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Sustainable Electrical Discharge Machining (EDM) Of Inconel 718 When Using RBD Palm Oil Based Dielectric Fluid

Said Ahmad[1*], Vellmurugan Mohan[2], Mohd Amri Lajis[3], Ho Fu Haw[2], Lee Woon Kiow[1], Norfazillah Talib[1], Reazul Haq Abdul Haq[1]

[1]Precision Machining Research Center (PREMACH), Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja 86400, Johor, MALAYSIA

[2]Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja 86400, Johor, MALAYSIA

[3]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (Pagoh Campus), Panchor 84600, Johor, MALAYSIA

*Corresponding Author

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Abstract: Electrical Discharge Machining (EDM) is the process of removing metal from a workpiece by discharging a sequence of discrete sparks from a high current and voltage electrical arc. Using a sustainable electrical discharge machining (EDM) technique using vegetable based or conventional dielectric fluid, the objective of this work was to evaluate the material removal rate (MRR), and surface roughness (Ra) of Inconel 718 and electrode wear rate (EWR) of copper (Cu) electrode, respectively. To attain the same viscosity concentration as kerosene fluids, refined, bleached, and deodorized (RBD) palm oil was trans-esterified. In this study, the influence of peak current from 6A to 12A and Pulse duration from 50µs to 150µs on the machinability performance were investigated. Scanning Electron Microscope (SEM) was used to examine the surface topography of Inconel 718. The outcome demonstrates that for RBD palm oil, modified RBD, and kerosene dielectric fluid, the highest MRR, EWR and Ra were produced at the highest I_p=12A and t_{on}=150s. When compared to kerosene at the same parameter settings, MRR for RBD palm oil and modified RBD as a dielectric fluid improved by about 49% and decreased by almost 9%. The lowest EWR and Ra, however, are produced by machining with RBD palm oil, modified RBD, and kerosene at I_p=6A and t_{on}=150s. When compared to kerosene and modified RBD, the value of EWR and Ra for RBD palm is marginally greater. Overall, within selected parameters, RBD palm oil yields the greatest outcomes when EDM machining of Inconel 718.

Keywords: EDM machining, RBD palm oil, Inconel 718, material removal rate, electrode wear rate, surface roughness, surface topography

1. Introduction

A non-traditional machining method called electrical discharge machining (EDM) uses heat energy to remove material from a work piece. The removal process employing EDM does not include the use of mechanical force. Because of this, this machining strategy is known as non-traditional [1]. Due to its applicability for hard materials like Inconel 718 or for exceedingly complicated geometries that are difficult to create using milling, EDM is extensively employed in the tool and mold industry. Inconel 718 is often used within the aviation and aerospace industries due to its

*Corresponding author: said@uthm.edu.my

physical ability encountered in extreme environments. It is exceedingly difficult to machine this material using traditional methods at a high rate of speed and with acceptable surface quality. Therefore, the optimum alternative for machining Inconel 718 is a non-traditional machining technique like EDM.

EDM machining is a technique involves a series of discharge sparking occurring between electrodes and workpiece that are separated from one another by a dielectric fluid. Due to its availability, kerosene was the dielectric fluid that was most frequently employed in die-sink EDM. Kerosene was one of the dielectric fluid's contaminating potentials, since it was used repeatedly in EDM, carcinogenesis was caused [2]. In order to reduce environmental impact while retaining machining capabilities, much research has been done. Palm oil has a higher sustainability influence index, as well as being less expensive, more widely available, and simpler to use. It has the added benefits of being non-toxic and safe for both the environment and human health in addition to its versatility as a recyclable material [3]. As a result, kerosene was substituted with RBD palm oil to cut expenses and create an eco-friendly machining process. It is essential to employ a proper dielectric fluid during EDM operations in order to enhance machining performance.

In the EDM process, bio-based fluids may eventually take the place of hydrocarbon, water, and gas-based dielectrics [4]. The vegetable oil-based dielectric properties are comparable to those of synthetic and hydrocarbon oils. Based on how they affect sustainability, vegetable oils are divided into three categories: edible, non-edible, and used oil. Old vegetable oils can potentially be cleaned up and used again, which would be extremely beneficial for sustainability. Valaki and Rathod [5] has studied the feasibility of used vegetable oil as a dielectric fluid for environmentally friendly EDM. In order to assess the practical viability of used vegetable oil as a potential substitute dielectric fluid, the analysis compared the response patterns of used vegetable oil with hydrocarbon oil, kerosene. The findings suggest that synthetic, hydrocarbon, and water-based dielectric fluids for EDM can be replaced with a water-based, waste vegetable oil-based bio-dielectric fluid. The use of bio fluids provides a safer, cleaner, and greener option for dielectric to boost the sustainability of the EDM process by enhancing environmental friendliness, operational safety, and personnel health issues of the process. Supawi et al. [6] investigation of the effectiveness of RBD palm oil dielectric fluid in AISI D2 steel EDM machining. Their research revealed that RBD palm oil performed better than kerosene due to its greater MRR, lower EWR, and higher Ra. The use of RBD palm oil as a dielectric fluid in the EDM process, according to additional research by Supawi et al. [7], would further improve the performance of machining when used to examine the surface integrity of AISI D2 steel. In comparison to kerosene, RBD palm oil was able to obtain the thinnest recast layer and become a better solution for EDM machining of AISI D2 steel.

The machinability performance of Inconel alloy is investigated in this study using three different types of dielectric fluid, including RBD palm oil, modified RBD palm oil, and kerosene. These fluids are used to measure the MRR, EWR, and Ra. Using a scanning electron microscope (SEM), the surface topography of Inconel 718 and the surface morphology of copper electrodes were examined.

2. Experiment Methods

Figure 1 shows a schematic of the experimental setup, and the dielectric fluid’s properties used in this study were shown in Table 1.

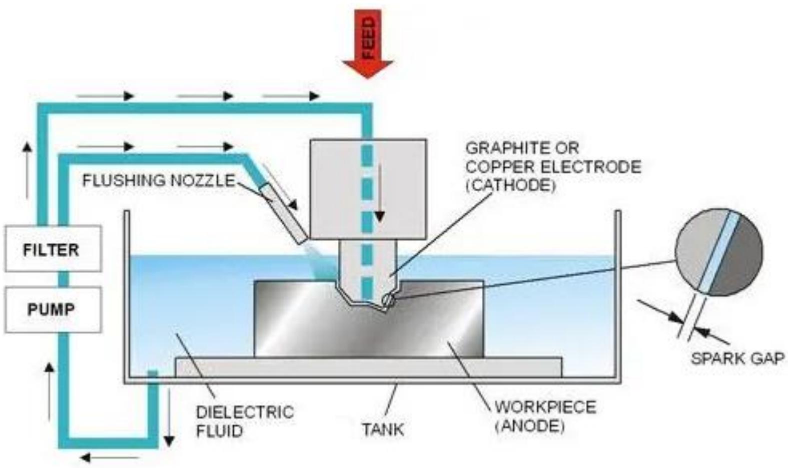


Fig. 1 – Schematic diagram of the machine setup

Table 1 – Properties of dielectric fluid

Properties	Kerosene	RBD Palm Oil	Modified RBD Palm Oil
Density (kg/cm^3)	730	870	879
Specific Heat (KJ/KgK)	2.01	1.872	1.98
Viscosity at (40°C) (cST)	5.42	40.27	5.1
Thermal Conductivity (W/mK)	0.13	0.163	0.15
Flash Point (°C)	65	154	174

2.1 Experiment Set-Up and Details

The experiment was performed using a CNC Sodick EDM die sink AQ55L (3 Axis Linear) machine. A custom-made external working tank was used to carry out the experiment involving RBD palm oil. The workpiece of this project is Inconel 718 with dimensions 40mm(L) x 30mm(W) x 10mm(H). Filing was also used to eliminate burrs and sharp corners. This material has a high compressive strength and outstanding wear resistance. Then, copper electrode with dimension of 10mm Ø x 30mm(L) was selected as a cutting tool. Copper electrodes were often used in EDM operations because of their high electrical and thermal conductivity. Both palm oil and kerosene were used in 9 different trials, for a total of 27 runs per set. The study's experimental setup and parameters setting are detailed in Table 2. Figure 2 shows the experimental condition during machining operation.

Table 2 – Experimental condition and parameters

Parameter	Details
Workpiece material	Inconel 718
Electrode	Copper (Cu)
Dielectric fluid	RBD palm oil, modified RBD palm oil, kerosene
Peak Current, I_P (A)	6, 9, 12
Pulse On/Duration, t_{on} (µs)	50, 100, 150
Pulse Off/interval, t_{off} (µs)	50
Voltage, V	120
Electrode Polarity	Positive (+ve)
Depth of cut, (mm)	1

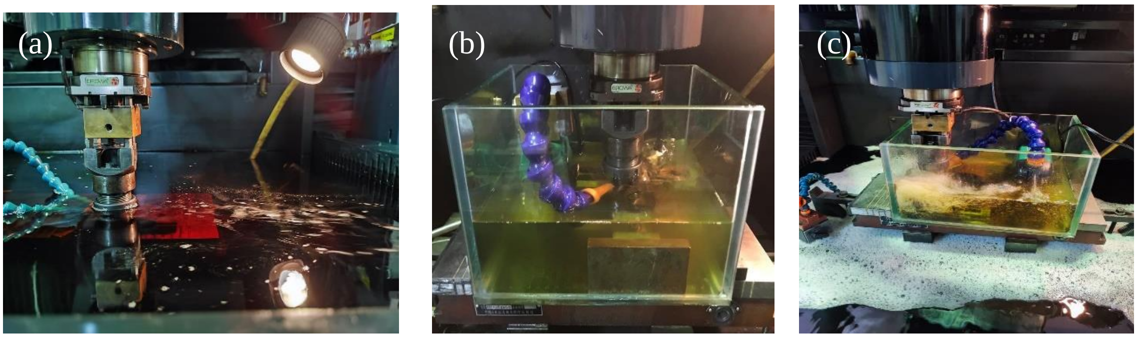


Fig. 2 – Dielectric fluid; (a)kerosene; (b)RBD palm oil; (c)modified RBD palm oil

2.2 Responses

Although there are other methods of calculating MRR, the values used in this study are based on the volumes of work piece losses per time period of machining. The measurement is in millimeters per minute. After each machining procedure was finished, the part was dried out completely before its weight was measured to rule out the presence of any debris or dielectric. Here is the formula for determining the MRR:

$$\mathrm{MRR} = m_W/\rho_W t \quad (1)$$

Where;

mW is mass loss of workpiece after machining.

ρ_w is the workpiece's density.
t is time of machining.

The amount of electrode wear that occurs during a single machining process is used to determine the electrode wear rate. In this investigation, mm^3/min was utilized as the measurement unit. The following equation was used to draw a conclusion on the value of EWR:

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

Where;
m_e is mass loss of electrode after machining.
ρ_e is the electrode's density.
t is time of machining.

Surface roughness is one of the most important machining process performance metrics in terms of product quality. Surface roughness, tool wear, and material removal rate are the EDM performance metrics that are most frequently assessed. Surface roughness is a technological necessity for mechanical items in most sectors. The surface roughness tester needs to be calibrated before testing to produce an accurate result.

3. Results and Discussions

The effects of varying cutting parameters on MRR, EWR, and surface roughness were evaluated using RBD palm oil based and kerosene as dielectric fluids. The results were analyzed and discussed below. With a focus on the impacts of peak current (I_p) and pulse on time (t_{on}), this study compared the effectiveness of the cutting process of Inconel 718 when utilizing RBD palm oil based dielectric fluid and kerosene as a benchmark value.

3.1 Material Removal Rate (MRR)

A material's machinability, particularly in EDM machining, is a measure of how easy or difficult it is to mill using an electrode to obtain an appropriate surface quality. The experiments was to look into the MRR of Inconel alloys with regard to peak currents from 6A to 12A, and pulse duration from 50µs to 150µs, respectively,. One of the most important things to consider when using electrical discharge machining (EDM) is MRR, or the quantity of material removed per unit of time (mm^3/min).

Fig 3 and Fig 4 show a comparison of MRR between 3 different types of dielectric fluid. All the graphs on those figures show that the MRR increased dramatically as the peak current and pulse duration increased. In EDM, electrical power generates a thermally charged electrical spark to aid in the removal of material from the workpiece. This is because by using a high peak current and longer pulse duration creates a high temperature around the sparking point, causing the material to melt and evaporate quickly [8]. From the experiment as indicated in Fig 3, it was discovered that the MRR when using the RBD palm oil is higher than kerosene. Because of its density and viscosity, RBD palm oil offers better confinement, resulting in a higher MRR score. The MRR percentage difference was found to be roughly around 47% when comparing RBD palm oil and kerosene using identical settings (I_p=12A of and t_{on}=150µs).

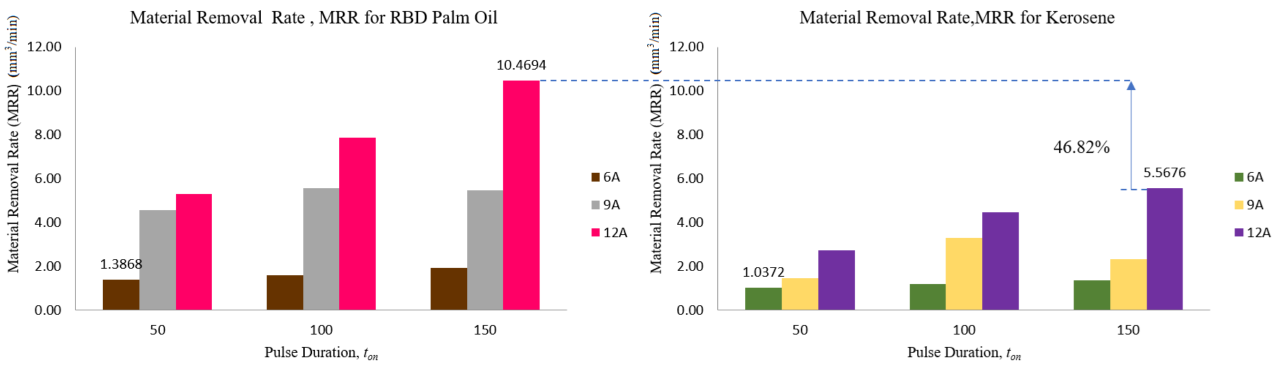


Fig. 3 – MRR of RBD Palm Oil and Kerosene

The highest MRR of RBD palm oil is 10.4694 mm^3/min, while the highest MRR value for kerosene is 5.5676 mm^3/min. Both results were obtained at I_p and t_{on} of 12A and 150µs, respectively. Due to the palm oil's high density and viscosity, which both helped to increase confinement and hence lead to a greater MRR, RBD palm oil was able to yield higher MRR. The amount of sparking increased because RBD palm oil had a higher flash point and viscosity than kerosene [3]. As shown in Fig 4. kerosene obtained slightly higher MRR than modified RBD palm oil with the difference approximately 9%. The alteration of properties of RBD palm oil through esterification process to reach the same viscosity as kerosene, may affect the performance of modified RBD palm oil. This result proved that the viscosity of dielectric is one of the factors affecting the machinability in EDM [5][9]. The MRR of kerosene reached a highest value of 5.5676 mm^3/min, and for modified RBD palm oil the highest MRR was 5.0728 mm3/min obtained at I_p=12A and t_{on}=150μs, respectively.

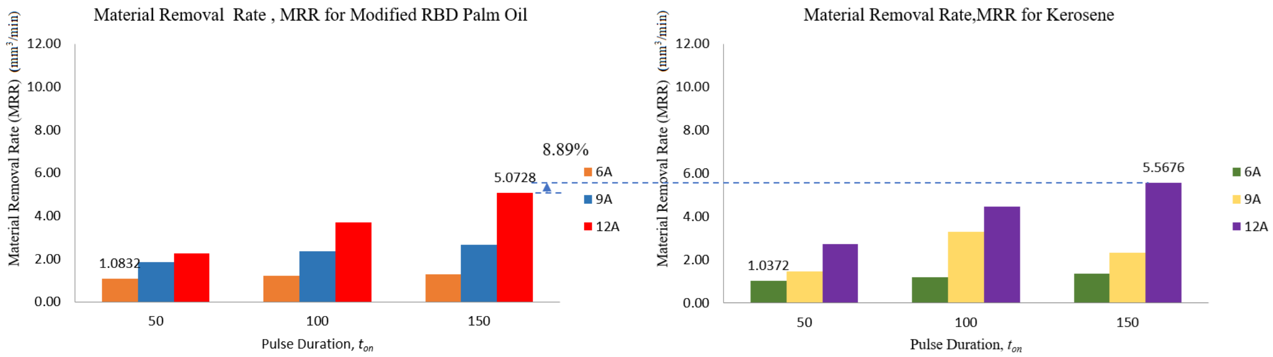


Fig. 4 – MRR of Modified RBD Palm Oil and Kerosene

3.2 Electrode Wear Rate (EWR)

Fig. 5 displays the EWR comparison results of RBD palm oil and kerosene. At the identical machining conditions of I_p and t_{on}, RBD palm oil produced a higher EWR than kerosene. At I_p=12A and t_{on}= 150μs, RBD palm oil's EWR increases by almost 34% in comparison to kerosene. It is crucial to keep in mind that elements like peak current and pulse duration have a big impact on the EWR. As I_p and t_{on} increases will result in higher MRR and higher EWR [10]. Kerosene produced a lower EWR than RBD palm oil, which may be related to the protective layer effect of the carbon layer that has been placed on the copper electrode [5].

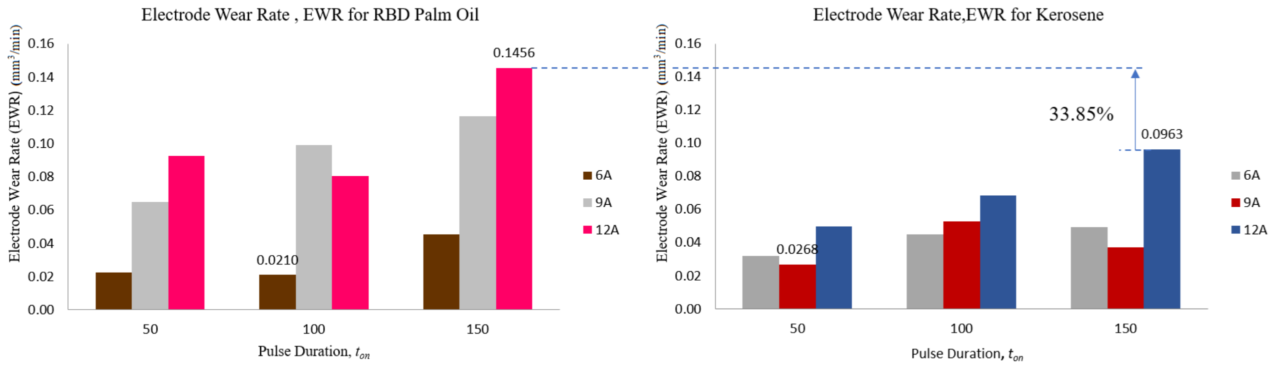


Fig. 5 – Effect of EWR on RBD Palm Oil and Kerosene

Fig. 6 displays the EWR comparison results for I_p applied at various t_{on} for modified RBD and kerosene. Modified RBD palm oil produced a lower EWR than kerosene. The increase of EWR for kerosene at I_p=12A and t_{on}=150μs is around 23% when compared to modified RBD palm oil. For modified RBD palm oil, the lowest EWR value 0.0257mm^3/min obtained I_p=6A and t_{on}=150μs pulse duration, and the highest EWR value 0.074 mm^3/min was achieved at I_p=12A. Then, the lowest EWR value for kerosene was found to be 0.0268 mm^3/min at I_p=9A and t_{on}= 50μs, and the highest EWR value was 0.0963 mm^3/min at I_p=12A t_{on}=150μs. Kerosene produced more EWR than modified RBD palm oil.

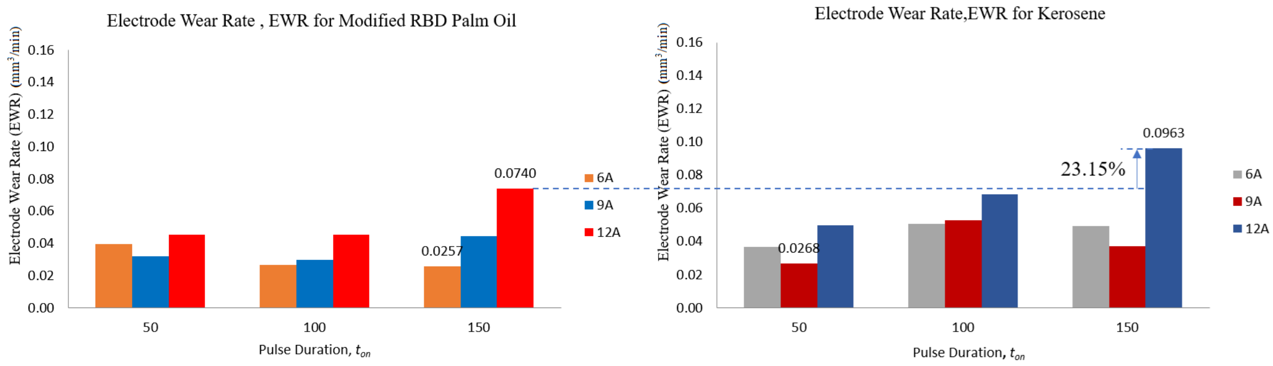


Fig. 6 – Effect of EWR on Modified RBD Palm Oil and Kerosene

3.3 Surface Roughness (Ra)

Fig 7 and Fig 8 shows a similar trend of graph plotted of surface roughness for all types of dielectric fluid. The surface roughness increases as the I_p and t_{on} increase. The surface of workpiece becomes rougher due to higher energy penetration as deeper and wider craters begin to form as current energy increases [9]. The increasing of Ra for RBD palm oil when compare with kerosene is about 4.7% at I_p=12A and t_{on}=150µs. Then, at the highest parameters setting, the increasing of Ra for modified RBD palm oil to kerosene is about 4.3%.

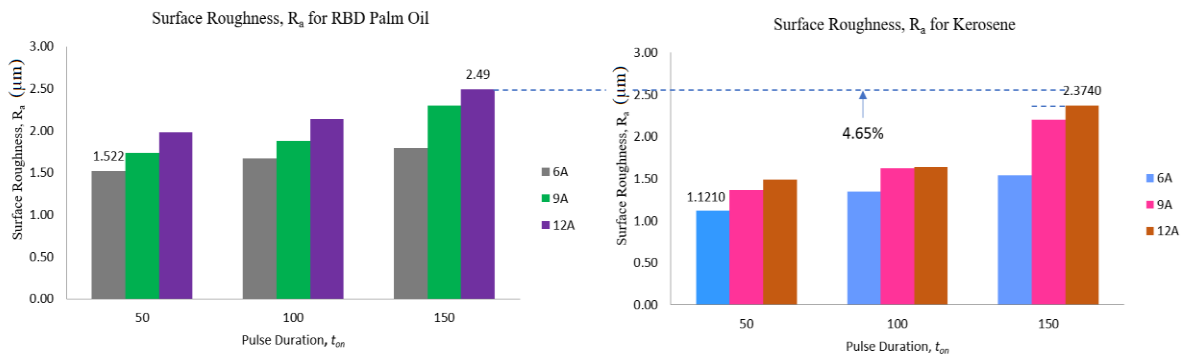


Fig. 7 – Effect of EWR on RBD Palm Oil and Kerosene

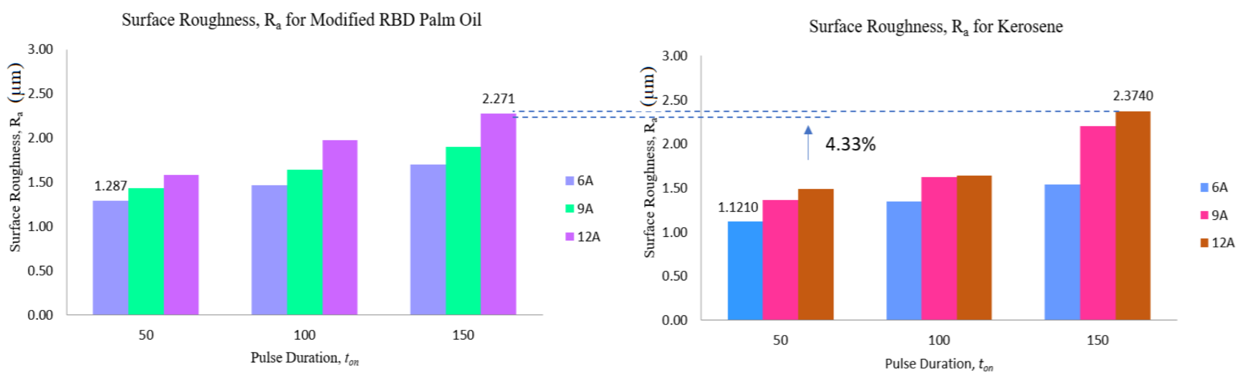


Fig. 8 – Effect of EWR on Modified RBD Palm Oil and Kerosene

Fig 9 illustrates the surface topography of Inconel 718 on the machined surface using a variety of dielectric fluids in compliance with low and high Ra values. The machining surface topography is directly correlated with the surface roughness and wholly dependent on the energy being discharged onto it. At low MRR and Ra, crater diameters are smaller and at high MRR and Ra, the craters look wider and bigger. This is owing to the fact that increased sparking will occur during the machining process with a high peak current produced bigger craters [11]. Furthermore, a longer pulse duration produced more sparks, which prolonged the material melting and evaporation, resulting in a larger crater [12]. This result also shows that, when high MRR was obtained, it will lead to high surface roughness [13]. Fig 9 also indicates that RBD palm oil recorded the biggest crater size of 154 µm at the highest parameters setting.

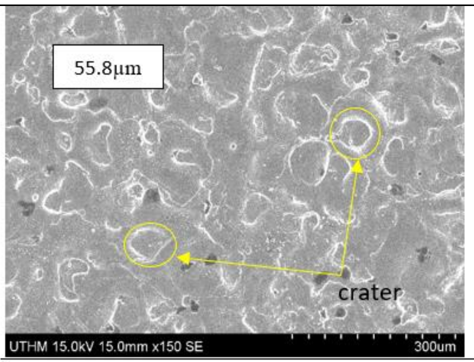
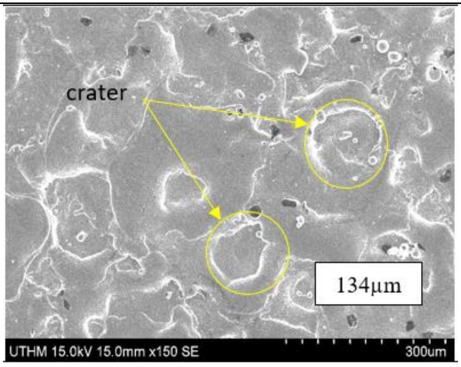
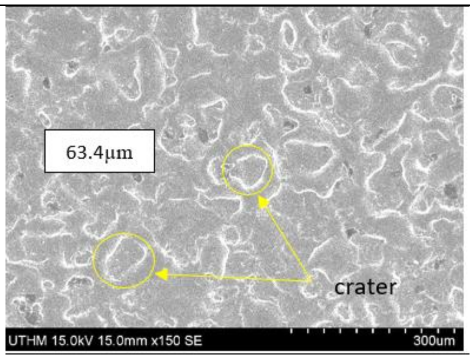
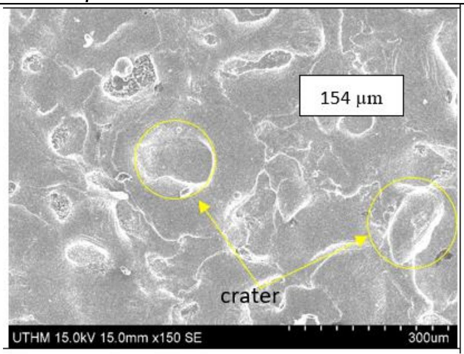
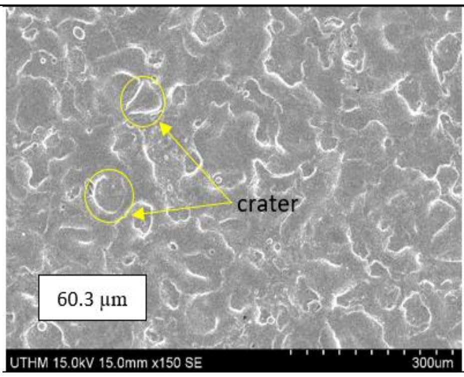
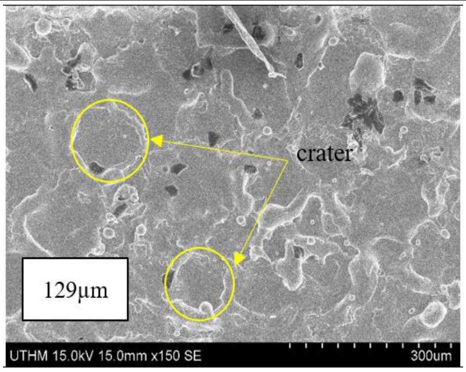
Dielectric	Low MRR	High MRR
a) Kerosene	 a-1) MRR= 1.0372 mm3/min; I_p=6A; t_{on}=50µs	 a-2) MRR= 5.5676mm3/min; I_p=12A; t_{on}=150µs
b) RBD Palm Oil	 b-1) MRR= 1.3868 mm3/min; I_p=6A; t_{on}=50µs	 b-2) MRR= 10.4694 mm3/min; I_p=12A; t_{on}=150µs
c) Modified RBD Palm Oil	 c-1) MRR= 1.0832 mm3/min, I_p=6A, t_{on}=50µs	 c-2) MRR= 5.0728 mm3/min, I_p=12A, t_{on}=150µs

Fig. 9 – Comparison of surface topography of Inconel 718 on; (a) kerosene; (b) RBD palm oil; (c) modified RBD palm oil

4. Conclusion

The results demonstrate that using RBD palm oil instead of a typical dielectric fluid increases machining efficiency. Additionally, it was shown that using RBD palm oil reduces the amount of time needed for machining when compared to using kerosene or modified RBD palm oil. Peak current and pulse duration (MRR) together have the greatest impact on the rate of material removal. In general, the effect of peak current and pulse duration is directly proportional to the MRR. The highest value of MRR was obtained when using RBD palm oil as dielectric fluid.

Higher peak current and pulse duration also contributed to high EWR. The lowest EWR was achieved when applied modified RBD palm oil dielectric fluid while the highest EWR is obtained when using RBD palm oil. Increasing the peak current and pulse duration also increases the surface roughness. For all types of dielectric fluid applied, the results show that the surface roughness was deteriorated with the increment of peak current and pulse duration. RBD palm oil produced the maximum surface roughness with the widest crater size on the surface topography, followed by kerosene and modified RBD palm oil.

As conclusion, the performance of RBD palm oil when EDM machining of Inconel 718 is considered good in terms of machinability when comparing with kerosene and modified RBD palm oil within specific parameters. RBD palm oil produced the highest MRR, but it may sacrifice EWR. Compared to the other two dielectric fluids, RBD Palm oil may have yielded somewhat higher Ra, although the percentage of difference is minimal.

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