Research Progress in Mechanical and Manufacturing Engineering Vol. 2 No. 2 (2021) 775-787
© Universiti Tun Hussein Onn Malaysia Publisher's Office

RPMME

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Machinability Performance of Titanium Alloy When Using Modified RBD Palm Oil Dielectric Fluid in Electrical Discharge Machining Process

Shazwan Ishak[1], **Said Ahmad**[1]*

[1,]Additive Manufacturing Research Group,
Faculty of Mechanical and Manufacturing Engineering,
Universiti of Tun Hussein Onn Malaysia,Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rpmme.2021.02.02.084
Received 30 July 2021; Accepted 25 Nov. 2021; Available online 25 December 2021

Abstract: Electric discharge machining (EDM) is a non-traditional machining because it does not use hard tools or abrasive materials, otherwise it uses EDM to cut materials that are difficult to machine. Titanium has a low Young's modulus and high hardness value, making it difficult to process. It is one of the materials used in EDM. In this project, based on the selection of appropriate parameters, the machinability performance of titanium alloy and copper electrode when modified RBD palm oil dielectric fluid is used in EDM is analyzed. Peak current (I_p), voltage (V), pulse on time (t_{on}) and pulse off time ($t_o$ff) are the parameters selected in this project. In this experiment, a copper electrode with a diameter of 10 mm is used to cut a titanium alloy. Palm oil properties was modified through transesterification process to imitate properties of conventional hydrocarbon dielectric fluid which is kerosene. The modified RBD palm oil is then being used in the EDM process to machine titanium alloy and the machinability were observed. From the reviewed, the data collected show that MRR of titanium alloy when using modified vegetable oil is higher than when using kerosene. EWR also show that there is decreasing in value when using modified vegetable oil, while for surface roughness, kerosene displayed higher surface roughness in the surface of working piece. To sum it up, by utilizing modified vegetable oil in the electrical discharge machining process as a dielectric fluid, the machining process will become sustainable and environmental friendly.

Keywords: Electrical Discharge Machining, Properties of Modified RBD Palm Oil, Machinability

1. Introduction

In the manufacturing industry, electrical discharge machining (EDM) has been commonly used by many manufacturing companies because it carries out the process of removing material. Other processing that can be classified as traditional processing, such as milling, turning, and drilling, has

Corresponding author: said@uthm.edu.my

limitations such as the inability to cut difficult-to-process materials. An example of such materials is titanium, stainless steel, hardened steel and superalloys, which are produced to meet the requirements of extreme applications in industry. As a non-traditional machining, EDM has the special ability to transform a variety of material types into complex geometric shapes, providing fine surface treatment and excellent geometric accuracy. During the removal process, EDM does not require mechanical force because heat energy is used to remove material from the workpiece.

In the electrical discharge machining process, its working principle is based on the thermoelectric energy generated by the current flowing between the workpiece and the electrode immersed in the dielectric fluid. Dielectric fluid is used in EDM to wash the debris particles in the machining gap and as a coolant to extract heat from the workpiece and the electrode. The dielectric fluid will also control the discharge of the current and ensure that material is removed during EDM operation. Generally, the workpiece and the electrode must be immersed in the dielectric fluid before the cutting process. However, the hydrocarbon-based dielectric fluid used in EDM generates harmful elements that affect the environment and the health and safety of operators. Therefore, other dielectric fluids, such as vegetable-based dielectric fluids, must be used instead of traditional dielectric fluids.

In order to solve the environmental problem, the researchers took several steps to adapt the EDM process to the green process to replace the traditional dielectric fluid. According to reports, vegetable oil can reduce environmental pollution, save energy, and is more economical. This means that using vegetable oil as a dielectric fluid will protect workers while reducing the negative impact on the environment. Some other factors that need to be emphasized in this research are performance indicators. Machining performance indicators such as material removal rate (MRR), surface roughness, electrode wear rate (EWR), and dimensional accuracy depend on the characteristics of the dielectric fluid. Therefore, vegetable oil must have dielectric properties, that is, electrochemical properties and electrophysical properties, in order to find the applicability of vegetable oil as a substitute for traditional dielectrics [1]. In addition, the development of vegetable-based dielectric fluid as a new dielectric fluid will change the EDM process to an environmentally friendly process and establish a sustainable EDM process.

2. Materials and Methods

The methodology of this project is discussed in order to meet the objectives of this project. The method and procedure will be explained in this section. Some of the methods and information from the literature review also will be mention in this section.

2.1 Materials

The titanium alloy grade 5 was utilised in this experiment (Ti-6Al-4V). It's also called alpha/beta titanium alloy. The ideal size of titanium flat plates for this experiment is (40 x 30 x 6) mm^3. The material is cut using a wire EDM machine to get the appropriate dimensions. The material was fitted to eliminate burrs and sharp corners.. The mechanical properties of Titanium Alloy used in this experiment are shown in Table 1.

Table 1: Mechanical Properties of Titanium Alloy (Ti-6Al-4V)

Properties	Value
Material	Titanium (Ti-6Al-4V)
Ultimate Tensile Strength (MPa)	832

Elastic Modulus (GPa)	114
Impact-toughness (J)	34
Melting Point (ºC)	560
Hardness (HV)	600
Yield Strength (MPa)	745

The electrode chosen are from copper due to its high conductivity and low cost. The mechanical properties of electrode material are show in Table 2.

Table 2: Mechanical Properties of Copper (cu)

Properties	Value
Melting Point (ºC)	1083
Boiling Point (ºC)	2562
Specific Heat (J/kg K)	385
Specific Gravity (g/cm^3)	8.94
Electric Resistivity (Ohm · $mm^2/\ m$)	0.00171
Density (g · cm^3)	8.960

2.2 Dielectrics

Refined Bleached Deodorized (RBD) palm oil and kerosene is chosen in this experiment as a dielectric fluid for machining titanium alloy (Ti-Al-6V) in EDM. The properties of RBD palm oil based dielectric fluid are shown in Table 3.

Table 3: Properties of RBD Palm Oil based Dielectric Fluid

Properties	Value
Density (Kg/m³)	730
Viscosity at (40ºC) (Cst)	5.42
Thermal Conductivity (W/mK)	0.13
Specific Heat (KJ/KgK)	2.01
Flash Point (ºC)	65

2.3 Parameter

There are several elements that may be examined in order to influence the EDM process. Based on the previous literature, four factors will be employed in this experiment to evaluate the machinability of the working piece: 1) pulse on time, 2) pulse off time, 3) peak current, and 4) voltage. The values for pulse off time and voltage remain constant throughout the experiment.

Table 4: Experimental condition in EDM machining of titanium alloy

Parameters	Levels
Peak Current, I_p (A)	6, 9, 12
Pulse On Time, t_{on} (µs)	50, 100, 150
Pulse Off Time, t_{off} (µs)	50
Voltage, V	120

2.4 Methods

2.4.1 Modified RBD Palm Oil

After being harvested from the palm tree, fresh fruit bunch (FFB) were undergoing two types of process (milling and refining) in order to be made as RBD palm oil. Next, a refined process is needed in order to develop the crude palm oil to be suitable for consumption or as a raw material that needed for manufacturing industries. Therefore, the refined process is started with crude palm oil is transferred into the physical method of degumming and bleaching. After generating a RBD palm oil. A transesterification process were carried out to modify the properties of the RBD palm oil. The step of transesterification process are shown below.

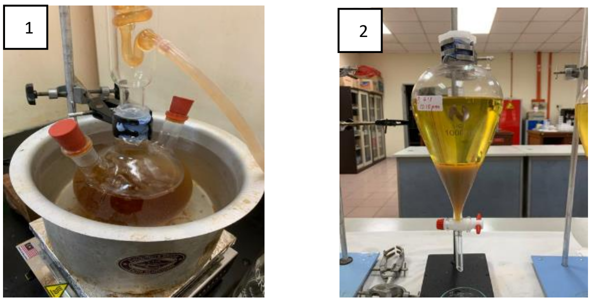

Figure 1: 1) Heating and stirring process. 2) Separating process

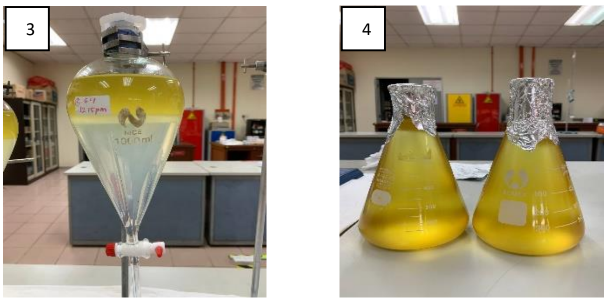

Figure 2: 3) Washing process. 4) Drying Process

2.4.2 Machinability Testing

The working piece and electrode were weighed before processing in EDM to measure the initial weight. After machining process, working piece and electrode were cleaned with acetone to avoid any other particles such as debris at the surface of the material. Working piece and electrode are weighed using digital weight balance to determine the weight after the EDM process. Substitute the weight before and after the cutting process to obtain the mass loss of electrode and working piece. Measurement of surface roughness (Ra) value was carried out using Mitutoyo SJ-400 Surface Roughness Tester. It will measures various types of profiles such as actual, measured, primary, roughness and waviness profiles. During testing, the surface roughness (Ra) measurements are carried out on the surface of the material using detector and repeated for three times with depth of cut 1 mm and the average values are taken and considered as surface roughness value. The formula in Eq. 1 and Eq. 2 were used to calculate the value of for MRR and EWR.

2.5 Equations

Material Removal Rate (MRR) of titanium alloy was determined using the following equation:

$$MRR\ (mm^3/min) = \frac{Mass\ loss\ of\ working\ piece\ (g)}{Density\ of\ working\ piece\ (g/mm^3)\ x\ Machining\ time\ (min)} \quad \text{Eq. 1}$$

Electrode Wear Rate (EWR) was determined using the following equation:

$$EWR\ (mm^3/min) = \frac{Mass\ loss\ of\ electrode\ (g)}{Density\ of\ electrode\ (g/mm^3)\ x\ Machining\ time\ (min)} \quad \text{Eq. 2}$$

3. Results and Discussion

The results and discussion in this section includes the properties of modified RBD palm oil and the machinability performance when using modified RBD palm oil and kerosene as dielectric fluid.

3.1 Properties of Modified RBD palm oil

Table 5: Properties of Modified RBD Palm Oil (6:1)

No	Properties	Unit	Range	Ratio		
				T1	T2	T3
1	Density	(g/cm^3)	0.86-0.90	0.8822	0.8732	0.8779
	Pycnometer, Wp	g		18.3112	18.4229	18.3223
	Weight, W_1	g		22.0539	21.8305	21.8405
	Weight, W_2	g		22.0538	21.8304	21.8406
	Weight, W_3	g		22.0538	21.8305	21.8403
	Average, W_a	g		22.0538	21.8305	21.8405
2		(mPa.s)	40ºC	4.3	3.9	4.1

	Dynamic Viscosity (test)	(mPa.s)	100ºC	3.2	2.4	2.8
3	Kinematic Viscosity (calc)	(mm^2/s) or (cSt)	1.9-1.6	[redacted]		
			40ºC	4.8744	4.4662	4.7522
			100ºC	3.6275	2.7484	3.1278
4	Flash Point	(ºC)	93/101	92	91	91

Based on the table 4.5, the properties of Modified RBD palm oil such as viscosity, density and flash point were obtained after conduct an experiment. Transesterification process are carried out using cooking oil and methanol ratio 6:1 with 1% (wt. based on oil used) sodium hydroxide (NaOH) as catalyst. NaOH were mixed first with the methanol before added into the cooking oil. Heating and stirring process were conducted after that for 2 hours. Separating, washing and dried to obtain RBD palm oil methyl ester. From the result, dynamic viscosity of the modified RBD palm oil at 40ºC are in the range of 3.9 until 4.3 (mPa.s). While for 100ºC, the range are around 2.8 until 3.2 (mPa.s). Besides that, the density for the esterified RBD palm oil methyl ester are located in the range of 0.87 until 0.89.

3.2 Reviewed on Material Removal Rate

The amount of materials removed from the workpiece per unit time is denoted as the material removal rate (MRR). The amount of material removed or the weight difference before and after machining is used to compute the material removal rate. Table below shows the experimental findings for MRR using modified vegetable-based dielectric fluid and kerosene in electrical discharge machining (EDM).

Table 6: MRR results of Transesterified Vegetable Oil [2]

No	Dielectric Fluid	Peak Current, I_p (A)	Pulse On Time, T_{on} (μs)	Material Removal Rate (mm^3/min)
1	Vegetable Oil	10	50	12.0067
2		10	100	15.8798
3		10	200	19.5581
4		24	50	21.0426
5		24	100	32.9239
6		24	200	41.2251
7		50	50	41.6234
8		50	100	81.1088
9		50	200	87.0872

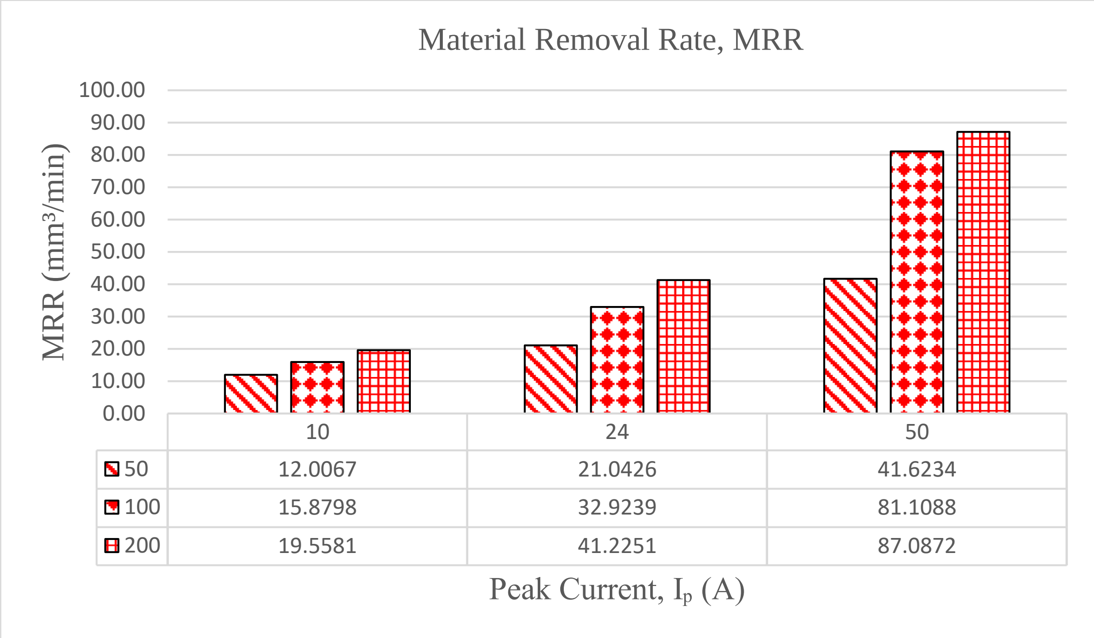

Figure 3: Material Removal of Transesterified Vegetable Oil [2]

The results above are based on the journal by Aghdeab et al., (2018) which to study the effect of different dielectric on MRR, EWR and surface roughness in EDM process. Stainless steel 316L sheet and copper were utilised in this experiment as the working piece and electrode. Transesterified vegetable oil are used as dielectric fluid that contain less than 1% of fatty acids. Three level of parameters such as current and pulse on time has been set up. Based on the results, it shown that the least MRR (12.0067mm³/min) obtained is at the lowest level of peak current (10A) and pulse on time (50μs) whereas the highest MRR that is 87.0872mm³/min is obtained at the highest value of peak current and pulse on time. The increasing value of MRR are due to the increasing value of the peak current and pulse on time. Aghdeab et al., (2018) stated that, increased current density raises the pressure and temperature inside the plasma channel, causing the work material to erode [2].

Table 7: MRR results for Kerosene [3]

No	Dielectric Fluid	Peak Current, I_p (A)	Pulse On Time, T_{on} (μs)	Material Removal Rate (mm³/min)
1	Kerosene	10	50	12.0067
2		10	100	15.8798
3		10	200	19.5581
4		24	50	21.0426
5		24	100	32.9239
6		24	200	41.2251
7		50	50	41.6234
8		50	100	81.1088

9	50	200	87.0872

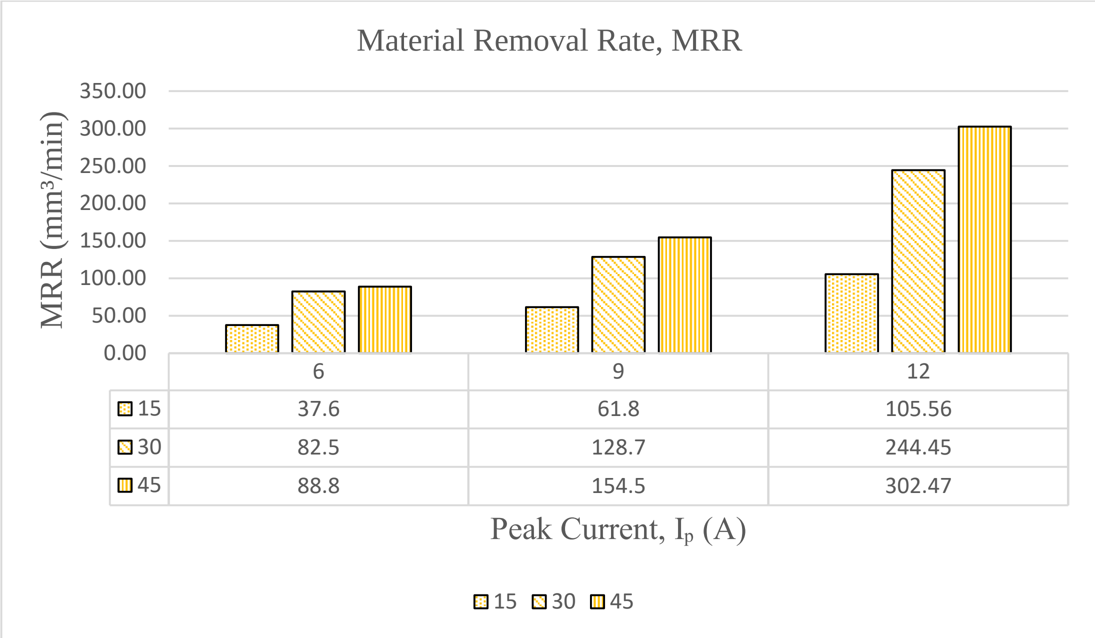

Figure 4: Material Removal Rate of Kerosene [3]

The effect of different dielectrics on material removal rate, electrode wear rate and microstructures in EDM written by Misbah et al., (2017) [3] was reviewed. Die sinking NEUAR EDM was used as an EDM machine, Aluminium 6061T6 as working piece and copper electrode. Two parameters consists of current and pulse on time were applied with three levels at each parameters. Based on table and figure 4.4 above, it can be see that for kerosene, when at highest peak current which I_p is equal to 12A, the highest MRR was obtained (302.47mm³/min) at highest pulse on time, t_{on} equal to 45µs. Meanwhile, the least MRR was observed was 37.6mm³/min which at the lowest peak current, I_p=6A and at lowest pulse on time, t_{on}=15µs. Overall, it can be said that MRR is significantly affected by the value of peak current (I_p) when machining titanium alloy (Ti-6Al-4V) using copper (cu) as electrode and kerosene as dielectric fluid in electrical discharge machining process. Whereas, for the other parameter, pulse on time was also play a major part in improving a MRR as longer duration of pulse on time will create a better flushing for the dielectrics fluid.

3.3 Reviewed on Electrode Wear Rate

The electrode wear ratio (EWR) is the most widely used term for obtaining information on electrode wear and is defined as the mass loss from the tool electrode divided by the density of the electrode material. High tool wear rates lead to incorrect machining and significantly increase costs because the tool electrode must first be effectively machined. Table below presented the experimental findings for EWR using modified vegetable-based dielectric fluid and kerosene in electrical discharge machining (EDM). A case reviewed from several paper were included in this section.

Table 8: EWR results for Vegetable Oil [2]

No	Dielectric Fluid	Peak Current, I_p (A)	Pulse On Time, T_{on} (μs)	Electrode Wear Rate (%)
1	Vegetable Oil	10	50	0.00339
2		10	100	0.00247
3		10	200	0.01344
4		24	50	0.05224
5		24	100	0.04870
6		24	200	0.04654
7		50	50	0.05410
8		50	100	0.04952
9		50	200	0.03745

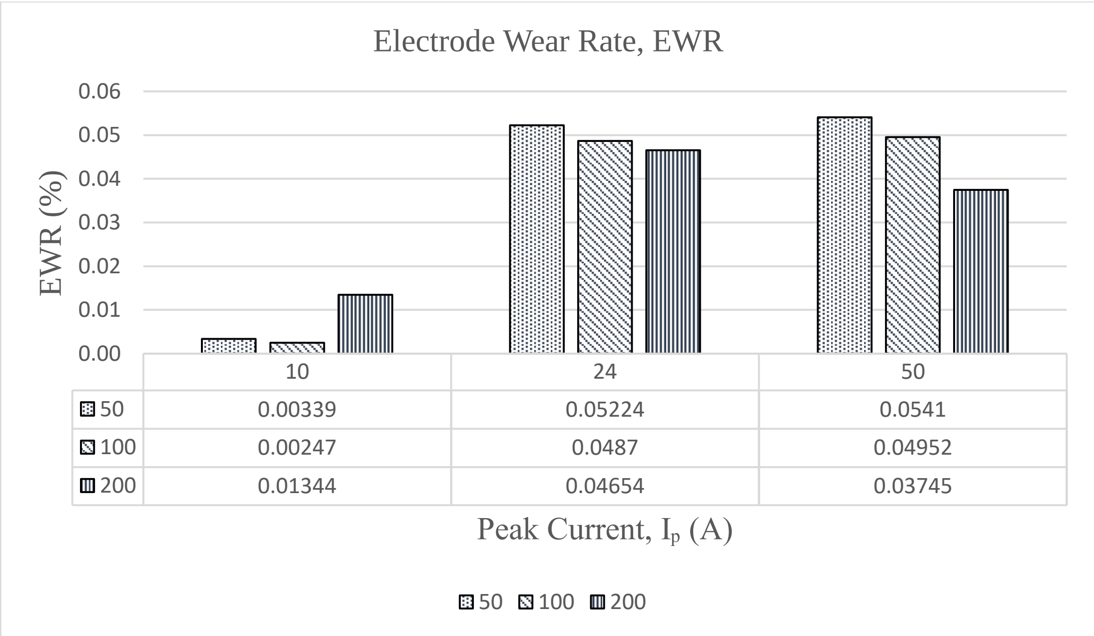

Figure 5: Electrode Wear Rate of Vegetable Oil [2]

The journal from Aghdeab et al., (2018) also has been conducted the study of the vegetable oil on the machinability of EDM such as EWR. The results presented above shown the influence of two parameter which are peak current, (I_p) and pulse on time, *(*t_{on}*)* regarding EWR by using vegetable oil. The EWR in the chart above appear to be high in value with the increasing value of peak current respectively. It also has recorded the highest value of MRR which is 0.0541% at third level of the peak current, I_p=50A. We can observed that when the value of peak current increasing from 10A to 50A, EWR were also increasing in value which is from 0.00339% to 0.0541%. However it also show that using higher value of pulse in time resulting in decreasing of EWR when the peak current were at 24A and 50A. The observation that can be made is value of peak current need to be consider as it will affect the value of EWR during machining process. The occurrence of this phenomenon are because of higher number of positive ions has been on the surface of electrode and causing a higher thermal state of electrode that will further increasing the EWR [2]. Meanwhile, EWR decreased as pulse on time increase. The longer the duration of pulse on time will wider the discharge channel and at the same time slowing the discharge energy density and plasma flushing efficiency that responsible to lessen the value of EWR [2].

Table 9: EWR results for Kerosene [4]

No	Dielectric Fluid	Peak Current, I_p (A)	Pulse On Time, T_{on} (μs)	Electrode Wear Rate (%)
1	Kerosene	9	50	0.15
2		9	150	0.08
3		9	200	0.10
4		12	50	0.02
5		12	150	0.03
6		12	200	0.04
7		15	50	0.05
8		15	150	0.06
9		15	200	0.07

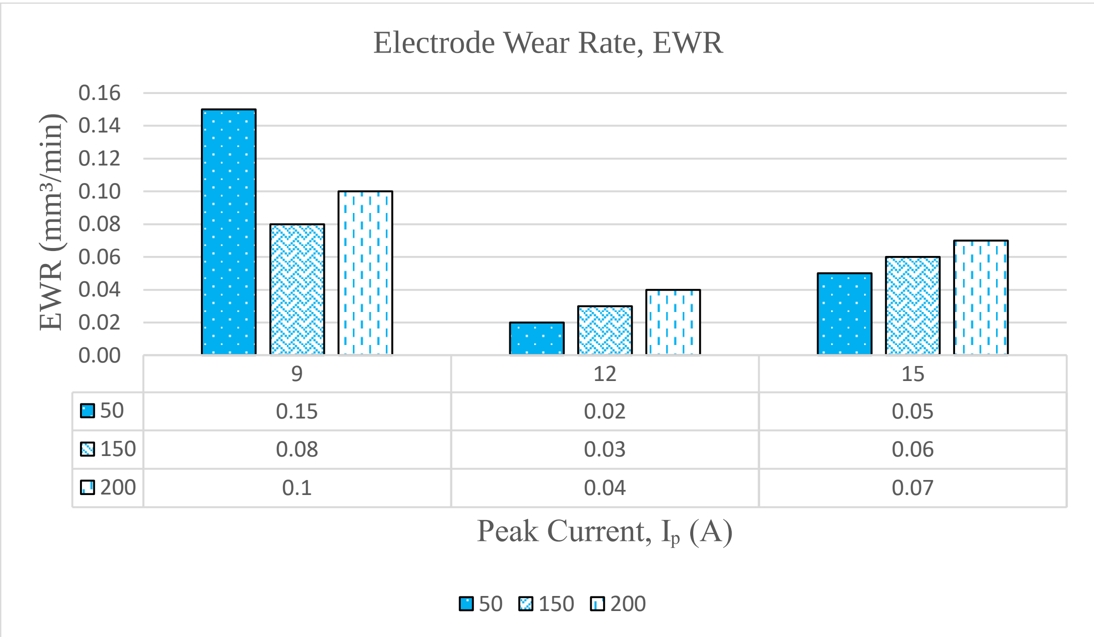

Figure 6: Electrode Wear Rate of Kerosene [4]

The results above were obtained from MangapathiRao et al., (2021) [4] which investigate the effect electrode wear rate (EWR) when using kerosene and sunflower oil as a dielectric fluid. It show that EWR increasing as the peak current (I_p) and pulse on time (t_{on}) decelerate. Minimum value of EWR shown in the figure above was 0.02mm³/min at the medium level of peak current, I_p=12A and lowest level of pulse on time, t_{on}=150µs. Meanwhile, the maximum value obtained was 0.15mm³/min which at the first lowest level of peak current and pulse on time. By applying high value of the peak current, it will be able to reduce the electrode wear rate during cutting process. While for pulse on time, it show that with lower value of peak current, the duration need to be longer but with the higher peak current, the duration need to be shorter to create the lower EWR value in kerosene.

3.4 Reviewed on Surface Roughness

The study of surface roughness were conducted in this experimental work to compare the surface finished of the titanium alloy (Ti-6Al-4V) when using two different types of dielectric fluid. Average value of surface roughness were measured using surface roughness tester for this experiment. Several journal on analysis of surface roughness when using modified vegetable oil in electrical discharge machining (EDM) will be reviewed in this section.

In Basha et al., (2020) journal, they investigate on the quality of electric discharge machined titanium alloy using bio-oil and biodiesel. Two response parameter, surface roughness and overcut were being analysed to evaluate the efficiency of bio-oil and biodiesel as a dielectric fluid. Four level of each parameters which are current, voltage, pulse on time and pulse off time employed in this investigation. Electrolytic copper with 8.91g/cm³ was used as tool electrode. Overall results obtained are biodiesel produce lower surface roughness than the bio-oil. Increasing of current value, voltage (except from 55V to 70V) and pulse on time lead to higher surface roughness [5]. Meanwhile, when pulse off time increase the reduction of surface roughness will occur [5]. As compared to bio-oil, as the current and pulse off time increased, value of surface roughness were leaps and bound considerably. Thus, the author suggest that the perfect parameter value in order to get lower surface roughness for bio-oil are 9A, 70V, 315µs for pulse on time and pulse off time, and for biodiesel are 9A, 40V, 315µs and 385µs for pulse off time [5].

Following are the analysis of EDM process by Mangapathi et al., (2020) [4] using hydrocarbon and sunflower oil and mixed of aluminium oxide with sunflower oil. Analysis has been made by select AISI D2 steel as a workpiece and copper tungsten as electrode. Pulse on time, current and voltage as input parameters with three level on each parameters. As revealed by author, the results clearly shown using sunflower oil as dielectric fluid create a lower surface roughness compared to hydrocarbon and aluminium oxide mixed with sunflower oil. However, the results of aluminium oxide mixed with sunflower oil is still outstanding as the material removal rate increased by 38% and producing lower value of surface roughness and EWR [4]. The researcher concluded that using sunflower oil or mixed with aluminium oxide will improve a productivity and lead to less harmful gases emissions by the EDM process which will make the process environmental friendly.

Additionally, Sadagopan et al., (2017) [6] conduct an investigation on surface roughness between kerosene, biodiesel and transformer oil. Three levels of input parameters were used during machining aluminium 6063 alloy with electrolytic copper. In biodiesel, it was observed that the input parameter that give greatest effect on surface roughness was peak current while the pulse off time was remarkably give almost none effect to surface roughness. Furthermore, the author stated that increase in pulse on time generate a higher value of surface roughness. Unlike biodiesel, kerosene obtained higher surface roughness value than biodiesel and has the highest value of surface roughness between the three types of dielectric fluid used during machining process. The author suggested that, the study of surface integrity should be take into consideration as the surface integrity is one of the important factor in producing a quality product.

3.6 Summary

From the discussion that has been reviewed on machinability and surface roughness of electrical discharge machining process, the result can be sum up as follow:

I. The application of vegetable oil in electrical discharge machining is possible if the characteristics and properties are effectively altered and meet the standard requirements.

II. A higher flushing velocity are needed when using vegetable oil as dielectric fluid to increase machinability performance due to higher viscosity of vegetable oil.

III. Utilizing higher value of peak current will boost up the material removal rate (MRR) value.

IV. A higher peak current will increase the temperature of the modified vegetable oil because low viscosity of the oil will be obtained at high temperature, thus it can increase MRR efficiency.

V. The increases of electrode wear rate (EWR) are causing by ascent value of peak current.

VI. When a longer pulse on time is used, the least value of electrode wear rate (EWR) is achieved.

VII. Majority of the researcher agreed that vegetable oil produce lower surface roughness value than conventional hydrocarbon dielectric fluid.

4. Conclusion

The objective of this experiment are to study the properties of modified vegetables based dielectric fluid and to compare the machinability of titanium alloy (Ti-6Al-4V) between when apply vegetables based dielectric fluid and hydrocarbon based dielectric fluid using electrical discharge machining (EDM). An experiment to modified RBD palm oil were conducted, the aim is to change the properties of the palm oil so that it can be used as a dielectric fluid in electrical discharge machining. After the process of transesterification, the properties such as viscosity, density and flash point of the palm oil were meet the standard for biodiesel. However, many other factor need to be taken into consideration such as the acidity, thermal conductivity and specific heat capacity of the RBP palm oil. The experiment were conducted using specific value of each parameter such as peak current, pulse on time and pulse off time. From the results that have been reviewed from various journal, when using modified vegetable oil as dielectric fluid it clearly show that it produces higher MRR than kerosene. Increasing value of peak current and pulse on time to the higher level significantly improves MRR. Based on the reviewed, the effect of higher peak current will expand the pressure and temperature inside the plasma channel and forcing a material to remove material immediately, while impact of longer pulse on time is a spark energy from current were available for a long period generate melting and evaporation process extended to produce a good MRR. In the case of EWR, the lower value are needed to prevent in extra usage of electrode. The data collected show that minimum value ($0.94 mm^3/min$) are obtained when using modified RBD palm oil, but the maximum value ($1.77 mm^3/min$) of the EWR were also shown when using modified vegetable oil. EWR of copper (cu) when using both type of dielectric fluid were increased with high level of peak current value because particles tend to move faster with the higher energy supplied by the current and resulted in increasing EWR. Otherwise, longer pulse on time will created a longer flushing time to remove all the wasted material contribute to lower EWR as no foreign matter will interrupt the cutting process. Next, the reviewed also show that using kerosene as dielectric fluid producing a higher surface roughness value than vegetable oil or biodiesel. Additionaly, using kerosene also will resulted in poor surface finishing but higher MRR due to higher level of peak current applied.

Acknowledgement

The authors would like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for their support.

References

[1] B. Singaravel, K. C. Shekar, G. G. Reddy, and S. D. Prasad, "Experimental investigation of vegetable oil as dielectric fluid in Electric discharge machining of Ti-6Al-4V," *Ain Shams Eng. J.*, vol. 11, no. 1, pp. 143–147, 2020, doi: 10.1016/j.asej.2019.07.010.

[2] S. Hammed, "Study The Effect Of Different Dielectric On Material Removal," no. December 2018, 2019, doi: 10.5281/zenodo.2528760.

[3] M. Niamat *et al.*, "Effect of Different Dielectrics on Material Removal Rate, Electrode Wear Rate and Microstructures in EDM," *Procedia CIRP*, vol. 60, pp. 2–7, 2017, doi: 10.1016/j.procir.2017.02.023.

[4] K. MangapathiRao, D. Vinaykumar, K. Chandra Shekar, and R. R. Kumar, " Investigation and analysis of EDM process – a new approach with Al 2 O 3 nano powder mixed in sunflower oil ," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1057, p. 012059, 2021, doi: 10.1088/1757-899x/1057/1/012059.

[5] S. M. Basha, H. K. Dave, and H. V. Patel, "Experimental investigation on the quality of electric discharge machined Ti-6Al-4V using bio-oil and biodiesel," *Mater. Today Proc.*, vol. 38, pp. 2249–2255, 2020, doi: 10.1016/j.matpr.2020.06.314.

[6] P. Sadagopan and B. Mouliprasanth, "Investigation on the influence of different types of dielectrics in electrical discharge machining," pp. 277–291, 2017, doi: 10.1007/s00170-017-0039-1.