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Electrode Wear Rate On Electrical Discharge Machining of Titanium Alloys (Ti-6Al-4V) At Different Peak Current and Pulse Duration by Using Modified RBD Palm Oil as Dielectric Fluids

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Abstract: Electrical Discharge Machining (EDM) is a machining process in terms of thermoelectric that removes metal by discharging a discrete sparks series of the metal and workpiece. The cutting tool in EDM has used an electric spark to cut the workpiece of sample and produce the finished part to the demanded shape. Vegetable oil as the dielectric fluid is one way to ensure EDM's long-term viability because it is environmentally friendly and biodegradable. The main objective of this preliminary study is to compare the uses of modified bio-degradable and conventional dielectric fluid performance for a titanium alloy (Ti-6Al-4V) with a copper (Cu) electrode using a sustainable EDM process in terms of electrode wear rate (EWR). To achieve a concentration of viscosity rate as kerosene fluids, RBD palm oil has been transesterified. The effect of EWR of kerosene and modified RBD palm oil as dielectric fluids was investigated in this paper for response variables of pulse duration (t_{on}) of 50, 100, and 150µs, and peak current (I_p) of 6, 9, and 12A. The morphology of the copper electrode, as well as the migration of workpiece material elements to the tool electrode, were studied by using scanning electron microscopy (SEM). The lowest EWR was recorded at I_p=6A with t_{on}=150µs, which is 0.0416mm^3/min and 0.0432mm^3/min, and the highest EWR was recorded at I_p=12A with t_{on}=50µs, which is 0.1725mm^3/min and 0.2324mm^3/min, for modified RBD palm oil compared to kerosene, respectively. The EWR rises as the peak current rises, but it decreases as the pulse duration increases. The uses of modified RBD palm oil shows slightly different results compared to kerosene.

Keywords: Electrical discharge machining, titanium alloys, modify RBD palm oil

1. Introduction

The growing demand for energy in the industrialized sector and the domestic sector, as well as the pollution issues caused by the ongoing use of fossil fuels, make it required to develop renewable energy sources with an extended lifespan and lower environmental impact than existing energy sources [1]. Modern sectors and applications that require high precision and tolerance include transportation systems, aerospace, electrical components, and medical parts [2]. Traditional machining methods, which require a lot of force and are incapable of producing small parts or complex shapes, cannot meet these requirements. To meet these specific requirements, advanced machines such as laser beam

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machining, water jet machining, electrochemical machines, electron beam machining, and electrical discharge machines can be used. An EDM operation is one in which a workpiece is eroded using thermoelectric energy and then automatically repeated using sparks [3]. When a spark occurs, enough pressure is created between the tool and the workpiece, where the high temperature occurs, and some metal is melted and eroded as a result of the high pressure and temperature. It's important to figure out how erosion parameters influence the machining process. The findings will be useful in achieving the best possible process performance.

Electrical discharge machining (EDM) is classified into many types which is wire EDM, micro EDM, die-sinking EDM, dry EDM, and powder-mixed EDM. The voltage within the spark gap zone growths to a point where the fluid ionizes and becomes conductive, resulting in the production and discharge of an electric pulse, which starts the process [4, 5]. Many manufacturing companies are currently employing a variety of dielectric fluids, including hydrocarbon oil, mineral oil, and deionized water, among other options [6-8]. However, there are numerous disadvantages to the current dielectric fluid that have an impact on the environment and workers. Environmental concerns have been raised due to toxic emissions from EDM. As well as operator health concerns, there is a poor operational safety aspect due to the release of vapours, toxic fumes, aerosols, the generation of toxic and dielectric waste that is non-biodegradable [9]. There are a numeral of specific characteristics and properties of biodiesel fuel that regulate its performance as an energy source when compared to other alternative fuels. Flashpoint, viscosity, pour point, density, iodine value, heating value, and cetane number are some of these qualities [10, 11].

In electrical discharge machining, researchers have experimented with a variety of vegetable oils as dielectric fluids. Palm oil, soybean oil, sunflower oil, waste vegetable oil, canola oil, blended used vegetable oil, and jatropha oil are some of the vegetable oils that have been tested [12-15]. The fruit of the palm tree, also known as the mesocarp, is used to make refined bleached deodorized (RBD) palm oil. The life span of dielectric fluid decreases over time, and as a result, it gradually loses its toughness and capabilities, such as the stability of spark gap ionization, which negatively impacts the machining process and the final product [16]. Simple tests, such as the "sight and smell" test, can be used by the manufacturer to prevent dielectric fluid from becoming aged, which compares the old dielectric fluid to the new dielectric fluid to make sure it does not become aged.

EDM has significant advantages over conventional machining as it has been used to machine hardened and heat-treated workpieces and can cut electrically conductive material [17, 18]. Complex and intricate profiles can be cut faster, more accurately, and at a lower cost of production. Burr-free, fragile, and thin sections have been made with ease. The die and tool industry are where EDM is most commonly used. EDM is now an important part of the manufacturing process for prototypes and production parts. When evaluating the quality of a machined surface, surface integrity is one of the most important factors to consider. Hence, this study was focuses on the electrode wear rate (EWR) of copper electrode by using kerosene and modified RBD palm oil as dielectric fluid to the finishing operation of titanium alloy (Ti-6Al-4V) in EDM operation. It was generally expected that it would enhance EDM machining performance.

2. Experiment Setup

The workpiece material selected for investigation was titanium alloy (Ti-6Al-4V). The electrode used was a copper cylindrical rod with diameter of 10mm with 30mm of length. The machining was performed using two types of dielectric fluid, which is kerosene and modified RBD palm oil. The properties of kerosene and modified RBD palm oil used as dielectric fluid in this experiment were shown in Table 1. RBD palm oil has undergo transesterification process to achieve viscosity as almost as synthetic dielectric fluid which is kerosene. The transesterification process as shown in Figure 1 is a crude oil pre-treatment that converts RBD palm oil into esters, lowering the percentage of free fatty acid (FFA) in the RBD palm oil to less than 1%.

Table 1 - Properties of dielectric fluid

Properties	Kerosene	Modify RBD palm oil
Density (kg/m^3)	730	879
Viscosity (at 40^{o}C)	5.42	5.6
Thermal Conductivity (W/mC)	0.13	0.15
Specific heat (KJ/KgC)	2.01	1.98
Flash Point (^{o}C)	65	220

This study was carried out using a computer numerical control (CNC) machine in 3 Axis Linear (sodick high speed electrical discharge machining of die sink AQ55L). Since the conventional machine only can use the synthetic dielectric fluid, glass tank with dimension of 25x20x15cm^3 is designed to conduct the experiment by using modified RBD palm oil fluid as shown in Figure 2.

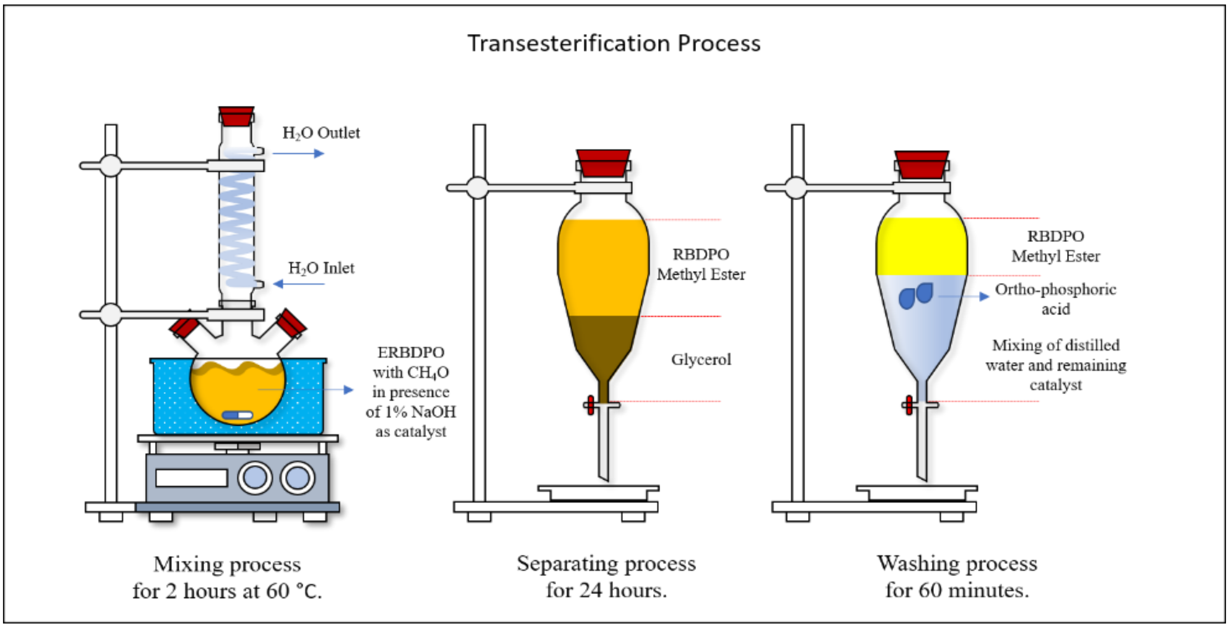


Fig. 1 - The modification of RBD palm oil through transesterification process

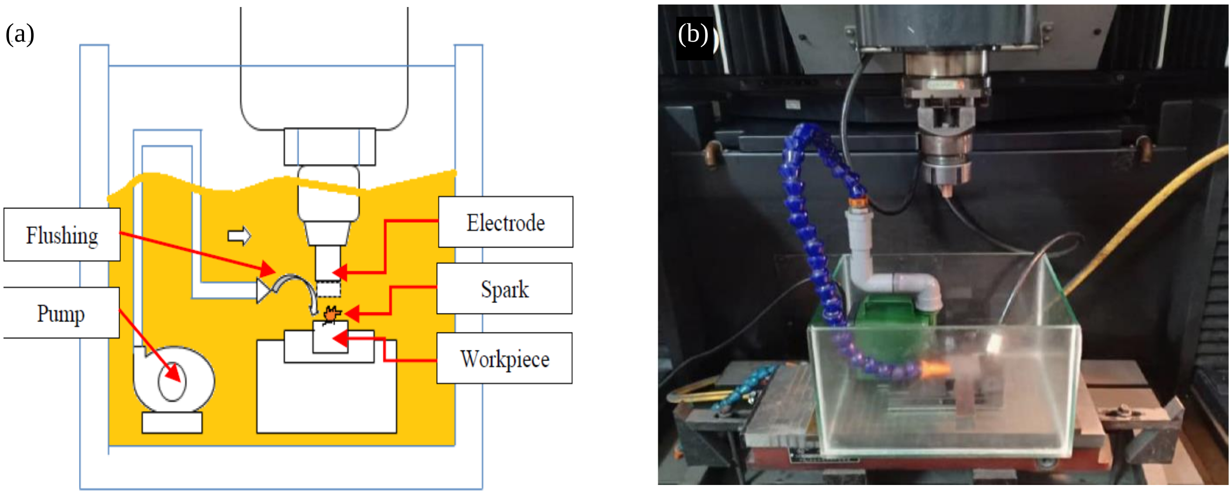


Fig. 2 - (a) Schematic diagram of the machine setup; (b) external glass tank [15]

2.1 Responses

The electrode wear rate (EWR) was analyzed by applying a selection of dielectric fluids, namely kerosene and modified RBD palm oil. The amount of electrode wear per machining operation is used to calculate EWR in mm^3/min units. The workpiece was dried after each material removal process and before the measure of weight to make sure that there was no debris or dielectric on it. The value of EWR was calculated using the following equation:

$$EWR = m_e / \rho_e t \quad (1)$$

Where,

EWR = Electrode wear rate (mm^3/min)
m_e = Mass loss of electrode (g)
ρ_e = Density of electrode (Cu=0.00896g/mm^3)
t = Machining time (min)

In the following step of the analysis, the surface morphology is examined with a Scanning Electron Microscope (SEM with model number JSM-7600f) to analyse the workpiece's surface finish.

3. Results

The spark from the electrical discharge machining (EDM) created a significant electron strike on the surface of the softer electrode, resulting in electrode surface erosion. This erosion significantly changed the shape and size of the electrode, as well as the cavity that was formed [19]. The electrode, like the workpiece in the EDM process, will be eroded by the sparks generated by the electrical current, however the rate of electrode erosion will be far slower than the rate of material erosion on the workpiece. The EWR is significantly influenced by factors such as pulse duration and peak current. In order to achieve improved dimension and scale, a low EWR is recommended. A tool's life expectancy must be high for efficient machining. As a result, a high EWR will lead to more tool consumption, which will lead to higher tooling costs. The electrode wear rate (EWR) was investigated using kerosene and modified RBD palm oil as dielectric fluids under control parameters of 6A, 9A, and 12A of peak current with increases of varied pulse durations at 50µs, 100µs, and 150µs.

Figure 3 illustrates the EWR comparisons for kerosene and modified RBD palm oil as dielectric fluids, as influenced by peak current, I_P, and pulse duration, t_{on}. The comparative response of EWR shows that the EWR increased as the peak current was increased from 6A to 12A, but decreased as the pulse duration was increased from 50µs to 150µs. Higher pulse duration leads to less amplified discharge energy, and this decrease in discharge intensity leads to a lower EWR. Figure 3(a) shows that the highest EWR was found at 12A of peak current for both kerosene and modified RBD palm oil, while the lowest EWR was found at 6A of peak current for both kerosene and modified RBD palm oil when the pulse duration was at 50µs. At 6A of peak current condition, the EWR recorded for the lowest of kerosene used was 0.0494mm^3/min, compared to 0.0545mm^3/min for modified RBD palm oil. The EWR for kerosene was increases up to 0.1725mm^3/min, while the EWR of modified RBD palm oil increases up to 0.2324mm^3/min. It reveals that a 34.72% increase occurs between kerosene used and modified RBD palm oil at pulse durations of 50µs and peak currents of 12A.

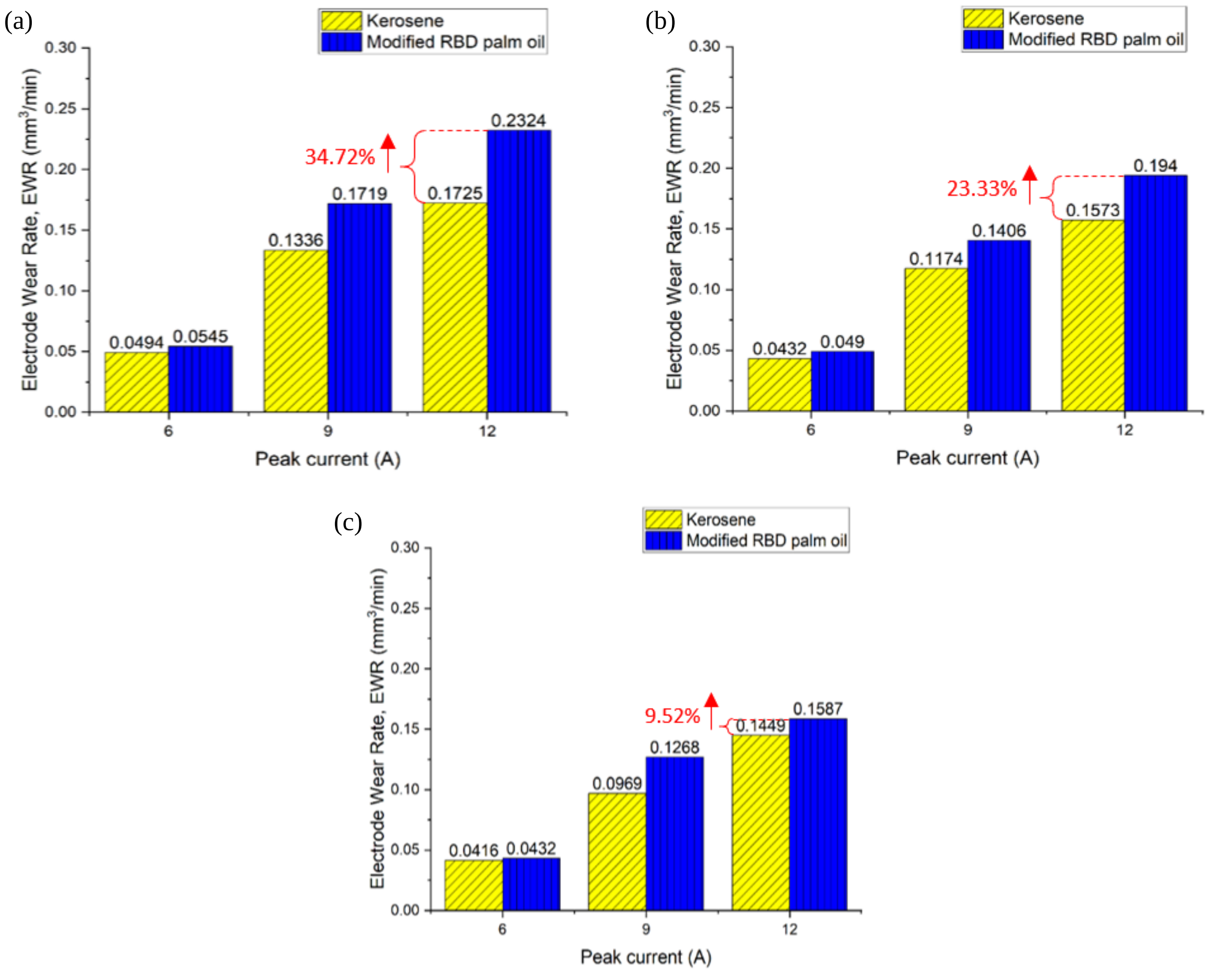


Fig. 3 - Electrode wear rate (EWR) of kerosene and modified RBD palm oil at different pulse duration (a) pulse duration of 50µs; (b) pulse duration of 100µs; (c) pulse duration of 150µs

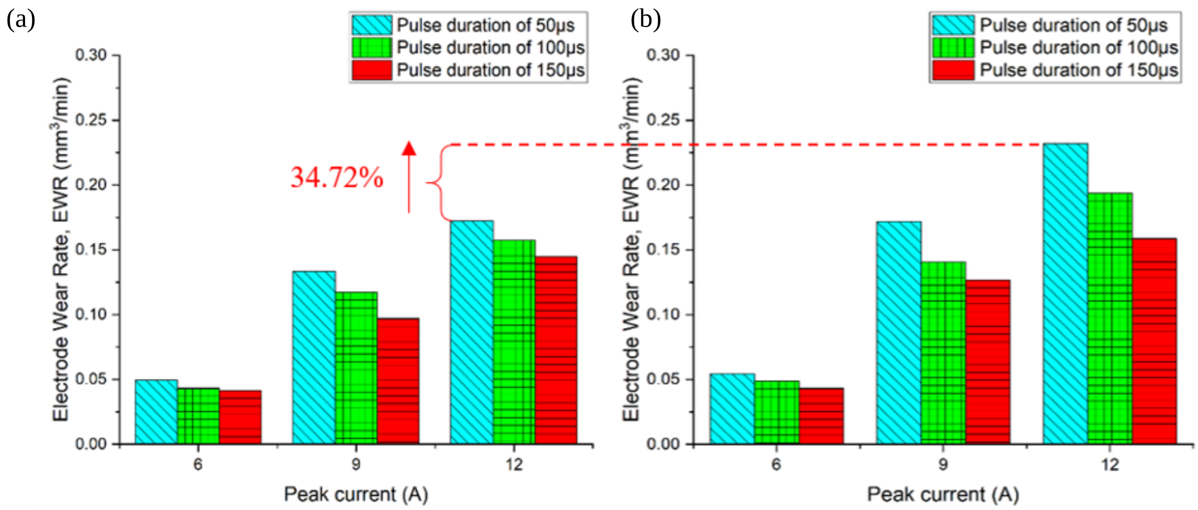


Fig. 4 - The comparison on peak current and pulse duration of electrode wear rate (EWR) by using dielectric fluid (a) kerosene; (b) modified RBD palm oil

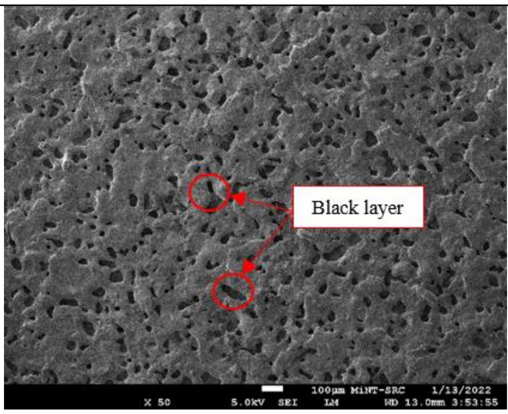
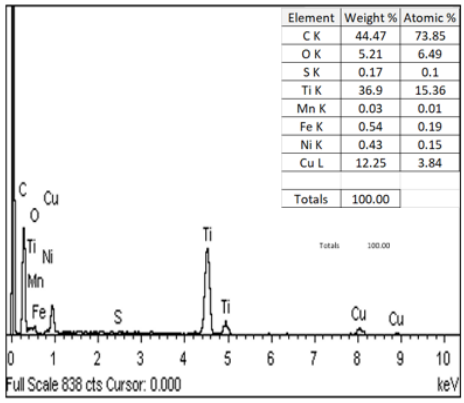
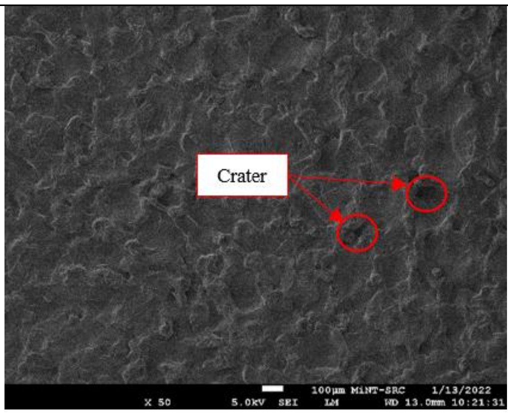
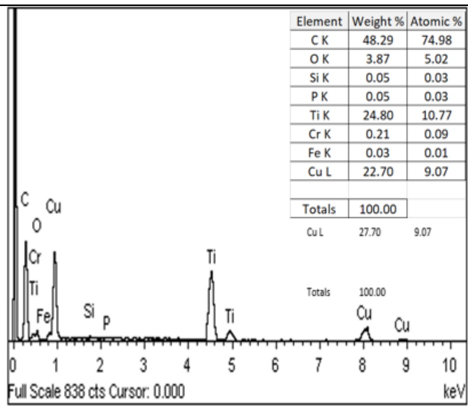
<table>
<tr><th>Dielectric fluid</th><th colspan="2">Kerosene</th></tr>
<tr><td>Lowest</td><td>
(a-1) EWR=0.0494mm^3/min, I_p=6A, t_{on}=50μs</td><td>
(a-2) EDX test, I_p=6A, t_{on}=50μs</td></tr>
<tr><td>Highest</td><td>
(b-1) EWR=0.1725mm^3/min, I_p=12A, t_{on}=150μs</td><td>
(b-2) EDX test, I_p=12A, t_{on}=150μs</td></tr>
</table>

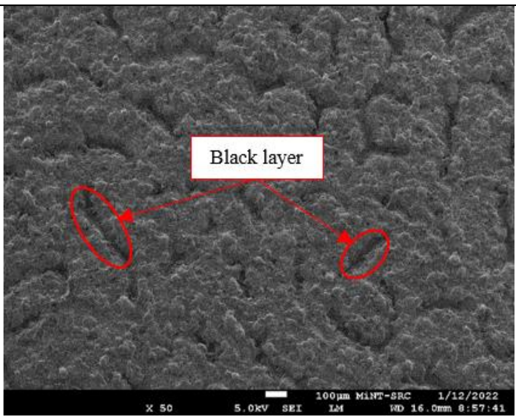
Fig. 5 - The comparison of surface morphology for copper electrode surfaces on kerosene at (a) lowest EWR; (b) highest EWR

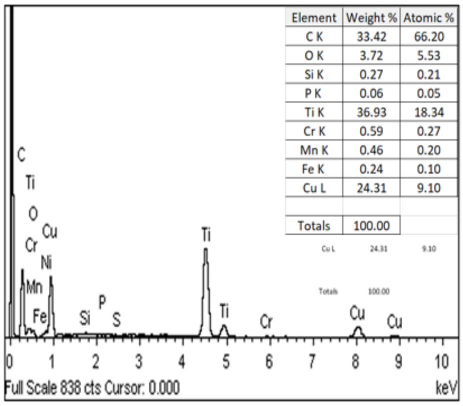
Figure 3(b) illustrates the patterns of EWR at pulse durations of 100μs of kerosene and modified RBD palm oil, as well as the increase in EDM operations. The highest EWR measured by using kerosene was 0.1573mm^3/min, while the increment of EDM operations measured with modified RBD palm oil fluid was 0.1940mm^3/min. The increase in pulse duration from 50μs to 100μs resulted in a decrement with an increase in peak current. Higher pulse duration results in less amplified discharge energy, and this reduction in discharge intensity results in a lower EWR. In this experiment, kerosene produced less EWR than modified RBD palm oil, which could be attributed to the protecting effect of the deposited carbon layer on the copper electrode [18, 20].

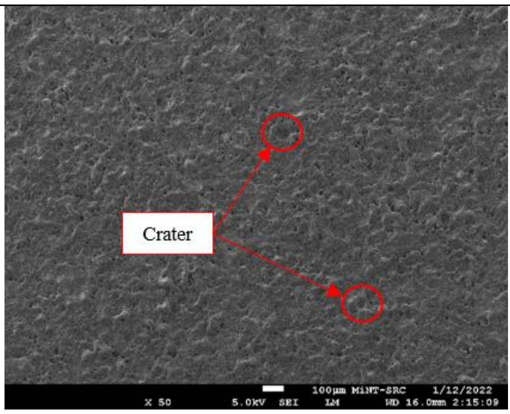
Figure 3(c) illustrates the pulse duration parameter setting of 150µs. At 6A of peak current, the lowest EWR was 0.0416mm^3/min for kerosene and 0.0432mm^3/min for modified RBD palm oil. The EWR increases as the peak current increases, with a result of 0.1449mm^3/min for kerosene and 0.1587mm^3/min for modified RBD palm oil. However, the EWR comparison revealed that the highest peak current at 12A slightly increased the EWR by 9.52% when using modified RBD palm oil. According to the findings, the slightly difference EWR between kerosene and modified RBD palm oil is due to the properties of dielectric fluids that has almost the same properties for this investigation.

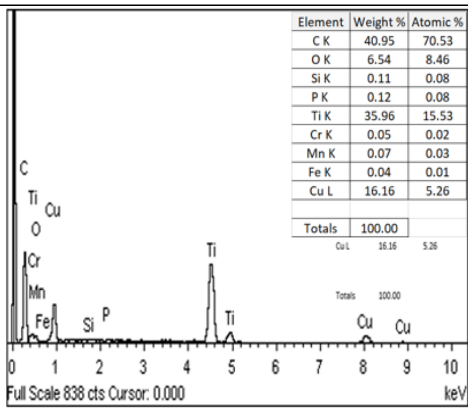
Figure 4 illustrates a comparison of EWR between kerosene and modified RBD palm oil in terms of peak current and pulse duration. It was observed, when the EWR for both kerosene and modified RBD palm oil were compared, kerosene produced the lowest EWR than modified RBD palm oil located at 6A peak current with 150µs pulse duration. As a result, at the equivalent machining parameters of peak current of 12A and pulse duration of 50µs, modified RBD palm oil produced higher EWR than kerosene with percentage increment of 34.72%. The higher EWR for modified RBD palm oil might be attributed to the higher oxygen content in modified RBD palm oil. As a result, it is clear that kerosene produced less EWR than modified RBD palm oil. It is because modified RBD palm oil has a lower carbon atom content than kerosene, and at higher pulse durations, kerosene has more decomposed and deposited carbon atoms on the electrode surface than modified RBD palm oil [18].

Analysis on copper electrodes surface was performed by using Scanning Electron Microscope (SEM) as indicated in Figure 5 and Figure 6. The figures depict the surface morphology based on the lowest and highest EWR when kerosene and modified RBD palm oil were used as dielectric fluids. 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.

<table>
<tr><th>Dielectric fluid</th><th colspan="2">Modified RBD palm oil</th></tr>
<tr><td>Lowest</td><td>


(a-1) EWR=0.0494mm^3/min, I_p=6A, t_{on}=50µs</td><td>


(a-2) EDX test, I_p=6A, t_{on}=50µs</td></tr>
<tr><td>Highest</td><td>


(b-1) EWR=0.1725mm^3/min, I_p=12A, t_{on}=150µs</td><td>


(b-2) EDX test, I_p=12A, t_{on}=150µs</td></tr>
</table>

Fig. 6 - The comparison of surface morphology for copper electrode surfaces on modified RBD palm oil at (a) lowest EWR; (b) highest EWR

According to EDX data for kerosene, the lowest EWR with the weight percentage of Carbon, C=44.47% in Figure 5 (a-2) from decomposed dielectric used while the main element of Ti-6Al-4V, Ti=36.90%. The data observed shows that when EWR increased, the carbon element increased while titanium element is decreased in the weight percentage as shown in Figure 5 (b-2) as C=48.29% meanwhile Ti=24.80%. Thus, it can be stated that the deposited materials formed on the tool surface is one of the factors that contributed in reducing the EWR. While, for modified RBD palm oil, the EDX data in Figure 6 (a-2), at lowest EWR, the weight percentage of Carbon, C=33.42% from decomposed dielectric used while main element Ti-6Al-4V, Ti=36.93%. The data is high when compared to highest EWR in Figure 6 (b-2) as the carbon content increased at C=40.95% meanwhile the titanium element decreased at Ti=35.96%. It has been revealed that an increase in peak current will eventually result in an increase in EWR. An increase in pulse duration, on the other hand, will result in a decrease in EWR. The reason why this occurred is due to an increase in pulse duration, which caused the density of current to be smaller. As a result, the effects of the spark on melting electrodes and vaporizing became less intense thus contributed to reducing the EWR [19].

4. Conclusion

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

1) As peak current increases, so does electrode wear rate (EWR), but pulse duration is inversely proportional. The lowest EWR of kerosene and modified RBD palm oil is 0.0416mm^3/min and 0.0432mm^3/min, respectively, at a peak current of 6A and a pulse duration of 150μs. The highest EWR for both dielectric fluids were 0.1725mm^3/min and 0.2324mm^3/min, respectively, at peak current of 12A and pulse duration of 50μs.
2) Modified RBD palm oil exhibits similar patterns of machining response in terms of EWR and electrode surface morphology. According to the findings, the lower EWR value for both dielectrics was influenced by the higher carbon deposition on the Cu electrode. It indicates that the EDM process for palm oil-based bio-dielectric is similar to that of kerosene.
3) At the lowest EWR, the mass percentage of carbon is low while the mass percentage of titanium is high compared to highest EWR. As a result, one of the factors that contributed to lowering the EWR is the deposited materials formed on the tool surface.

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