of the dielectric fluid are to clear the debris particles from the machining zone, increasing spark energy density in the plasma channel and cooling the electrodes [1,2].Ryota*et al.* [1] investigated the improvement in surface characteristics due to the addition of chromium powder with dielectric. Houriyeh*et al.* [3], made a review on the influence of powderedadditives with dielectric on output characteristics like surface finish, MRR and tool wear. Utilizing powder mixed dielectric in the process is called powder mixed EDM (PMEDM). Jeevamalar and Ramabalan [4] presented a review on EDM input parameters like discharge voltage, polarity and output parameters like surface roughness, MRR, wear ratio and over cut. Biing Hwa Yan *et al.*[5] discussed the effect of addition of urea with distilled water on the surface modifications of pure-titanium metal machined using EDM. Shuliang*et al.* [6] investigated the surface quality of micro holes machined using different dielectric fluids.

The literature review conducted to understand the problems in EDM revealed that there is scope for improving the quality and performance of dielectric fluid by adding additives with it which in turn will improve the output characteristics of the process. Therefore, the influence of the additives like graphite and aluminium powder with dielectric on surface roughness and MRR is investigated in this work.

2 Materials and Methods

2.1 Work piece material

The material chosen for conducting the experiments is D3 die steel. It was chosen because of its wide applications in tool and die making. The material was hardened by oil hardening method and the hardness of this material was found to be 58 HRC through hardness test.

2.2 Tool

The tool material selected for conducting the experiments is Copper rod of diameter 6 mm.Itis selected as it is cheap, readily available and has high thermal conductivity.Both the ends of each tool were ground to have flat ends.

2.3 Dielectric fluid and additives

The dielectric fluid used to conduct experiments is Daphne cut oil. The additives used are graphite and aluminium powders. They are mixed 2 grams each in one litre of dielectric fluid. Many research works have proved that the addition of graphite and aluminium helps in improving MRR, tool life and surface finish. But these powders were used individually with the dielectric fluid. Therefore, these additives are mixed in certain proportion with the dielectric fluid as mentioned above and the experiments were conducted.

3 Experimental Design

The input parameters chosen for conducting the experiments are current, pulse on time and pulse off time. The response parameters measured are surface roughness and MRR. Surface roughness was measured using MITUTOYO SJ 201 surface roughness tester. The volume of material is calculated analytically for the shape produced on the work piece. It is then divided by the time taken for machining to get volumetric material removal rate.

Design of experiments is a process by which experiments are planned to analyse data using established statistical methods and arrive at the conclusion. Taguchi method was used to determine the settings of parameters. L8 orthogonal array is used in experimental planning. The most significant control factors affecting the response and their levels are listed in Table 1.

Table 1:Factors and their levels

Factors(Unit)	Level 1	Level 2
Current (A) (Amp)	3	5
Pulse On (B) (µs)	4	8
Pulse Off (C) (µs)	6	7

The parameter design is contributed to determine the effect of the control factor in machining process and also to evaluate the optimal cutting conditions for obtaining the better surface finish and maximum material removal rate. The control factors and each parameter used in the experimental design were designed based on the information available in literatures and the capability of the machine used.

4. Analysis of experimental data for surface roughness

The experimental layouts for the machining parameters obtained as per L8 orthogonal array and the measured value of surface roughness with and without additives are shown in Table 2.ANOVA calculations reveal that all the three factors influence surface roughness of thecomponentwhen machining without additives whereas the factor B alone is found to beinfluencing the surface roughness of the component while using additives. The ANOVA table obtained is shown in Table 3 and 4.

Table 2: L_8 Orthogonal array with the input parameters and the output parameter surface roughness

Ex. No.	1 (A)	2 (B)	3 (AXB)	4 (C)	5 (AXC)	6 (BXC)	7 (D)	Surface roughness (µm)	
								Without additive	With additive
1	1	1	1	1	1	1	1	3.486	2.941
2	1	1	1	2	2	2	2	4.543	4.467
3	1	2	2	1	1	2	2	7.043	4.804
4	1	2	2	2	2	1	1	8.126	4.755
5	2	1	2	1	2	1	2	3.616	3.553
6	2	1	2	2	1	2	1	3.333	3.199
7	2	2	1	1	2	2	1	5.8	3.452
8	2	2	1	2	1	1	2	7.663	6.202

Table 3: ANOVA Tablefor surface roughness (without additives)

Source	DOF	SS	MS	F_{calc}	$F_{critical}$	Comments
A	1	2.91	2.91	5.902	4.45	**Significant**
B	1	69.91	69.91	141.805	4.45	**Significant**
C	1	5.193	5.193	10.533	4.45	**Significant**
AXB	1	0.1508	0.1508	0.305	4.45	Insignificant
AXC	1	0.115	0.115	0.233	4.45	Insignificant
BXC	1	1.768	1.768	3.586	4.45	Insignificant
Error	17	8.393	0.493			
Total	23	88.44				

Table 4: ANOVA Table for surface roughness (with additives)

Source	DOF	SS	MS	F_{calc}	$F_{critical}$	Comments
A	1	0.124	0.124	0.092	4.45	Insignificant
B	1	9.580	9.580	7.117	4.45	**Significant**
C	1	5.629	5.629	4.18	4.45	Insignificant
AXB	1	0.219	0.219	0.162	4.45	Insignificant
AXC	1	0.322	0.322	0.239	4.45	Insignificant
BXC	1	0.878	0.878	0.652	4.45	Insignificant
Error	17	22.89	1.346			
Total	23	39.65				

The optimum combination of process parameters was found out using Analysis Of Means (ANOM) technique. As minimum surface roughness is expected on any machined surface, smaller the better condition is chosen.The optimum process parameter combinationin both the casesis found to be A_2,B_1,C_1. That is surface roughness is minimum at level 2 of parameter A, level 1 of parameter B and level 1 for parameter C as shown in Table 5 and 6.

Table 5: ANOM Table for surface roughness (without additives)

Level	A	B	C
1	5.798	**3.744**	**4.986**
2	**5.102**	7.158	5.916

Table 6: ANOM Table for surface roughness (with additives)

Level	A	B	C
1	4.241	**3.54**	**3.687**
2	**4.101**	4.803	4.655

The experimental layouts for the machining parameters obtained as per L8 orthogonal array and the measured value of MRR with and without additives are shown in Table 7.ANOVA calculations reveal that all the factor A influenceMRR of the component when machining without additives whereas the factor B and interaction between A and B is found to be influencing the surface roughness of the component when using additives. The ANOVA table obtained is shown in Table 8 and 9.

Table 7. L_8 Orthogonal array with the input parameters and the output parameter MRR

Ex. No.	1 (A)	2 (B)	3 (AXB)	4 (C)	5 (AXC)	6 (BXC)	7 (D)	MRR (mm^3/min)	
								Without additive	With additive
1	1	1	1	1	1	1	1	0.87	1.61
2	1	1	1	2	2	2	2	0.776	0.801
3	1	2	2	1	1	2	2	3.282	1.07
4	1	2	2	2	2	1	1	2.834	0.797
5	2	1	2	1	2	1	2	0.87	1.46
6	2	1	2	2	1	2	1	0.48	1.4
7	2	2	1	1	2	2	1	1.93	1.75
8	2	2	1	2	1	1	2	2.196	4.67

Table 8: ANOVA Table for MRR (without additives)

Source	DOF	SS	MS	F_{calc}	$F_{critical}$	Comments
A	1	6.561	6.561	310.74	0.036	**Significant**
B	1	0.359	0.359	17.01	0.151	Insignificant
C	1	0.056	0.056	2.68	0.349	Insignificant
AXB	1	0.653	0.653	30.96	0.113	Insignificant
BXC	1	0.0108	0.0108	0.52	0.604	Insignificant
CXA	1	0.125	0.125	5.96	0.248	Insignificant
Error	1	0.0211	0.0211			
Total	7	7.788				

Table 9: ANOVA Tablefor MRR (with additives)

Source	DOF	SS	MS	F_{calc}	$F_{critical}$	Comments
A	1	1.137	1.137	0.59	0.584	Insignificant
B	1	2.105	2.105	1.08	0.487	**Significant**
C	1	0.395	0.395	0.20	0.730	Insignificant
AXB	1	3.128	3.128	1.61	0.425	**Significant**
BXC	1	1.545	1.545	0.80	0.536	Insignificant
CXA	1	0.747	0.747	0.38	0.647	Insignificant
Error	1	1.942	1.942			
Total	7	10.999				

As maximum MRR is expected in any machining process, larger the better condition is chosen. The optimum process parameter combination without additive is A_2,B_2,C_1 and with additive is A_2,B_1,C_1. That is MRR in case of without additive is maximum at level 2 of parameter A, level 2 of parameter B and level 1 for parameter C as shown in Table 10 and in case of with additive is maximum at level 2 of parameter A, level 1 of parameter B and level 1 for parameter C as shown in Table 11.

Table 10: ANOM table for MRR (without additives)

Level	A	B	C
1	0.749	1.442	**1.738**
2	**2.560**	**1.866**	1.570

Table 11: ANOM tablefor MRR (with additives)

Level	A	B	C
1	1.318	**2.208**	**1.917**
2	**2.072**	1.182	1.473

5. Results and discussions

The influence of various input process parameters on surface roughness is discussed in this section. Based on the study conducted by Houriyeh et al. [3], it is found that the debris particles are removed easily because of the shallower crater generated due to multiple discharge paths obtained. Multiple discharge paths are generated due to increase in the spark frequency and ionisation which is contributed due to addition of conductive powder in the dielectric medium.

5.1 Current Vs Surface roughness

The surface finish is a function of two parameters, peak current and pulse-on time [7]. Higher current leads to material removal in the form of larger craters and hence surface roughness is more and vice versa.If the energy input is increased (current), the amount of debris in the gap becomes too large. The particles can then form an electrically conducting path between the electrode and work piece, causing unwanted discharges which become arcs and damage both the electrode and the work piece surfaces. This causes poor surface finish. The same effect is shown in Figure 1(a).

5.2 Pulse On time Vs Surface roughness

The effect of pulse duration on surface finish is shown in Figure 1(b)for the current values between 11 A to 15 A, surface roughness increases with pulse duration. The reason for larger roughness values with higher pulse duration can be explained by the generation of large craters due to large amounts of energy. Therefore, low pulse on time is desirable for minimum surface roughness. Surface finish is improved using additives because the additive forms a conductive bridge around the spark channel guiding the discharge.

5.3 Pulse Off time Vs Surface roughness

The effect of the pulse off time in the surface roughness is shown in Figure 1(c), the results obtained are in contradiction with the explanation provided for pulse on time thus lower the pulse duration lower the surface roughness value. The results obtained shows that the surface roughness increases as the pulse off time increases.

5.4 Current Vs MRR

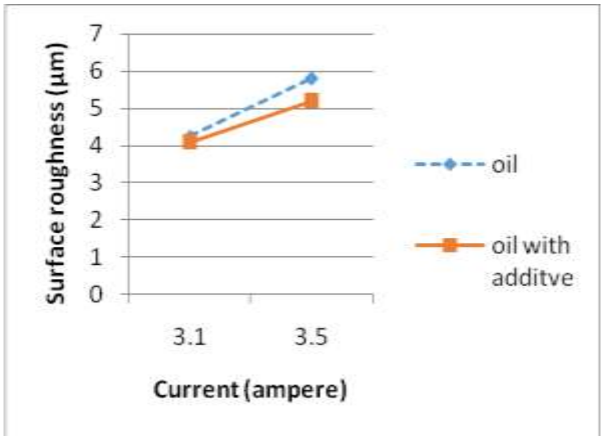
Material removal increases as the energy input increases. The total energy depends on the number of sparks per second and the amount of energy in each spark. The amount of material removal is normally proportional to the energy used.The effect of the current on MRR is shown in Figure 1(d). In case of dielectric with additives the MRR increases with increase in current. The decrease in the material removal rate may be susceptible due to the improper flushing of the dielectric.

5.5 Pulse On time Vs MRR

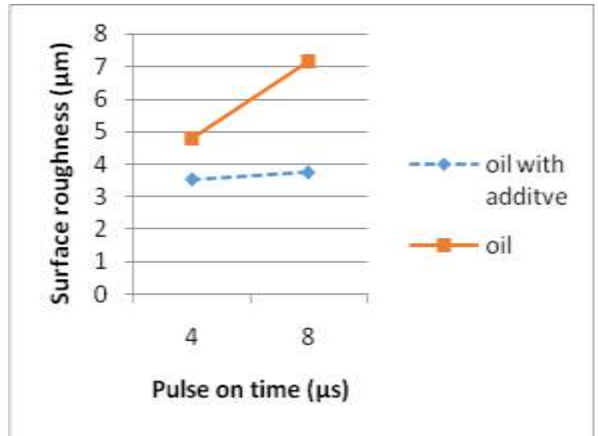
The MRR is also influenced by the pulse duration, the pulse on time defines the pulse duration of the cycle. This in turn increases machining rate and spark duration thus leading to higher MRR. Though in both the cases, the MRR increases with increase in pulse on time as shown in Figure 1(e), the usage of additives accelerates MRR on comparison with MRR values without additives.

5.6 Pulse Off time Vs MRR

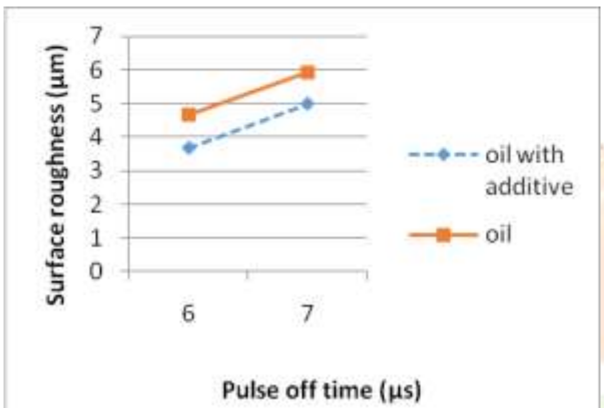
The results obtained for dielectric with additives are also in contradiction to the results and the explanation provided for the pulse on time as the pulse off time increases the spark duration is decreased thereby MRR decreases.The effect of the pulse off time on the MRR is shown in Figure 1(f). Because of the addition of additives lesser debris particles are produced, which inturn results in the higher MRR values when dielectric is added.



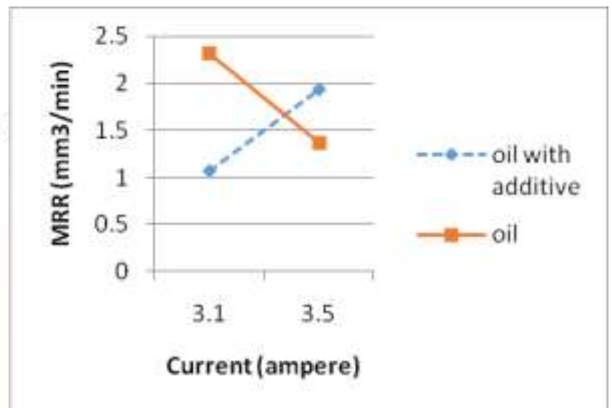
(a)



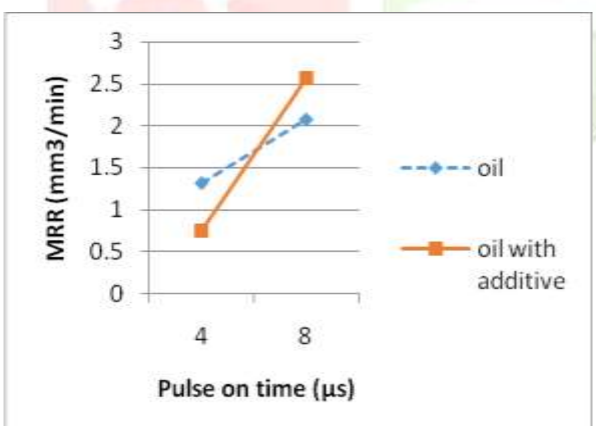
(b)



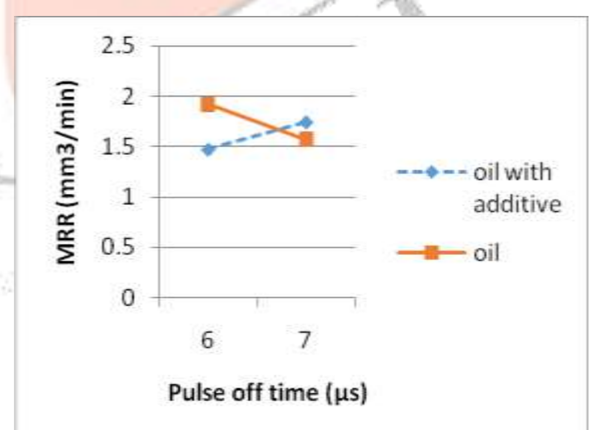
(c)



(d)



(e)



(f)

Fig.1: Input parameters Vs Responses: (a) Current Vs Surface roughness; (b) Pulse On time Vs Surface roughness; (c) Pulse Off time Vs Surface roughness; (d) Current Vs MRR; (e) Pulse On time Vs MRR; (f) Pulse Off time Vs MRR

Conclusions

This work evaluated the performance of EDM and the feasibility of improving the surface characteristics of EDMed components by adding additives in the dielectric medium. Surface roughness of the parts machined byEDM process using dielectric fluidmixedwith additives is found to belower than that of the EDMed parts without additives in dielectric fluid. Material removal rate is also found to be larger when dielectric fluid is used along with additives. Therefore, the results of this work provides good information on the use of additives in improving surface finish and MRR.

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