Jurnal
Teknologi

Full Paper

COMPARATIVE STUDY OF MATERIAL REMOVAL RATE AND TOOL WEAR RATE OF COPPER AND ALUMINIUM ON DIE SINKING EDM

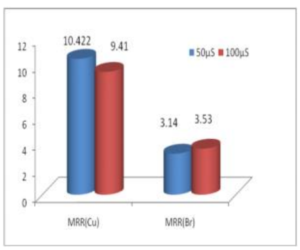
Maidin S.*, H.H. El Grour, Seeying C.

Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka Malaysia

Article history
Received
15 May 2015
Received in revised form
12 September 2015
Accepted
30 September 2015

*Corresponding author
shajahan@utem.edu.my

Graphical abstract



Abstract

The electrical discharge machining (EDM) is one of non - conventional machining process where the erosion of the work piece take place based on the thermal energy between the electrode and the work piece. Due to the widely used and its availability, copper and aluminium was used in this study. These two materials was machined using die sinking EDM to study the characteristics of each material using copper electrode. Few research has been conducted to study copper electrode to machined copper work piece and this was considered as a challenge in this research. More heat was generated and more time consumed was the reason behind machining small depth in this research. The important factors such as discharge current, voltage, pulse on time and pulse off time monitored and recorded to know how these factors effect on the Material Removal Rate (MRR) and Tool Wear Ratio (TWR) of the copper and aluminium work piece material. The experiments conducted under the designed full factorial procedure where pulse on-time and pulse current are used as the input parameters. It was found that material MRR increases with increase in current and pulse duration, but MRR is higher during machining of aluminum than that of copper. In term of TWR it is found that the TWR resulting of machining copper is lower than aluminium

Keywords: Electrical discharge machining, material removal rate, tool wear rate

Abstrak

Pemesinan discas elektrik (EDM) adalah salah satu daripada proses bukan pemesinan konvensional di mana hakisan benda kerja yang berlaku berdasarkan kepada tenaga haba antara elektrod dan benda kerja. Oleh kerana ia digunakan secara meluas dan ketersediaan bahan seperti tembaga dan aluminium telah digunakan dalam kajian ini. Kedua-dua bahan telah dimesin menggunakan EDM die tenggelam untuk mengkaji ciri-ciri setiap bahan menggunakan elektrod tembaga. Kurangnya kajian telah dijalankan untuk mengkaji elektrod tembaga memesin benda kerja tembaga ini dan dianggap sebagai cabaran dalam kajian ini. Lebihan haba telah dijana dan lebih banyak masa digunakan adalah faktor di sebalik pemesinan kedalaman kecil dalam kajian ini. Faktor-faktor penting seperti discharge current, voltage, pulse on time and pulse off time dipantau dan direkodkan untuk mengetahui kadar pembuangan bahan (MRR) dan kadar kehausan mata (TWR) dari bahan tembaga dan aluminium. Eksperimen yang dijalankan di bawah prosedur faktorial penuh yang direka di mana nadi dalam masa dan nadi semasa digunakan sebagai parameter input. Kajian mendapati bahawa MRR adalah lebih tinggi semasa pemesinan aluminium daripada tembaga. TWR yang terhasil daripada pemesinan tembaga adalah lebih rendah daripada aluminium

Kata Kunci: Pemesinan discas elektrik, kadar pembuangan bahan, kadar kehausan mata

1.0 INTRODUCTION

In case of requiring close tolerance, high precision and surface quality, EDM is one of the best processes that can be used to obtain the desired shape [1]. The erosion of the work piece take place due to thermal energy generated between the work piece and electrode. Both electrode and work piece are immersed in dielectric fluid (ionized water or kerosene usually used). When the high voltage (300 v) is applied in modulated pulses, this cause the free electrons of the tool be subjected to high force which in turn emitting the electrons. These electrons then accelerated toward the work piece via the dielectric fluid. As they are moving quickly from tool to work piece, collision with dielectric molecules takes place. Because of this reaction between the free electrons and the molecules more positive ions and electrons will be generated due to the collision. These actions reoccurring again and again till the plasma channel is formed where the temperature approximately 8000 to 10,000^{0}C and because of the very low electrical conductivity that the plasma has, this makes the electrons move from the tool to the work piece whereas the ions move from the work piece to the tool [2]. The material removed from work piece due to the collision of electrode which is desired is known as Material Removal Rate (MRR) whereas material removed from electrode due to the collision of ions is known as Tool Wear Rate (TWR)[3.

2.0 BACKGROUND

2.1 Machining Electrically Conductive Materials

An investigation done by Shabgard et al. (2011) to study the effect or the influence of electrical discharge machine input parameter on characteristics of EDM process using AISI H13 tool steel as work piece [4]. Also the important zone that formed on the work piece after being machined as a result of the thermal energy has been studied. These zones represented in white layer and depth of Heat Affected Zone (HAZ). Copper was used in this research as an electrode. As shown in Figure 1 the study found that the pulse current has a significant effect on the Material Removal Rate (MRR) where the data shows sharp increase on both the MRR and surface finish (Ra). It is observed that the increase of pulse on time leads to increase the MRR and Ra. Also by increasing the pulse current and pulse on time minimized both the white layer thickness and the HAZ In the work piece surface.

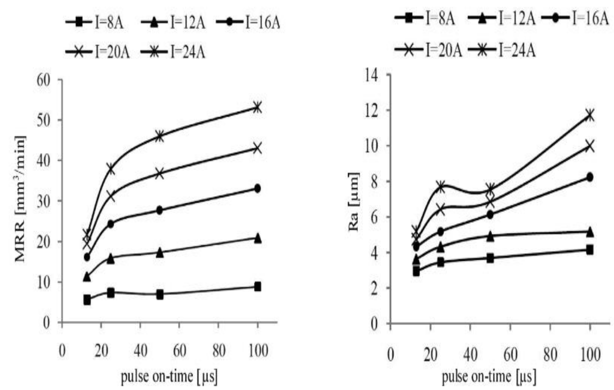


Figure 1 The effect of pulse on time on MRR and Ra

Nikhil Kumar et al. (2012) have studied the characteristics of the MRR using copper and graphite as electrode and AISI P20 steel as a work piece material [5]. The experiment was conducted using die sinking EDM. The second objective of his research was to choose or determine the less cost to machine the steel where suitable selection of electrode can reduce the cost of machining. Nikhil Kumar el al. (2012) noticed that choosing graphite as an electrode leads to more MRR achieved than the MRR using copper electrode to machine the steel also the study found that using graphite electrode is less costly than the copper electrode as shown in Figure 2

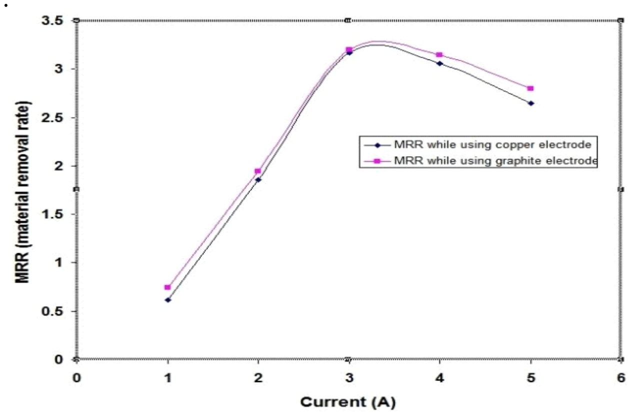


Figure 2 A comparison of MRR using electrode of copper and graphite

Harpreet Singh and Amandeep Singh (2012) performed an experiment to study Effect of Pulse On/Pulse off time on machining of AISI D3 die steel using copper and brass electrode in EDM. They found that maximum MRR is obtained by using a copper electrode for value of pulse on = 50µs. With the increase in pulse on-time from 50 -100 µs, the MRR decreased. This may be due to reason that with high pulse on time (100 µs) more material gets melted at the tool work piece interface which requires proper flushing time. In case of brass electrode the MRR increases with the increase in the pulse on-time from 50-100 µs (Figure 3). Figure 4 shows that with the increase in pulse off time from 15 µs to 20 µs the MRR increased for both copper and brass electrode

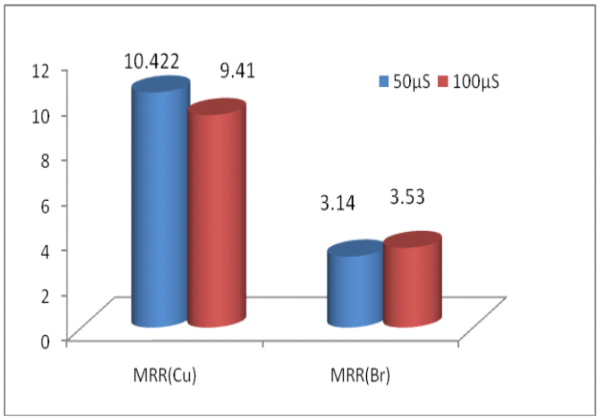


Figure 3 Influence of pulse on time on MRR

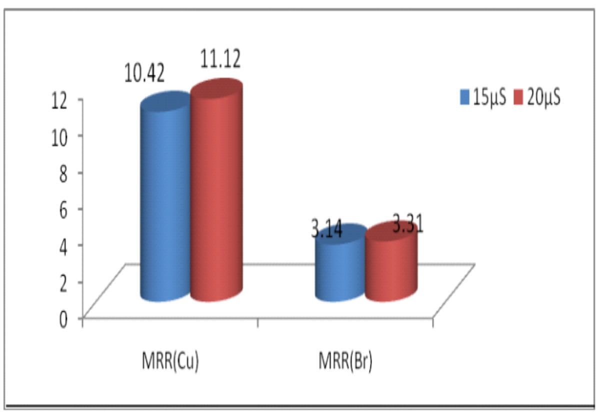


Figure 4 Influence of pulse on time on MRR

Another experiment conducted by Singh and Garg (2009) using wire cutting EDM. The study aimed to investigate various parameters like pulse on time, pulse off time, gap voltage, peak current, wire tension and travel on the material removal rate (MRR) [6]. Die steel (H11) is used as a work piece. The study used one variable at a time approach to test these parameters. It is found that both the wire feed (travel speed) and the wire tension have no effect on the material removal rate of the steel H11. But the MRR was sharply increased by increase the pulse on time and peak current. The material removal rate decreased by increase the pulse off time.

2.2 Machining Non Electrically Conductive Materials

Study conducted by Muttamara et al. (2010) aimed at minimizes the discharge energy to generate the conductive layer resulting to success micro-EDM on insulating ceramics [7]. In this study detailed investigation has been carried out on micro-EDM of Si3N4 using RC-generator. The machined surface was investigated in term of MRR and TWR an assisting electrode layer is created on the work piece. The study found that the most important factor which affects the electrode wear rate is the suitable polarity selected where the tool electrode should be on negative polarity. Three different types of electrode has been used (Cu, Cu w and Ag w) and it is found that the copper (Cu) is the best material that gives greater MRR (60000 micro3/sec) but with 50% of electrode wear ratio.

Another study conducted by Basanta Kumar and Vinod Yadava (2012) where the machining characteristics of Borosilicate Glass have been analyzed by using traveling wire electro-chemical spark machining [8]. The borosilicate glass is electrically non conductive material, which was a challenge in this study. The important factor that affect the machining properties has been analyzed such as the effect of supply voltage, pulse on time and electrolyte concentration on MRR and Ra the researchers found that the MRR and Ra are increased with the increase of supply voltage and pulse on time as illustrated in Figure 5 and 6. But the MRR and Ra found to be increased with the increase of electrolyte concentration at specific value 20% then it is decreased after this value

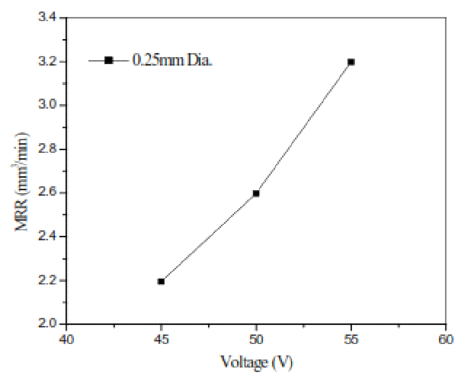


Figure 5 Effect of applied voltage on the MRR for the 0.2mm brass wire diameter

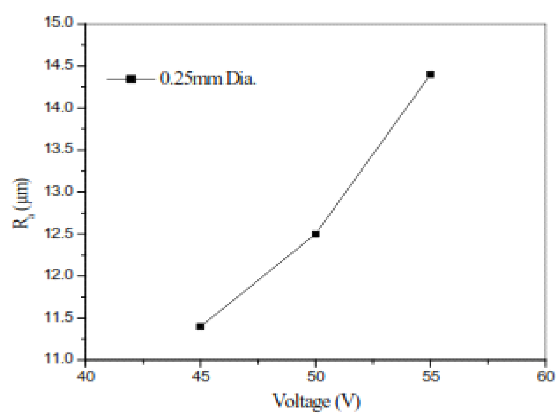


Figure 6 Effect of applied voltage on the Ra for the 0.25mm brass wire diameter

2.3 Powder mixed EDM (PMEDM)

To improve the machining surface and decrease the tool wear ratio powder of conductive material is used by mixed the powder with the dielectric fluid. When pure dielectric fluid is used, the tool wear will be increased and it is preferred to use the mixed powder to maintain the wear rate. The reason is that when using the powder, the particles will hinder the ions that strike the tool and reduce its energy Singh et al. (2010) [9].

C. Mai and Hong Hocheng (2011) have analyzed the effect of various powder that mixed with dielectric fluid on MRR and Ra [10]. The study found that the surface finish of the work piece and the efficiency of machining improved by 70% and 66% respectively. The various mixed powder tested are Si, Al, Gr and CNT where 4g for each litre for Si, Al and Gr is used. And 0.4g/l for CNT was used Figure 7.

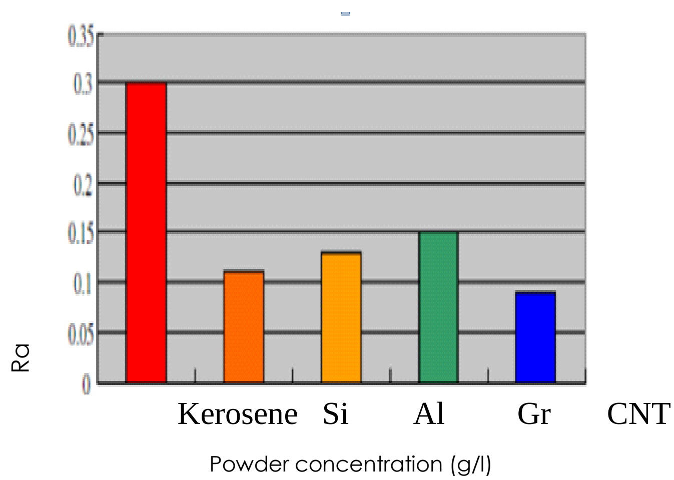


Figure 7 Effect of powder concentration on surface roughness

Other experiment conducted by M.Y. Ali et al. (2011) studied the influence of adding silicon carbide SiC powder concentration in dielectric fluid using micro electro discharge machining where the titanium alloy is used as a work piece and tungsten carbide as an electrode [11]. Sixteen experiments were performed in this study along with two factors and four levels. The factors represented in electrical discharge energy and powder concentration while the levels represented in four different values of currents and concentration. The study showed that when the concentration of powder is low and the energy is high, Ra is also high. But, the high concentration of powder with low energy resulted low Ra.

Kansal et al. (2005) performed a study which aimed to optimize the process parameters using powder mixed (PMEDM). The response surface methodology is used in this study to analyze the experiments [12]. Many variable such as duty cycle, peak current and concentration of the silicon powder were chosen to study the performance of MRR and Ra. The study showed that the silicon powder effect both the MRR and Ra where it showed that the MRR increases with the increase of the powder concentration also the results indicated that the improvement of Ra is expected at higher concentration of silicon powder and it shows that the high peak current and high concentration leads to more MRR generated and small desirable Ra.

2.4 The Effect of Electrode Polarity in EDM

Many researches were conducted in choosing the proper polarity when using the EDM and they come up with the result that indicates achieving more MRR and surface finish is a conflict goal where it is hard to obtain the MRR with good Rs at one time. Dilshad Ahmad Khan (2011) investigated the effect of tool polarity on the machine characteristics in EDM [13]. In this study, the direct polarity was used where the tool is connected to the negative polarity and the work piece is in positive polarity. The copper is used as an electrode and the silver steel is used as a work piece. Oil was used as a dielectric fluid. The study indicated that the higher MRR and lower electrode wear is achieved using direct polarity while by using reverse polarity better surface finish can be obtained. The study also indicated that the best value of pulse duration in 200µs that gives the higher MRR for both direct and reverse polarity. However, the direct one as illustrated in Figure 8 gives higher MRR compared with the reverse polarity. In terms of electrode wear ratio as shown in Figure 9, it is indicated that in both direct and reverse polarity the electrode wear ratio is decreased as the pulse duration is increased. This case can be justified by the mechanism and adhesion of carbon layer on the electrode when using high current duration so that the layer prevents more erosion to take place.

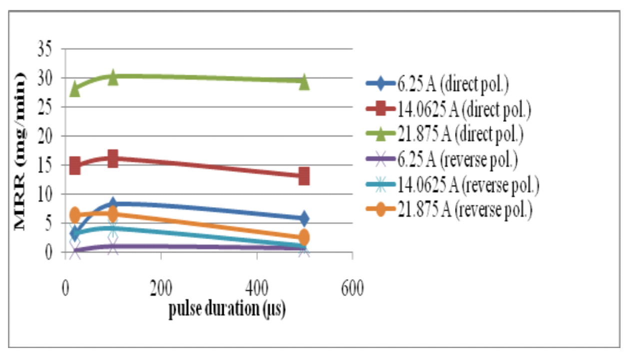


Figure 8 MRR vs. pulse duration at different current levels with direct and reverse polarity

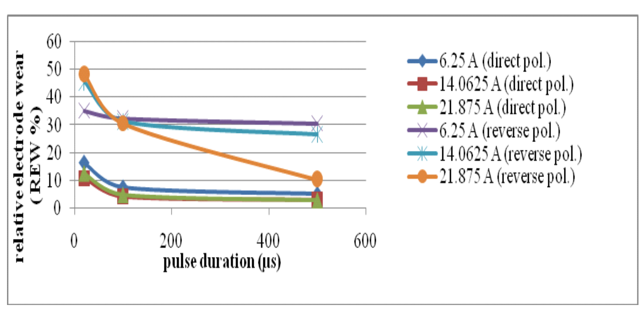


Figure 9 Relative electrode wear vs. pulse duration at different current levels with direct and reverse polarity

3.0 EXPERIMENTAL PROCEDURES

In this experiment copper electrode was used to machine aluminum and copper. The properties of those two materials are shown in Table 1. Sodick CNC EDM die sinking was used to machine 100 x 50 x 6mm work piece of copper and aluminum. 16 mm radius and 75.20 mm length of copper electrode was used to conduct engraves. Pulse current and pulse on time are changed from time to time while keeping other factors such as pulse off time and voltage constants. These parameters are given in Table 2. Direct polarity was used in order to achieve higher material removal and less tool wear rate.

Table 1 Properties of Aluminum and Copper work material

Material	Thermal conductivity (w/m-k)	Melting point (C)	Density (gm. /cm3)
Aluminum	173	580	2.70
Copper	401	1083	8.92

Table 2 Die sinking EDM conditions

Dielectric fluid	Kerosene
Reference voltage	22
Pulse current (A)	8,12,16 and 20
Polarity	direct polarity
Pulse on time (µs)	50, 100, 150 and 200
Pulse off time (µs)	50

4.0 RESULTS AND DISCUSSION

The values listed in Table 2 are used as an input in mini-tap software by using the full-factorial design where two factors and four levels were used to compare the response values of MRR and TWR. Then all the results obtained are drawn using excel software. Two factors and four levels were used to compare the response values of MRR and TWR Table 3 shows the parameters combinations using Mini-tab software.

Table 3 The parameters combinations using Mini-tab software

Pt Type	Run Order	Pt Type	Blocks	I current	I duration
10	1	1	1	16	100
1	2	1	1	8	50
9	3	1	1	16	50
7	4	1	1	12	150
16	5	1	1	20	200
4	6	1	1	8	200
8	7	1	1	12	200
3	8	1	1	8	150
6	9	1	1	12	100
14	10	1	1	20	100
5	11	1	1	12	50
2	12	1	1	8	100
11	13	1	1	16	150
12	14	1	1	16	200
15	15	1	1	20	150
13	16	1	1	20	50

4.1 Material Removal Rate

The work pieces were weighted before and after machining to calculate the material removed for both aluminum and copper work piece (Equation 1).

$$MRR = (M1 - M2) / T \qquad (1)$$

Where M1 and M2 are the weight of work piece before and after machining (g), respectively. T is the machining time (min). Figure 10 shows that the MRR increased with the increase of pulse currents for both materials when 50 µs is applied. Figure 10 also shows that MRR is higher when aluminum is machined compared with copper this is due to the fact that aluminum melting point is lower than copper. When the melting point of the work piece is lower than the other this means for the same energy or current applied, more material will be eroded and the time machining is lower. Figure 11 to 13 shows that for 20 Ampere there is a slight drop in MRR during 200 µs (0.1875 to 0.166 gm/min), this might be because of the too short pulse-off time that is applied leads to insufficient time for cooling and debris removal with the flow of the dielectric fluid and due to shorter pulse-off time, the dielectric fluid does not get sufficient time to deionize before the start of the next discharge cycle. This causes the next spark to be unstable and slows down the cutting process.

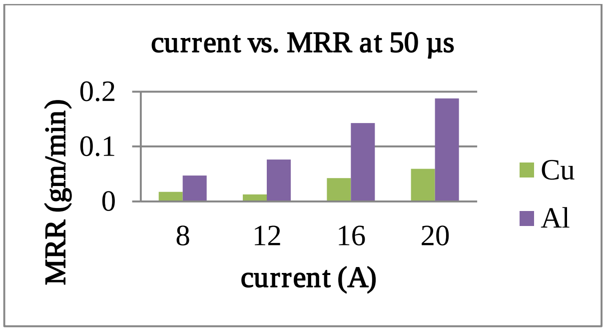


Figure 10 Current vs. MRR at 50 µs

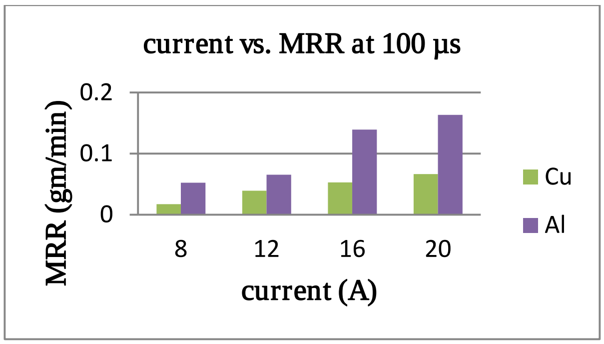


Figure 11 Current vs MRR at 100 µs

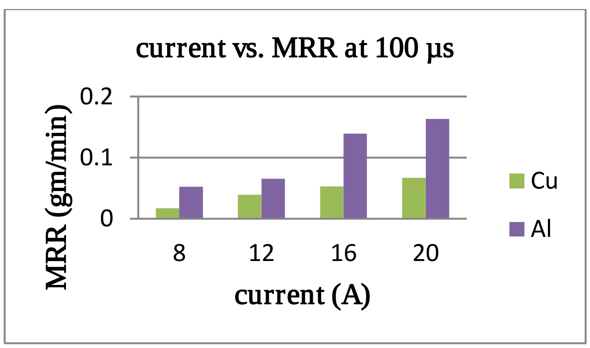


Figure 12 Current vs. MRR at 150 µs

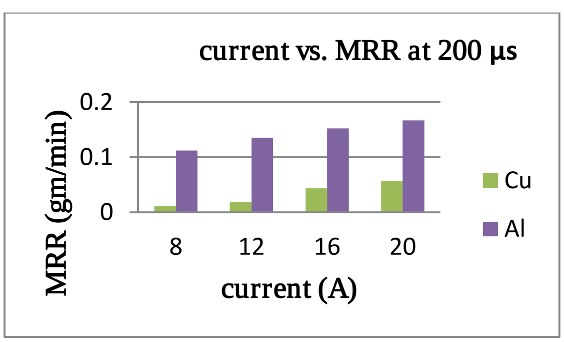


Figure 13 Current vs. MRR at 200µs

Tool wear ratio can be calculated using the equation 2

$$EWR\ (\%) = [EWW/WRW] \times 100 \quad (2)$$

Where EWW = Electrode Wear
WRW = Work Piece Removal Weight

It is noticed that machining copper using copper electrode has less wear value compared with machining aluminum as shown from Figure 14 to 17, this is because copper has higher value of thermal conductivity so that the heat energy will be diffused easily in case of copper work piece keeping the TWR in small value. But in case of using aluminum which has lower thermal conductivity compared with copper, the electrode showed more wear so that the thermal energy cannot be diffused easily resulting in higher wear ratio. In general, and from the data obtained it is obviously that there is no electrode wear in this experiment since the electrode wear ration is less that 1% [14] and it is close to zero value when the copper is machined. Also it is noticed that the TWR become less during highest pulse duration this is because as long as the pulse duration increase the carbon layer will increase on the electrode and the layer becomes thicker and thicker with the increase of pulse durations

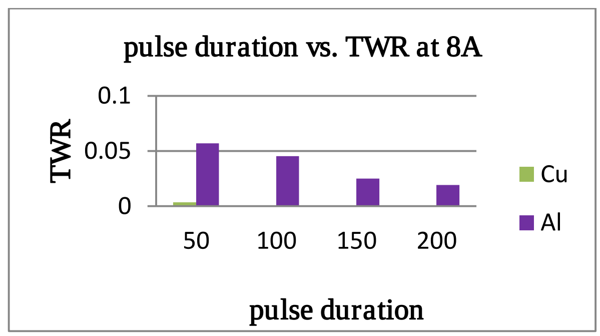


Figure 14 Pulse duration vs. TWR at 8A

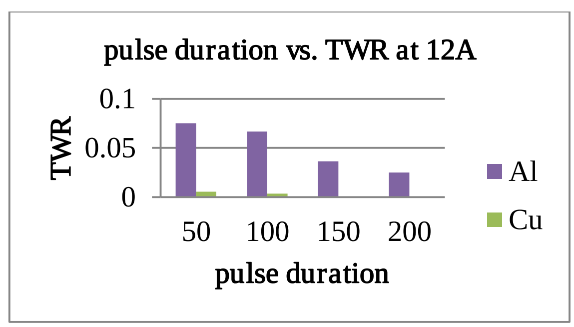


Figure 15 Pulse duration vs. TWR at 12A

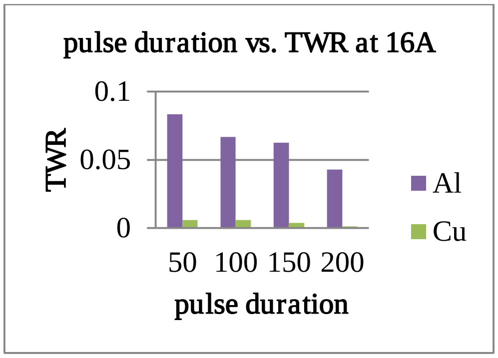


Figure 16 Pulse duration vs. TWR at 16A

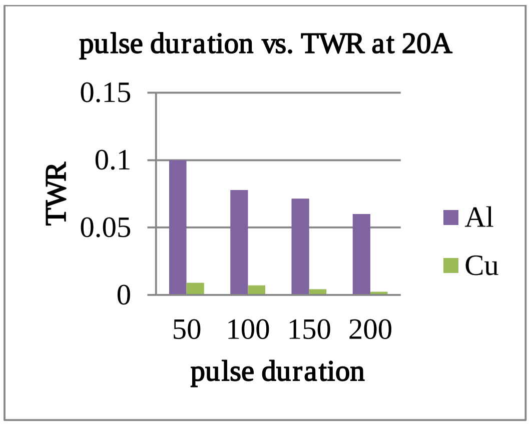


Figure17 Pulse duration vs. TWR at 20 A

In term of current it is observed that when the current is increased the TWR is increased as we can see from Figure 18 to 21 when pulse duration is 50 µs, the TWR values are ranged from 0.0035 to 0.009 at 8 and 20 Ampere respectively for copper and from 0.057 to 0.1 for aluminum. This is because the stronger current will erode more material from both electrode and work piece.

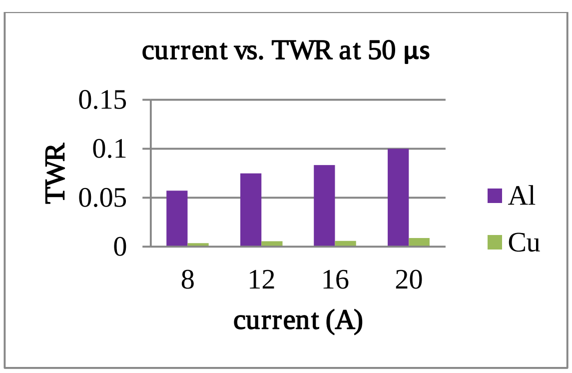


Figure 18 Pulse current vs. TWR at 50µs

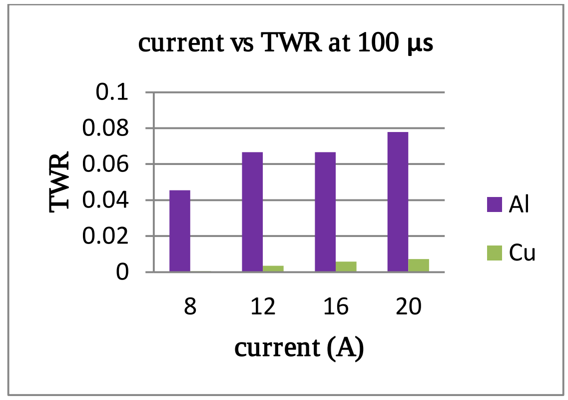


Figure 19 Pulse current vs. TWR at 100 µs

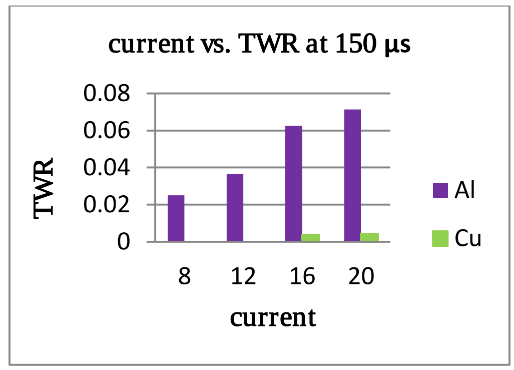


Figure 20 Pulse current vs. TWR at 150 µs

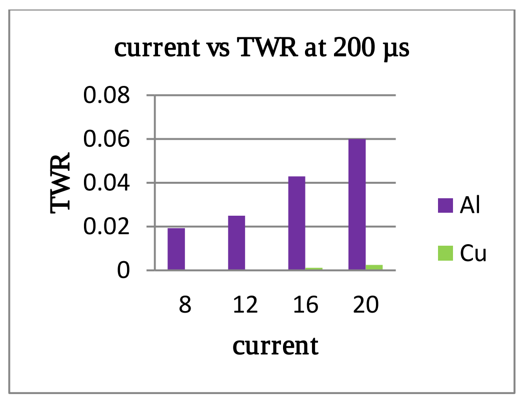


Figure 21 Pulse current vs. TWR at 200 µs

5.0 CONCLUSIONS

From the above analysis and discussions the followingconclusions can be made:

- MRR increases with the increase of current. MRR of aluminum is higher than that of copper due to less melting point of aluminum than copper
- Pulse duration has a little effect on the MRR
- Decrease of the TWR along with the increase of pulse duration this is because of the presence of carbon layer that precipitated on the surface of the electrode and

the thickness of this layer increased with the increase of pulse duration and in turn decrease the TWR.

- Copper has little amount of tool wear when machined using copper electrode, this is because the copper has higher thermal conductivity compared to aluminum which has higher TWR when machined using same copper electrode. The higher thermal conductivity means more thermal energy this work piece can carry and more facilitating the thermal energy will be diffused which maintain the tool wear.

Acknowledgement

The authors are grateful for the assistance provided from all those who are related at the Universiti Teknikal Malaysia Melaka to complete this research.

References

[1] Pandey, A. and Singh, S., 2010. "Current Research Trends in Variants of Electrical Discharge Machining," International *Journal Of Engineering Science And Technology*. 2(6): 2172-2191.

[2] Moarrefzadeh, A., and Mahshahr, 2012. "Study of Work Piece Thermal Profile in Electrical Discharge Machining process." *WSEAS Transaction on Applied and Theoretical Mechanics*. 7(2): 83-92.

[3] Khan, A. A., 2008, "Electrode Wear And Material Removal Rate During EDM Of Aluminum and Mild Steel Using Copper And Brass Electrodes." *International Journal of Advanced Manufacturing Technology*. 39: 482-487.

[4] Mohammad Reza Shabgard, Mirsadegh Seyedz Avvar, Samad Nadimi Bavil Oliaei. 2011. "Influence of input parameters on the Characteristics of the EDM process" , *Journal Of Mechanical Engineering.* 57(9): 689-696.

[5] Nikhil Kumar, Lalit Kumar, Harichand Tewatia, Rakeshyadav. 2012. comparative study for MRR on die sinking EDM using electrode of copper and graphite, *International Journal of Advanced Technology & Engineering Research (IJATER)*. 2: 170-174.

[6] Singh. H., Garg. R. 2009. Effect of Process Parameters on Material Removal Rate in WEDM. *Journal of Achievement in Materials and Manufacturing Engineering*. 32(1): 70-74

[7] Apiwat Muttamara, Pichai Janmanee, Yasushi Fukuzawa. 2010. A Study of Micro-EDM on Silicon Nitride Using Electrode Materials. *International Transaction Journal of Engineering, Management & Applied Science & Technology.*

[8] Basanta Kumar Bhuyan, VinodYadava. 2012. Machining Characteristics Glass Using Travelling Wire Electro-Chemical Spark Machining (TW-ESCM) Process, *Proceeding Of The National Conference On Trends And Advance In Mechanical Engineering. YMCA University Of Science & Technology*, Faridabad, Haryana, Oct 19-20, 2012.

[9] Paramjit Singh, Anil Kumar*, Naveen Beri, Vijay Kumar. 2010. Some Experimental investigation on aluminum powder mixed EDM on machining performance of Hastelloy Steel. *International Journal of Advanced Engineering Technology*, 1(2): 28-45.

[10] Mai, C. & Hong Hocheng. 2011. Advances of carbon nanotubes in electrical discharge, *Int j Adv Manuf Technol.* Doi 10.1007/s00170-011-3476-2.

[11] Ali, M.Y., Atiqah, N., and Erniyati. 2011. Silicon Carbide Powder Mixed Micro Electro Discharge Milling Of Titanium Alloy. *International Journal of Mechanical and Materials Engineering (IJMME)*.6(3): 338-342.

[12] Singh. S., Kansal H. K., Kumar. P. 2005. Parametric Optimization of Power Mixed Electrical Discharge Machining by Response Surface Methodology. *Journal Of Material Processing Technology*. 169(3): 427-436.

[13] Dilshad Ahmad Khan. 2011. Effect of tool polarity on the machining characteristics in electrical discharge machining of silver steel and statistical of the process. *International Journal of Engineering Science and Technology (IJEST*). 3(6): 5001-5010.

[14] Jaharah, A. G., Liang, C. G., Wahid, S. Z., Ab Rahman, M. N., and Che Hassan, C. H 2008. "*Performance of Copper Electrode in Electrical Discharge Machining (EDM) of AISIH13 Harden Steel*. 3(1): 25-29.