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# Surface Integrity of RBD Palm Oil as a Bio Degradable Oil Based Dielectric Fluid on Sustainable Electrical Discharge Machining (EDM) of AISI D2 Steel

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**Abstract**: In electrical discharge machining (EDM), material removal occurs through successive electrical discharges between an electrode and a workpiece in the presence of dielectric fluid. A proper selection of dielectric medium is an important consideration for EDM efficiency, as dielectric fluid plays a significant role in any EDM activity. The aim of this research is to discover the usability of Refined, Bleached and Deodorized (RBD) palm oil based dielectric fluid (cooking oil) on the EDM operation of AISI D2 steel using a copper electrode relative to conventional dielectric fluid in term of surface integrity which covers the analysis of a recast layers ($R_L$) and microharderness (MH) at deeper layer of the machined surface. Peak current, $I_p$ 5A to 12A, and pulse duration, $t_{on}$ 50µs to 150µs were selected as the main parameters. The result shows the lowest and highest $R_L$ was recorded at $I_p$=6A and ton=50µs, which is 7.64µm and $I_p$=12A and $t_{on}$=150µs which is 15.50µm for RBD palm oil. While the lowest and highest $R_L$ for kerosene is 10.60µm and 17.00µm at the same parameter as RBD palm oil, respectively. The thinness of $R_L$ in the EDM process produces better machining performance. The thickness $R_L$ for both dielectric fluids were increased with an increase of $I_p$ and $t_{on}$. The MH on the $R_L$ is much higher when compared to the base material. In the case of surface integrity, the bio-degradable dielectric fluid based on dielectric fluid, RBD palm oil, shows considerable potential for its success in AISI D2 steel EDM machining.

Keywords: rbd palm oil; electrical discharge machining; AISI D2 steel

## 1. Introduction

Electrical discharge machining (EDM) is a non-conventional method of removal of material that is generally used for the manufacture of dies, punches and molds, finishing components for many industries such as the aerospace and automotive industry, and surgical components[1-3]. EDM is therefore generally used to machine difficult materials and alloys resistant to high strength temperatures, which are otherwise difficult to manufacture by conventional machining[4-8]. This machine may even be capable of machining complex geometries in small lots or even on a job shop basis[9, 10]. There are two types of EDM process, which are Die-Sinking EDM and Wire-Cut EDM. Both of them have different features, but they serve the same function[11-14]. This process can be successfully employed to machine electrically conductive parts of their hardness, shape, and toughness[15-18]. Generally, the efficiency of the workpiece surface machined by EDM is affected by its machining parameters such as pulse duration, voltage, current, pulse interval and condition of pulse produced[19]. A lot of technology, however, has been committed to developing machining capacities, but environmental sustainability is not a major concern. Thus, one relatively new technique is used to enhance EDM's sustainability concern by using an alternative bio-dielectric fluid.

Besides that, EDM is one of the vital metal removal processes in any modern-day shop floor. The dielectric fluid plays an important role in this process as it concentrates the plasma channel over the machining region and serves as a debris carrier. The dielectric used in EDM is an environmental contaminant and, in long-term usage, causes the operator a carcinogenic problem. Using bio-dielectric fluid in EDM is the most sustainable dielectric fluid for environmental considerations, in order to create a sustainable climate in manufacturing practise.

In addition, because of the fundamental issues of this new development, bio-dielectric fluid is used in the EDM process in the industry at a very slow speed, including the machining mechanism are still not well understood[19]. It is desirable to choose a suitable dielectric during EDM operation in order to boost EDM efficiency. Most of the researchers have been studied on the effect of machining condition and parameter changes, but very few studies have been done on dielectric fluid efficiency by testing the process in EDM with the introduction of dielectric fluid based on bio-degradable oil in EDM.

The EDM process creates three types of surfaces. The top surface contains a thin layer of splattered material that has been formed from the molten metal and the small amounts of electrode material. This surface layer of splattered EDM residue is easily removed. Underneath the splattered material is the recast (white) layer. When the current from the EDM process melts the material, it heats up the underlying surface and alters the metallurgical structure. This recast layer is formed because some of the molten metal has not been expelled and has instead been rapidly quenched by the dielectric oil. Depending on the material, the recast layer surface can be altered to such an extent that it becomes a hardened brittle surface where micro cracks can appear. This layer can be reduced substantially by finishing operations. The next layer is the heat-affected zone. This area is affected by the amount of current applied in the roughing and finishing operations. The material has been heated but not melted as in the recast layer. The heat-affected zone may alter the performance of the material.

There can be significant differences between wire and ram EDM heat affected zones. When roughing with ram EDM, much more energy can be supplied than with wire EDM. This greatly increases the heat- affected zone with Ram EDM. On thin webs it can create serious problems because the material will be heat treated and quenched in the dielectric oil. This can cause thin webs to become brittle. When dielectric oil is heated, the hydrocarbon in the oil breaks down and creates an enriched carbon area in the cutting zone. This carbon becomes impregnated into the surface and alters the parent material. Often this surface becomes hard and makes polishing more difficult. To avoid heat problems when EDM thin webs, parts should be premachined and EDM with lower power settings. The depth of the altered metal zone changes according to the amount of current applied. A careful finishing operation can greatly reduce these three layers of the heat-affected zones.

However, the procedure involves further analysis and testing in order to apply bio-dielectric fluid to EDM. Therefore, this study will investigate how the dielectric fluid based on bio-degradable oil is capable of EDM processes relevant to the fundamental performance of dielectric formation. In this case, it is highly expected that it can improve the performance of EDM machining in term of surface integrity.

## 2. Methodology

The details process of sustainable electrical discharge machining operation in this study were described technically through the process that had been carried out. The proper steps should be taken in order to obtain the best and accurate result and there are several ways in obtaining the appropriate result had been used. Table 1 shows the properties of dielectric fluid that was used in this research. The schematic diagram and the machine set-up of external working tank that was used in this research is shown in Fig. 1 and Fig. 2, respectively.

Table 1. Properties of dielectric fluid used in this research

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

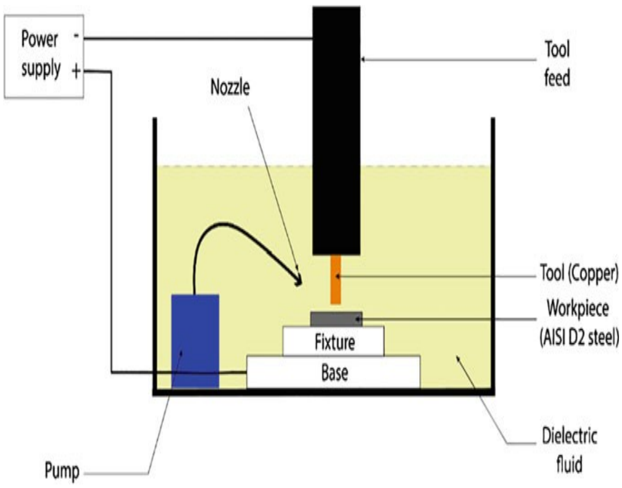



**Fig. 1:** Schematic diagram of the machine set-up for this research.

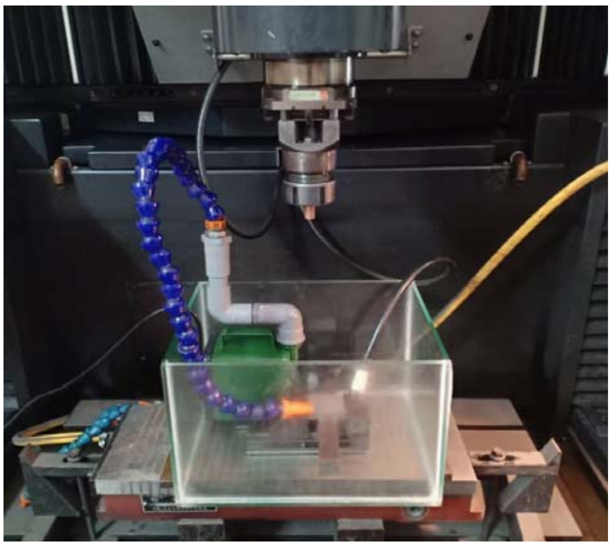


**Fig. 2:** Machine set-up for this research.

### 2.1 Experiment set up

The experimental work was conducted on the AQ55L (3 Axis Linear) Computer Numerical Control (CNC) Sodick High Speed EDM die sink unit. RBD palm oil as a bio-degradable oil dielectric fluid and kerosene as a conventional dielectric fluid are two different types of dielectric fluid used.

For the case of experimental work by using RBD palm oil as a dielectric fluid, a custom-made glass tank (25 x 20 x 15) $cm^3$ was used to conduct the experiment. As shown on Fig. 2. During the machining process, a pump was placed into the tank to do the flushing process. In terms of low price, ease of use, abundant supply and higher sustainability impact index, bio-oils such as palm oil have strong properties. Other than that, it has features that can be reused and do not affect the environment and the health of the operator running the system[21)].

As a workpiece, AISI D2 steel (40 x 30 x 10) mm3 is used in this work. Needed measurements are cut by abrasive cutter machines from 'as-received' raw material. Via filing, burrs and sharp corners are also eliminated. This steel has outstanding resistance to wear and high compressive strength. Commercially available 99.58% pure copper electrode with dimension Ø (10 x 30) mm and dimension tolerance $\pm$ 0.02mm used for conducting EDM experiments. Due to its high thermal conductivity, copper electrodes are widely used as electrodes in the EDM phase [22-25)]. Table 2 shows the experimental condition and parameters setting for the research.

Table 2. Experiment condition and parameter setting

| **Properties** | **Percentage (%)** |
|---|---|
| Dielectric fluid | RBD palm oil, Kerosene |
| Workpiece material | AISI D2 steel |
| Tool electrode | Copper (Cu) |
| Peak current (A) | 6, 9,12 |
| Pulse duration, $t_{on}$ (μs) | 50, 100, 150 |
| Pulse off-time, $t_{off}$ (μs) | 50 |
| Voltage, V | 120 |
| Electrode polarity | Positive (+ve) |
| Depth off cut, (mm) | 1.5 |

### 2.2 Responses

The surface integrity (SI) study of this research focuses on two primary responses; recast layer ($R_L$) and microhardness (MH). SI can be defined as a surface condition of a workpiece after being modified by a manufacturing process that changes the material properties. There are five major variables in the manufacturing phase: the workpiece, the instrument, the machine tool, the environment, and process variables. Almost all of these factors influence the workpiece's SI [26)]. The significance of SI studies in EDM machining because it is related to cutting precision. It will help the operator to decide the parameters of machining to do cutting precisely.

In this research, the specimen was observed using Scanning Electron Microscope (SEM) to analyze the $R_L$ thickness and Vickers Microhardness Tester, HMV Shimadzu to conduct a microhardness test at the sub-surface of machined workpiece, respectively. Before performing the test, the material is cut using an abrasive cutter to look for the machining area's cross-sectional. The cross-section area is then mounted using cold mounting technique and followed by grinding and polishing process for smooth surface, and the surface sample must be through the etching process. Fig. 3 shows the mounted sample on this research.

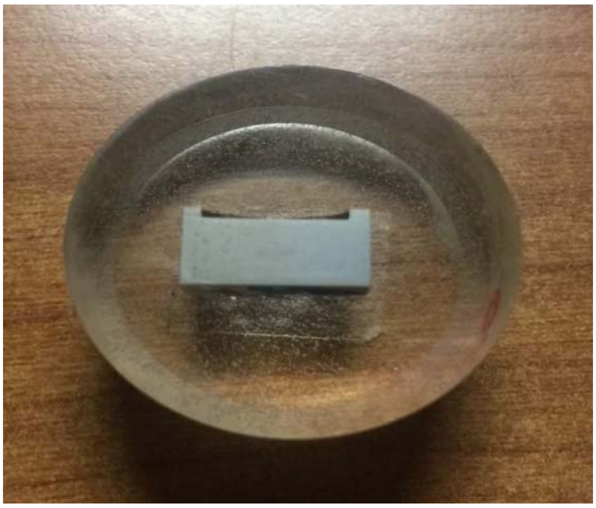


**Fig. 3:** Mounted sample

## 3. Result and discussion

This topic presents the experimental result on the SI study of RBD palm oil dielectric fluid performance compared with kerosene on sustainable EDM.

### 3.1 Recast layer ($R_L$)

The EDM method is usually used to machine hard metals and perform complex tasks that can not be performed using conventional methods. The sparks produced during the EDM process melt the surface of the metal, which then undergoes ultra-rapid quenching. A layer forms on the surface of the workpiece that is described after solidification as a recast layer. The processed part surface generates a heat-affected zone (HAZ) of Ni-based super alloy because the EDM process is a heat energy process[27)]. This zone includes the recast layer structure and surface morphology after removal processes in this study.

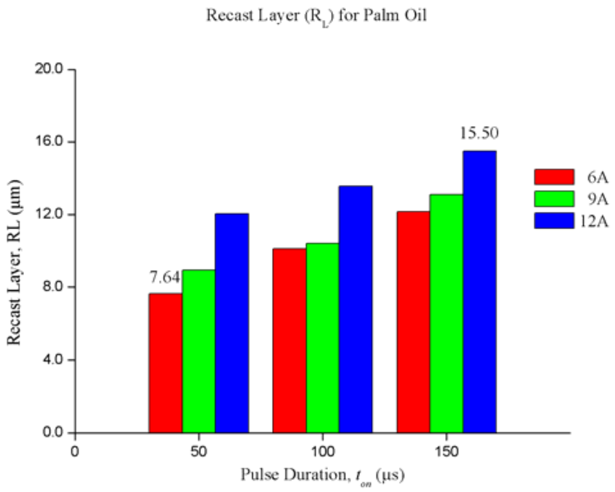
During the EDM process, the melting and removal material progresses between two polarities (electrode and workpiece). Some materials experience a re-solidification phenomenon. Mixing carbon elements of dielectric fluid, melting electrode, and melting workpiece is easy during re-solidification, forming the recast structure after the processes. The recast structure has micro-cracks and discharge craters causing bad surface quality that are difficult to remove due to high cohesion and hardness characteristics compared to the base material[23)]. The experiment was done under three different $I_p$ (6, 9 and 12A) and three different $t_{on}$ (50, 100 and 150µs). Fig. 4 shows $I_p$ and $t_{on}$'s effect on $R_L$ thickness of AISI D2 steel for both dielectric fluids, RBD palm oil and kerosene.

In general, the thinnest of the $R_L$ in EDM process is a desirable result. According to Fig. 4, the $R_L$ thickness is influenced by the $I_p$ and $t_{on}$,. With increasing the $I_p$ and $t_{on}$, $R_L$ thickness was increased[28-30)]. Fig. 4(a-b) shows a similar trend; the $R_L$ thickness increase when the $I_p$ and $t_{on}$ increase. This is due to the higher $I_p$ setup with the longer $t_{on}$ caused more material to be melted and set to leave from the machining area of the sample[31, 32)]. After the machining process was done, the excessive molten metal was solidified and cooled down on the work piece's surface, thus creating a recast layer. According to Fig. 4(a), the $R_L$ thickness shows an increment from 6A to 12A linearly with the $t_{on}$ from 50µs to 150µs. The lowest and highest $R_L$ was recorded at $I_p$=6A and $t_{on}$=50µs which is 7.64µm and $I_p$=12A and $t_{on}$=150µs which is 15.50µm for RBD palm oil. While, the lowest and highest $R_L$ for kerosene is 10.60µm and 17.00µm at the same parameter as RBD palm oil based on Fig. 4(b).

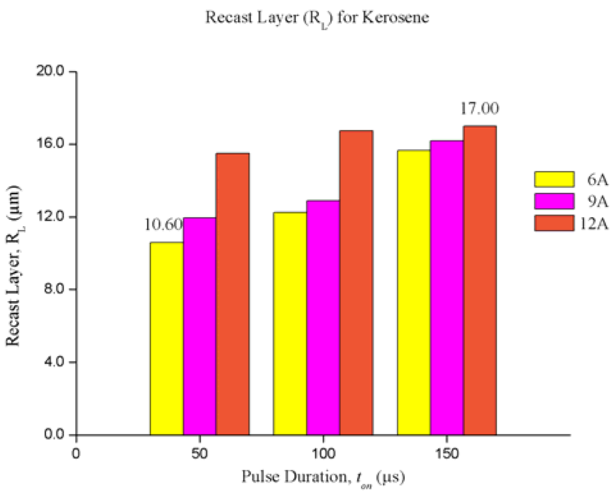
Furthermore, this can be explained by the longer pulse duration and higher peak current that affected the plasma channel to expand the larger area. Thus, a higher size of the recast layer was formed on the surface of the machining area. Therefore, the viscosity of the dielectric fluid used may affected the machining process of EDM. RBD palm oil has a higher viscosity compared to kerosene. However, after many machining processes, the RBD palm oil's viscosity becomes lighter and may evenly distribute the machining area's excessive temperature. Thus, material removal from the workpiece becomes faster and smoother, and SI become better.

Fig. 5 shows the formation of cracks on RL area. The creation of surface cracks was due to elevated contraction stresses exceeding the final tensile strength of the materials inside the recast layer[30)]. When the discharges bombard the surface during the machining process, thermal stress is generated. Tensile stress is produced inside the machined surface because the dielectric fluid does not sweep all of the material melted during discharge away from the surface. Due to its resistance to etching on ferrous material, $R_L$ is commonly referred to as the white layer and is often formed on the surface. This layer is composed of many metallurgical microscopic layers and relies on the machining conditions for its composition[33)]. During the cooling process, the melt material contracts more than the unimpacted parent component, and cracks are created when the stress on the surface exceeds the ultimate tensile strength of the materials[34, 35)]. Results from previous research have shown that cracking increases as the energy of the pulse increases[34, 35)]. However, with respect to pulse energy, the increase in surface crack density was not found to be linear, i.e., increasing pulse energy does not lead to increased crack formation.

In fact, under the machining conditions of minimum discharge current and maximum pulse-on duration, the maximum crack density takes place[34)]. The crack density is inversely proportional to the work material's thermal conductivity, and as the carbon content inside the white layer rises from the dielectric fluid, the intensity of the surface crack increases very rapidly[33, 36)]. Surface cracks initiate from the surface and propagate in a vertical direction toward the parent material. In extreme cases, though most of these cracks end within the recast layer or at the interface between the recast layer and the base material, cracks may penetrate into the base material itself[36)]. Although many examples of EDM surface cracking have been given, crack formation cannot be adequately described in terms of the composition of the white layer, the properties of the base material and operating parameters, such as discharge current and pulse-on length.




(a)




(b)

**Fig. 4:** Effect of recast layer, $R_L$ thickness of AISI D2 steel: (a) RBD palm oil, (b) kerosene.

It could be summarized from the above result that RBD palm oil is better than kerosene in term $R_L$ because the result show highest $R_L$ thickness in kerosene while lowest with palm oil. By setting the machine parameters at a low $I_p$ and low $t_{on}$, a better surface finish can be achieved, but this method will take longer machining time and decrease productivity. The usage of RBD palm oil as dielectric fluid will decrease the $R_L$ thickness as well. Fig. 5 also shows the analysis of $R_L$ for both dielectric fluids, which is RBD palm oil and kerosene at higher and lower $R_L$ thickness. This result proves that using RBD palm oil as a dielectric fluid in the machining process of EDM is better in terms of RL measure. Furthermore, smaller recast layer is expected to occur to the surface of the material because the industry standard has stated that one and the half times the $R_L$ and HAZ need to be removed by using chemical etching or conventional machining so that less step will be add to the manufacturing process that will increase the delivery time and also add more cost to the industry budget that will not profit them[37-38].

### 3.2 Microhardness (MH)

The MH test had been conducted by using the Vickers Hardness Tester with setting load at 980.7mN. The starting point (0 point) and the second point were indented at the recast layer region. Then, the specimens were indented at another 8 points continuously with the range approximately 0.025mm and 10 second at each point levels and load duration, respectively. The total of indented point for MH test was 10 on each sample. Before the MH test is measurable, the specimen needs to be polished and etching in order to reveal the recast layer and microstructure. Fig. 6 shows the result of MH for palm oil and kerosene as dielectric fluid.

In overall, the MH on $R_L$ region (0 point) increased as the peak current, $I_p$ increased for both dielectric fluids. For palm oil, the lowest MH is at $I_p$=6A and $t_{on}$=50µs while the highest is at $I_p$=12A and $t_{on}$=150µs.

The similar trend shows on kerosene which the lowest and highest MH is located at the same parameter as palm oil. For the second point of $R_L$ region, it shows a decrement for both dielectrics at corresponding parameters and fluctuated with increasing of pulse duration, $t_{on}$. Therefore, the MH value in the $R_L$ region is almost double as the base material. According to the analysis that has been done and the result shown, it can be conclude that palm oil has higher MH value compare to kerosene. This proves that the higher MH value, the better performance of dielectric can be achieved.

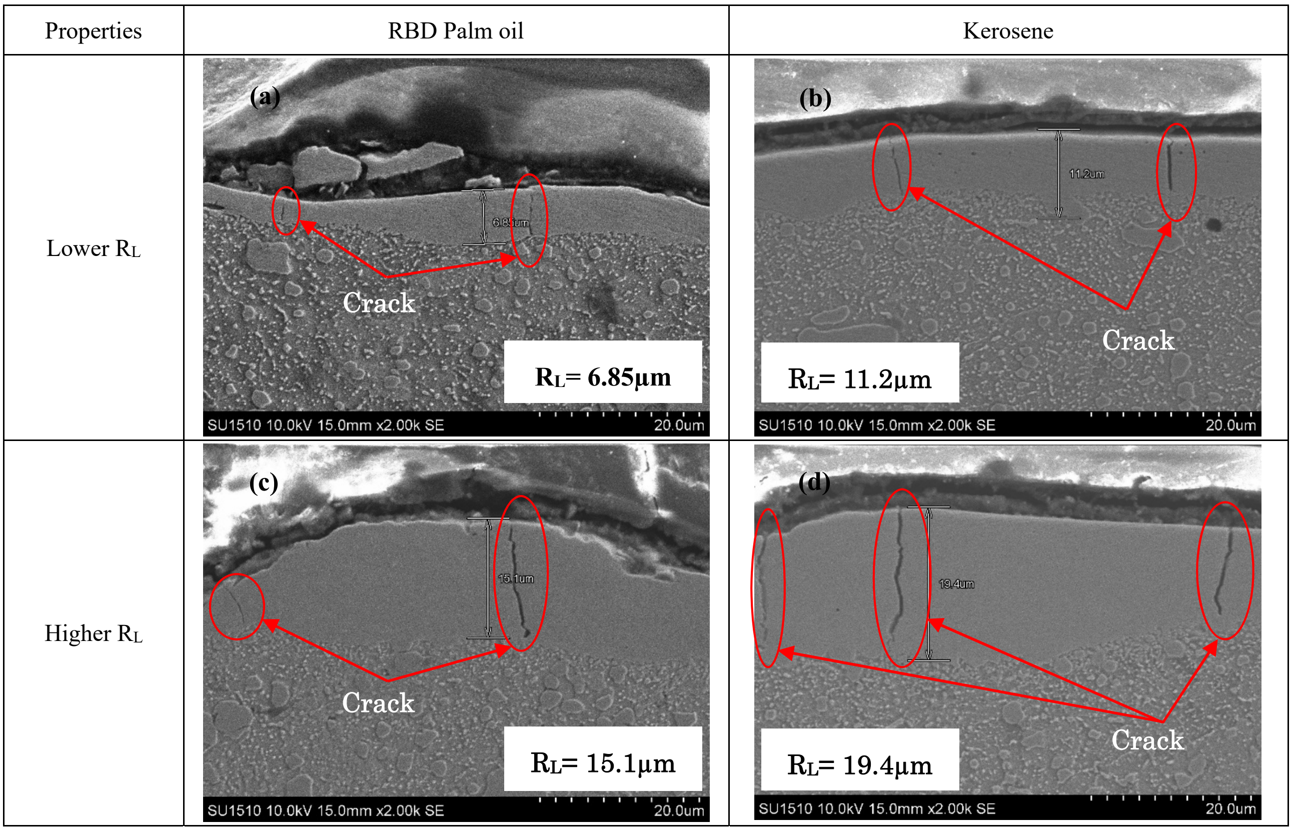



**Fig. 5:** Analysis of recast layer, $R_L$ thickness of AISI D2 steel of (a) RBD palm oil, (b) kerosene.

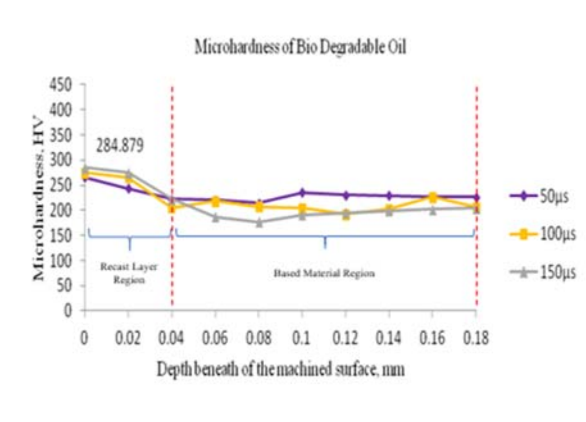
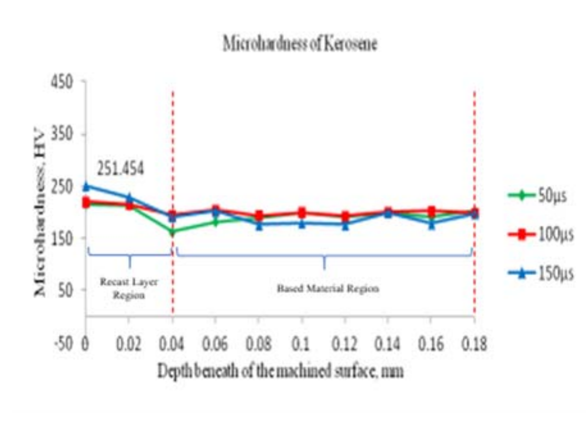
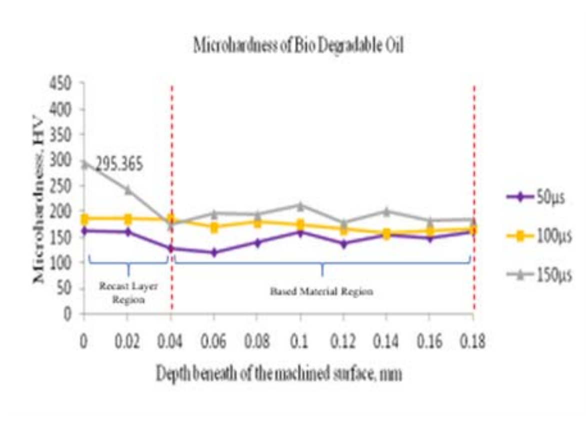
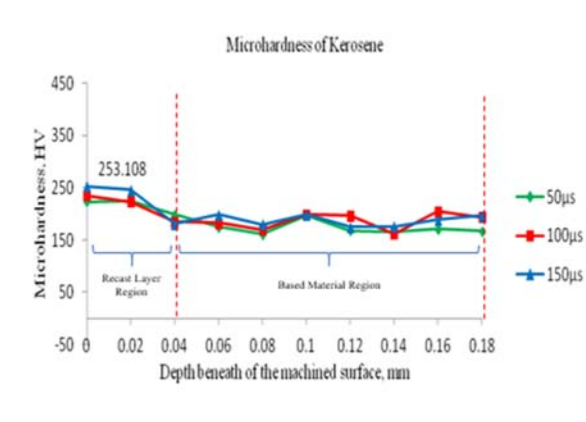
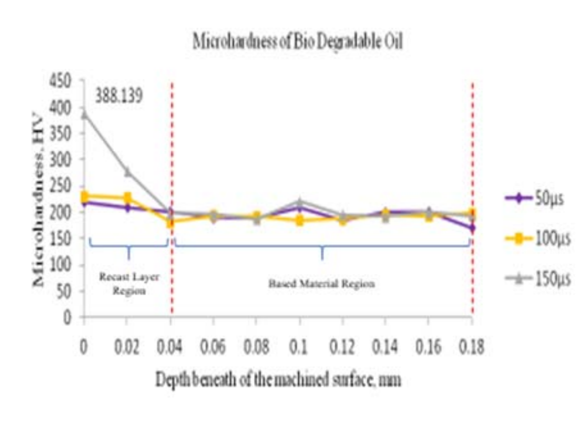
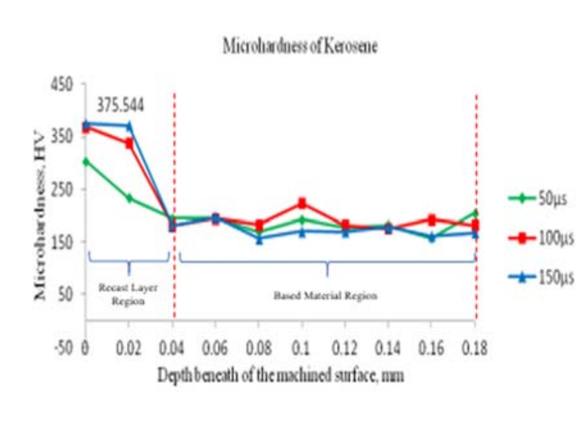
| $I_p$, (A) | RBD Palm oil | Kerosene |
|---|---|---|
| 6 |  |  |
| 9 |  |  |
| 12 |  |  |

**Fig. 6:** Recast layer ($R_L$) thickness of AISI D2 steel of (a) RBD palm oil, (b) kerosene.

## 4. Conclusion

As a consequence of this study, which was conducted, the entire objective to improve the performance of EDM by using bio-degradable oil as dielectric fluid was reached successfully. From the analysis, the effect of machining parameter on the surface integrity can be summarized as follows:

- The $R_L$ relates all factors of parameters selected; $I_p$ and $t_{on}$. A higher $I_p$ causes the thickest recast layer. The result also shows that the increasing of $t_{on}$ will increase the recast layer. The lower $R_L$ thickness is desirable in EDM performance measure.
- According to the result, the lowest $R_L$ obtained on RBD palm oil with the value of 23.76µm at $I_p$= 6A and $t_{on}$=50µs while the highest $R_L$ obtained on kerosene with the value of 69.27µm at $I_p$= 12A and $t_{on}$=150µs.
- The MH on $R_L$ on the sub surface is higher than on the base material of AISI D2 steel. The hardness of $R_L$ increased as the $t_{on}$ is increased. In overall, the MH of $R_L$ is also decreased with increasing $t_{on}$. It is noticed that the increment of hardness value in the recast layer region is almost as double in the base material hardness. The highest MH value obtained is 375.544HV.

- The result shows that the introduction of RBD palm oil as a dielectric fluid would further increase the performance of machining. The result within the selected parameters shows that RBD palm oil is the better option for EDM machining of AISI D2 steel by comparing the performance of palm oil and kerosene as dielectric fluid.

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## Nomenclature

| | |
|---|---|
| EDM | Electrical Discharge Machining |
| RBD | Refine, Bleached and Deodorized |
| CNC | Computer Numerical Control |
| SI | Surface Integrity |
| $R_L$ | Recast Layer |
| MH | Microhardness |
| SEM | Scanning Electron Microscope |
| $I_p$ | Peak Current |
| $t_{on}$ | Pulse On-time |
| $t_{off}$ | Pulse Off-time |

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