Experimental investigation of eco-friendly vegetable oil as dielectric fluid in electrical discharge machining

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ABSTRACT

KEYWORDS

EDM,
Dielectric fluid,
Vegetable Oil,
Inconel 800,
Performance.

Electric Discharge Machining (EDM) is used to machine complex geometries on hard to difficult material. In this investigation, vegetable oil based dielectric fluids are used and their performance is compared with conventional dielectric fluid during the machining of Inconel 800. Two different categories of dielectrics such as vegetable oil (sunflower, canola and jatropha) and hydrocarbon oil (kerosene) are used. Three set of energy settings are used during the process to analyze the Material Removal Rate (MRR) and Tool Wear Rate (TWR). The result showed that vegetable oil based dielectric fluid showed higher MRR than conventional dielectric fluid. Also, the result of TWR is observed as higher than conventional dielectric fluid. Further studies are required to understand high TWR using vegetable oil as dielectric. This work concludes vegetable oils that are similar in dielectric properties could be used as dielectric fluid.

1. Introduction

EDM process is widely used due to their applications however; it produces environmental, social and economical issues such as low MRR, high electrode wear, hazardous emissions, fire explosions, sludge generations and toxic waste [1, 2]. In EDM, dielectric fluid plays a significant role in ionization rate and followed by melting of metal. Hydrocarbon oil based dielectric fluid generates solid, liquid and gaseous bi-products which are not environment friendly. Researchers are taken steps against these issues and working to convert EDM process as sustainable. Dry EDM, near dry EDM and water as dielectric in EDM process are the important sustainability approach as attempted by researchers. In dry EDM, gas used as dielectric medium instead of liquid dielectric. In general, liquid based dielectric is used for the stability during the process. The demerits observed in dry EDM process include low stability, micro-crack formation over the machined surface, suspension of debris particle in the machining zone, recirculation of used gas and debris adherence to the electrode surface [3]. Near dry EDM is another approach which uses gas and liquid mixture as dielectric during the process of machining. There is a chance of fire and explosion due to volatile mixture liquid and gaseous element present in the process [4]. Water based dielectric fluid is also one of the approach for sustainable EDM [5]. Leao and Pashby [6] reported that water based dielectric has few environmental issues like sludge, de-ionized resin, vapor of water, ozone, carbon monoxide, aerosols and pollution of operator environment. This dielectric fluid is differed from conventional dielectric in terms of specific weight, viscosity, dielectric strength and ionization mechanism. Another problem is observed that electrolysis corrosion of the tool and work materials. In addition to these, more energy is consumed as compared to energy used in other approaches having different dielectrics [7]. There are few issues to be resolved, though many research works are attempted to convert conventional EDM into sustainable. In order to have sustainability in EDM, researchers are attempted vegetable oil as dielectric fluid for machining [8-12].

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2. Literature Review

Valaki and Rathood [8] attempted sustainability enhancement in EDM process by applying vegetable oil as dielectric fluid. Two category of dielectric fluids were used such as hydrocarbon oil based and vegetable oil based dielectric fluids. The effect of input parameters on output parameters were analyzed by ANOVA techniques. The result concluded that process performances were enhanced vegetable oil as dielectric fluid. Ng et al. [9] investigated that vegetable oil as dielectric fluids on EDM process of bulk metallic glass and titanium alloy. Canola oil and sunflower oils were used to investigate on MRR and TWR. The result revealed that the proposed dielectric fluids were having dielectric properties and given good machining performance. Sadagopan and Mouliprasanth [10] used different dielectric fluids (biodiesel, transformer oil and kerosene) and their machining performances were studied. Taguchi methods such as orthogonal array, signal to noise ratio and ANOVA were used to investigate the experimental results. The result showed biodies el as dielectric fluid was given good machining performance than other dielectric fluids. Valaki et al. [11] used jatropha oil as dielectric fluid and the results were compared with conventional dielectric fluid for enhancement of sustainability in EDM process. The effect of current, pulse on time, pulse off time and voltage on MRR, TWR and surface hardness were studied. The result pointed out jatropha oil based dielectric could be used as alternative dielectric in place of conventional dielectric fluid. Valaki et al. [12] used jatropha oil as dielectric fluid and the results were compared with conventional dielectric fluid for enhancement of sustainability in EDM process. The effect of current, pulse on time, pulse off time and voltage on MRR, TWR and surface hardness were studied. The result pointed out jatropha oil based dielectric could use as alternative dielectric to conventional dielectric fluid.

Kumar et al., [13] optimized process parameters using desirability approach in powder mixed EDM process. The powders were used for tungsten carbide, cobalt and boron carbide to analyze the MRR and TWR on machining of Inconel 800. The result concluded that powder additives added EDM process was significantly affected the TWR. Karunakaran and Chandrasekaran [14] used aluminum nano powder added during machining of Inconel 800 using EDM process. The result observed that coated electrodes increases the MRR, TWR and less percentage of decreases in surface roughness than plain electrodes. Paul et al., [15] studied that die sinking EDM process for machining of Inconel 800. In their study, pulse on time, pulse off time and current were the process parameters and MRR was considered as output parameters. Result concluded that linearly increased MRR was observed with pulsed current.

From the literature, the minimum research work is carried out in the area of vegetable oil as dielectric (such as sunflower, canola and jatropha oil) in EDM process. Hence, in this paper, an effort has been made to investigate the effect of dielectric fluids (kerosene, sunflower, canola and jatropha oil) and their machining performance with different electrodes and energy levels during machining of Inconel 800.

3. Experimental Setup

In this present work die-sinking EDM machine was used to conduct the various experiments (Figure 1). In this work, Inconel 800 is selected as work piece material which is used for corrosion resistance and high temperature resistance. Copper, Brass and Tungsten copper are used as electrode materials. In this work, two category of dielectric fluids are used namely conventional dielectric fluid (kerosene) and vegetable oil based dielectric fluid (sunflower oil, canola and jatropha

Fig. 1. Die sink EDM setup.

oil). Table 1 shows the various properties of conventional dielectric and vegetable oils [8-12].

Input parameters considered are pulse on/off time, voltage and current. In this work, three set of energy levels are followed namely high energy level (current =9 Amps, pulse on and off time are 800 and 600 μs respectively), medium energy level (current =7 Amps, pulse on and off time are 600 and 400 μs respectively) and low energy levels (current =5 Amps, pulse on and off time are 400 and 200 μs respectively). These parameters are selected based on literature study and some preliminary tests. Output parameters considered are MRR and TWR. The depth of cut for all experiments and voltage are kept constant and the values are 1.5 mm and 55 V respectively. Table 2 shows the results of experiments are conducted. Figures 2 a and d show the machined samples with kerosene and sunflower, canola and jatropha oil as dielectric fluids.

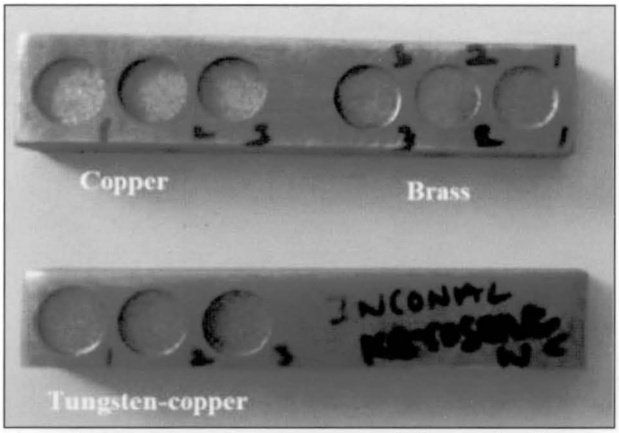
Weight difference between before machining and after machining of work piece and electrodes are observed using digital weighing machine and the

Table 1
Dielectric properties.

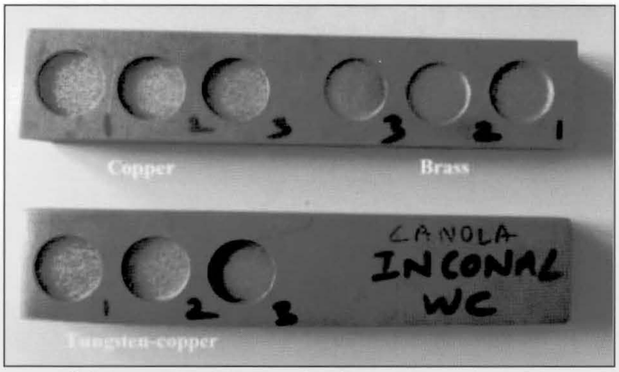
Sl.No	Properties	Kerosene	Sunflower oil	Canola oil	Jatropha oil
1	Viscosity (At 40º C) in cSt	1.2199	5.2	5.8	6.5
2	Density (gm/ml)	0.802	0.879	0.920	0.870
3	Flash point (°C)	47	330	330	240
4	Fire point (ºC)	52	355	350	270
5	Dielectric constant	4.7	3.0	3.2	2.53
6	Thermal Conductivity (W/m-K)	0.15	0.152	0.168	0.157
7	Specific heat (kJ/kg K)	2.01	1.833	1.910	1.900
8	Break down Voltage (kV)	48	14	24	26
9	Oxygen content (% wt)	0.05	0.24	0.42	1.11

Table 2
Experimental results.

Levels	Kerosene as dielectric		Canola oil as dielectric		Jatropha oil as dielectric		Sunflower oil as dielectric	
	MRR	TWR	MRR	TWR	MRR	TWR	MRR	TWR
C1	4.04	0.13	9.40	0.28	8.119	0.16	7.76	0.15
C2	7.20	0.15	12.00	0.59	11.79	0.49	10.05	0.28
C3	8.00	0.19	13.60	0.65	13.06	0.60	12.17	0.40
B1	2.60	1.13	5.86	2.34	4.402	2.31	3.522	1.88
B2	2.77	1.61	6.39	4.05	6.067	3.66	4.771	2.46
B3	3.21	1.84	8.42	4.96	7.750	3.30	6.501	2.80
Tc1	5.06	0.12	10.74	0.25	8.852	0.18	8.452	0.16
Tc2	7.80	0.18	13.58	0.31	12.18	0.26	11.06	0.21
Tc3	9.90	0.21	15.03	0.48	13.69	0.29	12.38	0.26

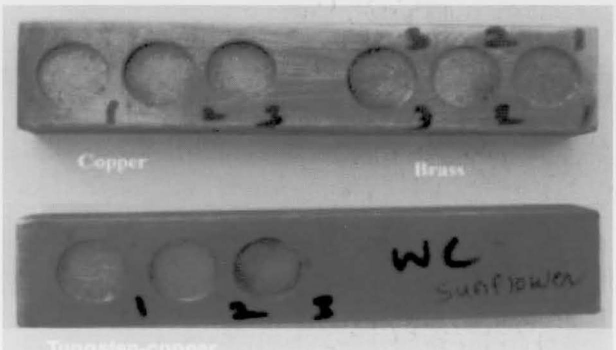


(a) Sample with kerosene as dielectric fluid.



(b) Sample with canola oil as dielectric fluid.

(c) Sample with Jatropha oil as dielectric fluid.



(d) Sample with sunflower oil as dielectric fluid.

Fig. 2 a-d. Machined samples.

equation (1) is used to calculate the MRR [11] and equation (2) is used to calculate TWR [16]

$$MRR = \frac{W_{wbm} - W_{wam}}{t \times \rho_w}\ mm^3/min \quad (1)$$

$$TWR = \frac{W_{ebm} - W_{eam}}{t \times \rho_e}\ mm^3/min \quad (2)$$

Where, W_{wbm} = weight (wt) of the workpiece before EDM (g), W_{wam} = wt of the workpiece after EDM (g), W_{ebm} = wt of electrode before EDM, W_{eam} = wt of the electrode after EDM, t = time required for machining (min), ρ_w = workpiece material density (g/cm^3) and ρ_e = electrode material density (g/cm^3).

4. Result and Discussions

In this work, vegetable oil based dielectric fluid is attempted as dielectric fluid and process performance parameters considered are MRR and TWR. MRR is related to the cost of production. Tool wear is directly influences the accuracy of shape to be reproduces. Figures 3-6 show the performance analysis of different dielectric fluids.

Vegetable oil has higher breakdown voltage and viscosity than conventional dielectric resulting in high spark energy density and higher 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 sun flower oil which could have ensured significant thermal energy transfer 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 [17, 18] so, 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 [17].

At higher pulse on time, decomposition of

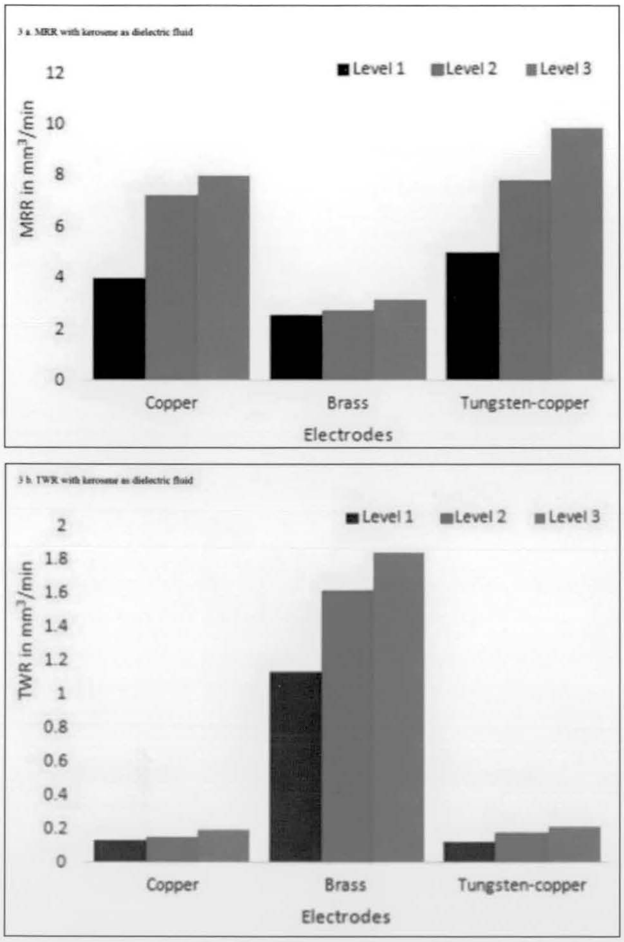


Fig. 3. a-c. MRR and TWR with kerosene as dielectric fluid.

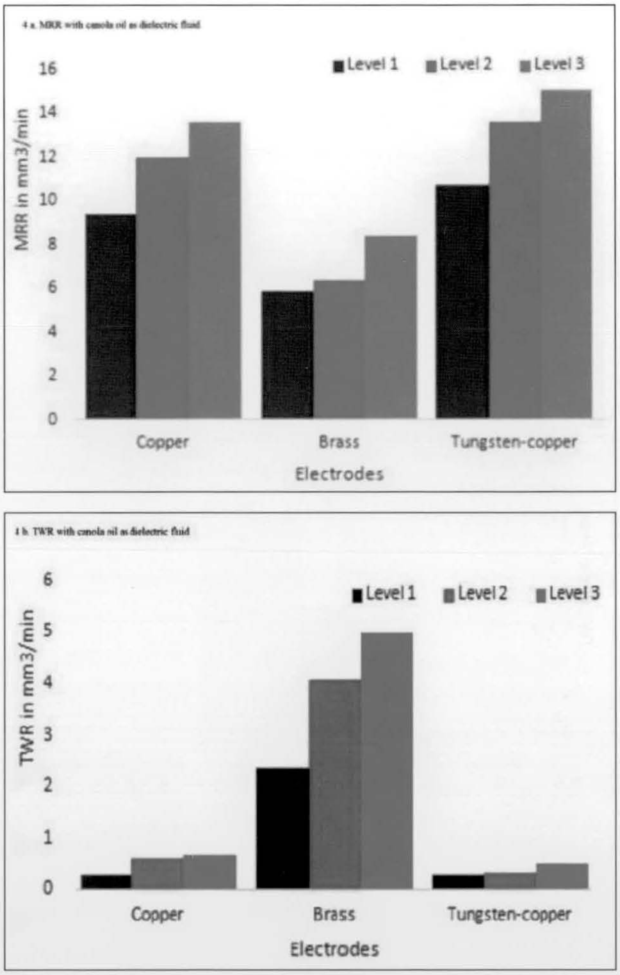


Fig. 4. a-c. MRR and TWR with sunflower oil as dielectric fluid.

carbon atoms takes place and deposit on the surface of electrode while kerosene as dielectric fluid. Hence, the obtained lower TWR in the case of kerosene as dielectric fluid than vegetable oil based dielectric fluid. Rise of pulse on time widens the discharge channel; hence longer duration of discharge energy is obtained. It leads to prolonged evaporation and melting as a result of which MRR increases. Whenever pulse on time increases, there is positive ions striking on the surface of electrode for a prolonged duration. Due to this reason many researchers have reported that there is a rise in TWR [19, 20, 21]. In case of higher current values, work surface is subjected to more number of electron strikes, pressure and temperature of inside plasma enhances, increase of temperature, hence erosion of bulk volume of material. Due to the same reason, TWR also more at the higher value of current.

In EDM, performance parameters such as MRR, and TWR are depends on process parameters and dielectric fluid used [23]. Also, electrode materials and its properties such as electrical and thermal properties influence the performance of machining. The significant electrical and thermal properties of electrode material are electrical conductivity, thermal conductivity and melting point. In this work copper, brass and tungsten-copper are used as electrode material. High value of electrical conductivity influences efficient spark distribution, high value of thermal conductivity enhances work piece temperature followed by quick melting and high value of melting point helps to withstand its original shape of the electrode During EDM process, electrode releases electrons towards the workpiece thereby bombarding of emitted electrons on the work piece surface which leads to melting. From the experimental result, it is noticed that tungsten-copper electrode gives higher MRR, copper gives moderate MRR and brass giving low MRR. Tungsten-copper electrode shows higher MRR because of its higher melting point. Even though copper has higher thermal conductivity tungsten-copper electrode provides better

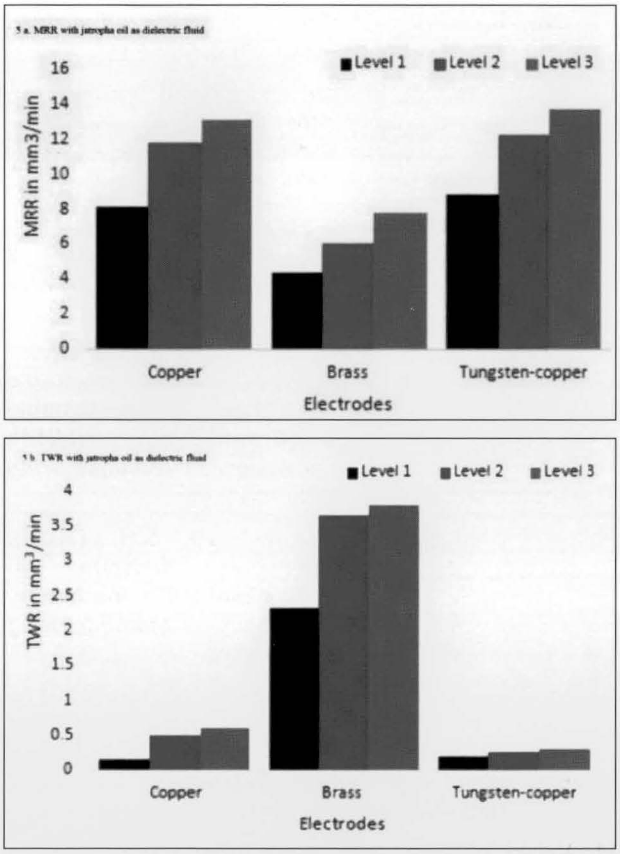


Fig. 5. a-c. MRR and TWR with canola oil as dielectric fluid.

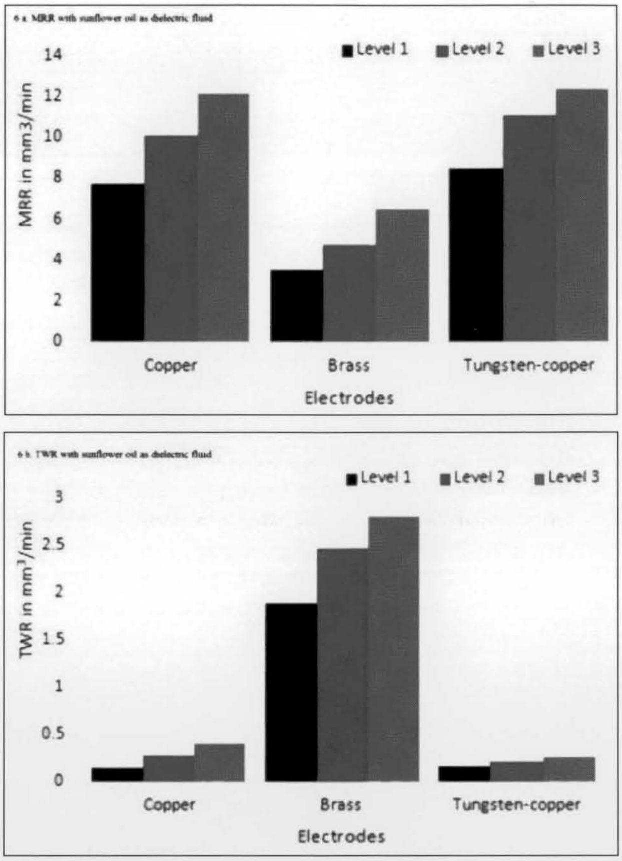


Fig. 6. a-c. MRR and TWR with jatropha oil as dielectric fluid.

performance this is may be due to its high value of melting point [24, 25].

The melting point of electrode material also influences electrode wear. Electrode wear must be lower to retain its original shape for long time to show better performance. High melting point of electrode leads to less electrode wear and inversely proportional. Electrode wear is mainly due to electrical and thermal effect during machining [26-27]. Brass electrode showing more wear rate because of low melting point and it has low ability to resist spark during machining. Tungsten-copper electrode has high melting point and spark resisting capacity than copper and brass electrode because of this reason it is more stable during the process. Hence, result indicates less TWR for tungsten-copper electrode and followed by copper and brass. Thus, it clearly reveals output parameters of EDM process are influenced by electrical and thermal properties of the electrode materials.

Vegetable oils are natural products and the proposed vegetable oils are capable to act as an alternative dielectric for fluids due to their dielectric properties and erosion. Other significant advantages include biodegradability, less toxicity, easy to handle, reduce dependency of import oil and thereby economy enhancement in agriculture activity.

5. Conclusions

In this work, performance analysis of vegetable oil as dielectric fluid and the results are compared with conventional dielectric fluid. The following conclusions are drawn from the investigations.

- Vegetable oils are successfully used as dielectric fluid and result revealed that vegetable oil based dielectric fluid showed higher MRR than conventional dielectric fluid. It is indicated that it has similar dielectric properties and erosion mechanism as conventional dielectric and it can be replaced.
- The result of TWR observed that during the process are higher than conventional dielectric fluid. Further research work is required to reduce the same.
- Canola oil is given good machining performance than other dielectric fluid

such as kerosene, sunflower and jatropha oil. There is a experimental investigation and optimization are required to analyze the effect of different dielectric properties such as breakdown voltage, oxygen content, thermal conductivity and viscosity on responses.

- Tungsten-copper electrode is performed better than copper and brass.
- Implementation of vegetable oil as dielectric fluid is creating awareness about enhancement of socio-cost benefit in industries.
- It will be used by researchers, practitioners and industrialists for their development and implementation of sustainable manufacturing practice.

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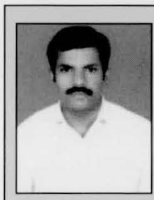

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