Improvement of surface quality using silicon carbide powder added dielectric fluid during EDM

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Abstract. In recent years there is an increasing interest of Electrical Discharge Machining (EDM) process, with particular emphasis on the potential of this process for surface modification. In this study, the effect of various EDM parameters on the material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) using powder-mixed electrical discharge machining (PMEDM) was carried out by using Silicon Carbide (SiC) powder. The workpiece material used was high carbon steel AISI 1050 and the electrode tool material was copper (Cu). Experiments have been designed using full factorial design of experiment (DOE) and the 3 factors were designed for 2 levels. The input process parameters used were the concentration of powder from 0.0 to 5.0g/L, peak current ranging from 2.5A to 4.5A and pulse-on time ranging from 8μs to 10μs. The result shows that when silicon carbide powder is mixed into dielectric fluid during EDM process, it gives minor effect on material removal rate (MRR), but improves tool wear rate (TWR) and surface roughness (Ra). However, as peak current and pulse-on time increase gradually, all responses follow the same trend.

1. Introduction
Electrical Discharge Machining (EDM) is one of the most used nonconventional material removal process applications due to its ability to produce geometrically complex shapes and its ability to machine materials irrespective to their hardness and toughness. A spark is produced at the point of smallest inter-electrode gap generating temperature in the range of 8,000-12,000°C, causing erosion and vaporization of material. Based on Pecas and Henriques [1], die sinking version of electrical discharge machining (EDM) is a current manufacturing technology widely disseminated in several industrial sectors. Recent studies show that one type EDM, powder mixed electrical discharge machining (PMEDM) is being investigated to improve machining efficiency and surface finish. PMEDM is one of the advanced techniques that have been used to enhance the capability of EDM. Using PMEDM a mirror like finish can be obtained on the already machined components at relatively high machining rate [2]. PMEDM can enhance EDM process by controlling the process parameters setting. Bhattacharya, [3], M.Y Ali et al. [4] mentioned in their studies that under the same particle concentration, the smallest suspended particle powder led to the best surface finish. Kumar et al. [5] reported that when the silicon carbide particles are suspended in the dielectric fluid, it makes uniform in discharging energy dispersion; it displays multiple discharging effects within a single input pulse in the PMEDM. This phenomenon results in reducing TWR and improving Ra. In the present study the work material, the electrode material and additive powder were AISI 1050 steel, copper and silicon carbide respectively.
2. Experimental Procedure.
The main composition of the workpiece material AISI 1050 steel is: Mn: 0.6-0.9%, C: 0.47-0.55%, S: 0.05% and P: 0.04%. Its general properties include: density 7.85 g/cm$^3$, melting point 1400-1450°C, modulus of elasticity 210 GPA, electrical resistivity 0.163 $\mu\Omega$m, thermal conductivity 49.8 W/mK and thermal expansion 1.9 $\mu$m/mK. The main characteristics of copper electrode were: density 8.96 g·cm$^{-3}$; melting point 1083 °C, boiling point 2925 °C and electrical resistivity 1.96 $\mu$Ω/cm. Properties of silicon powder are: powder size 0.1-1.0 micron, density 3.21 g/cm$^3$, thermal conductivity 1.0-5.0 W/cm K, melting point 2987 °C and electrical resistivity 1×10$^9$ $\mu$Ω cm. Kerosene was used as dielectric fluid. Rectangular holes of 15mm x 10 mm were machined on the workpiece. Experiments were conducted on MITSUBISHI EX 22 die-sinking EDM machine. Work surface roughness was measured using Mitutoyo SURFTEST SV.500. Weight of the workpiece and the electrode before and after each machining was measured by an electronic balance. Experiments were conducted according to DoE. Two level factorial design has been used to plan and analyze the experimental results.

3. Results and Discussions.
In the present study, two level factorial design has been used to plan and analyze the experiments. The detailed plan of the experiments is shown in Table 1. Peak current, spark on time (T-on) and powder concentration are taken as the input parameters. MRR, TWR and Ra were the responses.

Table 1: Experimental plan

| Std | Run | Block  | Factor 1 | Factor 2 | Factor 3 | Response 1 | Response 2 | Response 3 |
|-----|-----|--------|----------|----------|----------|------------|------------|------------|
| 3   | 1   | Block 1| 4.5      | 10       | 0        | 0          | 0          | 0          |
| 7   | 2   | Block 1| 4.5      | 10       | 5        | 0          | 0          | 0          |
| 1   | 3   | Block 1| 4.5      | 8        | 0        | 0          | 0          | 0          |
| 4   | 4   | Block 1| 2.5      | 10       | 0        | 0          | 0          | 0          |
| 8   | 5   | Block 1| 2.5      | 10       | 5        | 0          | 0          | 0          |
| 5   | 6   | Block 1| 4.5      | 8        | 5        | 0          | 0          | 0          |
| 2   | 7   | Block 1| 2.5      | 8        | 0        | 0          | 0          | 0          |

3.1 Material Removal Rate (MRR).
Fig.1 shows the relationship between MRR with design parameters of peak current (Ip) and pulse on time (Ton). It can be seen that as the peak current and pulse on time increase, MRR tends to increase too. This is due to the fact that sparks with more energy are generated during machining with higher current that would assist to remove more material from the workpiece. So, the relationship between current and MRR is directly proportional. If Ton is increased, more time is available for the workpiece to absorb heat. As a result, MRR increases.
Fig.1: 3D surface plot of MRR as a function of current and Ton

Fig.2 displays the effect of peak current and concentration of SiC carbide powder on MRR. It can be seen from the figure, the value of MRR increases with increase in peak current. However, the value of MRR decreases as powder concentration is increased to 5.0g/L. This is because silicon carbide is nonconductive and it decreases the effective current. Silicon carbide reduced the intensity of the sparks. Due to this phenomenon, MRR slightly decreases.

Fig.2: Interaction effect of current and SiC concentration on MRR

3.2. Tool Wear Rate (TWR).

The interaction between peak current and pulse on time for TWR is demonstrated in Fig.3. As can be noticed from this figure, high peak current gives remarkable effect in increasing the TWR. Higher current intensifies the sparks and more material is eroded from the electrode. Ton also results increase
in TWR, but its effect is not as strong as that of current. As Ton is increased, electrode gets more time to absorb heat and erodes more. This reason causes the TWR to increase.

Fig. 3: Interaction effect of current and Ton on EWR

Fig. 4 illustrates the relationship of current and SiC powder concentration on EWR. It shows that though with increase in current EWR increases sharply, EWR decreases. SiC is an electrically nonconductive material. Its presence in dielectric reduces the effectiveness of the spark and so TWR reduces.

Fig. 4: Interaction effect of current and SiC concentration on EWR

3.3. Surface Roughness (Ra).
Current of higher value results sparks of higher energy and deeper craters are formed on the work surface. As a result work surface becomes rough (Fig. 5). It can be observed that current has a very strong effect on work surface roughness Ra. However the effect of Ton on Ra is not significant. With
increase in Ton, work surface receive more heat and deeper crates are produced on the surface. But this effect is not prominent.

Interaction effect of peak current and SiC concentration on Ra is illustrated in Fig. 6. It is obvious from the figure that Ra increases with increase in current. This effect is very significant. But as powder concentration is increased, it gives smoother surface. SiC carbide is electrically nonconductive. Its presence in dielectric reduces the effective current of the plasma channel. Therefore, craters on the work surface are not deeper, which results a smoother surface.

4. Conclusion
High carbon steel AISI 1050 was machined using EDM. SiC powder was added to the dielectric during EDM. Peak current, Ton and SiC powder concentrations were the variables for the study. It was found that MRR, Ra and TWR increase with increase in current. If Ton is increased, MRR, TWR are increased and at the same time work surface becomes rougher. Addition of SiC to dielectric fluid reduces MRR and TWR, but work surface becomes smoother.
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