© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie

The International Journal of Integrated Engineering

The Influence of Graphitization Catalyst Electrode in Electrical Discharge Machining of Polycrystalline Diamond-Finishing Condition

Rino Andias[2], M.A. Haikal Ahmad[1], M. Zulafif Rahim[1,*], RHA Haq[1], A. M Sabri[1], N. Hafizah Aziz[1], Ahmad Mubarak Tajul Ariffin[1], Al Emran Ismail[1], Rasidi Ibrahim[1]

[1]Faculty of Mechanical and Manufacturing Engineering,
University Tun Hussein Onn Malaysia (UTHM), Batu Pahat, 86400, MALAYSIA

[2]Faculty of Industrial Engineering, Telkom University, Bandung, 40257, INDONESIA

*Corresponding author

DOI: https://doi.org/10.30880/ijie.2020.12.02.025
Received 26 April 2019; Accepted 9 January 2020; Available online 28 February 2020

Abstract: Electrical Discharge Machining (EDM) is a non-contact machining process that becomes famous in machining of Polycrystalline Diamond (PCD). The material is typically used as the cutting tools for aerospace and automotive industries. However, low electrical conductivity and high melting temperature of PCD has caused slower EDM process. This investigation purposely designed to investigate the influence of different types of electrode which are Copper (ordinary electrode) and Copper-Nickel (newly proposed graphitization catalyst electrode) on EDM performance of MRR and Ra. Interestingly the newly proposed electrode gave positive impact to the investigated performance indication. Cu-Ni electrode recorded 35% better in MRR than the Cu electrode, though with higher short-circuiting rate. Cu-Ni also provided the lowest Ra value with 10% better than the best Ra produced by Cu electrode. This phenomenon occurred as due to the high interaction between the catalyst materials of nickel and diamond which supported by the qualification data provided in this investigation.

Keywords: Electrical Discharge Machining (EDM), Polycrystalline Diamond (PCD), Copper- Nickel (Cu-Ni), Cop-per (Cu).

1. Introduction

Polycrystalline diamond (PCD) is widely used in various application, mainly as cutting tools for machining of non-ferrous metals, non-metallic materials and also applied in rock drilling application [1, 2]. Considered as among the hardest materials in the world, Polycrystalline diamond was found as suitable cutting tools for high speed machining application of aerospace materials such as Carbon fibre reinforced plastic (CFRP), aluminum alloys and titanium alloys [3- 5]. PCD is produced by sintering of diamond particles at temperature and pressure of approximately 1400°C and 600 MPa respectively. There are several methods to machine PCD into the required tool shape including, Ultrasonic vibration assisted micro milling (UVAM), conventional grinding, laser machining, polishing, and Electrical discharge machining (EDM). UVAM is consider as an effective method for machining hard material but had huge downfall in machining temperature [4, 5], but among the advanced process, EDM was mentioned as the most appropriate and economical method [6, 7, 8].

*Corresponding author: zulafif@uthm.edu.my

EDM is a non-conventional machining where the material is removed through the uses of thermal energy, produced by machining sparks [9, 10]. The quality of the workpiece surface machined by EDM is generally influenced by its machining parameters such as pulse duration, pulse interval, current, voltage and condition of pulse produced [11, 12]. The fundamental problem that caused to low machining efficiency in Electrical Discharge Machining (EDM) of Polycrystalline Diamond (PCD) is the high melting point of diamond grains (approximately 3400°C)[13]. Numbers of research in EDM of PCD are only focused on parameter optimization for better performance in material removal rate (MRR) and surface quality (Ra), with the use of ordinary electrode [8,9, 10 14]. In other study, Cu-Ni electrode was mentioned as able to improve the MRR and Ra of the machined PCD in micro-EDM process. Nickel content in the electrode was theorized as influenced the machining performance which speeds up the erosion process of diamond through chemical reaction [15]. This carbon absorbent material acts as catalyst which accelerates the graphitization of diamond when it is in contact with diamond at high temperature of more than 700oC. This is happened through the following steps; (1) catalytically process will be happened during short circuiting when electrode touches the workpiece at low voltage (closed to zero). (2) This catalytic phenomenon exists as the carbon atom can be easily diffuse into nickel that consequently assists the graphitization of diamond [16].

As the available research focuses on the micro-EDM process, the effect of nickel in normal EDM is remained unknown. In fact, the influence of Ni has not been scientifically proven and thus remained as a theory. In this re-search, the influence of Ni was further investigated in the application of normal EDM. The sparking characteristic of the process was qualified to support the chemical reaction phenomenon explanation.

2. Methodology

The experiment was conducted by using 4-axis SOD-ICK EDM die sinking machine with kerosene as the dielectric. Figure 1 shows the experiment set up for erosion process of PCD. Tektronix MDO3024 oscilloscope was used as the voltage feedback signal acquisition system. Similar to as used by M. Zulafif et al, [17] CTB 010 (89.7 % diamond particles of 10 µm grain and 10.3% cobalt fction) grade of PCD was used as the workpiece in this erosion process. The dimension of the PCD is 7.5mm and 0.5 mm for the width and thickness respectively. The influence of two electrode material of Cu and Cu-Ni with diameter of 10mm was tested. Figure 2 illustrates the PCD and electrode used in this investigation. The erosion process was conducted at a high peak volt-age of 120V and servo voltage gap of 40V. These values were fixed at every experimental run. In many researches, pulse duration (pulse-on), pulse interval (pulse-off) and current are typically categorized as significant erosion parameters for MRR and Ra. Negative polarity was selected in this study as believed to provide better performance (better MRR and Ra) than positive polarity in finishing condition. Based on polarity study, Rahim, M.Z et al mentioned that the negative polarity produced better MRR, compare to the positive polarity [8]. Table 1 summarizes the parameter used in this study.

Ultrasonic Cleaning Machine was used to clean the workpiece and electrode to remove any deposited debris on the surface [18]. With the used of Acetone liquid, clean-ing process was conducted before and after the machining process. In this research, the erosion performance was quantified base on the MRR and Ra. The eroded surface of PCD was analyzed by Surface Roughness Tester SJ-400 according to EN ISO 4288 while the materials removal was calculated by using the following formula (1):

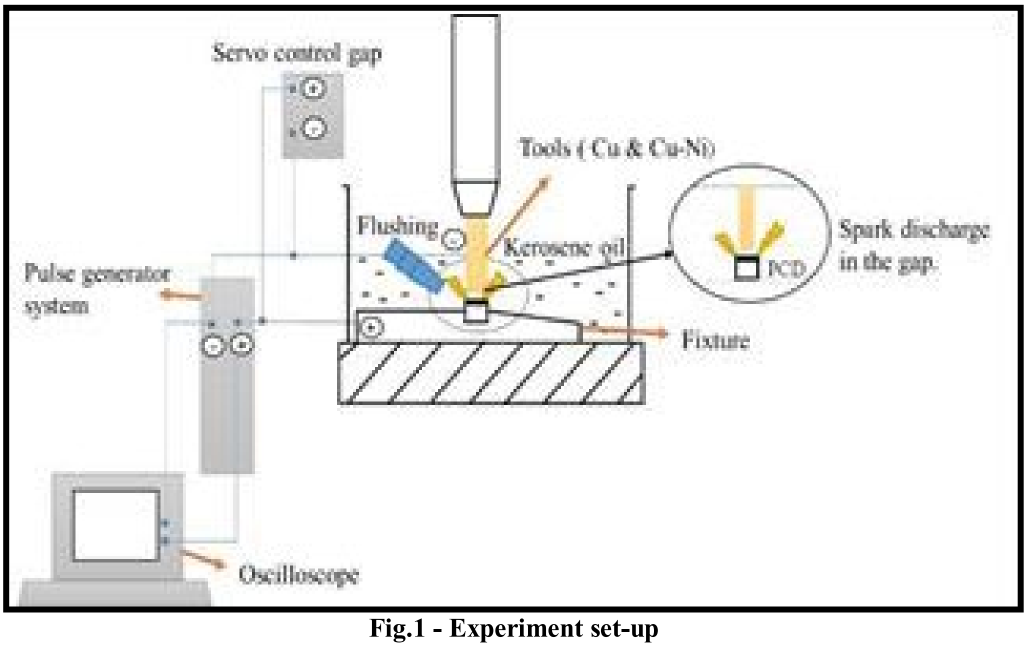


Fig.1 - Experiment set-up

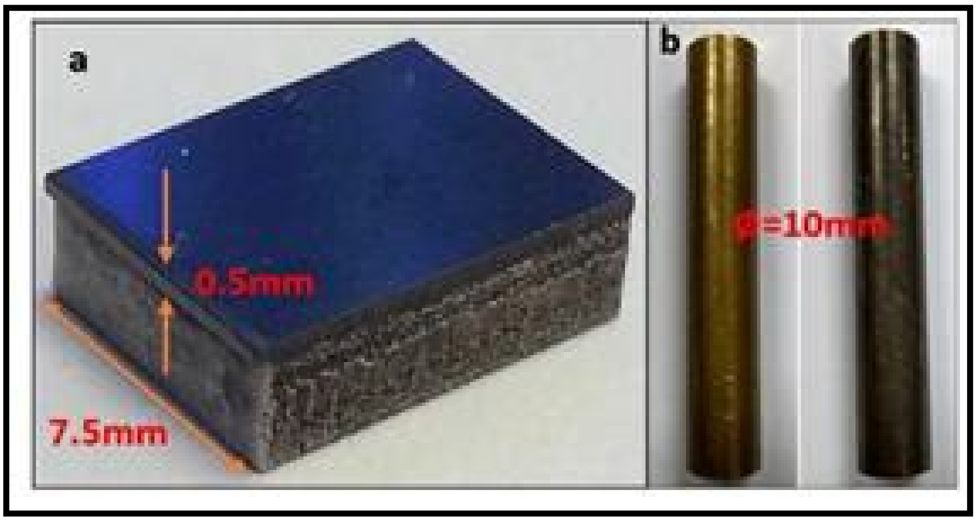


Fig.2 - Workpiece and tools; (a) CTB 101 PCD grade; (b) Cu & Cu-Ni electrode

Table 1 - Erosion process of PCD parameter

Condition	Finishing
Polarity	Negative (-)
Depth of cut (mm)	0.1
Pulse-on (µs)	1 and 5
Pulse-off (µs)	1 and 5
Current I, (A)	1 and 5
Supply voltage (v)	120

$$MRR = \frac{volume(mm3)}{machiningtime(s)} = - \frac{mm3}{s} \qquad (1)$$

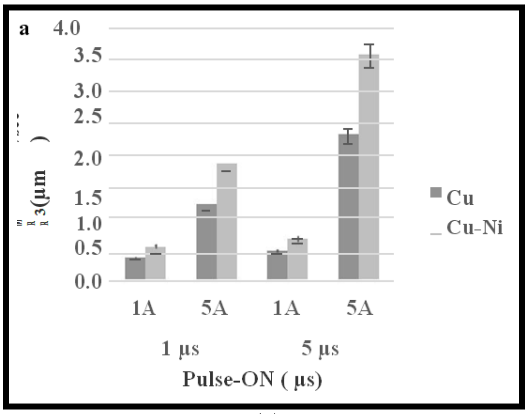
3. Results and Discussion

In this investigation, the machining performance of PCD were influenced by the following electrical discharge machining parameters; voltage (V), pulse duration (ON), pulse interval (OFF), and peak current (I). Figure 3 (a) and Figure 3 (b) show the graph of MRR obtained by both electrodes with the used of pulse interval parameter of 1µs and 5µs respectively (error bar indicates 95% confident interval). In overall, comparing both electrodes, Cu-Ni produced better MRR than Cu at any energy level. The highest value of MRR was recorded 3.12 µm3/s and 3.56 µm3/s for Cu and Cu-Ni electrode respectively. These were obtained by using similar machining parameters of 5A current, 5µs pulse duration and 1µs pulse interval, indicating 35% different. At any cases, it can be seen that the higher the sparking current is, the faster is the erosion process for both electrodes as due to the higher sparking energy. This was found similar as the previous finding of M.A. Haikal et al [19]

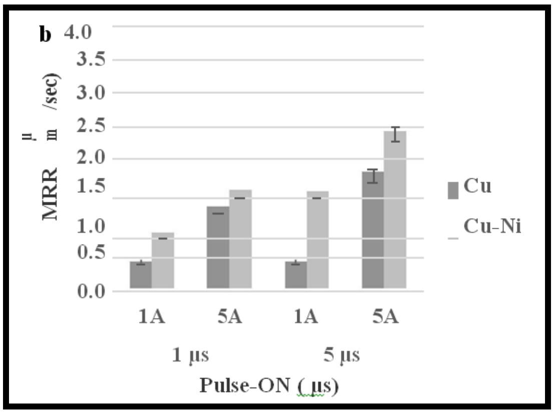
With any electrode, lower sparking interval condition (1 µs) produced better MRR than the higher sparking interval (5 µs). This proved that the shorter sparking interval of 1 µs is enough for debris removal and dielectric strength recovery before the next spark is taking place. There is no indication of insufficient sparking interval as arching is rarely found from the voltage feedback spectrum as shown in Figure 4 for either Cu-Ni or Cu electrode. Hence, this smaller sparking interval ensures higher cumulative energy of sparks is produced per unit time. Refer to the N.K Patel et al, [20] poor machining efficiency will be obtained if improper interval and duration are used.

Catalyst of Nickel in PCD provides significant improvement to the machining performance as Cu-Ni provides better MRR than Cu electrode. This theory was further supported by the voltage feedback signal obtained by the oscilloscope during the machining as shown in Figure 4. From the established theory on material erosion using EDM, the short circuit was categorized as unused pulse that provides nothing to material removal. Spark is not produced during short circuit and noticeable reduction in MRR could be expected with higher short circuit to normal pulses ratio. Interestingly, in the case of Cu-Ni electrode, better MRR was obtained although the feedback signal indicates higher short circuit frequency. Due to the lower thermal conductivity of Cu-Ni electrode (29 W/mok) com-pare to Cu electrode (401 W/mok), it consequently produced lower sparking energy and noticeable produce lower gap voltage (narrow gap between workpiece and tools) [4]. It has been mentioned in previous researches that the nickel is one of carbon absorbent materials [21]. Diamond particles protruding above PCD surface may contact the electrode made of catalytic material, and diffuse into it. It was happened when electrodes touched the workpiece (short circuit) at high temperature during short circuit condition to improve MRR with produced higher short circuit frequency.

The chemical interaction of nickel and diamond (Cu-Ni) believed as happened when the electrode is touching the workpiece (PCD). This provides additional information on erosion process of diamond. Currently, researchers believed that, increasing the energy per spark is an option to increase the material removal rate [16, 17]. However, this would normally contribute to rougher surface. As carbon absorbent phenomenon occurs when the electrode touching the workpiece (short circuit), the migration of carbon atoms from diamond to nickel occurs at significantly low or no voltage (during short circuit). This is interesting as the authors found that the relatively lower energy is used by the Cu-Ni electrode than Cu electrode, although in return it produced better MRR. This signifies the contribution of this finding in which the use of Cu-Ni not only increased the MRR but also reduced the energy required for the erosion process of PCD.



(a)



(b)

Fig. 3 - Result on Material Removal Rate (MRR) by using Cu and Cu-Ni electrode ; (a) Using 1µs pulse-Off; (b) Us-ing 5µs Pulse Pulse-Off

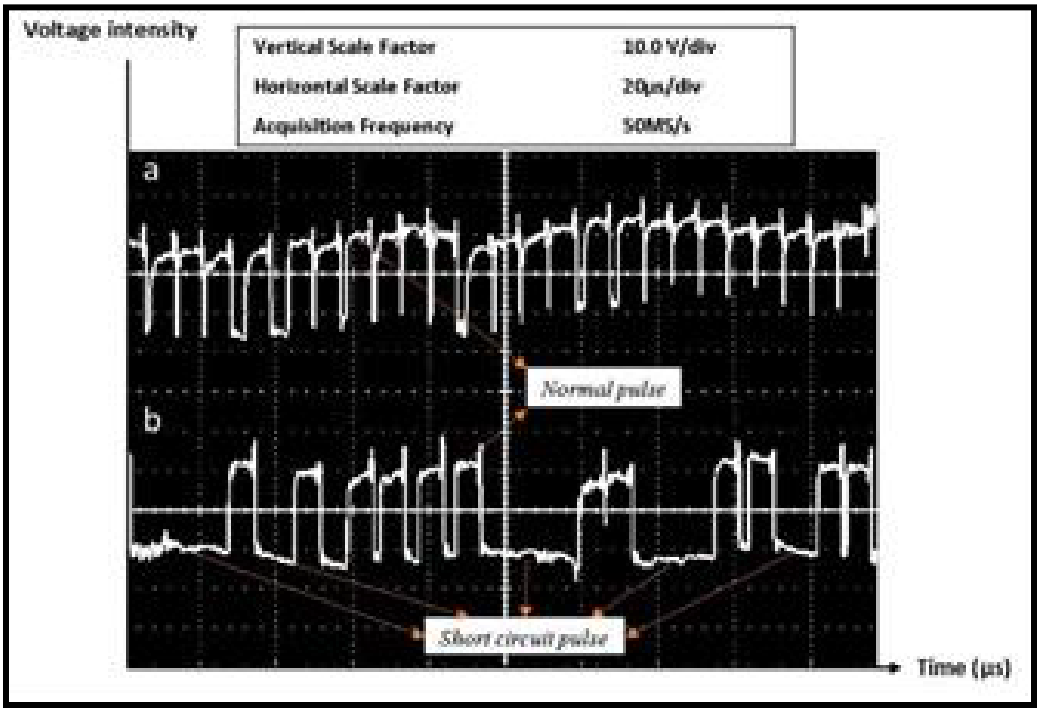


Fig. 4 - Snapshot of voltage feedback for highest MRR (5A current, 5µs pulse duration, 1µs pulse interval), (a) Cu electrode; (b) Cu-Ni electrode

Similar to as MRR, the surface quality of workpiece was affected by the investigated parameters. Figure 5 (a) and Figure 5 (b) show the surface finish after EDM with different pulse interval of 1µs and 5µs respectively. As commonly found, lower sparking energy produced better surface finish indicating by the lower Ra [12, 14, 18]. Remarkably, the newly proposed electrode recoded better mean Ra value than the ordinary electrode at any parameter combination. The lowest Ra obtained by both electrodes in this investigation is 0.58µm and 0.52µm for Cu and Cu-Ni respectively. Both electrodes achieved their best surface roughness when the lowest sparking energy is used (1A current, 1µs pulse-ON and 5µs pulse-OFF). Figure 6 shows the voltage feedback obtained from the experiment with the used of as mentioned parameters.

From the feedback analysis, Cu-Ni electrode produced higher frequency of short circuit with relatively similar energy per spark with Cu electrode. As mentioned by P. J. Liew et al, [22] surface roughness is the result of combination of craters produced by each spark. In this case, approximately similar surface roughness should be obtained by both processes with similar energy per spark in similar gap condition. However, different case was found in this experiment. Although similar in energy per spark, better Ra was obtained by Cu-Ni. In fact, this is true at any experimental condition. Similar to as found in micro-EDM of PCD using cupronickel, Nickel-Diamond chemical reaction was improved the surface quality to certain extend [15]. In the erosion through graphitization mechanism, the diamond grains on the top surface would graphitize and dissolve into the molten cobalt before being flushed away by the dielectric. Since the energy applied in each spark is relatively low, and is below the energy required to shatter the diamond particles, the machined surface appears smooth and without crater [22].

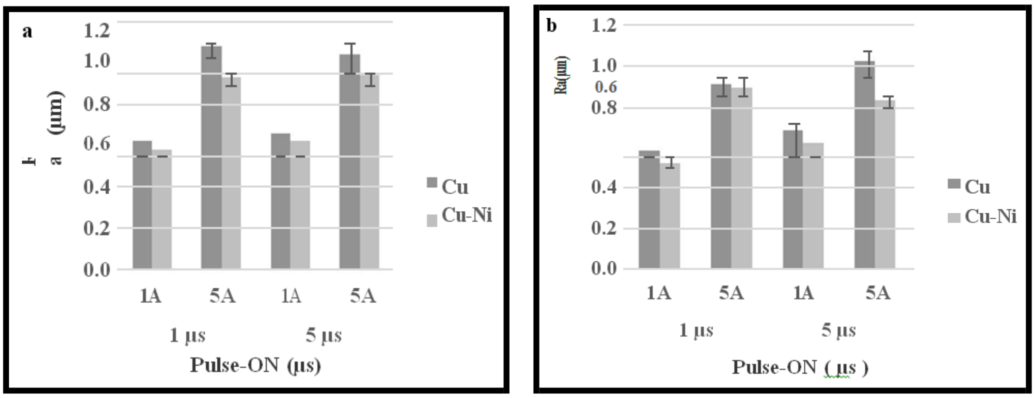


Fig. 5 - Result on Surface Roughness (Ra) by using Cu and Cu-Ni electrode; (a) Using 1µs pulse-Off; (b) Using 5µs Pulse Pulse-Off

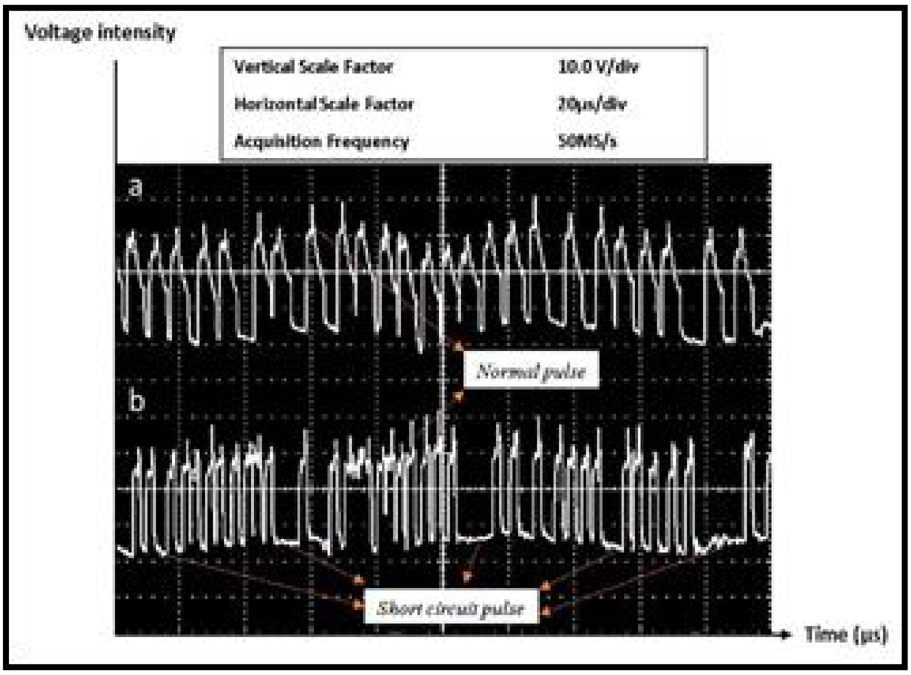


Fig. 6 - Snapshot of voltage feedback for lowest Ra (1A cur-rent, 1µs pulse duration, 5µs pulse interval), (a) Cu electrode; (b) Cu-Ni electrode

4. Conclusion

The machining performance of MRR and Ra offered by different electrode (ordinary electrode (copper) and newly proposed electrode (copper nickel)) in PCD EDM were experimentally determined. Significant different in MRR and

Ra for both electrodes were observed. In this investigation, Cu-Ni electrode leads to better machining performance. With any electrode material used, 5A current, 5µs pulse-ON and 1µs pulse-OFF was found as the best parameter combination for MRR. Compare to Cu electrode, Cu-Ni electrode produced 35% better in MRR. On the other hand, combination parameter of 1A current, 1µs pulse-ON and 5µs pulse-OFF was found as the best parameter combination for Ra. In this case, Cu-Ni electrode provided 10% better in Ra than the Cu electrode. Interestingly, the best EDM performance was provided by the Cu-Ni electrode though with the higher percentage of short circuiting during the process. It can be concluded that, the high inter-action among catalyst materials of nickel and diamond which then brought into better EDM performance occurred while electrode touch the workpiece in a small gap (termed as the short circuit short circuit). This supported the theory that the nickel-diamond interaction speeds up the graphitization process to improve the machining performance of MRR and Ra.

5. Acknowledgement

The authors would like to acknowledge the Ministry of Higher Education (MOHE) Malaysia under Fundamental Research Grant Scheme (FRGS) grant, Vot 1586 and Universiti Tun Hussein Onn Malaysia (UTHM) under Postgraduate Research Grant (GPPS), Vot U805 for financial support.

References

[1] M. Petrović, A. Ivanković, And N. Murphy, “High Rate And High Temperature Fracture Behaviour Of Polycrystalline Diamond,” Key Eng. Mater., Vol. 488–489, Pp. 670–673, 2011.
[2] U. Tun, H. Onn, G. Li, S. Ding, And J. P. T. Mo, “Diamond Machining Jurnal Teknologi E Lectrical D Ischarge G Rinding Versus A Brasive,” No. June, 2015.
[3] C. Dold, M. Henerichs, L. Bochmann, And K.Wegener, “Comparison Of Ground And Laser Machined Polycrystalline Diamond (Pcd) Tools In Cutting Carbon Fiber Reinforced Plastics (Cfrp) For Aircraft Structures,” Procedia Cirp, Vol. 1, No. 1, Pp. 178–183, 2012.
[4] Rasidi I, N H Rafai1,E A Rahim, S A Kamaruddin1 H Ding and K Cheng, I. O. P. Conf, And I. P. Address, “An Investigation Of Cutting Mechanics In 2 Dimensional Ultrasonic Vibration Assisted Milling Toward Chip Thickness And Chip Formation,” Vol. 012057.
[5] R. Ibrahim, E. A. Rahim, A. A. Ibrahim, N. A. Maskam, And S. C. Ghani, “The Effect On The Application Of Coolant And Ultrasonic Vibration Assisted Micro Milling On Machining Performance.”
[6] M. Zeren, “Materials & Design Sintering Of Polycrystalline Diamond Cutting Tools,” Vol. 28, Pp. 1055–1058, 2007.
[7] J. Y. Pei, C. H. N. Guo, And D. J. Hu, “Electrical Discharge Grinding Of Polycrystalline Diamond,”Vol. 472, Pp. 457–461, 2004.
[8] M. Zulafif Rahim, S. Ding, And J. Mo, “Electrical Discharge Grinding Of Polycrystalline Diamond—Effect Of Machining Parameters And Finishing In-Feed,” J. Manuf. Sci. Eng., Vol. 137, No. 2, P. 021017, 2015.
[9] G. Li, M. Z. Rahim, S. Ding, S. Sun, And J. Mo.“Experimental Study On Quality Of Pcd Tools Machined By Different Electric Discharge Grinding Processes,” Cogent Eng., Vol. 41, No. 1, Pp. 1–12, 2016.
[10] M. Z. Rahim, S. Ding, J. Mo, G. Li, R. Ibrahim, And E. A. Rahim, “Electrical Discharge Machining Of Polycrystalline Diamond - A Review.”
[11] S. Clijsters, K. Liu, D. Reynaerts, And B. Lauwers, “Edm Technology And Strategy Development For The Manufacturing Of Complex Parts In Sisic,” J. Mater. Process. Technol., Vol. 210, No. 4, Pp. 631–641, 2010.
[12] S. S. Habib, “Study Of The Parameters In ElectricalDischargeMachiningThrough Response Surface Methodology Approach,” Appl. Math. Model., Vol. 33, No. 12, Pp. 4397–4407, 2009.
[13] D. Wang, W. S. Zhao, L. Gu, And X. M. Kang,“Journal Of Materials Processing Technology A Study On Micro-Hole Machining Of Polycrystalline Diamond By Micro-Electrical Discharge Machining,” Vol. 211, Pp. 3–11, 2011.
[14] H. Rachmat, T. Mulyana, S. H. Hasan, And M. Rasidi, “Design Selection Of In-UVAT Using MATLAB Fuzzy Logic Toolbox.”
[15] J. Yan, K. Watanabe, And T. Aoyama, “CIRP Annals - Manufacturing Technology Micro-Electrical Discharge Machining Of Polycrystalline Diamond Using Rotary Cupronickel Electrode,” CIRP Ann. - Manuf. Technol., Pp. 8–11, 2014.
[16] S. Ion, M. Spectrometry, T. Nakagawa, And I. Sakaguchi, “Catalytic Aided Electrical Discharge Machining Of Polycrystalline Diamond - Parameter Analysis Of Finishing Condition Catalytic Aided Electrical Discharge Machining Of Polycrystalline Diamond - Parameter Analysis Of Finishing Condition,” No. September, Pp. 13–15, 2017.
[17] M. Z. Rahim, “Research On Electrical Discharge Machining Of Polycrystalline Diamond,” No. June, 2015.
[18] R. Ibrahim, N. H. Rafai, K. Cheng, And H. Ding, “A Performance Of 2 Dimensional Ultrasonic Vibration Assisted Milling In Cutting Force Reduction , On Aluminium,” Vol. 11, No. 18, Pp. 11124–11128, 2016.

[19] M. A. Haikal Ahmad Et Al., “Electrical Discharge Machining Of Polycrystalline Diamond Using Copper Electrode - Finishing Condition,” IOP Conf. Ser. Mater. Sci. Eng., Vol. 203, No. 1, 2017.
[20] N. K. Patel, “Parametric Optimization Of Process Parameters For EDM Of Stainless Steel 304 Narendra Kumar Patel National Institute Of Technology Rourkela,” No. May, 2014.
[21] R. J. Borg And D. Y. F. Lai, “The Diffusion Of Gold, Nickel, And Cobalt In Alpha Iron: A Study Of The Effect Of Ferromagnetism Upon Diffusion,” Acta Metall., Vol. 11, No. 8, Pp. 861–866, 1963.
[22] P. J. Liew, J. Yan, And T. Kuriyagawa, “Experimental Investigation On Material Migration Phenomena In Micro-EDM Of Reaction-Bonded Silicon Carbide,” Appl. Surf. Sci., Vol. 276, Pp. 731–743, 2013.