九州大学学術情報リポジトリ
Kyushu University Institutional Repository

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

Supawi, Aiman
Precision Machining Research Center (PREMACH)

Ahmad, Said
Precision Machining Research Center (PREMACH)

Nurul Farahin Mohd Joharudin
Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia

Karim, Fazida
Universiti Sultan Zainal Abidin

https://doi.org/10.5109/4774215

出版情報：Evergreen. 9 (1), pp.41-48, 2022-03. Transdisciplinary Research and Education Center for Green Technologies, Kyushu University
バージョン：
権利関係：Creative Commons Attribution-NonCommercial 4.0 International

KYUSHU UNIVERSITY

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

Aiman Supawi[1], Said Ahmad[1,*], Nurul Farahin Mohd Joharudin[2], Fazida Karim[3]
[1]Precision Machining Research Center (PREMACH), [2]Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia
[3]Universiti Sultan Zainal Abidin, Malaysia

*Author to whom correspondence should be addressed:
E-mail: said@uthm.edu.my

(Received June 26, 2021; Revised October 25, 2021; accepted January 25, 2022).

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°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

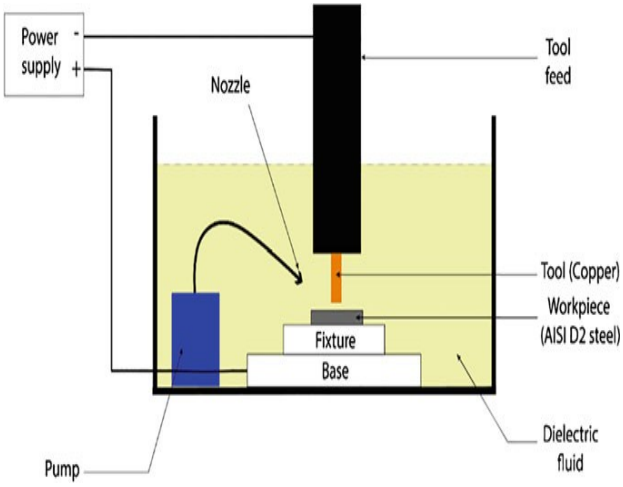


Fig. 1: Schematic diagram of the machine set-up for this research.

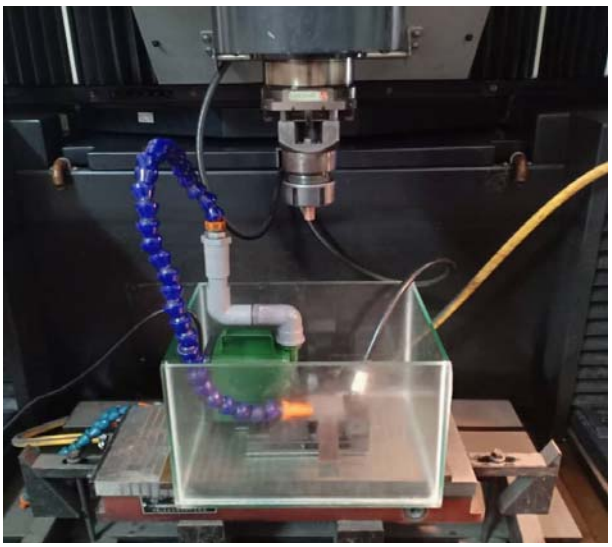


Fig. 2: Machine set-up for this research.

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 ± 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.

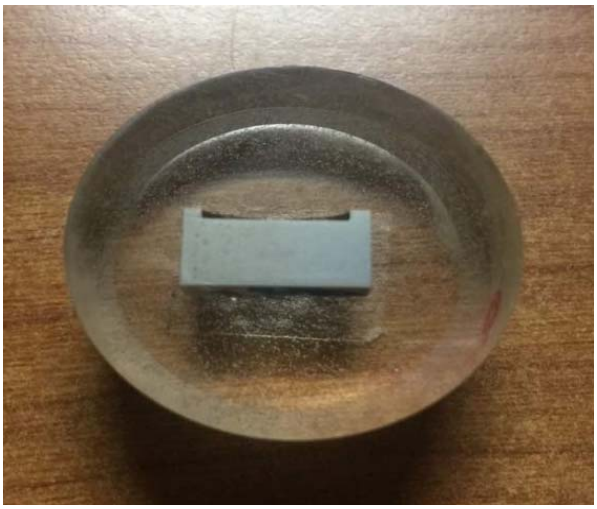


Fig. 3: Mounted sample

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

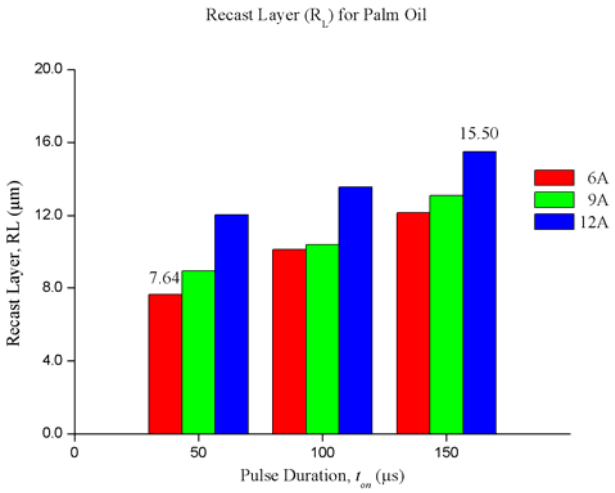
discharge craters causing bad surface quality that are difficult to remove due to high cohesion and hardness characteristics compared to the base material[23]. The experiment was done under three different I_p (6, 9 and 12A) and three different t_{on} (50, 100 and 150µs). Fig. 4 shows I_p and t_{on}'s 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).

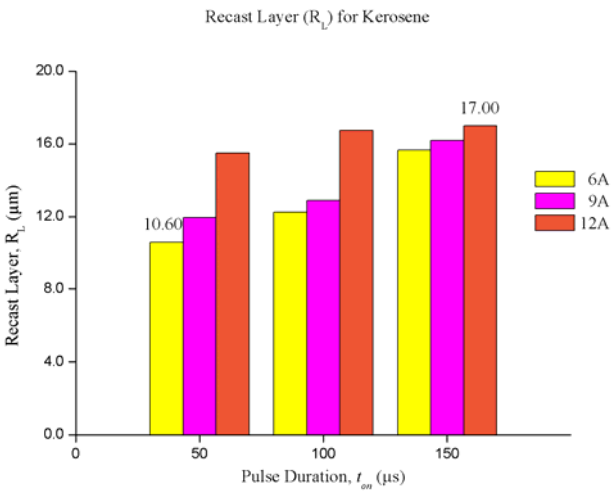
Furthermore, this can be explained by the longer pulse duration and higher peak current that affected the plasma channel to expand the larger area. Thus, a higher size of the recast layer was formed on the surface of the machining area. Therefore, the viscosity of the dielectric fluid used may affected 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.

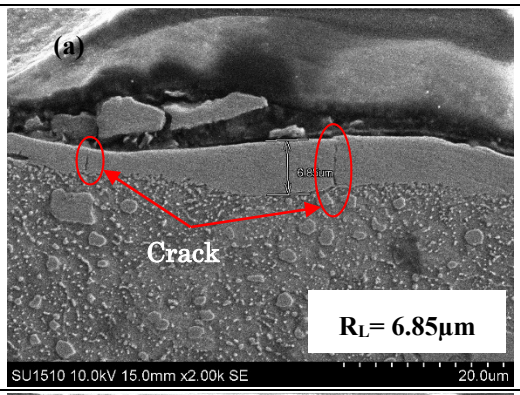
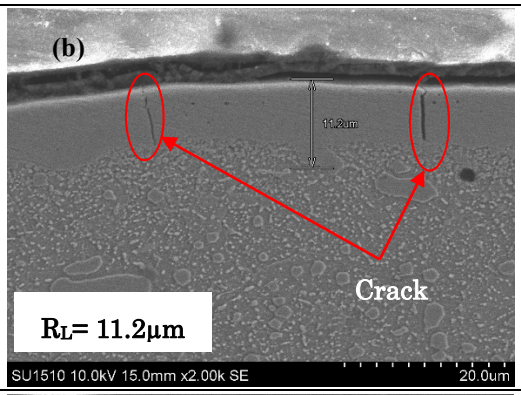
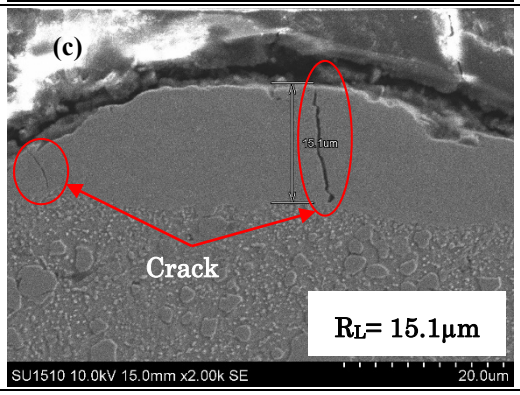
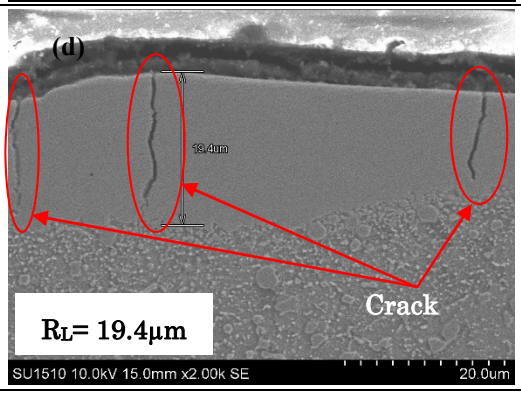
Properties	RBD Palm oil	Kerosene
Lower R_L		
Higher R_L		

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

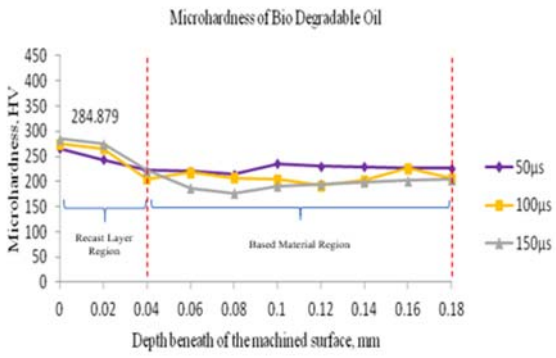
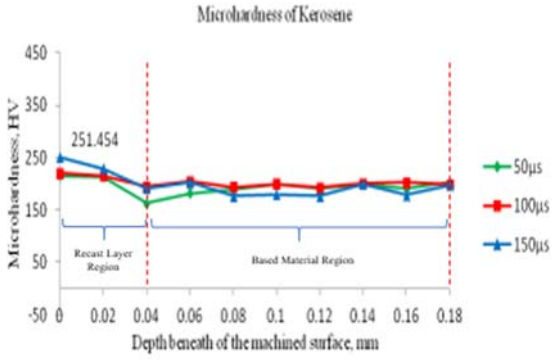
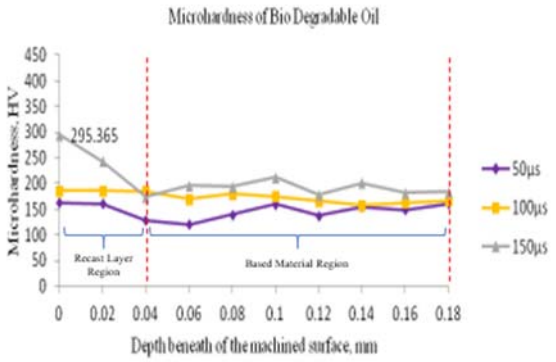
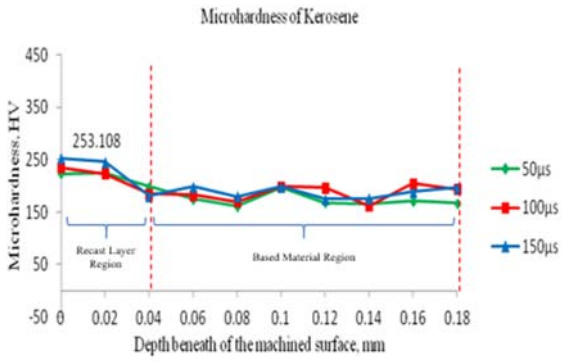
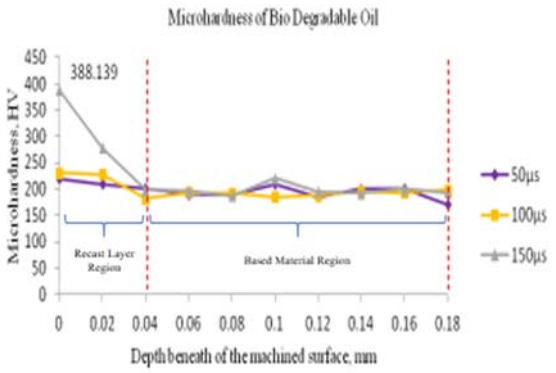
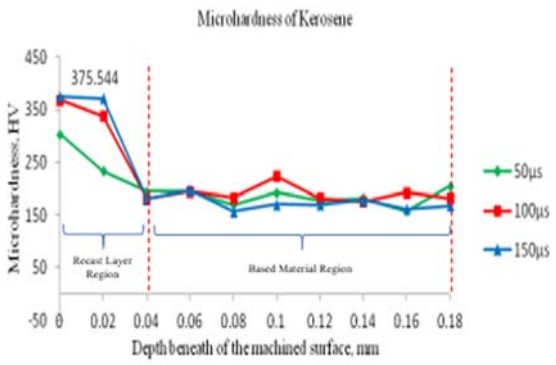
I_p, (A)	RBD Palm oil	Kerosene
6		
9		
12		

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.

Acknowledgements

The authors would like to thanks to Ministry of Higher Education (MOHE), Malaysia and Universiti Tun Hussein Onn Malaysia (UTHM) for funding this research through Fundamental Research Grant Scheme (FRGS/1/2020/TK0/UTHM/03/11) K318 and Graduate Student Research Grant (GPPS H547).

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

References

1) T. Muthramalingam and B. Mohan, "A review on influence of electrical process parameters in EDM," *Achieves of Civil and Mechanical Engineering (ACME)*, **5** (1) 87-94 (2014).
2) A. Bilal, M. P. Jahan, D. Talamona, and A. Perveen, "Electro-discharge machining of ceramics: A review," *Micromachines*, **10** (1) 10 (2019).
3) J.E.A. Qudeiri, A. H. I. Mourad, A. Ziout, M. H. Abidi, and A. Elkaseer, "Electric discharge machining of titanium and its alloys," *Int. J. Adv. Manuf. Technol.,* **96** 1319–1339 (2018).
4) J. Pérez, J. I. Llorente, and J. A. Sanchez, "Advanced cutting conditions for the milling of aeronautical alloys," *J. Mater. Process. Technol.*, **100** (1-3) 1–11(2000).
5) R. Komanduri, and Z. B. Hou, "On thermoplastic shear instability in the machining of a titanium alloy (Ti-6Al-4V)," *Met. Mater. Trans. A.*, **33** (9) 2995-3010 (2002).
6) I. Cascón, J. A. Sarasua, and A. Elkaseer, "Tailored Chip Breaker Development for Polycrystalline Diamond Inserts: FEM-Based Design and Validation," A*ppl. Sci.,* **9** (19) 4117 (2019).
7) A. Elkaseer, A. Abdelaziz, M. Saber, and A. Nassef, "FEM-Based Study of Precision Hard Turning of Stainless Steel 316L," *Materials*, **12** (16) 2522 (2019).
8) A.S. Baskoro, M.A. Amat, R.D. Putra, A. Widyianto, and Y. Abrara, "Investigation of temperature history, porosity and fracture mode on aa1100 using the controlled intermittent wire feeder method," Evergreen, **7** (1) 86–91 (2020)
9) J. E. Abu Qudeiri, A. Saleh, A. Ziout, A. H. I. Mourad, M. H. Abidi, and A. Elkaseer, "Advanced electric discharge machining of stainless steels: Assessment of the state of the art, gaps and future prospect," *Materials*, **12** (6) 907 (2019).
10) A. Elkaseer, J. Lambarri, J. Ander Sarasua, and I. Cascón, "On the development of a chip breaker in a metal-matrix polycrystalline diamond insert: Finite element based design with ns-laser ablation and machining verification," *J. Micro Nano-Manuf.*, **5** (3) (2017).
11) D. N. Mishra, A. Bhatia, and V. Rana, "Study on electro discharge machining (EDM)," *Engineering and Science*, **3** (2) 24-35 (2014).
12) A. Gupta, H. Kumar, L. Nagdeve and K. A. Pawan, "EDM parameter study of composite Materials: A Review," Evergreen, **7** (4) 519-529 (2020).
13) S. Hirata, and M. Ohtaki, "Simultaneous enhancement in the electrical conductivity and reduction in the lattice thermal conductivity leading to enhanced thermoelectric zt realized by incorporation of metallic nanoparticles into oxide matrix," Evergreen, **7** (1) 1–6 (2020). doi:10.5109/2740934.
14) A. K. Srivastava, S. P. Dwidewi, N. K. Maurya and M. Maurya, "3D Visualization and Topographical Analysis in turning of hybrid MMC by CNC Lathe Sprint 16TC made of Batliboi," Evergreen, **7** (2) 202-208 (2020).
15) R. Andias, R. Ibrahim, C. B. Hong, M. Z. Rahim, and S. Ahmad, (2020). "Design and development of open architecture CNC movement control system for analysing precision motion of EDM machine," *International Journal of Integrated Engineering*, **12** (3) 97-106 (2020).
16) H. S. Lim, Y. S. Wong, M. Rahman, and M. K. E. Lee, "A study on the machining of high-aspect ratio micro-structures using micro-EDM," *J. Mater. Process. Technol.,* **140** (1-3) 318–325 (2003).
17) Y. Tzeng, and F. Chen, "A simple approach for robust design of high-speed electrical-discharge machining technology," *Int. J. Mach. Tools Manuf.*, **43** (3) 217–227 (2003).
18) K. H. Ho, S. T. Newman, S. Rahimifard, and R. D. Allen, "State of the art in wire electrical discharge machining (WEDM)," *Int. J. Mach. Tools Manuf.,* **44** (12-13) 1247–1259 (2004).
19) R. Andias, M. A. H. Ahmad, M. Z. Rahim, R. H. A. Haq, A. M. Sabri, N. H. Aziz, A. M. T. Ariffin, A. E. Ismail, and R. Ibrahim, "The influence of graphitization catalyst electrode in electrical

discharge machining of polycrystalline diamondC. finishing condition," *International Journal of Integrated Engineering*, **12** (2) 211-217 (2020).
20) H. K. Kansal, S. Singh, and P. Kumar, "Technology and research developments in powder mixed electric discharge machining (PMEDM)," *Materials Processing Technology*, **184** (1-3) 32-41 (2007).
21) C. Paper, and T. Jaipur, "Investigating feasibility of waste vegetable oil for sustainable EDM investigating feasibility of waste vegetable," *Materials Process Technology*, **18** (3) 38-51 (2016).
22) N.K. Maurya, V. Rastogi, and P. Singh, "Experimental and computational investigation on mechanical properties of reinforced additive manufactured component," Evergreen, **6** (3) 207–214 (2019).
23) M. Maurya, N.K. Maurya, and V. Bajpai, "Effect of sic reinforced particle parameters in the development of aluminium based metal matrix composite," Evergreen, **6** (3) 200–206 (2019).
24) S. Hirata, and M. Ohtaki, "Simultaneous enhancement in the electrical conductivity and reduction in the lattice thermal conductivity leading to enhanced thermoelectric zt realized by incorporation of metallic nanoparticles into oxide matrix," Evergreen, **7** (1) 1–6 (2020).
25) Y. F. Tzeng, and C. Y. Lee, "Effects of powder characteristics on electro-discharge machining efficiency," *Advanced Manufacturing Technology*, **17** (8) 586-592 (2001).
26) E. P. DeGarmo, E. P., J. T. Black, and R. A. Kohsel, *Materials and process in manufacturing*, 9th edition. John Wiley and Son, Inc. USA (2003).
27) H. Ramasawmy, and L. Blunt, "Effect of EDM process parameters on 3D surface topography," *Materials Processing Technology*, **148** (2) 155-164 (2004).
28) L. Li, Y.B. Guo, X.T. Wei, and W. Li, "Surface integrity characteristics in wire EDM of Inconel 718 at different discharge energy," *Procedia CIRP*, **6** 220-225 (2013).
29) K. M. Patel, P. M. Pandey, and R. P. Venkateswara, "Surface integrity and material removal mechanism associated with the EDM of Al_2O_3 ceramic composite," *Refractory Metals and Hard Materials*, **7** (5) 892-899 (2009).
30) H. T. Lee, and T. Y. Tai, "Relationship between EDM parameters and surface crack formation," *Material Technology*, **142** (3) 676–683 (2003).
31) S. M. Harlal, and K. Nitesh, "Investigating feasibility of waste vegetable oil for sustainability EDM," *Proceeding of All India Manufacturing Technology, Design and Research Conference*, 405-410 (2016).
32) Y.H. Guu, H. Hocheng, C. Y. Chou, and C. S. Deng, (2003). "Effect of electrical discharge machining on surface characteristics and machining damage of AISI D2 tool steel," *Materials Science and Engineering*, **358** (1-2) 37-43 (2003).
33) L. C. Lee, L. C. Lim, Y. S. Wong, H. S. Fong, and H. H. Lu, "Towards a better understanding of the surface featueres of electro discharge machined tool steels," *Materials Processing Technology*, **24** 513-523 (1990).
34) L. C. Lee, L. C. Lim, Y. S. Wong, and H. S. Fong, "Crack susceptibility of electro discharges machined surfaces," *Materials Processing Technology*, **29** (1-3) 213-221 (1992).
35) A. G. Mamalis, G. C. Voaniakos, N. M. Vaxevanidis, and J. Prohaszka, "An experiment investigation in macroscopic and microscopic phenomena of electro-discharge machined steel surface," *Mechanical Working Technology*, **15** (3) 335-356 (1987).
36) B. Ekemekci, O. Elkoca, and A. Erden, "A comparative study on the surface integrity of plastic mold steel due to electrical discharge machining," *Metallurgical and Material Transaction; Process Metallurgy and Materials Processing Science*, **36** (1) 117-124 (2005).
37) A. Fikri, "Research of developments in die sinking electric discharge machining (EDM)" *Material Processing Technology*, **2** (3) 324-354 (2012).
38) J. A. Hidayat and S. Bambang, "Characteristic, structure, and morphology of carbon deposited from biodiesel blend," Evergreen, **7** (4) 609-614 (2020)