Improvement of MRR and surface roughness during electrical discharge machining (EDM) using aluminum oxide powder mixed dielectric fluid

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Abstract. This paper discusses the effect of aluminium oxide (Al₂O₃) addition to dielectric fluid during electrical discharge machining (EDM). Aluminium oxide was added to the dielectric used in the EDM process to improve its performance when machining the stainless steel AISI 304, while copper was used as the electrode. Effect of the concentration of Al₂O₃ (0.3 mg/L) in dielectric fluid was compared with EDM without any addition of Al₂O₃. Surface quality of stainless steel and the material removal rate were investigated. Design of the experiment (DOE) was used for the experimental plan. Statistical analysis was done using ANOVA and then appropriate model was designated. The experimental results show that with dispersing of aluminium oxide in dielectric fluid surface roughness was improved while the material removal rate (MRR) was increased to some extent. These indicate the improvement of EDM performance using aluminium oxide in dielectric fluid. It was also found that with increase in pulse on time both MRR and surface roughness increase sharply.

1. Introduction

Electrical discharge machining (EDM) is one of the most extensively used non-conventional material removal processes. EDM works by using the principle of erosion of metals by using spark discharges [1]. The surface finish of the workpiece produced depends on many factors. The basic die sinking EDM system consists of an electrode and workpiece connected to a direct current (DC) power supply and placed in dielectric fluid. Usually the tool is connected to the negative terminal and the workpiece is connected to the positive terminal of the power source.

The dielectric breaks down and a transient spark discharges through the fluid when the potential difference between the tool and the workpiece is sufficiently high. This will remove a very small amount of metal from the workpiece surface [2]. Since the surface of the workpiece at the location of the previous discharge is now separated from the tool by a greater distance, this location is less likely to be the site of another spark until the surrounding regions have been reduced to the same level or below. The individual discharges occur hundreds or thousands of time per second to ensure that
constant erosion of the entire surface occurs in the area of gap [3]. The discharge occurs at the location where the two surfaces are closest.

Electrical Discharge Machining (EDM) is one of the most reliable and precise manufacturing processes applicable for creating complex geometries [4]. The superior performance of EDM has been validated in applications involving materials with high strength, high hardness, or complicated shapes. EDM erodes material with the high heat of electrical discharges generating sparks between an electrode tool and the workpiece. EDM manufacturing is economical and relevant when high accuracy is required. Nevertheless, EDM process has some drawback such as formation of white layer on the workpiece surface due to deposition of materials melted during electrical discharges. As a result, the quality of surface diminishes. Thus, the aim of this study is to develop an EDM process for improved work surface quality and increase MRR. A comparatively new approach of powder mixed electrical discharge machining (PMEDM) has been developed for this purpose. In the PMEDM, a suitable fine abrasive powder material is mixed with the dielectric fluid.

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula (Al$_2$O$_3$). It specifically identifies as aluminium (III) oxide and commonly called alumina. PMEDM is used to produce a surface coated with hard layer of Al$_2$O$_3$.

2. Experimental procedures
This project was aimed to study the effect of powder added dielectric fluid. The workpiece and the electrode material for this study were stainless steel and copper. Dimension of the workpiece was 13mm x 14mm x 44mm. DOE version Design Expert 6.08 was used in order to reduce the number of experiments. Experiments were conducted on an EDM machine shown in figure 1. Dielectric fluid used was kerosene. During the experiments current and pulse off time were kept constant at 6.5 A and 9.0 μs respectively. Variable parameters were powder concentration of Al$_2$O$_3$ and pulse off time ($t_{off}$). The size of the powders was 35-40μ. The experimental plan is shown in table 1. Square holes of 6 mm x 6 mm were machined on the workpiece to a depth of 1 mm. The weight of the workpiece was measured before and after each of the experiments. The responses were material removal rate (MRR) and work surface finish ($R_a$). Ra was measured using a surface roughness-measuring machine shown in figure 2.

![Figure 1. EDM Die-Sinking Machine](image-url)
Table 1. Experimental plan

| Std | Run | Block | Factor 1 | Factor 2 |
|-----|-----|-------|----------|----------|
|     |     |       | A: Powder Concentration (mg/L) | B: Pulse on time (μs) |
| 3   | 1   | Block 1 | 0.0 | 7.5 |
| 6   | 2   | Block 1 | 0.3 | 10.0 |
| 1   | 3   | Block 1 | 0.0 | 6.0 |
| 5   | 4   | Block 1 | 0.0 | 10.0 |
| 2   | 5   | Block 1 | 0.3 | 6.0 |
| 4   | 6   | Block 1 | 0.3 | 7.5 |

Figure 2. Mitutoyo Surface Test Equipment

3. Results and Discussion
Measurements of Ra and MRR are shown in table 2.
Table 2. Experimental results

| No | T<sub>on</sub> | Powder Concentration (mg/L) | Time | Surface roughness Ra (μm) | Weight of workpiece | MRR (g/min) |
|----|---------------|------------------------------|------|---------------------------|---------------------|-------------|
|    |               |                              |      |                           | Before (g)          | After (g)   |             |
| 1  | 6             | No powder                    | 23min 5s | 8.63μm                   | 192.0451           | 191.1802  | 0.0375     |
| 2  | 7.5           |                              | 5min 1s | 15.45μm                  | 191.1802           | 190.4516  | 0.1452     |
| 3  | 10            |                              | 3min 1s | 25.41μm                  | 190.4516           | 189.2405  | 0.4015     |
| 4  | 6             | 0.3                          | 6min 29s | 8.7μm                    | 189.2405           | 189.0251  | 0.0332     |
| 5  | 7.5           |                              | 6min 18s | 13.11μm                 | 189.0251           | 187.7185  | 0.2074     |
| 6  | 10            |                              | 1min 47s | 20.53μm                 | 187.7185           | 186.9711  | 0.4191     |

Material Removal Rate (MRR). The contour plot in figure 3 shows the relationship between powder concentration and pulse on time on MRR. It can be seen from the figure that MRR increases with increase in pulse on time. The maximum MRR is 0.4191 g/min with the highest pulse on time at 10µs and powder concentration of 0.3mg/L. Due to the presence of powders the electrical discharge is scattered and electrons passes more uniformly in the discharge area. As a result, MRR increases [5, 6, 7]. It can also be observed that with increase of T<sub>on</sub>, MRR increases more sharply. As T<sub>on</sub> increases, the workpiece gets more time to absorb heat energy that melts and vaporizes the work material [8]. 3D plot for influence of powder concentration and T<sub>on</sub> on MRR is illustrated in figure 4.

![Figure 3. 2D plot for powder concentration and T<sub>on</sub> on MRR](image-url)
Figure 4. 3D surface plot of MRR versus powder concentration and $T_{on}$

The contour plot in figure 5 shows the relationship between powder concentration and pulse on time on surface roughness. From the graph, it was observed that minimum surface roughness at $T_{on}$ 6μs. It can be observed that with increase in powder concentration surface roughness decreases. The electrical discharge is broken into many small discharges due to the presence of powders [9, 10]. As a result many small cavities are formed with smaller depths on the work surface. This in turn produces a smoother surface. and without any powder concentration. Figure 6 shows the 3D surface plot of surface roughness versus powder concentration and peak current. It can be observed that surface roughness improves with increase in $T_{on}$. As $T_{on}$ is increased, heat energy is absorbed during a longer time making the surface less stressed that produces a better surface [11].
4. Conclusion
In this study, the effect of EDM parameters like addition of aluminium oxide in dielectric fluid and pulse on time on material removal rate (MRR) and surface roughness, $R_a$ have been investigated. The workpiece material and electrode materials were stainless steel AISI 304 and copper respectively. Based on the experimental results, by adding 0.3mg/L of Al$_2$O$_3$ in dielectric fluid, the surface roughness was improved and MRR was increased. The electrical discharge is broken into many small discharges due to the presence of powders. As a result, many small cavities are formed with smaller
depths on the work surface. This in turn produces a smoother surface. As Ton is increased, heat energy is absorbed during a longer time making the surface less stressed that produces a better surface. MRR increases with increase in pulse on time. Due to the presence of powders, the electrical discharge is scattered and electrons passes more uniformly in the discharge area. As a result, MRR increases. As Ton increases, the workpiece gets more time to absorb heat energy that melts and vaporizes the work material. This results increase in MRR.

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