Study on Effects of Powder-Mixed Dielectric Fluids on Electrical Discharge Machining Processes

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Abstract

Powder-mixed electrical discharge machining is a technique for improving material removal rate and electrode wear ratio. Its utilization in the manufacturing industry is very low because many fundamental issues like machining mechanism, cost effectiveness of powders and powder concentration in the working fluid are not well understood. This study investigated the potential of diatomite powder suspension in distilled water for electrical discharge machining and compared its performance with that of aluminium and copper which are established in industry. Mild steel workpieces were machined using graphite. Completely randomized design was used to plan and analyze the experiments on effects of powders and concentrations on material removal rate and electrode wear ratio. Analysis of variance was performed at 5% level of significance. At optimum machining condition of 6 g/l, MRR increased by 32%, 44% and 7% while EWR decreased by 14%, 23% and 12% for diatomite, aluminium and copper, respectively.

1. Introduction

Electrical Discharge Machining (EDM) is a non-traditional production method which has been widely used in the die and mould industries, aerospace and machinery throughout the world in recent years [5]. EDM is a well-established machining option for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining processes. Since there is no direct contact between workpiece and tool electrode in EDM, machining problems like mechanical stresses and vibrations do not arise during EDM processes [12]. The EDM process uses thermal energy to erode the tool and the workpiece immersed in a dielectric fluid through a series of current discharges subject to an electric voltage [13]. When a voltage of 35 – 320 V is applied between the tool electrode and the workpiece placed close to each other, an electric field in the range of 105- 107 V/m is generated [12]. This potential difference is the one that enables sparking and hence, material removal. However, in spite of its remarkable capabilities, electrical discharge machining process suffers from low volumetric removal rate and high tool wear rate which restrict its applications [13]. To address these limitations, Powder-Mixed EDM (PMEDM) has emerged as one of the new techniques of enhancing the EDM capabilities [9].

The machining mechanism for PEDM is somewhat different from that of EDM [3]. In the PMEDM process, a suitable material in the powder form of e.g. Aluminium, Nickel, Iron,Cobalt, Copper, Carbon or Silicon carbide [8, 10] is mixed into the dielectric fluid in the same tank or in a separate tank.

The powder particles filling the spark gap get energized and are accelerated by the electric field and act as conductors forming chains which bridge the gap between the tool electrode and the workpiece, leading to an early explosion. As a result, the gap voltage and the insulating strength of the dielectric fluid reduce which enhances the ignition process causing faster erosion from the work piece surface [14]. The discharge occurs haphazardly and spreads uniformly in all directions, resulting to an enlarged and widened discharge channel with uniform distribution of sparking on the workpiece, leading to decreased electric density and improved surface finish [16].

In their study, [1] reported that machining rate of mild steel workpiece increases when carbon, iron, aluminum or copper powder particles are added into the dielectric fluid of EDM.

[8], analyzed Material Removal Rate (MRR) and Electrode Wear Ratio (EWR) in Powder-Mixed Electrical Discharge Machining (PMEDM) of cobalt-bonded tungsten carbide by suspending aluminium powder in dielectric fluid and reported that the powder particles disperse, making the discharge energy dispersion uniform.

[4] optimized the process parameters of PMEDM and concluded that silicon powder suspended in the dielectric fluid of the EDM increases MRR and was set to improve with increased powder concentration. But on the contrary, [7] studied electrical discharge machining using powder suspended in working media and reported that MRR decreased as powder concentration increased. Increase in powder concentration results in higher Tool Wear Rate (TWR) but after certain level it starts to reduce [9].

Material removal in conventional EDM is usually very low [11]. However, with the addition of aluminium powder in the dielectric fluid, material removal rate increased sharply. [15] studied the effects of powder characteristics on electrical discharge machining efficiency and concluded that particle size, concentration, density, electrical resistivity and thermal conductivity are the most important characteristics that affect the EDM performance. [11] investigated the effects of aluminium powder addition during electric discharge machining of hastelloy on machining performance using reverse polarity and concluded that increase in powder concentration results in sharp decrease in wear rate. They reported that material removal rate increases with addition of aluminium powder in the dielectric fluid, and those larger particle sizes of the powder led to improved material removal rate.

From the above literature; it is clear that PMEDM improves the machining performance of the EDM process. However, its application in the manufacturing industry is still very low. This is because fundamental issues of this new development such as the amount of powder consumption, machining mechanism and cost effectiveness of the powders in the working fluid are not well understood.

In this study, diatomite powder is suspended in distilled water and its effects on material removal rate and electrode wear ratio compared to that of aluminium, copper and pure dielectrics. Diatomite and distilled water are chosen since these are readily available, cheap, safe to use and environmentally friendly.

2. Methodology

This research was conducted in Nairobi, Kenya at Diemould Machinery Product and Services (DMPS) premises using Toolcraft A25 sinker EDM as shown in Figure 1. The dielectric fluid system of this machine was retrofitted to allow easy accessibility, cleaning, suspension and circulation of diatomite powder-mixed distilled water besides filtering the debris using permanent magnets placed within the machining and mixing tanks as shown in Figure 2. This system consisted of a stirring motor and a centrifugal pump which were mounted on a stand housing the mixing tank.

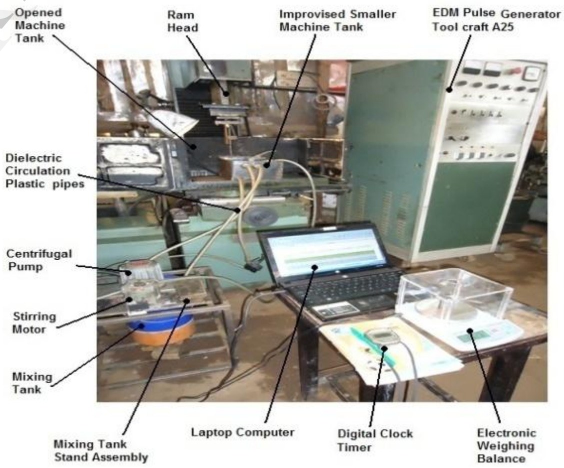

Figure 1: Instrumentation of the PMEDM experiments.

Figure1 shows the instrumentation of experimental setup, data collection equipments and the retrofitted dielectric circulation system integrated with the pulse generator. A stop watch with accuracy of 0.01 s and an electronic balance (AF 300/0.01) with an accuracy of 0.01 g were used for time and weight measurements. Line and block diagrams of the experimental arrangement of the retrofitted dielectric fluid circulation system of Toolcraft A25 Sinker EDM are shown in Figures 2 and 3, respectively.

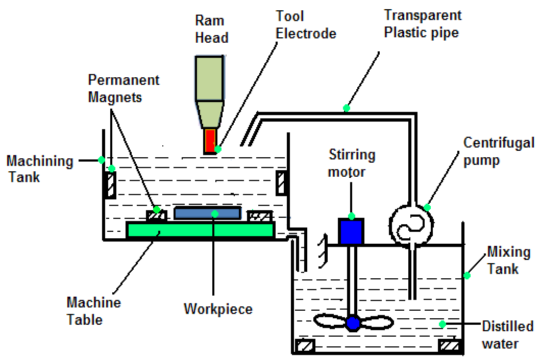

Figure 2: Line diagram of the Powder Mixed EDM experimental set-up.

Machining was done initially with pure distilled water (without powder) for 10 minutes and the amount of material removed determined by taking the differences in weights of the workpiece before and after the machining processes. A digital balance was used in weight measurements. Except for the input process parameters, which were assigned four levels, the rest of the variables were treated as design factors as given in Table 1. Pilot experiments were conducted as suggested by [2] and the selection of the range and values of process parameters was based on suggestions made by [9], the machine specifications and personal experience gained through trial runs.

A duty cycle of 0.5 was adopted as standard in the experiments on peak currents since this would give optimum MRR [8], while powder concentration experiments were done at the same duty cycle and peak current of 21A which ensured maximum MRR. Since MRR and EWR machining characteristics depict the efficiency of the machining process [6], they were considered essential performance parameters in EDM.

Graphite electrodes were turned 25 mm diameter and the workpieces were surface-ground so that when fixed at the bottom of the machine tank, it would be easier to set the tool flat and perpendicular to the workpiece. The choice of direct polarity was based on the finding of [6] since it results in a higher material removal rate and lower relative electrode wear as compared to reverse polarity in EDM.

Table 1: Standard process parameters used for PMEDM.

Process Variable	Value
Supply voltage (V)	70 [V]
Peak Current (I)	21 [A]
Pulse duration (Ton)	105 [µS]
Pulse off time (Toff)	50 [µs]
Powder concentration	2 - 8 [g/l]
Type of flushing	Straight nozzle flushing
Polarity of electrode	Negative (Direct polarity)
Duty cycle	0.5
Electrode lift time	0.2 [s]
Electrode diameter	25 [mm]
Powder type	Copper,Diatomite, Aluminium
Tool material	Graphite
Workpiece material	Mild steel
Dielectric fluid	Distilled water

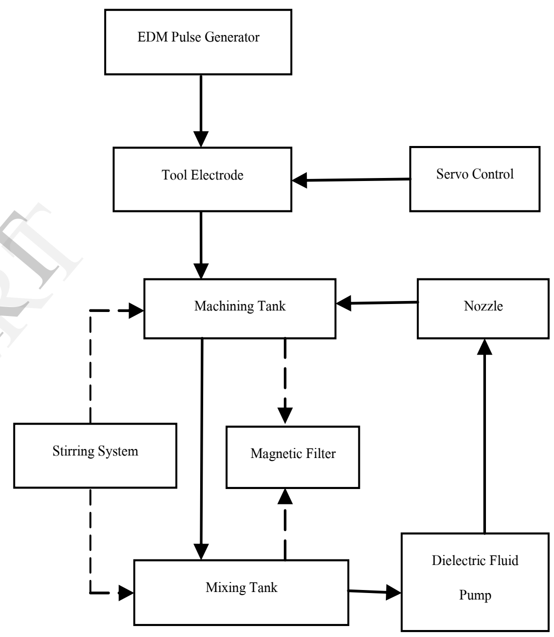

Figure 3: Block diagram of the powder mixed EDM system.

2.1. Dielectric fluid circulation system

A machining tank of 260 mm x 198 mm x 130 mm was fabricated for use in these experiments. This tank was placed inside the main machine tank (Figure 4) at a height that ensured dielectric fluid flowed back to the mixing tank by gravity. A zigzag flushing method was incorporated as per the recommendations of [13] to prevent the particles from settling at the bottom of the tanks and to ensure uniform distribution of powder particles in the dielectric circulation system. The dielectric pump was used to maintain a constant flow of the dielectric between the mixing and machining tanks.

Figure 4: Retrofitted dielectric fluid circulation system.

Permanent magnets were strategically placed inside the mixing and machining tanks in order to segregate the debris from the dielectric fluid immediately after the machining process (See Figure 2) and reduce impurities.

2.2. Influences of powder types and powder concentrations in distilled water on selected machine performance characteristics

In these experiments, powder types and powder concentrations were varied against material removal and tool wear rates. Copper, aluminium and diatomite powders were each separately suspended in distilled water at concentrations ranging from 2 to 8 g/l and machining done for 10 minutes at a peak current of 21A, pulse frequency of 10 KHz and duty of 0.5 After the machining process, the machining tank was drained off the dielectric fluid and both the electrode and workpiece removed, properly cleaned, dried and their weight losses determined. Then, electrode wear ratio was computed by dividing the tool wear rate by material removal rate. The means of MRR and EWR obtained for each powder were used as the base for comparing their performance characteristics. The Material Removal Rate (MRR) and Electrode Wear Ratio (EWR) are expressed by (1) and (2).

$$MRR = \frac{(m_f - m_i)}{t} \quad (1)$$

Where, m_f = Mass of the workpiece before machining.

m_i = Mass of the workpiece after machining.

t = Time taken to machine the surface.

$$EWR = \frac{m_1 - m_2}{m_f - m_i} \quad (2)$$

Where, m_1 = Mass of the tool before machining.

m_2 = Mass of the tool after machining.

2.2.1. Influence of powder types on machine performance characteristics

First of all, machine performance characteristics for pure dielectric at peak current of 21A, pulse frequency of 10 KHz and duty of 0.5 were used for control. Then, each powder was separately suspended in distilled water at 6 g/l. Machining was then done for 10 minutes for each experimental set of copper, aluminium and diatomite powders at the same machine settings as in pure dielectric. After machining, the machining tank was always drained of the dielectric fluid and the electrode and workpiece removed, properly cleaned, dried and the weight differences of electrode and workpiece determined. Values of MRR and EWR were obtained for each powder type and the performance characteristics due powder types were plotted on bar graphs against pure and the best identified through ranking.

2.2.2. Effects of powder concentrations on electrical discharge machine performance characteristics

To find out the effects of powder concentration on machine performance characteristics, each powder type was separately suspended in distilled water and machining done for 10 minutes at peak current of 21A, pulse frequency of 10 KHz and duty of 0.5 for concentrations of 2, 4, 6 and 8 g/l using copper, aluminium and diatomite powders.

Completely Randomized Design (CRD) was adopted for this study to test the effects of powder types and concentrations on the EDM machining performance, MRR and EWR were subjected to analysis of variance using Statistical Analysis of Systems (SAS) at 5% level of significance.

3. Results and discussion

3.1. Influence of powder types and concentrations on material removal rate and electrode wear ratio

In this section, equal amount of diatomite, copper and aluminum powders were separately suspended in distilled water, respectively.

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3.1.1. Effects of powder types on material removal rate

One of the machine characteristics for assessing the performance of electrical discharge machining process is Material Removal Rates (MRR). MRR due to suspension of different types of powders in distilled water are given in Table 2 and experimental conditions are specified in Figure 5. The MRR (0.2005 g/min) for no-powder (Pure) was used for control under similar experimental conditions as spelt out in the methodology section 2.2.1.

Table 2: Effects of powder types on MRR [g/min].

Powder Type	MRR (g/min)
Copper	0.2150y
Aluminum	0.2885x
Diatomite	0.2655x
No-powder (Pure)	0.2005y

NB: The values of MRR followed by the same letter superscript (x or y) are not significantly different at α=0.05 and Least Significant difference (LSD) of 0.0143.

Then, the data was plotted in Figure 5 and error bars included for comparison purposes. As observed from Table 2 and Figure 5, addition of copper into distilled water did not significantly improve MRR (same superscript) because its error bar overlapped with that of no-powder at 5% level of significance. However, aluminium and diatomite powders had significantly equal contribution to MRR (same superscript) as their error bars overlapped but they did not overlap with those of copper and no-powder. Hence, aluminium and diatomite powders were significantly different and better than copper powder in terms of improving MRR when suspended in distilled water.

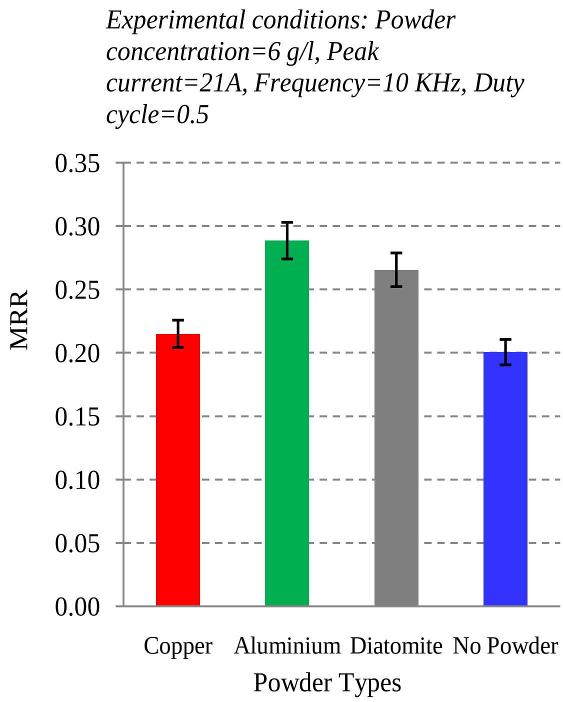

Figure 5: Influence of powder types on MRR.

Aluminium produced the highest MRR (0.2885 g/min) whereas that due to copper (0.2150 g/min) was slightly higher than that of no-powder, but lower than that of diatomite powder. This phenomenon could be due to the fact that aluminium has higher thermal conductivity than copper and diatomite. Diatomite powder produced higher MRR than copper powder probably because of its chemical composition and physical properties. During experimentation, it was observed that much of the copper powder settled down at the bottom of the machining tank resulting to less participation in the electro-discharge machining process due to its high density.

3.1.2. Effects of powder types on electrode wear ratio

Electrode Wear Ratio (EWR) depends upon the ratio of tool wear rate to material removal rate. Since low values EWR are more desirable for efficient EDM processes, low tool wear and high material removal rates are recommended. Addition of copper, aluminium and diatomite powders in distilled water resulted to values of EWR lower than that due to no-powder at a concentration of 6 g/l, peak current of 21A, frequency of 10 KHz and duty cycle of 0.5 as shown in Table 3. Observations on these data reveal that EWR for no-powder was the highest followed by copper and diatomite powders, respectively.

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Table 3: EWR due to various powder types.

Powder Type	EWR
Copper	0.1186y
Aluminum	0.1039z
Diatomite	0.1167y
No-powder (Pure)	0.1355x

NB: The EWR values followed by the same letter superscript (x, y or z) are not significantly different at α=0.05 and Least Significant Difference (LSD) of 0.0121.

The data in Table 3 are presented in Figure 6. Diatomite and copper powders produced significantly equal but higher EWR than aluminium powder at α = 0.05 and LSD = 0.0121. This implies that copper and diatomite have lower machining efficiency than aluminium powder in this respect.

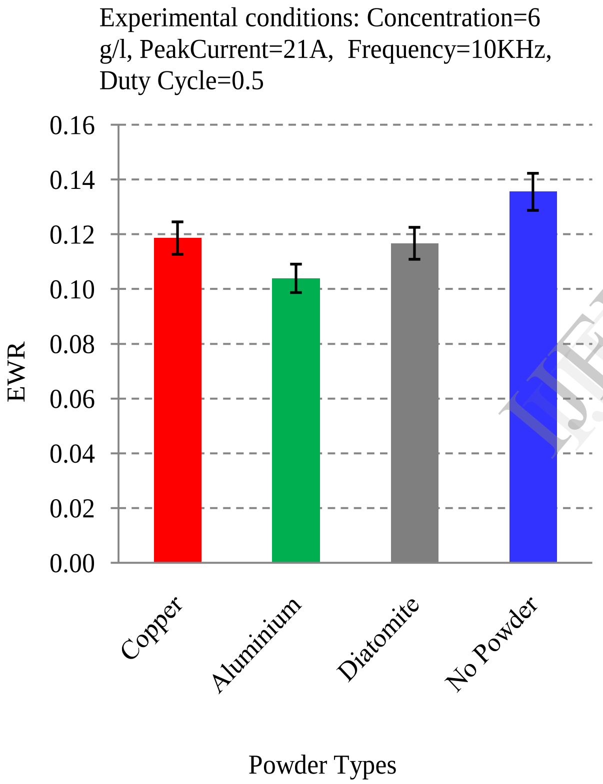

Figure 6: Influence of powder types on EWR.

3.2. Influence of powder concentrations on material removal rate and electrode wear ratio

For the determination of material removal rate and electrode wear ratio, copper, aluminium and diatomite powders were separately suspended in distilled water at concentrations of 2, 4, 6 and 8 g/l. Material removal rates and electrode wear ratios due to variations in concentrations were compared with no-powder values at the same machine settings.

3.2.1. Influence of powder concentrations on material removal rate

Material removal rates due to variations of copper, aluminium and diatomite powder concentrations are presented in Table 4 and in Figure 7, respectively. It is observed from Figure 7 that MRR due to concentrations of the three powders increased with increasing concentration up to some maximum point before starting to decrease with further increase in concentration.

Table 4: Effects of powder concentration on MRR [g/min].

Powder Concentration [g/l]	Copper	Aluminium	Diatomite	No-Powder	LSD
2	0.1935y	0.2525 y	0.2171z	0.2005x	0.0143
4	0.2165x	0.2565y	0.2361y	0.2005x	0.0143
6	0.2150x	0.2885x	0.2655x	0.2005x	0.0143
8	0.1990y	0.2565y	0.2514x	0.2005x	0.0143

NB: The MRR values followed by the same letter superscript (x, y or z) in the same column are not significantly different at α=0.05 and Least Significant Difference (LSD) of 0.0143, respectively.

For aluminium and diatomite, MRR increased steadily from 0.2525 and 0.2171 g/min at 2 g/l toward maxima (of 0.2885 and 0.2655 g/min) at 6 g/l before decreasing with further increase in concentration, respectively. Meanwhile, MRR for copper powder increased steadily from 0.1935 g/min at 2 g/l towards maximum at 4 g/l and then decreased with further increase in concentration.

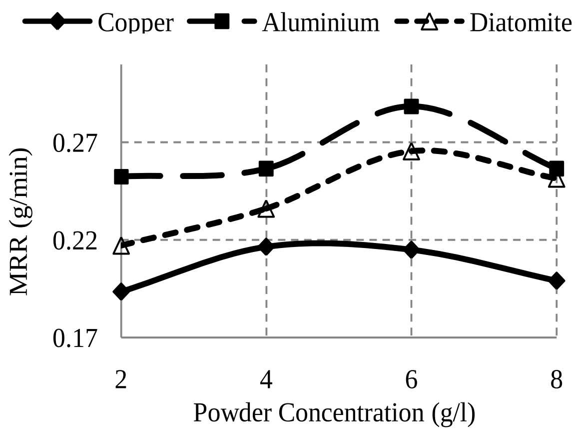

Figure 7: Influence of powder concentration on MRR.

The increase in MRR with powder concentration could be attributed to the fact that suspension of powder particles impedes the ignition process by creating a higher discharge probability which reduces the insulating strength of the dielectric fluid and increases the spark gap between the electrode and the workpiece resulting to increased MRR as suggested by [14]. However, this increase in MRR is hampered by arching between the facing faces of electrode and workpiece due to short circuiting with increase in powder density which leads to instability and inefficiency in the EDM process resulting to net reduction of MRR at higher powder concentration as exhibited by MRR for aluminium and diatomite after 6 g/l. It is supposed that at maximum MRR, the best combination of powder density and particles striking the workpiece surface took place at 6 g/l for aluminium and diatomite and 4 g/l for and copper powders, respectively. This agrees with the findings of [12,10] who witnessed a similar trend on aluminium powder-mixed EDM. These results agree with [15] who noted that copper powder did not enhance the EDM efficiency because of its higher density causing much of it to settle at the bottom of the machining tank, hence not participating in the EDM process.

3.2.2. Influence of powder concentrations on electrode wear ratio

The data on the effects of variation of powder concentration on Electrode Wear Ratio (EWR) are presented in Table 5 and Figure 8. Powder concentration was varied from 2 to 8 g/l and values for electrode wear ratio determined.

Table 5: Influence of powder concentration on EWR.

Powder Conc.[g/l]	Copper	Aluminium	Diatomite	No-powder	LSD
2	0.1473^{x}	0.1169^{x}	0.0736^{z}	0.1355^{x}	0.0121
4	0.1247^{y}	0.1111^{yx}	0.1032^{y}	0.1355^{x}	0.0121
6	0.1186^{y}	0.1039^{y}	0.1167^{x}	0.1355^{x}	0.0121
8	0.1031^{z}	0.0779^{z}	0.1237^{x}	0.1355^{x}	0.0121

NB: The EWR values followed by the same letter superscript (x, y or z) in the same column are not significantly different at α=0.05 and Least Significant Difference (LSD) of 0.0121, respectively.

The EWR trends presented in Figure 8 show that as powder concentration was increased from 2 to 8 g/l, the change in EWR due to diatomite powder ranged from 0.0736 to 0.1237, but that of copper and aluminium decreased from 0.1473 to 0.1031 and 0.1169 to 0.0779, respectively. This increase in EWR for diatomite agrees with the findings of [9] that material removal rate increases with powder concentration while tool wear rate increases up to some point before starting to decrease with further increase in concentration.

On the other hand, the decrease in EWR with increased concentration for copper and aluminium powders agree with the findings of [12] that attributed this phenomenon to powder particles coming in the path of ions moving towards the electrode surface. This reduces their momentum before striking the electrode surface resulting to less material erosion from the electrode. The response of EWR for copper, aluminium and diatomite powders could be attributed to the trends of their tool wear and material removal rates with variations in powder concentrations.

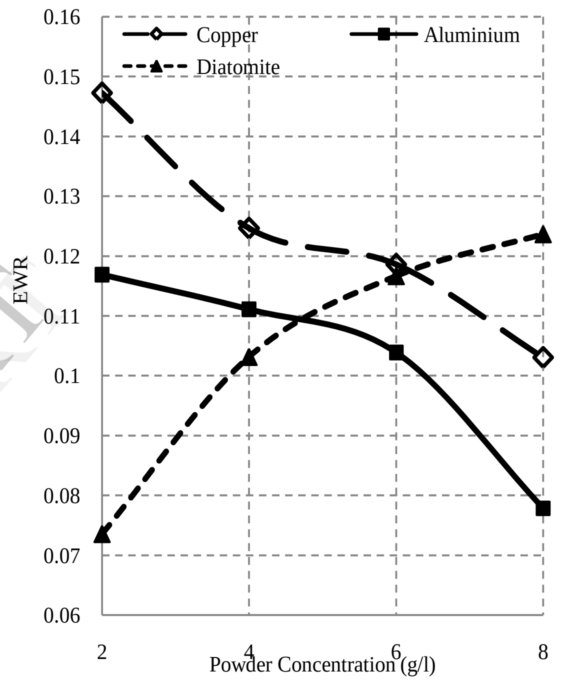

Figure 8: Effects of powder concentration on EWR.

4. Conclusions

In this paper, the influences of diatomite, aluminium and copper powders and their concentrations in distilled water on MRR and EWR were investigated. It was seen that addition of powders to dielectric fluid improves the material removal rate and electrode wear ratio. Moreover, MRR for copper, aluminium and diatomite powder increases to maximum and then decreases with further increase in powder concentration. Compared to conventional EDM, the optimum experimental conditions occurred at 6 g/l, pulse frequency of 10KHz, duty cycle of 0.5 and peak current of 21A which increased MRR by 32%, 44% and 7% while EWR decreased by 14%, 23% and 12% for diatomite, aluminium and copper, respectively. Maximum MRR for copper powder occurs at a concentration of 4 g/l, while that for aluminium and diatomite occur at 6 g/l, respectively. Diatomite powder is more effective in the improvement of MRR than copper powder but its performance is inferior to that of aluminium powder.

5. Recommendations

To fully understand the parameters affecting the performance characteristics of the EDM process it is recommended that the following investigations be carried out:

1. Effect of dielectric fluid temperature on the machine performance characteristics.
2. The effects of diatomite, aluminium and copper powder concentration on quality of surface generated.
3. Modelling and optimization of diatomite powder-mixed EDM process

6. Acknowledgements

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