Experimental investigation of electrode shape configuration in sustainable electric discharge machining process

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Abstract. Electric Discharge Machining (EDM) is also known as spark erosion process which is used to machine hard material and complex shape profile. In EDM process, dielectric fluid plays an important role for material removal as well as generates environmental and health related issues. In this work, an experimental effort is made to study the different categories of dielectric by varying shapes of electrodes during machining of die steel. In this work, an attempt of canola oil and jatropha oils used as dielectric fluid and the machining performance are analyzed with kerosene as dielectric fluid. Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR) are selected as performance measures. The result observed that higher MRR with canola oil as dielectric compared to commercial dielectric fluid due to its good dielectric properties. Also, it is observed that higher TWR and SR which is required further investigation. Each shape of electrodes and their machining performance are compared with different dielectric fluids and the results indicated that canola oil provides good performance when compared with jatropha and kerosene. This natural and biodegradable dielectric fluid can be replaced for hydrocarbon oil based dielectric fluid.

1. Introduction

EDM is most generally utilized non-traditional process as it is best known for expelling material from the most intense to cut materials for getting them into proper shape and measured segments. The specialty of EDM process is its functional accuracy and meticulous in accomplishing high tolerances with most of the hard materials at elevated temperatures. The high frequency electric energy produces sparks due to the disintegration of dielectric fluid at the temperature levels up to 13000 K. This temperature will vaporize and soften the workpiece material into required shape and size of the part. Currently, EDM processes use hydrocarbon oil-based dielectric fluids, which generates harmful elements and it affects the environment and operator health [1-3].

Ng et al. [4] perfumed spark erosion process using natural vegetable oil based dielectric oil to achieve green environment. Two types of vegetable oils such as sunflower and canola oil were used. The result showed that removal of material was increased at all set of machining conditions. Sadagopan and Mouliprasanth [5] investigated that the effect of various dielectric oils (biodiesel, transformer oil and kerosene) in the EDM process of aluminium alloy. The result showed better machining performance with biodiesel as dielectric oil. Valaki et al. [6] targeted that green EDM process using jatropha oil based as dielectric oil. Machining performance using jatropha oil based dielectric fluid was better than conventional one. They have suggested that vegetable oil based dielectric could be replaceable for hydro carbon oil based dielectric fluid. Singaravel et al. [7] conducted machinability analysis in terms of surface finish during EDM process. Dielectric oil was used as...
vegetable oils. The result pointed out hydrocarbon oil based dielectric oil leads to environmental and operator health issues. Vegetable oil as dielectric oil can be used as potential dielectric oil.

Sohani et al. [8] used different electrode shape and conducted machinability studies. The result revealed that shape of electrodes was used to generate complex shape during the process. Khan et al. [9] conducted a performance study on different electrode shapes (diamond, triangular, round and square) and their machining performance in the EDM process. The results indicated that the high rate of material removal and minimum surface roughness from round shape electrode than other electrode shapes. Yu et al. [10] experimental investigation of a square shaped electrode in 3D micro EDM process focused on tool wear compensation and its mathematical formula. The results concluded that the micro EDM able to produce square shaped area with sharp corners and inclined plane machining also possible with the application of compensation. From the previous studies, minimum number of literatures is reported while performing EDM process of difficult to work material like AISI D2 die steel. To explore machinability analysis, canola oil is used as dielectric oil and the results are compared with commercial dielectric oil.

2. Experimental Details

The operations are conducted in EDM die sinking machine. Die sinking EDM setup shown in figure 1. Work piece material is considered as AISI D2 steel which is preferable for die making purpose in engineering industries. Electrodes are used in this experiment (Figure 2) is copper which are most commonly used electrode. Two types of dielectric oils are used namely vegetable oils (canola oil and jatropha) and kerosene. Table 1 shows the electrode shape and its dimensions. Table 2 shows the value of process parameters used in this work. Pulse on time, pulse off time, current are used. Throughout the experiment 1.0 mm is used as depth of cut. Previous literatures and preliminary studies are used for the section of these values. Figure 3 shows the machined samples.

| Sl.No | Electrode shape | Dimensions |
|-------|-----------------|------------|
| 1     | Circular        | Diameter =8mm |
| 2     | Square          | Side =8 mm  |

| Sl.No | Values |
|-------|--------|
| Energy setting 1 | Current =7 A; pulse on time = 300 µs ; Pulse off time =100 µs |
| Energy setting 2 | Current =9 A; pulse on time = 300 µs ; Pulse off time =100 µs |

Figure 1. EDM setup  Figure 2. Electrodes
MRR and TWR can be determined during EDM process using the equation (1) and (2). The weight difference between before and after process is determined with the help of precise weighing machine [1, 6]

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MRR = \frac{W_{bw} - W_{aw}}{T \times \rho_w} \quad \text{mm}^3/\text{min} \quad (1)
\]

\[
TWR = \frac{W_{be} - W_{ae}}{T \times \rho_e} \quad \text{mm}^3/\text{min} \quad (2)
\]

Where, \(W_{bw}\) = Work piece weight for before process in grams, \(W_{aw}\) = Work piece weight for after process in grams, \(W_{be}\) = Electrode weight for before process in grams, \(W_{ae}\) = Electrode weight for before process in grams, \(T\) is the machining time in minutes, \(\rho_w\) and \(\rho_e\) are the workpiece density and electrode density in g/cm\(^3\) respectively. SJ 210 Surface roughness meter is used to observe the machined profile and their value [11]. Table 3 and 4 shows the experimental results.
Table 3. Result of circular shape electrode

| Types of dielectric fluids | Energy setting | MRR (mm³/min) | TWR (mm³/min) | SR (µm) |
|----------------------------|----------------|---------------|---------------|--------|
| Kerosene                   | Level 1        | 2.883         | 0.448         | 1.82   |
|                            | Level 2        | 4.072         | 0.996         | 2.45   |
| Canola oil                 | Level 1        | 8.594         | 1.726         | 2.85   |
|                            | Level 2        | 9.321         | 1.864         | 3.44   |
| Jatropha oil               | Level 1        | 6.623         | 1.492         | 2.66   |
|                            | Level 2        | 7.92          | 1.629         | 3.25   |

Table 4. Result of square shape electrode

| Types of dielectric fluids | Energy setting | MRR (mm³/min) | TWR (mm³/min) | SR (µm) |
|----------------------------|----------------|---------------|---------------|--------|
| EDM oil                    | Level 1        | 5.093         | 0.729         | 1.49   |
|                            | Level 2        | 7.992         | 1.129         | 1.86   |
| Canola oil                 | Level 1        | 8.445         | 1.219         | 2.91   |
|                            | Level 2        | 11.668        | 1.630         | 3.35   |
| Jatropha oil               | Level 1        | 7.085         | 1.120         | 2.64   |
|                            | Level 2        | 9.522         | 1.494         | 2.86   |

3. Results and discussions

In EDM, complex shapes can be produced easily by machining with various electrodes shape such as circle and square forms. The effect of conventional and natural bio dielectric with various cross sections is attempted and the process performance parameters considered are MRR, TWR and SR. Figures 4 and 5 shows the performance analysis of the different shape of electrodes with various dielectric fluids.

Vegetable oil has lower breakdown voltage and viscosity than conventional dielectric resulting in high dense spark and high value of oxygen content generate increased average plasma channel temperature, which may improve melting and evaporation. From the above discussion it can be concluded that vegetable oil and its properties show high value of MRR. The obtained values of higher MRR attributed to their high values thermal conductivities of canola oil. It can transfer high thermal energy towards the area where the sparking occurs. Moreover, higher viscosity of vegetable oil based dielectric fluid is enhanced debris evacuation. The above reason, dielectric fluid such as vegetable oil based produced high value of MRR than conventional based dielectric fluids. Also, higher viscosity may leads to higher TWR. This is due to delayed heat transfer towards to workpiece to build up more heat into surface of the electrode causing enhanced erosion of electrode surface. In case of kerosene, it is observed that lower TWR than vegetable oil. This is because the vegetable oils having lower carbon atoms than dielectric fluid like kerosene. Machined surface integrity is directly related to crater size and height of the solidified molten material. Also, formation of crater is depends on succeed discharge and electrode material. If higher MRR, obliviously more molten material flow
with different size (longer, wider and deeper) and direction. The above reason higher value of surface roughness is noticed using canola oil as dielectric fluid. Canola oil as dielectric fluid eliminates hydrocarbon oil based dielectric fluids because of its dielectric properties [4-7]. Also it natural product and biodegradable leads to ISO 14000 environmental standard and green manufacturing. Electrode shapes are playing a major role for development of cavity and complex shapes during the EDM process In general, circular shape does not have any sharp corner compared with other shape like square. Hence, studies with different shapes are significant and challenges in EDM process [12].

Figure 4. a – c Results of (MRR TWR and SR) of circular shape electrode
4. Conclusion

The following results are noticed during the investigation

- Canola oil and jatropha oils are used as dielectric fluid which gives higher MRR than EDM oil due to its good dielectric properties.
- Higher TWR and Surface roughness are observed than EDM oil due to its dielectric properties. Further research is needed to control and reduce the same without sacrificing MRR.
- Different shape of electrodes could be machined to create intricate geometry with corners involve sharp in bottom as well as side.
- Vegetable oil is biodegradable and can be disposed easily and. This will help in the maintenance of an eco-friendly environment.

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