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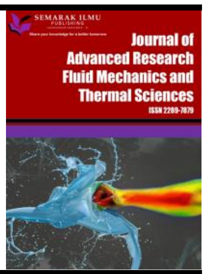

Electrode Wear Rate of RBD Palm Oil as Dielectric Fluids on Electrical Discharge Machining (EDM) at Different Peak Current and Pulse Duration of Titanium Alloys

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ABSTRACT

Electrical Discharge Machining (EDM) is a widely utilized commercial method for generating a variety of forms of materials that are used as the fundamental material in a wide range of industries. Vegetable oil as the dielectric fluid is one technique for assuring EDM's long-term viability because it is ecologically benign and biodegradable. This article presents experimental investigations on the influence of electrical discharge machining (EDM) input parameters on electrode wear rate (EWR) while using EDM oil and vegetable oil as dielectric fluid. Kerosene which is known as conventional oil for EDM has been used as a benchmark to compare the feasibility of the EDM process by using a different type of dielectric fluid which is RBD palm oil. Peak currents (I_p) in the 6 to 12A range and pulse durations (t_{on}) in the 50 to 150 µs range were chosen as the major factors for this study to improve the efficiency of EDM operation. Scanning electron microscopy (SEM) was used to observe the morphology surface characteristics of the copper electrode and the migration of workpiece material elements to the tool electrode. The EWR increases with increasing peak current, although it is inversely related to pulse duration. The lowest EWR for kerosene and RBD palm oil is 0.0416mm^3/min and 0.0480mm^3/min, respectively, at the same I_P=6A and t_{on}=150µs. Simultaneously, the highest EWR for both kerosene and RBD palm oil was at the same I_P=12A and t_{on}=50µs, which is 0.1725mm^3/min and 0.2425mm^3/min, respectively.

1. Introduction

Electrical discharge machining (EDM) is an advanced machine that enables drilling, grinding, and milling operations. Any material can be used for the processing workpiece as long as it has good electrical conductivity [1-9]. As a result, EDM is commonly used to process difficult materials due to its better machining features [4-7]. This machine might even be used to produce complex shapes in small volumes or as a job shop. The two types of EDM methods are die-sinking EDM and wire-cut EDM. Both have different features, but they provide the same function. In general, machining

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variables such as current, pulse duration, voltage, pulse interval, and pulse condition affect the efficiency of the workpiece surface cut by EDM [8,9]. There is no tension in the working material as there is no direct interaction between both the electrode and the workpiece. A lot of technology has gone into improving machining capabilities, but environmental sustainability isn't a major concern [9-12]. Thus, relatively new technology is being applied to improve EDM's sustainability concerns by using a bio-dielectric fluid.

The cutting tool's characteristics are critical in the machining process. Cutting tool shape, type, tool life, and material are all key factors that influence product cost and quality [9,10]. Cutting tool materials are created in tandem with the creation of new alloys. A sequence of electrical discharges occurs in an electrically isolated gap between a tool electrode and a workpiece during EDM processing of conductive materials. A high-temperature plasma channel forms in the gap during the discharge pluses, allowing evaporation and melting of the workpiece. The resulting explosion pressure removes material debris, allowing the workpiece to be machined [11-14]. A set of machining parameters connected to the properties of electrical discharge pulses controls the energy and frequency of discharges, and hence the power in the gap. As a result, the parameters that are chosen have an impact on the material removal rate, surface roughness, and relative electrode wear rate [11-14].

Supawi *et al.,* [7] used copper electrode to conduct multiple purpose upgrades and observed that lower parameter values greatly reduce tool wear ratio, whilst higher values significantly increase MRR on AISI tool steel [15]. When cutting tungsten carbide with a graphite electrode, MRR increases not only with increased discharge current but also with rising microcracks density [16]. The surface of the workpiece develops rougher as the discharge energy rises, as does the thickness of the white coating. Furthermore, when the number of particles in the gap grows, a conductive channel forms between the tool electrode and the workpiece, resulting in an undesired discharge and an arc. These arcs can cause microcracks on the electrode surface (the surface of tools and workpieces) [17-19]. During the EDM process, it has been found that a significant amount of workpiece material moves from the workpiece surface to the tool surface and vice versa. In addition, continuous combustion of cutting fluid produces carbon residues that appear as visible black films on the machined surface, reducing EWR [18-21].

For many years, manufacturers in the production industry have used dielectric fluids of various types for a range of purposes, including EDM. In the EDM process, kerosene is commonly used as the dielectric fluid, which has a poor environmental impact [8]. The dielectric fluid used with hydrocarbons has an environmental impact, produces toxic compounds, and puts the operator's health at risk [11,12]. Hydrocarbon-based dielectric fluids release benzene, polycyclic aromatic hydrocarbons, mineral oil vapor, aerosol, and by-products in the form of fumes and vapours [9,10]. As a result, at high temperatures, the higher discharge energy dissociates kerosene and generates carbon particles that stick to the electrode surface, reducing fast tool wear during machining compared to deionized water [22]. Wreckage globules, pockmarks, and molten beads were found on the surface of the more suspiciously noticeable dead end. The most important factors in optimizing a single quality attribute are voltage and current [23].

Metallic electrodes are suitable for EDM materials with low melting points like copper, aluminium, and brass, but graphite electrodes are better for steel and alloys [11-14]. The copper electrode is one of the metallic electrodes that can provide better results of fine surface quality when used in current EDM technology [24-28]. When choosing a material, factors such as the material's cost, the type of finishing required, the number of electrode wears, and other relevant factors should be considered.

When evaluating the quality of a machined surface, one of the most crucial characteristics to examine is surface integrity. In fact, the surface integrity achieved by finishing is directly related to product quality and performance. This study focuses on electrode wear rates in EDM at various peak currents and pulse widths. Therefore, comparisons of surface integrity qualities of titanium alloys using different types of dielectric fluids, including plant-based dielectric fluids and hydrocarbon-based dielectric fluids, have also been discussed. RBD palm oil is a good alternative fluid to hydrocarbon oils or mineral oils as dielectrics in EDM applications. It is recommended to utilize the right dielectric during the EDM process to optimize machining efficiency in terms of cost, time, and product performance.

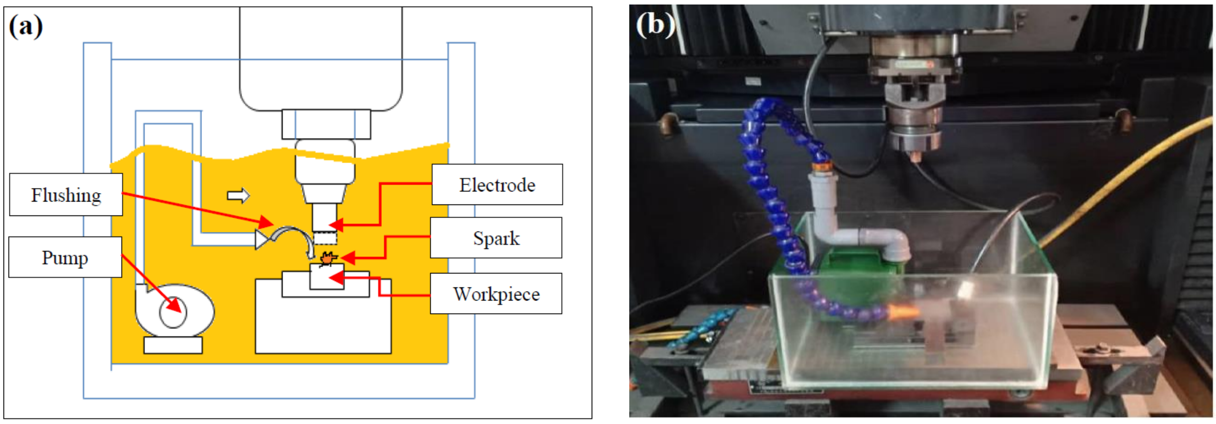
2. Methodology

2.1 Experiment Setup

The experiment was carried out using computer numerical control (CNC) in a 3 Axis linear, sodick high-speed EDM die sink AQ55L with two different types of dielectric fluids. Table 1. shows the properties of the dielectric fluid used. As shown in Figure 1, this experiment was carried out in a custom-made glass tank of 25x20x15cm^3 for palm oil fluid because the current EDM machine design can only use the conventional fluid, kerosene [11-14].

Table 1
The properties of the dielectric fluids [29]

Properties	Kerosene	RBD Palm Oil
Density, kg/cm3	730	870
Viscosity at 40°C, cSt	5.42	40.27
Thermal conductivity, W/mK	0.13	0.16
Specific heat, KJ/KgK	2.01	1.87
Flash point, °C	65	154



(a) (b)
Fig. 1. The custom made-made glass tank is setup in (a) Schematic diagram [20] (b) Actual diagram

As a workpiece for these experiments, a titanium alloy (Ti-6Al-4V) 40x30x6mm^3 with the chemical composition of Ti=89.47%, Al=6.08%, V=4.02%, Fe=0.22%, O=0.18%, C=0.02% and others are used. It is an alloy with a higher specific hardness and great dimensional stability and shape since it has high compressive strength and is wear resistant. The EDM tests were carried out using a conventional electrode made of 99.58 percent pure copper with 10x30mm^2 dimensions and dimensional tolerance of ±0.02mm. Because of their high heat conductivity, copper electrodes have been commonly employed as electrodes in EDM operations [13,14]. The chemical composition of copper electrode used was Cu=99.58%, Al=0.006%, Si=0.002%, Zn=0.25%, Pb=0.02% and others. Table 2 presents the experimental conditions and parameter settings for determining the electrode wear rate using two types of dielectric fluids.

Table 2
Experimental condition and parameter settings of machining process [20]

Properties	Kerosene
Dielectric fluids	Kerosene, RBD palm oil
Workpiece material	Copper (Cu)
Electrode tool	Titanium alloy (Ti-6Al-4V)
Peak current (A)	6, 9, 12
Pulse duration (µs)	50, 100, 150
Voltage (V)	120
Depth of cut (mm)	1

2.2 Responses

This study focused on electrode wear rate (EWR) by using different dielectric fluids; kerosene and RBD palm oil. The calculation of EWR with the unit is mm^3/min is based on the amount of electrode wear per machining operation. To ensure that there was no debris or dielectric on the workpiece, the workpiece was dried after each machining procedure and before the weight measurement. The value of EWR was determined using the formula:

$$EWR = \frac{m_e}{\rho_e t} \tag{1}$$

where the mass of electrode, m_e, machining time, t and density of electrode, ρ_e were taken as 0.00896 g/mm^3 respectively.

In the subsequent phase of the study, the surface morphology is evaluated using a scanning electron microscope (SEM). In this experiment, an SEM with the model number JSM-7600f was used. The scanned image can be used to evaluate the workpiece's surface finish.

3. Results

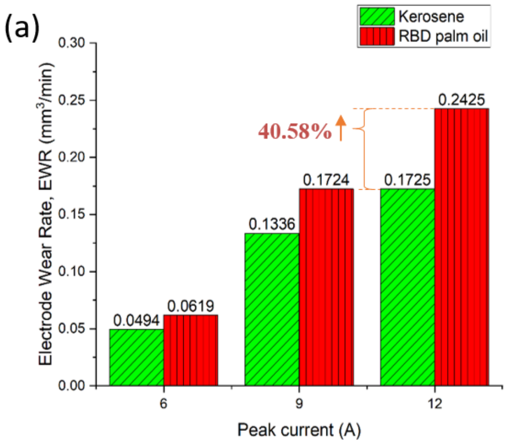
The electrical discharge machining (EDM) spark caused a high-speed electron strike on the softer electrode's surface, resulting in electrode surface erosion. This erosion changed the electrode's shape and size, as well as the created cavity. The workpiece of the EDM process will be eroded by the sparks generated by the electrical current and this will also be the case for the electrode, although the rate of eroded electrodes will be much slower than the rate of material erosion on the workpiece. The electrode wear rate (EWR) was measured under the control parameters of 6A, 9A, and 12A of peak current (I_p) with an increase of different pulse durations (t_{on}) at 50µs, 100µs, and 150µs by using kerosene and RBD palm oil as dielectric fluids as shown in Figure 2.

The comparative response of EWR reveals that using RBD palm oil as the dielectric fluid produces a better outcome than using kerosene. The higher the peak current, the higher the EWR results. At t_{on}=50µs, the highest EWR was shown at I_p=12A and I_p=6A shows the lowest EWR for both kerosene and RBD palm oil as shown in Figure 2(a). The EWR recorded for the lowest of kerosene used at 0.0494mm^3/min compared to 0.0619mm^3/min of RBD palm oil at I_p=6A setup. The highest EWR was recorded at 0.1725mm^3/min for kerosene, while the EWR of RBD palm oil increases up to

0.2425mm^3/min. It shows that about 40.58% increment happens between kerosene used and RBD palm oil at t_{on}= 50µs with I_p=12A.

The trends of EWR at t_{on}=100µs of kerosene and RBD palm oil also show the increment of EDM operations as shown in Figure 2(b). The highest EWR by using kerosene was recorded at 0.1573mm^3/min, while the increment of EDM operations by using RBD palm oil fluid was recorded at 0.2089mm^3/min. The increase of pulse duration from 50µs to 100µs was accompanied by a decrease in peak current. Higher pulse duration leads to less amplified discharge energy, and this decrease in discharge intensity leads to a lower EWR. Kerosene produced lower EWR than RBD palm oil in this experiment, which might be attributed to the protective effect of the deposited carbon layer on the copper electrode [13,14].

The parameter setting of t_{on}=150µs was shown in Figure 2(c). The lowest EWR was shown at I_p=6A with results of 0.0416mm^3/min for kerosene and 0.0480mm^3/min for RBD palm oil. The EWR increases as the peak current increases, with a value of 0.1449mm^3/min for kerosene and 0.1818mm^3/min for RBD palm oil. However, the comparison of EWR was showing that the highest I_p=12A has increased the EWR up to 25.46% by using RBD palm oil with 0.1818mm^3/min compared to kerosene at 0.1449mm^3/min. According to the results, the higher EWR for RBD palm oil was related to the greater oxygen concentration in the RBD palm oil, and the maximum EWR was attributed to a better conductive discharge channel [27-29].



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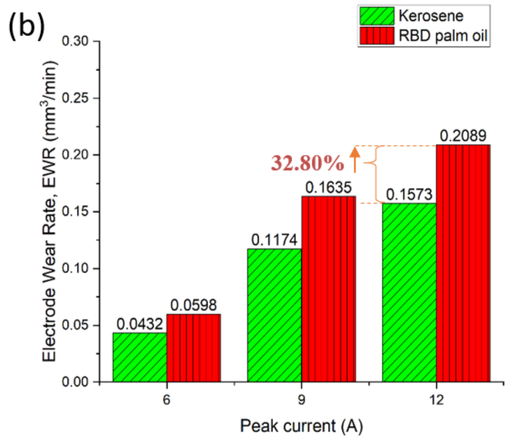

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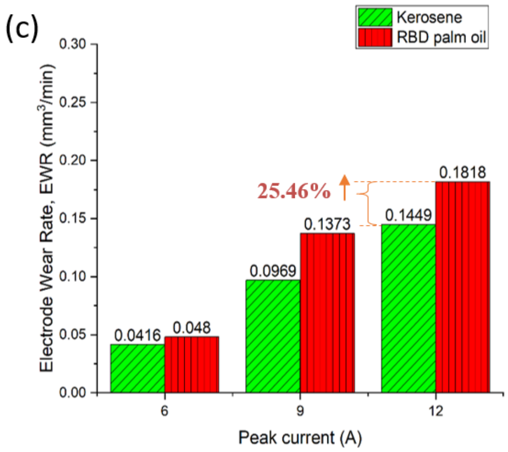
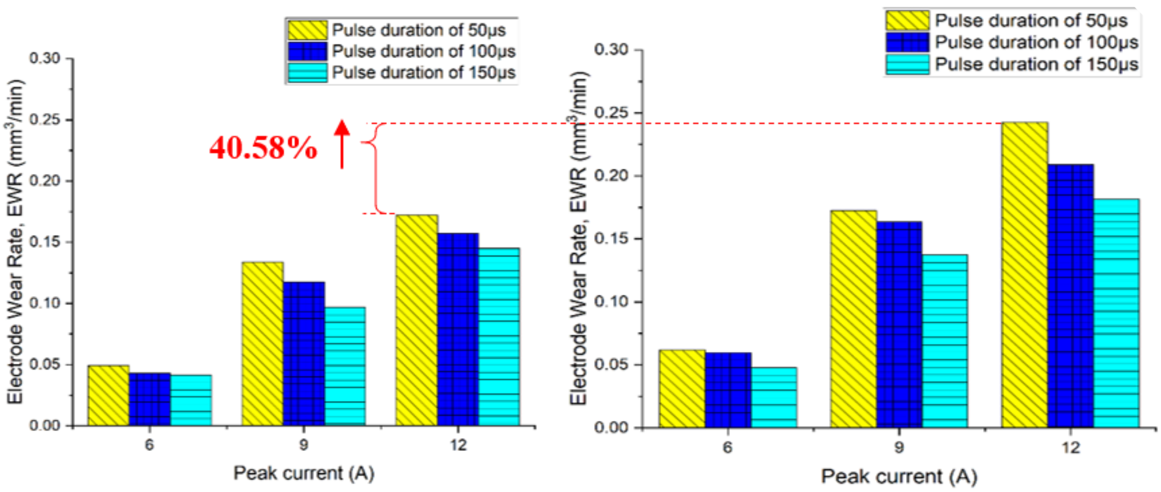


(c)

Fig. 2. Electrode wear rate of kerosene and RBD palm oil at, (a) t_{on}=50µs; (b) t_{on}=100µs; (c) t_{on}=50µs 100µs

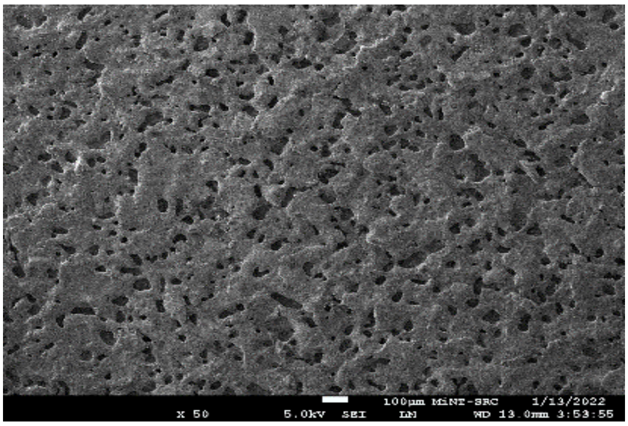
Figure 3 shows the comparison of EWR based on peak current and pulse duration for kerosene and RBD palm oil. It was observed that the EWR decreased as the peak current and pulse duration increased for both dielectric fluids; kerosene and RBD palm oil. As a result, the lowest EWR was created by kerosene at I_p=6A with t_{on}=150µs, which is 0.0416mm^3/min, while RBD palm oil was recorded at 0.0480mm^3/min. the highest EWR was recorded for kerosene at I_p=12A with t_{on}=50µs, which is 0.1725mm^3/min, while for RBD palm oil, the highest was recorded at 0.2425mm^3/min. As the kerosene was generated at lower EWR compared to RBD palm oil, it might due to the protective effect of the deposited carbon layer on the copper electrode. Thus, in terms of EWR, it can be concluded that RBD palm oil exhibited a pattern similar to kerosene, despite significant differences at higher peak current [29-34]. This proves that palm oil can be used in the EDM machining process.



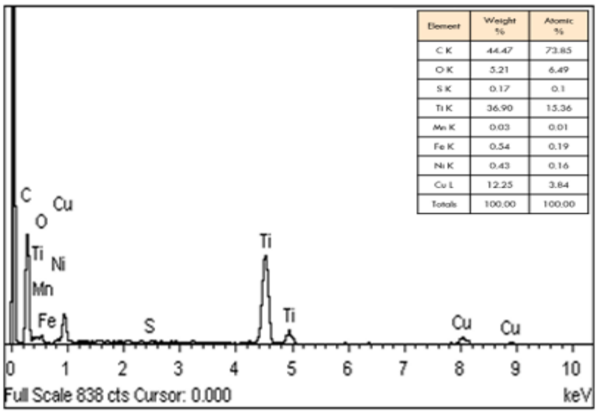
(a) (b)

Fig. 3. Comparison of EWR based on peak current and pulse duration for kerosene and RBD palm oil

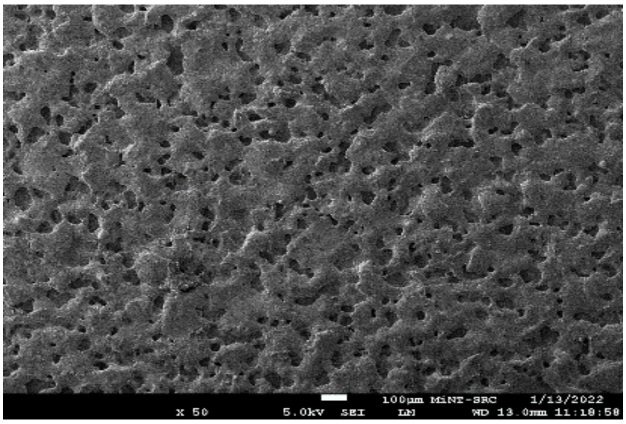
Analysis of copper electrodes surface was performed by using SEM as indicated in Figure 4 and Figure 5. The figures depict the surface morphology based on the lowest and highest EWR when kerosene and RBD palm oil were used as dielectric fluids. As a result, the lower EWR has shown the distribution of the deposited material is wider and more compared to the highest EWR resulted [13,29-35]. In contrast to lower EWR, higher EWR indicates a wider shape of material deposited upon that copper electrode surface despite the higher peak current applied, which resulted in more material deposited melting. On the electrode surface, the black layer and deposited metal from the workpiece were also visible. For both dielectric fluids, the distribution of the deposited material is wider and more at lower EWR conditions. In conversely to lower peak current, higher EWR shows a wider shape of material deposited formed on the copper electrode surface due to the higher peak current used, which resulted in more material deposited melted.



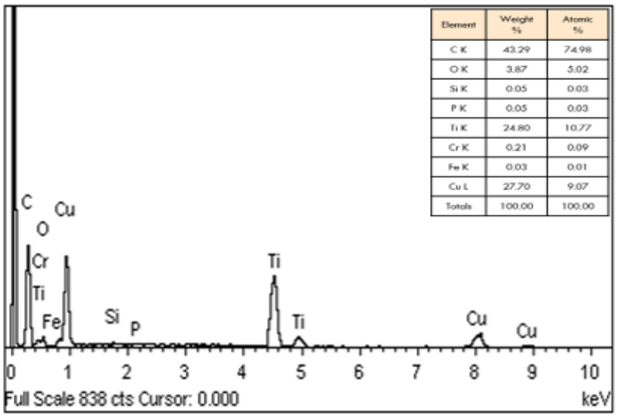
(a1) Surface morphology; EWR=0.0416mm^3/min, I_p=6A, t_{on}=150µs



(a2) EDX test, I_p=6A, t_{on}=150µs

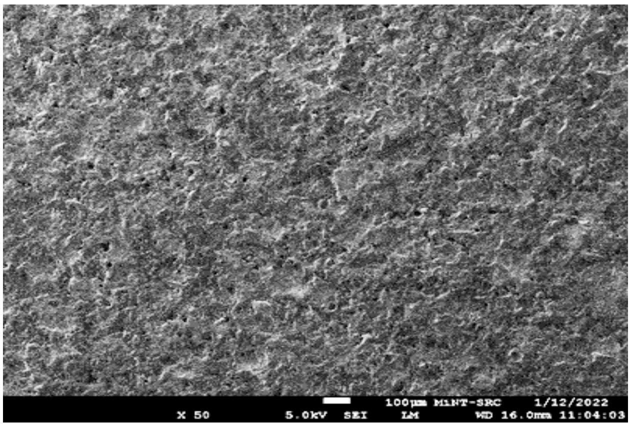


(b1) Surface morphology; EWR=0.1725mm^3/min, I_p=12A, t_{on}=50µs



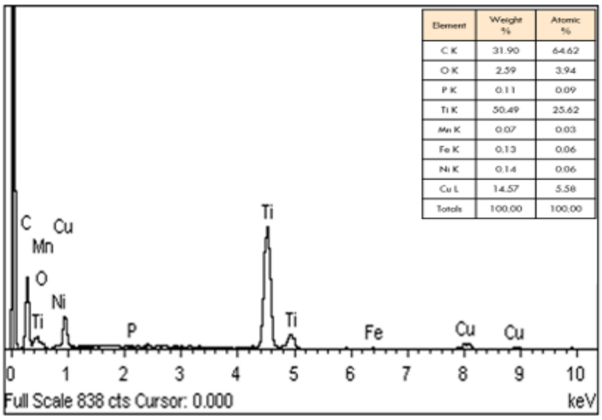
(b2) EDX test, I_p=12A, t_{on}=50µs

Fig. 4. The comparison of surface morphology for kerosene at (a) Lowest EWR (b) Highest EWR



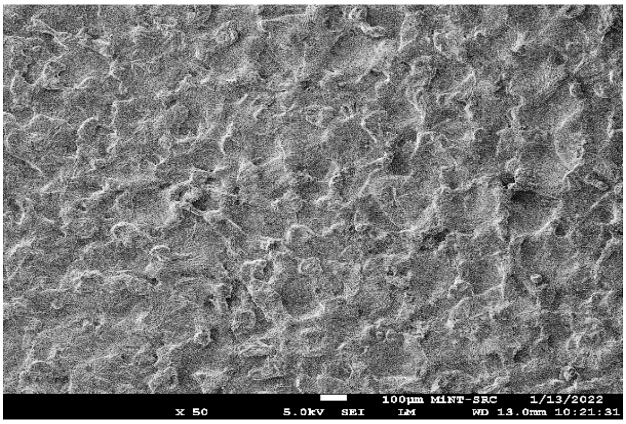
Surface morphology; EWR=0.0480mm^3/min, I_p=6A, t_{on}=150µs

(a1)



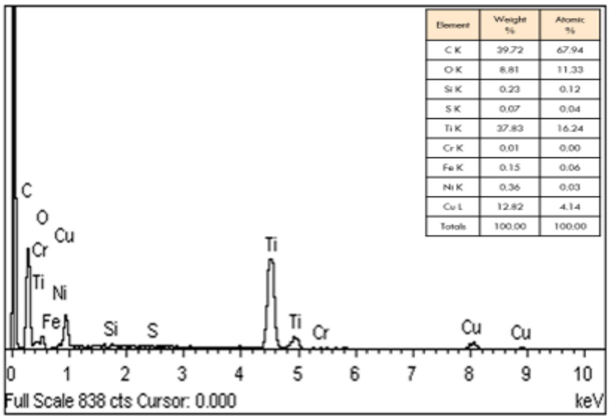
EDX test, I_p=6A, t_{on}=150µs

(a2)



Surface morphology; EWR=0.2425mm^3/min, I_p=12A, t_{on}=50µs

(b1)



EDX test, I_p=12A, t_{on}=50µs

(b2)

Fig. 5. The comparison of surface morphology for RBD palm oil at (a) Lowest (b) Highest EWR

4. Conclusions

The goal of studying the machinability of titanium alloy (Ti-6Al-4V) on the electrode wear rate (EWR) utilising various types of dielectric fluids was effectively accomplished. The following are the findings of the current study:

i. When peak current is increased, the electrode wear rate (EWR) increases, but pulse duration is inversely proportional. At peak current, I_p =6A, and pulse duration t_{on}=150µs, the lowest EWR of kerosene and RBD palm oil is 0.0416mm^3/min and 0.0480mm^3/min, respectively. The highest EWR for both dielectric fluids were at peak current, I_p =12A, and pulse duration t_{on}=50µs, which is 0.1725mm^3/min and 0.2425mm^3/min, respectively.
ii. In terms of EWR and electrode surface morphology, RBD palm oil shows similar patterns of machining response. The lowest EWR value for both dielectrics was influenced by the higher carbon deposition on the Cu electrode, according to the findings. It suggests that the EDM process for palm oil-based bio-dielectric is the same as for kerosene.
iii. Increased oxygen concentration causes more severe oxidation and a more conductive discharge channel, which allows more positive ions to strike the tool electrode surface. Higher electrode erosion volume changes the electrode's dimensional and geometrical accuracies more quickly, resulting in lower production per electrode. As a result, tooling costs may be greater in the case of RBD palm oil.

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