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Effect of Different Dielectrics on Material Removal Rate, Electrode Wear Rate and Microstructures in EDM

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Abstract

Diesinker electric discharge machining is widely used non-conventional technique for making high precision and complex shaped parts. Dielectrics and electrical parameters were considered as the main factors for EDM performance. In this paper, the effects of pulse-on-time (µs) and current (ampere) were evaluated for performance measures using kerosene and water as dielectrics. A comparison was performed for both dielectrics in terms of material removal rate (mm^3/min), electrode wear rate (mm^3/min), and microstructures. Aluminum 6061 T6 alloy was used as material for this research due to its extensive use in aerospace and automotive industries. Experiments were designed using Taguchi L9 orthogonal array (OA). Time series graphs were plotted to compare material removal rate and electrode wear rate. Microstructures were taken by scanning electron microscope to analyze the surface produced in terms of cracks, globules and micro-holes. Higher material removal rate and lower electrode wear were achieved with kerosene dielectric. The novelty of this research work, apart from its practical application, is that Aluminum 6061 T6 alloy is used as work material to compare the performance of dielectrics (kerosene and distilled water).

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*Keywords:*Electric Discharge Machining; Material Removal Rate; Electrode Wear Rate; Dielectric; Microstructures

1. Introduction

Electrical Discharge Machining (EDM) is a well-established non-conventional machining method based on the principal of thermal erosion. The mechanism of material removal is accomplished by series of recurring discharges between work piece and electrode (tool) in the presence of a dielectric media between them. EDM is used to machine intricate profiles, small diameter drillings and hard materials [1]. Tool and work part materials should be electrically conductive, and the absence of direct interaction between them avoids the phenomenon of chattering and mechanical stresses. EDM demand is growing for making parts used in automotive, medical and aerospace sector. No doubt, electrical parameters play a significant role to manage EDM process but other factors especially dielectrics also need attention for this process. Dielectric is the media present between work part and tool which is responsible for discharging phenomena and hence for productivity and quality of products [2]. Kerosene and other hydrocarbon oils are widely used in EDM but new dielectrics should be analyzed for enhancing EDM capabilities to meet the technological advances of the globe. This research work aims to study the effects of kerosene and distilled water on an aluminum alloy 6061 T6 by varying levels of current and Pulse-on-Time (Pon). These two electrical parameters have been employed because of their significant effect on EDM performance which is also reported by Gostimirovic et al [3] and Sarosh et al [4]. Material Removal Rate (MRR), Electrode Wear Rate (EWR) and microstructures were analyzed in this study. Dielectrics role is significant in EDM as they made the removal mechanism possible by facilitating the discharge phenomena. Surface characteristics and cost of the machined part depend on the type of dielectric used [5,6]. In EDM, dielectrics usually play four functions; insulation, ionization, debris removal from the

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working tank, and cool down the heat of a spark. Hydrocarbon oils, water base and gaseous are three main categories of dielectrics commonly used for EDM [7-9]. After knowing the importance of dielectrics, new field of research opens in EDM [10]. Zhang et al [11] investigated different dielectrics with same experimental situation which showed craters of varying shapes and sizes and found that liquid dielectrics have higher removal efficiency and water/oil emulsion stand pressure for longer time. Wang et al [12] performed comparative experiments in distilled water, compound dielectric and kerosene on titanium alloy to evaluate MRR, EWR and surface roughness. Compound dielectric showed better results as compared to other dielectrics. Chen et al [10] performed experimentation using Ti–6A1–4V, MRR was found higher in distilled water than kerosene. Yan et al also observed variation in titanium surface while using urea in water which enhanced surface characterization [13]. Kerosene provides better surface for Al /SiC composite [14]. As water content increases in water/oil emulsion, it reduces the MRR and EWR which results in low cost of process [15,16]. Valaki and and Rathod [17] experimentally assessed the feasibility of using waste vegetable oil as an alternative dielectric in EDM for performance measures (MRR and EWR). Zhao et al [18] and Tzeng and Lee [19] investigated addition of nano-powered particles, aluminum and silicon in dielectrics which increased the performance of EDM process by increase in MRR and reduction in EWR. Tao et al [20] reported increase in MRR when oxygen gas used as dielectric. Shen et al [21] experimentally evaluated EWR and found enhancement in EWR with the increase in current and Pon for dry EDM. Liquid dielectrics are preferred over dry EDM, since they offer stable discharging [22,23]. Proper flushing of dielectrics is required during discharging otherwise arcing occurs that is an abnormal process. Arcing is unwanted phenomena which decreases EWR and reduces MRR [24]. The study of Muthuramalingam and Mohan [25] revealed that higher current and Pon enhances removal mechanism. It is also verified by Sen at al [26] and Lin et al [27] that increase in current results in higher MRR and EWR.

It is verified from literature review that dielectrics play a critical role in EDM for enhancing productivity and improving quality of product. Different dielectrics have different impact on the performance of EDM process. Therefore, their performances should be compared to attain better results. Mostly comparison of dielectrics is made for steels, titanium, and composites but aluminum alloys are little or not so much studied. In this research, kerosene and distilled water dielectrics are evaluated for Aluminum 6061 T6 alloy due to its wide applications in aerospace and automotive sector. In this study, the effects of parameters on MRR and EWR were evaluated and comparisons were made for the accomplishment of dielectrics (kerosene and distilled water).

2. Materials and methods

Die-sinking (Taiwan) NEUAR EDM was used for the experimentation and jet-flushing method was employed for dielectrics. Chemical composition of the work part material (Aluminum 6061T6) used for this study is displayed in Table 1.

Table 1. Chemical composition of Al 6061 T6

Si	Fe	Cu	Ti	Zn	Mg	Cr
1.4	0.5	0.8	0.12	0.2	1.1	0.32

All specimens were made of equal sizes of 22 mm x 20 mm (diameter x length) as shown in Fig. 1. Copper was used as electrode material in cylindrical form with internal diameter 15 mm and external diameter of 25 mm (see Fig. 2).

Fig. 1. Dimensions of work part

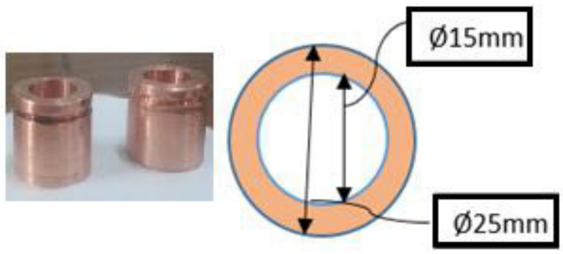

Fig. 2. Dimensions of electrode

Experiments were designed as per Taguchi L9 Orthogonal Array (OA) for two factors and three levels using commercial statistical software. Taguchi method have the capability to give lower number of experiment runs [28]. Parameters with selected levels are provided in Table 2. Nine experimental runs were performed individually for kerosene and distilled water. Sequence of experiments used for MRR and EWR are shown in Table 3. Effect of parameters (Pon and current) on MRR and EWR was determined for kerosene and distilled water separately. Furthermore, comparison of both dielectrics (kerosene and distilled water) was performed against MRR and EWR

Table 2. Parameters with selected levels

Sr. No	Parameter	Low level	Medium level	High level
1	Current (ampere)	6	9	12
2	Pulse-on-time (µs)	15	30	45

Following procedure was adopted to calculate the performance measures (MRR and EWR). Electrode and work parts were weighed using weight balance before and after performing each experimental run. Stopwatch was used to note the machining time for runs. After the completion of each run, electrode and work part were dipped in acetone to remove oil stains. MRR was calculated using equation (1) [29]:

$$MRR = \frac{\text{Volume of the workmaterial remove}}{\text{Machining time}} = \frac{w_b - w_a}{p * T_m} \quad (1)$$

Where, W_b and W_a represents the weight of work parts before and after machining, ρ shows density of work part and T_m reflects machining time (measured in minutes). EWR was calculated using following formula shown in relation (2) [29]:

$$EWR = \frac{\text{VolumeoftheToolMaterialRemoved}}{\text{MachiningTime}} = \frac{E_b - E_a}{\rho \times T_m} \qquad (2)$$

E_b, E_a indicates the weights of electrodes before and after machining respectively, ρ is density of electrode and T_m is machining time (measured in minutes). After computing the performance measures, signal to noise ratio was calculated to analyze the effects of parameters on MRR and EWR. Signal to noise ratio was calculated for MRR using larger the better ratio as shown in equation (3). On the other hand, minimum the better ratio was employed for EWR as presented in equation (4) [30].

$$\text{Larger the better } \left(\frac{S}{N}\right) = -\log\left(\frac{1}{n}\left(\sum\left(\frac{1}{y2}\right)\right)\right) \qquad (3)$$

$$\text{Smaller the better } \left(\frac{S}{N}\right) = -\log\left(\frac{1}{n}\left(\sum y^2\right)\right) \qquad (4)$$

Where, "n" shows number of experiments and "y" shows observed values of MRR and EWR.

Moreover, MRR and EWR were checked for residuals using normal probability graph. 3D surface plots were also drawn to analyze the trend of current and Pon against MRR and EWR.

Table 3. Experimental design with observed MRR-EWR values for kerosene and distilled water

Run	Current (A)	Pon (µs)	MRR (mm^3/min)		EWR (mm^3/min)		S/N for MRR (dB)		S/N for EWR (dB)	
			Kerosene	Distilled water	Kerosene	Distilled Water	Kerosene	Distilled water	Kerosene	Distilled water
1	6	15	37.60	34.75	0.86	0.60	31.5038	30.8191	1.3100	4.4370
2	6	30	82.50	40.74	0.77	0.52	38.3291	32.2004	2.2702	5.6799
3	6	45	88.80	42.74	0.56	0.86	38.9683	32.6167	5.0362	1.3100
4	9	15	61.80	49.90	1.98	2.06	35.8198	33.9620	-5.9333	-6.2773
5	9	30	128.70	90.60	1.96	1.72	42.1916	39.1426	-5.8451	-4.7106
6	9	45	154.50	68.52	1.28	2.10	43.7786	36.7163	-2.1442	-6.4444
7	12	15	105.56	52.70	3.50	4.13	40.4700	34.4362	-10.8814	-12.3190
8	12	30	244.45	112.96	2.24	4.75	47.7638	41.0585	-7.0050	-13.5339
9	12	45	302.47	102.47	1.49	3.73	49.6136	40.2119	-3.4637	-11.4342

3. Results and discussions

3.1. Analysis of MRR for kerosene and distilled water

Fig. 3a shows normal probability plot and Fig. 3b represents surface plot of MRR for kerosene. It is evident from normal probability plot (see Fig. 3a) that residuals points are laying on or very close to straight line which shows that data is normal. Surface plot (see Fig. 3b) demonstrates that MRR increases with the increase in current (6 ampere to 12 ampere). This is because more energy density become available at higher values of current that melt and removes more material [25]. Similarly, Pon exhibited same effect, MRR is increased with increase of Pon from 15 µs to 45 µs.

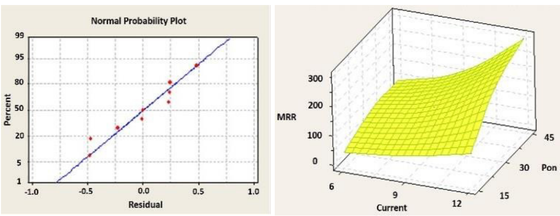

Fig. 3. (a) Normal probability plot; (b) Surface plot of MRR for kerosene

The normal probability plot of MRR for distilled water is displayed in Fig. 4a which depicts that residuals are normally distributed. Surface plot of MRR for distilled water is displayed in Fig. 4b. It is clearly evident that MRR enhances with increase in current (up to 9 ampere). At high level of current (12 ampere), reverse effect is observed (MRR decreases with the increase in current). Similar effect can be observed when considering the effect of Pon on MRR at low and high levels. The reason for this behaviour is due to rapid decomposition of water molecules at higher current levels. For present condition, higher MRR is occurred at 9 ampere current and 30 µs Pon. Similar results have been reported by Muthuramalingam and Mohan [25], Sen et al [26] and Lin et al [27].

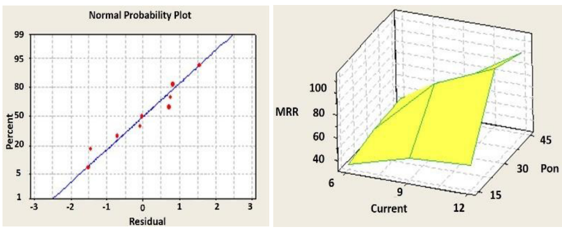

Fig. 4. (a) Normal probability plot; (b) Surface plot of MRR for distilled water

A comparison graph of MRR for both dielectrics is plotted in Fig. 5. It can be observed from the graph that MRR is higher in kerosene as compared to distilled water. This is because arcing occurred in distilled water due to early decomposition of water molecules [24].

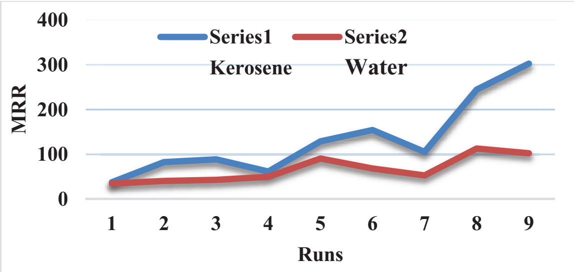

Fig. 5. Comparisons of MRR for kerosene and distilled water

3.2. Analysis of EWR for kerosene and distilled water

Normal probability plot of EWR for kerosene is provided in Fig. 6a. It is evident from figure that residuals are normally distributed. Fig. 6b demonstrates the surface plot of EWR for kerosene. It can be identified that EWR increases with the increase in current while a varying effect was observed with increase in Pon value. Normal probability plot and surface plot of EWR, for distilled water, are shown in Fig. 7a and Fig. 7b, respectively. It is evident from normal probability plot (see Fig. 7a) that residuals points are laying on or very close to straight line which shows that data is normal. Surface plot (see Fig. 7b) indicates that EWR increases significantly at higher levels of current. Moreover, maximum EWR is observed up to 38 µs. Lower EWR is observed at 6 ampere current and 30 µs Pon.

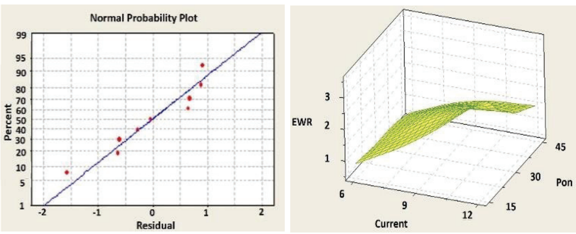

Fig. 6. (a) Normal probability plot; (b) Surface plot of EWR for kerosene

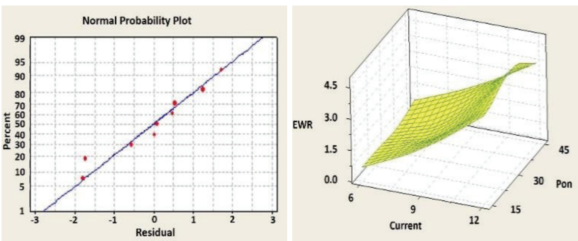

Fig. 7. (a) Normal probability plot; (b) Surface plot of EWR for distilled water

Comparison of EWR for both dielectrics has been shown in Fig. 8. It is evident that EWR in water has higher values than in kerosene. Decomposed carbon got stuck on the electrode surface in the form of carbide layer in kerosene, which protected electrode from further wearing resulting in lower EWR. Nevertheless, in water, oxide layer is deposited at electrode surface which breaks easily even at lower temperatures and consequently results in higher EWR [24].

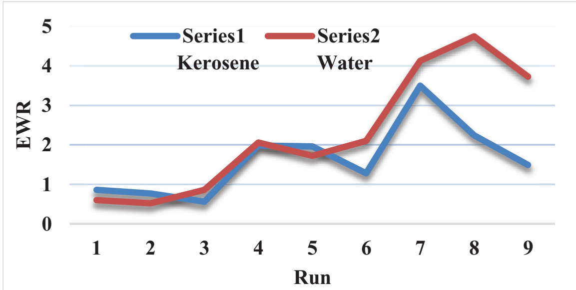

Fig. 8. Comparisons of MRR for kerosene and distilled water

3.3. Analysis of microstructures

Higher discharge energy during electric discharge machining produced higher temperature at spark point which caused melting and evaporation of material. The melted material which was not washed away properly from the surface re-solidified and produced rougher surface. In addition to that, more discharge energy became available at higher levels of current and Pon, and resulted in the formation of large cracks and crater. To visualize these micro cracks, debris and globules, micrographs were taken with SEM TESCAN (3 XMU, MIRA).

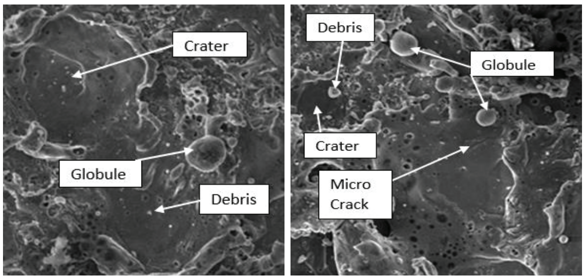

Fig. 9. Micrographs for kerosene dielectric (a) Current 6 (ampere), Pon 45 (µs); (b) Current 12 (ampere), Pon 45 (µs)

Analysis of micro graphs has been performed for different current levels while keeping Pon value at 45 µs for both kerosene and distilled water. Comparison of micro graphs at 6 ampre and 12 ampere current for kerosene (Fig. 9a, b) showed that at higher current, more cracks and micro holes are imminent that make the surface rougher. Similarly, examination of Fig. 10a and 10b demonstrates that in distilled water with increase of current level, crater size increased and more cracks appeared on surface. Furthermore, Fig. 9a and Fig.10a depict that at 45 µs Pon and 6 ampere current, kerosene showed smaller roughness than distilled water. A similar effect was observed at 45 µs Pon and 12 ampere current (see Fig. 9b, 10b). Usually removal of material in kerosene is accomplished by melting and vaporization while in distilled water, it occurs by melting and propagation of cracks which results in more cracks and produces rougher surface.

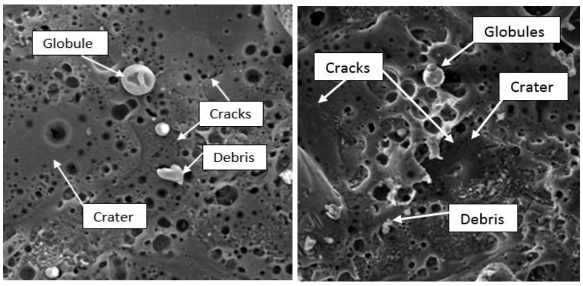

Fig. 10. Micrographs for distilled water dielectric (a) Current 6 (ampere), Pon 45 (µs); (b) Current 12 (ampere), Pon 45 (µs)

4. Conclusions

In this research, performance of EDM has been analyzed for MRR, EWR using kerosene and distilled water for Aluminum 6061 T6 alloy. Furthermore, the effects of current and pulse-on-time have been evaluated for both MRR and EWR. The main findings of this research can be summarized as follows:

- At higher values of current and pulse-on-time, maximum MRR is obtained.
- MRR is higher for kerosene than distilled water because of the arcing phenomena which occurred in distilled water.
- Higher pulse-on-time exhibited lower EWR, however, reverse effect has been observed with higher values of current.
- Kerosene showed lower EWR than distilled water because carbon content got stuck to electrode surface which hindered further wearing.
- Higher value of current results in rougher surface since more discharge energy become available at higher current values.
- Rougher surface is obtained with distilled water dielectric in comparison with kerosene as illustrated by micrographs.
- It is confirmed that for present parametric range kerosene is a preferable dielectric as compared to distilled water.

For this study, microstructures have been examined to evaluate the quality of machined parts in both dielectrics as well as at different levels of electrical parameters. It will be a great help for the designers to choose suitable dielectric and levels of current and pulse-on-time in accordance to quality requirement.

In future, Al 6061 T6 and other aluminum alloys should be evaluated for other dielectrics including water/oil emulsions and dry medium to find alternate dielectrics for EDM.

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