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# The Machinability Performance of RBD Palm Oil Dielectric Fluid on Electrical Discharge Machining (EDM) of AISI D2 Steel

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**Abstract:** Electrical discharge machining (EDM) is a high-precision manufacturing process that may be implemented to any electrically conductive material, notwithstanding its of mechanical residences. It's far a non-contact process using thermal energy that is used in a wide range of applications, especially for difficult-to-cut materials with complicated shapes and geometries. The dielectric is critical in this process as it focuses the plasma channel above the processing and also serves as a debris carrier. The long-term use of dielectric used in EDM process pollutes to the atmosphere and is harmful to the operator's health. This study compares the efficiency of refined, bleached, and deodorized (RBD) palm oil (cooking oil) with traditional hydrocarbon dielectric, kerosene using copper electrode in the finishing process of AISI D2 steel. Low peak current, $I_p$ 1A to 5A and pulse duration, $t_{on}$ up to 150µs were chosen as the main parameters. The effects of material removal rate (MRR), electrode wear rate (EWR), and surface roughness ($R_a$) were evaluated. The result shows that RBD palm oil has higher MRR which is 33.4821mm$^3$/min while kerosene is 22.4888mm$^3$/min, both at $I_p$=5A and $t_{on}$=150µs. The improvement when RBD palm oil is used as dielectric is 48.88% compared to kerosene. With the increase in peak current, the EWR increases but it is inversely proportional to the pulse duration. The lowest EWR is obtained at the same $I_P$=1A and $t_{on}$=150µs for both RBD palm oil and kerosene which is 0.0010mm$^3$/min and 0.0002mm$^3$/min respectively. The minimum value of $R_a$ for RBD palm oil is 2.15µm at $I_P$=1A and $t_{on}$=150µs, while for kerosene it is 2.11µm at $I_P$=1A and $t_{on}$=150µs. In terms of finishing process efficiency, RBD palm oil, a biodegradable oil-based dielectric fluid, has shown significant potential in EDM processing of AISI D2 steel.

**Keywords:** RBD palm oil, electrical discharge machining, AISI D2 steel

## 1. Introduction

Rapid technological advancements in aerospace, transportation, medical, and such other industries have demanded the processing of more material at a higher capacity and efficiency. Most advanced materials, due to their unique characteristics, need the use of advanced production techniques in order to be machined efficiently [1, 2]. The majority of these items are tough to cut using standard manufacturing processes [3–7]. The specific properties of these materials have broadened their range of applications and prompted manufacturers to develop

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new low-cost and high-precision machining processes [10, 11]. EDM is among the most sophisticated technologies for cutting conductive materials [10, 12–16]. In modern industries, EDM is the method of choice for machining difficult-to-cut materials typically used to facilitate precise machining, complex shape machining and better surface integrity [17–22]. The method is used to manufacture electrically conductive materials by repeatedly applying sparks between electrodes and workpieces. In contrast to mechanical machining, there is no deformation force between the workpiece and the electrode, and machining occurs without any physical contact between them [20, 23–25].

EDM methods that employ the same material removal mechanism include die-sinking EDM, wire EDM, micro EDM, powder-mix EDM, and dry EDM. Different technologies make the process more flexible and ideal for machining relatively wide and microscopic. Die-sinking EDM is a method of removing material from a workpiece that includes a series of quickly occurring current discharges along electrodes separated by a dielectric fluid and exposed to an electrical voltage. To produce sparks, both the electrode and the workpiece must have electrical conductivity.

In addition, while many technologies had been invested in improving machining capabilities, environmental sustainability had received little attention. Several problems with the machining process arose during the EDM process. Because of their high flammability and instability, dielectric fluids were a source of concern [26]. The carcinogenic and polluting potential of the dielectric fluid, kerosene, which was frequently employed in EDM owing to its long-term usage, were some of the most worrisome problems. Many studies had been conducted to improve environmental machining capabilities, with some proposing tap water or deionized water with additives as an alternative to conventional hydrocarbon oil to reduce environmental impact while maintaining machining capabilities. [27, 28]. Other research initiatives included the use of RBD palm oil to replace kerosene to minimize costs and to create an environmentally sustainable method for machining [27-30].

RBD palm oil has a low price, is convenient to use, is widely available, and has a higher sustainability impact index. Furthermore, it has the property of being reusable and not causing damage to the environment or human health when used [6]. RBD palm oil had been shown to enhance the machining process and undoubtedly to be the best substitute for kerosene because of its biodegradability and pollutant-free [29, 30]. However, their performance has been questioned. It can reduce the pollutant and cost but up to this point, there is no detailed research on the performance and effect of repeated cycle use of RBD palm oil in EDM. Besides, biodegradable oil-based dielectric fluids are slow to be introduced in the industry due to the fundamental problems with this new development, such as the machining mechanism in the EDM process [25].

It is desirable to select an appropriate dielectric fluid during EDM operation to improve EDM efficiency. Most researchers investigated the effects of changes in the state and parameters of the machining [7, 25]. Still, very few studies had been done on dielectric fluid efficiency by looking at the mechanism in EDM with the introduction of bio-degradable dielectric fluid based on oil in EDM. However, the procedures involved require further analysis and testing to apply bio-dielectric fluid to EDM. Hence, this study was investigating on the performance of RBD palm oil dielectric fluid to the finishing operation of AISI D2 steel in a sustainable EDM process. In this case, it was highly expected that it would improve the performance of EDM machining

## 2. Experiment Methods

The procedure of long-term electrical discharge machining will be discussed throughout. To achieve the proper result for this analysis, the proper steps should be taken. The schematic diagram and machine setup are shown in Fig. 1, and Table 1 lists the properties of the dielectric fluid used in this study.

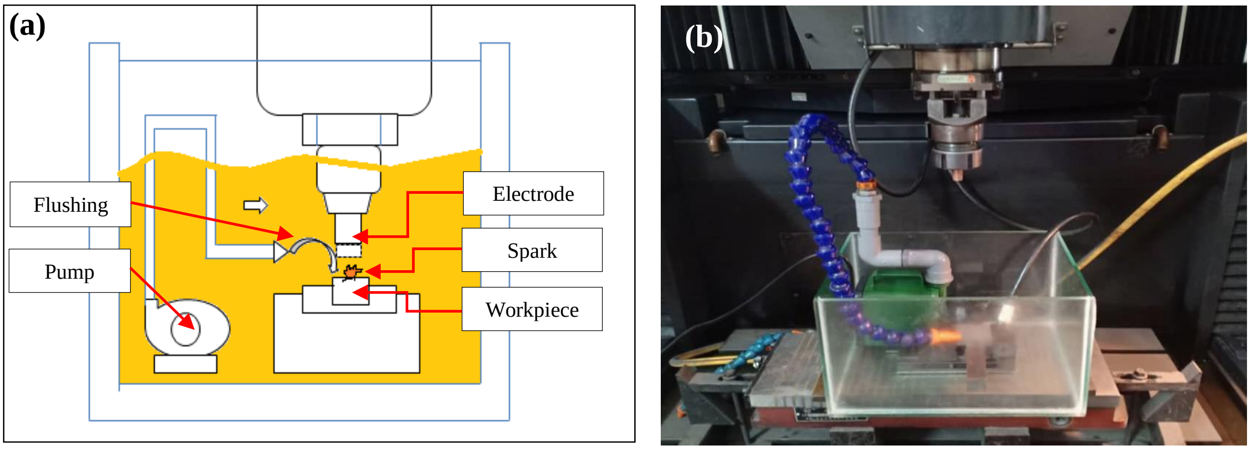


**Fig. 1 - (a) Schematic diagram of machine setup; (b) External working tank**

**Table 1 - Properties of dielectric fluid**

| Properties | RBD Palm Oil | Kerosene |
|---|---|---|
| Density (kg/m$^3$) | 870 | 820 |
| Viscosity, at 40$^o$C (cST) | 40.24 | 2.08 |
| Flash Point ($^o$C) | 160 | 38-41 |
| Specific heat (KJ/KgK) | 1.902 | 2.00 |
| Breakdown Voltage (KV) | 51-64 | 6.4-11.4 |
| Thermal Conductivity (W/mK) | 0.1708 | 0.145 |

## 2.1 Experiment Setup and Details

As shown in Fig. 2, RBD palm oil (cooking oil) was used biodegradable oil dielectric and kerosene as a conventional dielectric in this study. Computer Numerical Control (CNC), Sodick high speed EDM die sink AQ55L (3 Axis Linear) machine was used to carry out this study. A special made glass tank (25x20x15) cm$^3$ was used to perform this study with RBD palm oil as the dielectric fluid. This was done because the Sodick high speed EDM Die Sink (AQ55L) machine is designed to use kerosene only.

The workpiece in this project was AISI D2 steel (40x30x10) mm$^3$. A cut-off grinder was used to cut the required dimensions from the raw material as received. Filing was also used to remove burrs and sharp corners. This steel has high compressive strength and excellent wear resistance. The chemical composition (wt%) of AISI D2 steel was: C: 1.5%, S: 0.3%, Mn: 0.3%, Mo: 1.0%, Cr: 12%, Ni: 0.3%, V: 0.8%, Co: 1.0%, and the balance was Fe. A commercial electrode made of 99.58% pure copper with dimensions Ø (10 x30) mm and a dimensional tolerance of $\pm$ 0.02mm was used to perform the EDM experiments. The chemical composition (wt%) of the copper electrode was: Cu: 99.58%, Al: 0.006%, Si: 0.002%, S: 0.035%, P: 0.052%, Zn: 0.25%, Mn: 0.002%, Ni: 0.023%, Pb: 0.02%, and C: 0.028%. Due to its high thermal conductivity, copper electrodes have been widely used as electrodes in EDM processes [7, 8]. The sample image of the machined workpiece is shown in Fig. 3. For each set, a total of 18 runs were performed, 9 trials each with RBD palm oil and kerosene. The set was repeated twice and the best result was selected for analysis. Table 2 shows the experimental conditions and parameter settings for the study.

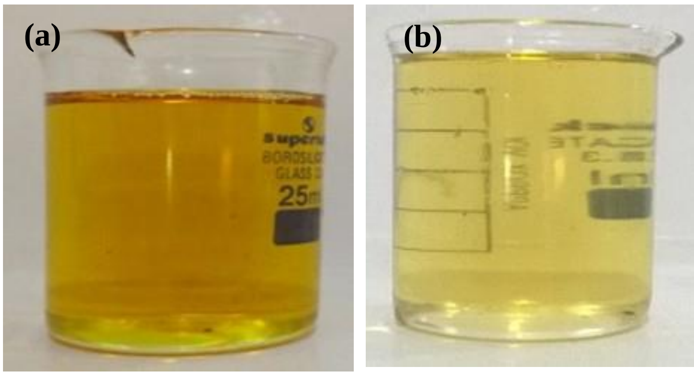



**Fig. 2 - Dielectric fluid; (a) RBD palm oil; (b) kerosene**

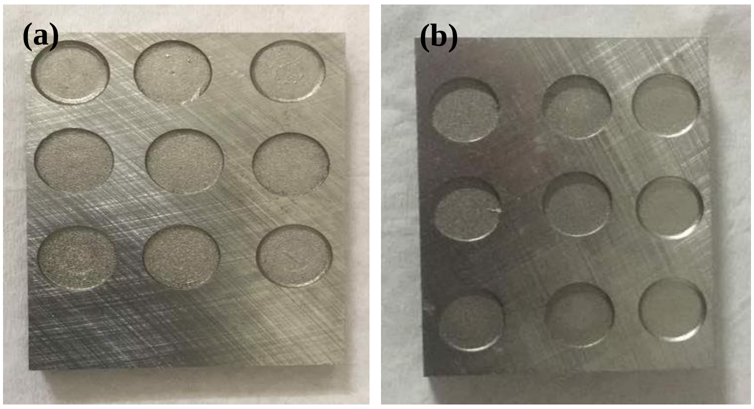



**Fig. 3 - AISI D2 steel machining using; (a) RBD palm oil; (b) kerosene**

**Table 2 - Experimental condition on EDM machining of AISI D2 steel**

| Parameter | Details |
|---|---|
| Workpiece material | AISI D2 steel |
| Electrode material | Copper |
| Peak current, $I_p$ (A) | 1, 3, 5 |
| Pulse on-time, $t_{on}$ (µs) | 50, 100, 150 |
| Pulse off-time, $t_{off}$ (µs) | 50 |
| Voltage, V | 120 |
| Electrode polarity | Positive (+ve) |
| Depth of cut (mm) | 1.5 |

## 2.2 Responses

In this study, the material removal rate (MRR), electrode wear rate (EWR) and surface roughness ($R_a$) were investigated. MRR can be defined as the volume loss of the workpiece per machining time ($mm^3$/min). Here, $m_w$ describes the mass loss of the workpiece (g), ρw is the density of the workpiece (0.00896 g/$mm^3$), and t is the machining time (min), as shown in Equation (1). The weights of the workpieces and electrodes before and after machining were measured using a Shimadzu weight balance instrument. It was assumed that the weight changes of the workpiece and electrode were small. Therefore, it was better to eliminate the possibility of a large error by using more decimal places. The decimal point was set to 4 decimal points to ensure accuracy and standardization.

$$MRR = m_w / \rho_w t \quad (1)$$

EWR is calculated in $mm^3$/min and is based on the amount of electrode wear per machining period. Where $m_e$ is the electrode mass loss (g), i.e. is the electrode density (0.0088852 g/$mm^3$), and t is the machining period (min).

$$EWR = m_e / \rho_e t \quad (2)$$

$R_a$ was measured using Mitutoyo SJ-400 Surface Roughness Tester to measure the average $R_a$ of the machining surface between RBD palm oil and kerosene. Therefore, topography analysis was performed using Scanning Electron Microscope (SEM). Based on the scanned image, the surface finish of the workpiece can be evaluated. In order to achieve good results in any research project, a proper experimental design is required.

## 3. Results

The discussion and analysis focused on the influence of dielectric fluid on MRR, EWR, and surface roughness. The attention of this takes a look at changed into to assess the impact of peak current, $I_p$ and pulse on time, $t_{on}$ at the overall performance of finishing process of AISI D2 steel using RBD palm oil as the bio-dielectric fluid and kerosene as the conventional method relying on the chosen reactions. The efficacy of this approach was determined by examining the cutting time achieved in each trial for cutting 1.5mm depth of AISI D2 workpieces with copper electrodes. The experiment's outcome is described.

## 3.1 Material Removal Rate (MRR)

The MRR response was recorded under the influence of the control parameters shown in Fig. 4. MRR is defined as the weight of material removed per unit time and is an important parameter for process economics. A higher MRR is ideal for more cost-effective production. The results obtained help to improve the efficiency of EDM operations, and many factors must be considered. The most important factor in increasing the processing speed is the amount of material that can be removed in a given time. The comparative results of MRR were affected by $I_p$ and $t_{on}$ during machining time. It was observed that MRR increased with the increase of $I_p$ and $t_{on}$ for both dielectric fluids.

In Fig. 4, the comparative response shows the effect of peak current, $I_p$ and pulse duration, $t_{on}$ on MRR. It was observed that the MRR increased with the increase in peak current, $I_p$ and pulse duration, $t_{on}$ for both dielectric fluids; RBD palm oil and kerosene. The highest and lowest MRR for both dielectrics were $I_p$=5A, $t_{on}$=150µs and $I_p$=1A, $t_{on}$=50µs respectively. The results showed that the highest MRR for RBD palm oil was 33.4821$mm^3$/min while kerosene was 22.4888$mm^3$/min, while the lowest MRR for RBD palm oil was 0.3252$mm^3$/min while kerosene was 0.3125$mm^3$/min. At high $I_p$=5A, the amount of energy released during sparking increases proportionally, with higher temperatures melting and removing more materials from the workpiece [7]. Therefore, it was able to generate more sparks, which effect the increase in MRR. Meanwhile, the increase in pulse duration had resulted in a slight decrease in MRR at $I_p$=1A of RBD palm oil and all $I_p$ conditions when kerosene was used. This was caused by the electrode not being properly flushed away and debris from the machining phase remaining in it, resulting in bulging. When comparing the MRR, RBD palm oil performed better than kerosene. This was due to the density and viscosity of RBD palm oil which resulted in better entrapment and hence higher MRR. The viscosity and flash point of RBD palm oil were both higher than kerosene, resulting in increased sparking [10]. The improvement was about 48.88% with the same parameter setting, namely $I_p$=5A and $t_{on}$=150.

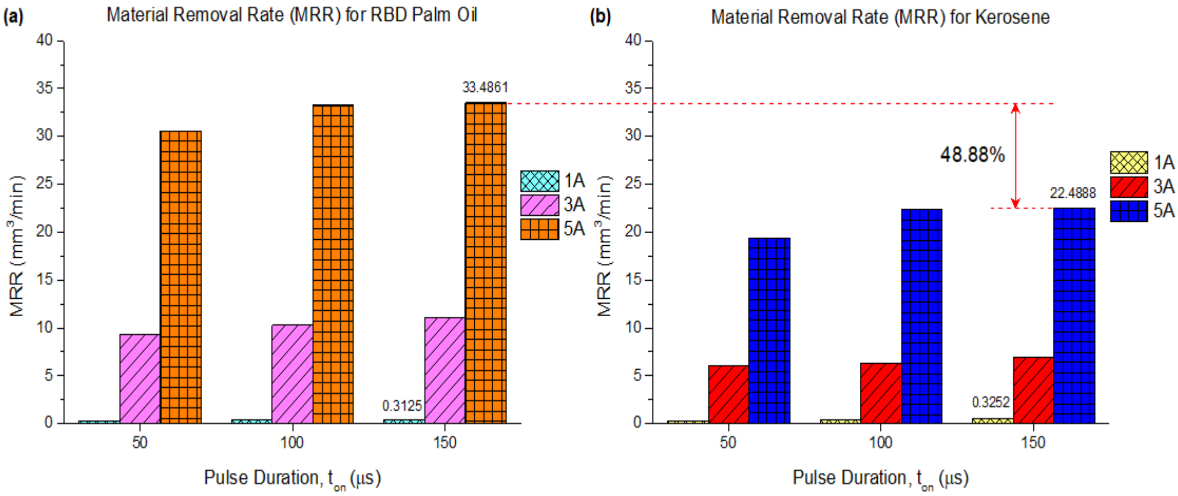



**Fig. 4 - Effect of MRR on; (a) RBD palm oil; (b) kerosene**

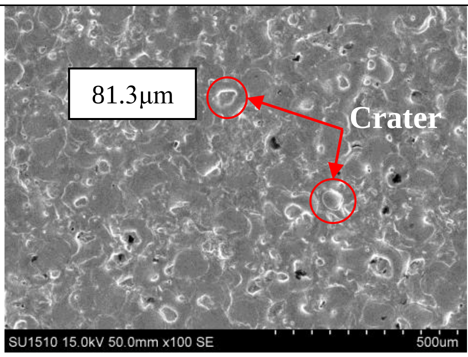
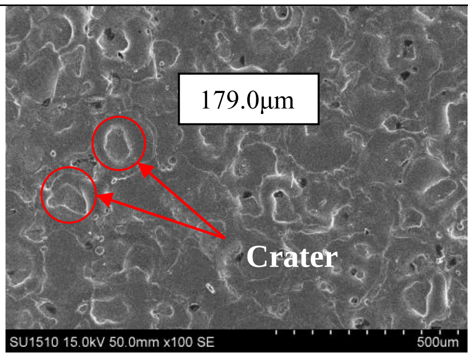
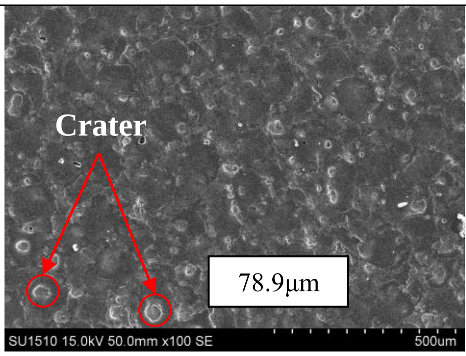
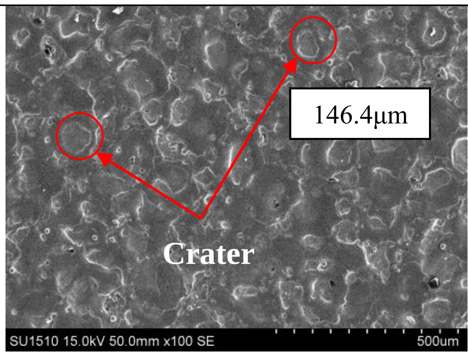
| Dielectric | Low MRR | High MRR |
|---|---|---|
| RBD Palm Oil |  a-1)MRR=0.3252mm³/min; $I_p$=1A; $t_{on}$=50µs |  a-2) MRR=33.4821mm³/min; $I_p$=5A; $t_{on}$=150µs |
| Kerosene |  b-1) MRR=0.3125mm³/min; $I_p$=1A; $t_{on}$=50µs |  b-2) MRR=22.4888mm³/min; $I_p$=5A; $t_{on}$=150µs |

**Fig. 5 - Comparison of surface topography for AISI D2 steel on; (a) RBD palm oil; (b) kerosene**

Furthermore, Fig. 5 shows the comparison of surface topography of RBD palm oil and kerosene. The high peak current, $I_p$ improved the MRR but affect the surface topography after machining. During the EDM process, when the setting parameter of high peak current in every spark had caused the material to melt and evaporate, and then leaving a crater on the machined surfaces [11]. Fig. 5(a-1) shows that at lower MRR for RBD palm oil, $I_p$=1A and $t_{on}$=50µs, the conditions of craters are shallow and flatten, whereas at higher MRR, $I_p$=5A and $t_{on}$=150µs as indicated in Fig. 5(a-2), the large crater is formed. This was because during the EDM process with high peak current, since the melted material was not adequately washed away from the workpiece's surface, the discharge craters grew deeper and wider [7]. Fig. 5(b-1) shows the effect of kerosene on the surface topography, at lower MRR, $I_p$=1A and $t_{on}$=50µs, the surface looks better than RBD palm oil dielectric, and at high MRR, $I_p$=5A and $t_{on}$=150µs in Fig. 5(b-2), looks rough and bigger compared to the RBD palm oil at high MRR. This was because of the viscosity of the RBD palm oil which helped in gaining higher sparking during the machining. The higher sparking in high peak current affected the results in lowering the breakdown strength of the dielectric fluid which had caused an early explosion in the gap [10].

## 3.2 Electrode Wear Rate (EWR)

The spark produced in the EDM process created a high-speed electron strike on the surface of the softer electrode, resulting in electrode surface erosion. The geometry and dimension of the electrode, as well as the formed cavity were changed by this erosion. As a result, a low EWR is desirable to achieve better dimension and scale. Additionally, due to this corrosion, the electrode required regular dressing, resulting in an increased electrode material loss and, as a result, increased the electrode cost. Fig. 6 shows the comparison of the EWR for RBD palm oil and kerosene as dielectric fluid under the influence of peak current, $I_P$ and pulse duration, $t_{on}$. The result shows that the EWR increases with the increases of peak current from 1A to 5A but decreases when the pulse duration increased from 50µs. to 150µs. This is because a high discharge current produces high spark energy, which causes more material to be removed from the workpiece and tool electrode, thus increasing the EWR [12].

The highest and the lowest EWR for RBD palm oil and kerosene were located at the same condition. A similar trend of EWR was shown for both dielectric, however RBD Palm oil produces higher EWR compared to the kerosene which was located at $I_P$=5A and $t_{on}$=50µs, the value was 2.5149mm$^3$/min while for the kerosene was 0.3304mm$^3$/min. The lowest EWR was located at $I_P$=1A and $t_{on}$=50µs with the value is 0.0010mm$^3$/min while for the kerosene, it was 0.0002mm$^3$/min. From the result, the higher EWR for RBD palm oil was due to the higher oxygen content in the RBD palm oil and it was a better conductive discharge channel which had resulted in the highest EWR. Therefore, it was because of the increase of peak current, the spark energy had increased resulting in the number for electron effect on the surface of the electrode [30]. Kerosene generated lower EWR than the RBD palm oil due to the protective effect of the deposited carbon layer on the copper electrode and the low content of carbon atoms in kerosene where kerosene tended to form more decomposed and deposited carbon atom on the electrode surface compared to the RBD palm oil [31].

In addition, an analysis of the copper electrode surface was performed by using SEM as indicated in Fig.7. The black layer and deposited metal from the workpiece were also revealed deposited on the electrode surface. The figure shows the surface morphology of the copper electrode after the lowest and highest EWR using RBD palm oil and kerosene. It was observed that the distribution of deposited material was wider and more at the low EWR condition than at the high EWR for both dielectrics. The shape of the deposited material formed on the electrode surface also looked smaller when the lowest EWR was determined. On the other hand, at the highest EWR, it was observed that a wider shape of deposited material formed on the copper electrode surface, which was due to the higher peak current used, which resulted in more material being deposited at a lower peak current.

## 3.3 Surface Roughness ($R_a$)

The quality of the machined surface of the EDM process can be analysed by surface roughness, $R_a$. In this study, an attempt was made to investigate the relationship between $I_p$ and $t_{on}$. Lower $R_a$ was required for good accuracy, low wear and long life. Fig. 8 shows similar trends of $R_a$ for both dielectric fluid; (a) RBD palm oil, (b) kerosene under the influence of control parameters. Based on Fig. 8(a-b), $R_a$ increases proportionally with $I_P$ from 1A to 5A. Due to the high density of the plasma channel and the higher breakdown voltage, the higher spark hits on the surface with greater intensity as the peak current increases to dissolves the substances [9-10, 30]. The higher impact forces affected the formation with wider and deeper craters generating coarse surfaces [7-9]. Furthermore, a longer pulse on time produced more sparks, which prolonged the melting and vaporization of the material resulted in a larger crater [13].

According to the results, the increase of $t_{on}$ is directly proportional to the increase of $R_a$ for 1A and 3A while it fluctuates for 5A. The lowest value of $R_a$ for RBD palm oil and kerosene is at $I_P$=1A and

$t_{on}$=150μs with 2.15μm and 2.11μm respectively, while the highest value of $R_a$ is at $I_P$=5A and $t_{on}$=150μs with 9.54 μm and 7.66μm respectively. This shows that the pulse duration certainly affects the surface roughness since for each $I_P$ the highest value of $R_a$ is at 150μs. This phenomenon of increase in surface roughness is due to the higher temperature at the spark point, which increases the duration of melting and evaporation of the material [28]. In Comparison, kerosene has a lower $R_a$ compared to RBD palm oil.

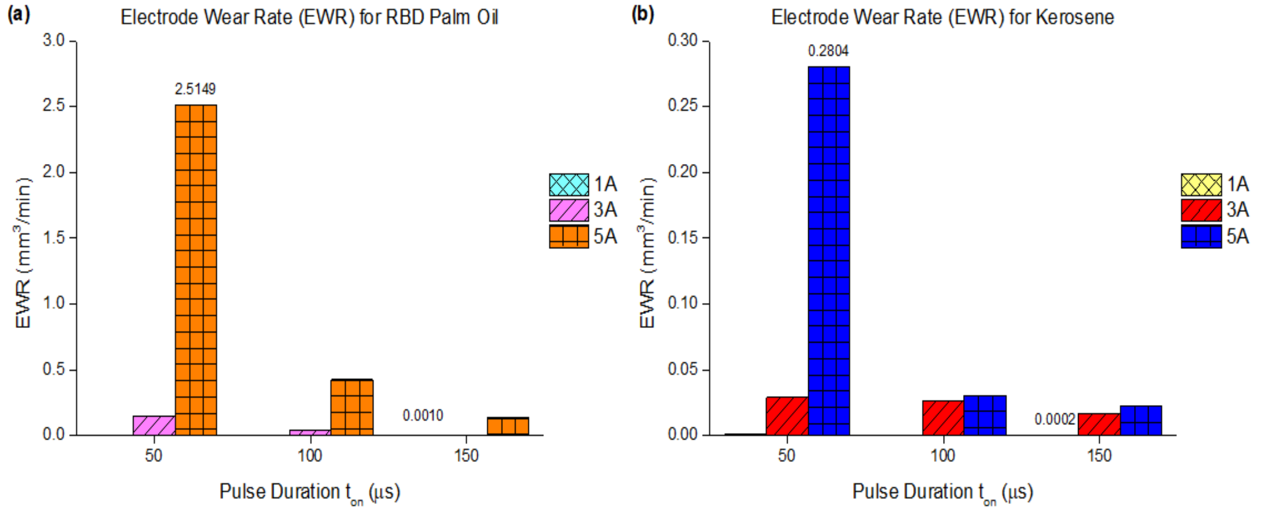



**Fig. 6 - Effect of EWR on; (a) RBD palm oil; (b) kerosene**

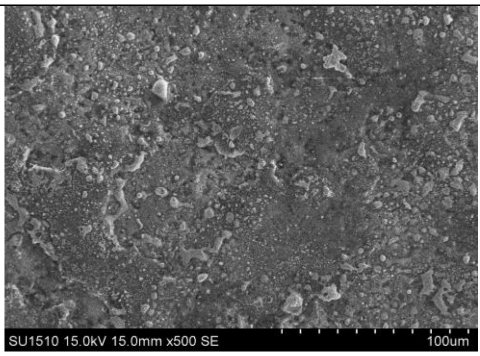
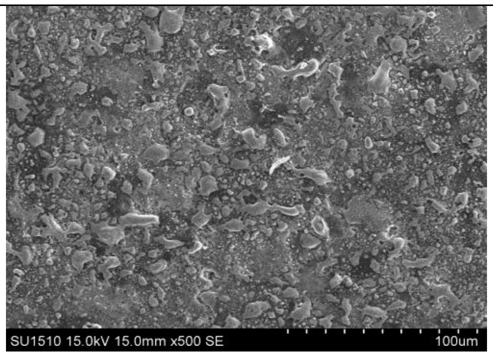
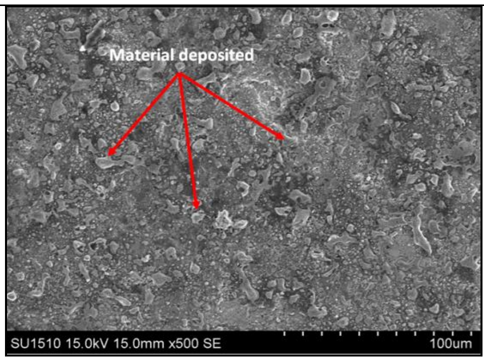
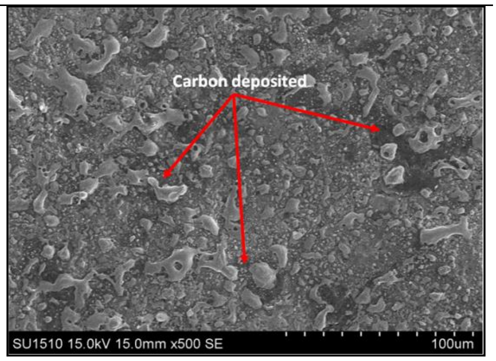
| Dielectric | Low EWR | High EWR |
|---|---|---|
| RBD Palm Oil |   a-1) EWR=0.0010mm³/min, $I_p$=5A; $t_{on}$=150μs |   a-2) EWR=2.5149mm³/min; $I_p$=5A; $t_{on}$=550μs |
| Kerosene |   b-1) EWR=0.0002mm³/min, $I_p$=5A; $t_{on}$=150μs |   b-2) EWR=0.3304mm³/min, $I_p$=5A; $t_{on}$=50μs |

**Fig. 7 - Comparison of surface morphology for copper on; (a) RBD palm oil; (b) kerosene**

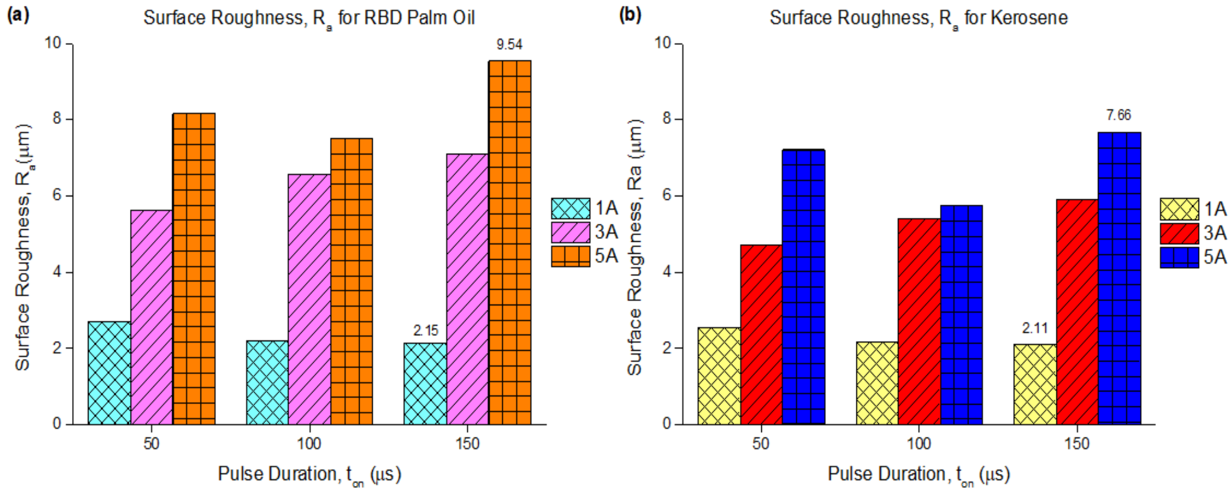



**Fig. 8 - Effect of $R_a$ on; (a) RBD palm oil; (b) kerosene**

## 4. Conclusion

As a result of the successful completion of this analysis, all of the objectives for improving the performance of RBD palm oil as a dielectric fluid for EDM have been met. The objective of this project was to investigate RBD palm oil as dielectric fluid on material removal rate (MRR), electrode wear rate (EWR) and surface roughness ($R_a$) of AISI D2 steel during EDM finishing operation and compare the result with the conventional hydrocarbon dielectric fluid, kerosene. The following inference can be drawn from the analysis:

1) Peak current, $I_p$ and pulse on-time, $t_{on}$ are the most important factors contributing to higher MRR. The MRR increased as $I_p$ and $t_{on}$ increased. The result shows that the highest MRR for RBD palm oil is 33.4821 $mm^3$/min while kerosene is 22.4888 $mm^3$/min at $I_p$=5A and $t_{on}$=150µs. The improvement when RBD palm oil is used as dielectric fluid is 48.88% compared to kerosene.
2) The EWR increased with the increase of $I_p$, but inversely proportional to the $t_{on}$. The lowest EWR for both dielectric fluids located at $I_P$=1A and $t_{on}$=150µs which was 0.0010 $mm^3$/min for RBD palm oil while kerosene was 0.0002 $mm^3$/min.
3) The results show that adding RBD palm oil, which acts as a bio dielectric fluid, increases machining speed. It was discovered that when RBD palm oil was used instead of kerosene, the machining process took less time.
4) The highest $I_p$ is not recommended for $R_a$ because lower $R_a$ is required for better machining performance of the surface finish. According to the results, the $R_a$ is increased with the increase of the $I_p$. The lowest $R_a$ for RBD palm oil was 2.15µm while kerosene was 2.11µm located at $I_P$=1A and $t_{on}$=150µs. Therefore, the highest $R_a$ for RBD palm oil was 9.54µm while kerosene was 7.66µm located at $I_P$=5A and $t_{on}$=150µs.
5) The performance of RBD palm oil and kerosene as dielectric fluids was compared and the results show that RBD palm oil has great potential for use as a dielectric fluid under certain parameters. In a machinability analysis, RBD palm oil outperformed kerosene by exhibiting higher MRR, lower EWR and higher Ra. MRR, EWR, and surface roughness during EDM are influenced by various parameters such as peak current and pulse length.

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