CENTRE FOR INSTRUCTOR AND ADVANCED SKILL TRAINING ( CIAST )
DEPARTMENT OF SKILLS DEVELOPMENT
MINISTRY OF HUMAN RESOURCES

**SkillsMalaysia Journal**

# The Electrode Wear Rate of Graphite on the Die Sinking Electrical Discharge Machining (EDM) of Copper Beryllium Alloy

Nor Mohamad Sulong[1], Mohd Razali Muhamad[2], Liew Pay June[3]

[1]Centre for Instructor and Advanced Skill Training (CIAST), Shah Alam, Selangor
[2,3] Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Melaka.

**Abstract**

Electrical discharge machining (EDM) is one of the important non-traditional machining processes and it is widely accepted as a standard machining process in the manufacture of forming tools to produce molds and dies. Machining method of process based on removing material from a material by means of a series of repeated electrical discharges between a tool, called the electrode, and the material being machined in the presence of a dielectric fluid. Electrode and workpiece are the basic components of EDM and the electrode plays an important role, which affects the results of the machining process. In EDM, the choice of electrode polarity is important in deciding the final surface structure. In this paper, a study on electrode wear (EW) of the electrical discharge machining (EDM) of copper beryllium alloy (CuBe) has been carried out. In this work, rough machining condition was tested using graphite as materials for electrode. A study was carried out on the influence of the factors of polarity, intensity, pulse on time and voltage over the listed technological characteristics. Mathematical models will be obtained using the technique of design of experiments (DOE), two level full factorial design to select the condition of the machining process.

***Keywords:*** *EDM, Graphite, Electrode Wear, DOE.*

## Introduction

Copper beryllium alloys are widely used for injection moulding tools, as well as cores and inserts in steel moulds, when a combination of high thermal conductivity, corrosion resistance and good polish ability is needed. The high thermal conductivity (3-10 times higher than steel) ensure uniform, rapid heat removal, minimizing part distortion, poor replication of details and similar defects. Beryllium gives copper the strength of steel, with the conductivity of a copper alloy and allow the mould maker to bring heat energy into the mould and dissipate that energy very quickly. The results are shorter cycle times, which lead to the ability to produce more parts. It can significantly reduce cycle times in injection moulding, even when used in a steel mould just for selected cores and inserts. The high thermal conductivity, however, requires a modification of electro-discharge machining (EDM) parameters compared to the well-known parameters of machining steels. Copper beryllium alloys have a good machinability in conventional metal cutting. However, EDM offers a good alternative, as the process is carried out in wet and submerged media, thereby reducing the health risks associated with machining beryllium and its alloys (Rebelo et al., 2000; Amorim et al., 2004).

EDM technology is increasingly being used in industry for high-precision machining of all types of conductive materials such as: metals, metallic alloys, graphite, or even some ceramic materials, of any hardness and also used in tool, die and mould making industries, for machining of heat treated tool steels and advanced materials (super alloys, ceramics, and metal matrix composites), complex shapes and high surface finish (Singh et al., 2004). Material with any hardness value that are electrically conductive can be cut (Ramasawmy and Blunt, 2004). The important component in EDM process is electrode because it acts like a “cutting tool”.

The materials that commonly used as electrode for EDM are graphite, copper, brass, copper tungsten, copper graphite, zinc alloys and carbon. Graphite is available in many different grades and used in rough and finish EDM operations, particularly in steel (Elman, 2001; Amorim and Weingaertner, 2007). Graphite provides a high material removal rate and low electrode wear, depending on the EDM parameter setting as compared to metallic electrode. Graphite has a much lower density than copper, which makes it the best material for large electrodes (Amorim and Weingaertner, 2007). Graphite does not melt, but rather sublimes, meaning it goes from a solid state directly into gas without melting and going through a liquid state (Elman, 2001). Graphite is easy to machine by all conventional machining process such as milling, drilling, turning and grinding. Graphite is the chosen material by the majority of EDM user in United States of America because most of EDM jobs can be done with copper can also be executed with graphite (Amorim and Weingaertner, 2007). The design of experiments (DOE) technique is a powerful work tool which allows us to model and analyse the influence of determined process variables over other specified variables, which are usually known as response variables. These response variables are unknown functions of the former design variables, which are also known as design factors. Within the design of experiments, there are various types that can be considered. One of the most widely known ones is the factorial design; this consists in experimenting with all the possible combinations of variables and levels (Luis et al., 2005; Puertas et al., 2005).

## Experimental details

### Experimental equipment and setup

The work material used in this study was Copper beryllium alloy. The chemical composition of the work material are as follows: Be = 1.84%, Co+Ni = 0.26%, Ni+Co+Fe = 0.29%, Cu+Be+Ni+Co+Fe = 99.92. The dimension of the work material is 25mm X 25mm X 5mm square shape were used. The EDM experiments were performed by using CNC EDM Sodick, model AQ35L. For the purpose of this study, graphite was selected as the electrode. The size of each electrode is 50mm X 15mm X 15mm. During EDM process graphite electrodes absorb some quantity of the dielectric fluid. To avoid any error when measuring the mass of the graphite tool, it was necessary to carry out a drying process. The electrode were kept in a furnace at $400^{o}$C for 10 hours after EDM test (Amorim and Weingaertner, 2007). The precise quantification of material removal rate (MRR) was possible by using a precise balance (resolution of 0.0001g) to weight the work piece before and after machining process.
Kerosene was selected as dielectric because of its high flash point, good dielectric strength, transparent characteristics, low viscosity and specific gravity (Bhattacharyya et al., 2007).

### Experimental design

The response variables selected for this study refer to the tool using for EDM process which is electrode wear rate (EW). The design of experiments (DOE) was performed through two level full factorial approach of experimental design. The design finally chosen was $2^4$ full factorial with two replications, where a total of 32 experiments for these design were made.

During experimental design, the input parameters (factors) were pulse on time (pulse on duration), peak current, pulsed voltage and polarity. The reason why these factor have been selected as design factors is that they are the most widespread and used amongst EDM researcher (Luis et al., 2005).

The graphs that are to be presented were produced using MINITAB 14 software. The low and high levels selected for pulse on time, peak current, pulsed voltage and polarity were: 50 and 300μs, 20 and 64A, 120 and 200V and –ve (negative) and +ve (positive) respectively. Table 1 shows the design matrix as well as the value obtained in the experiments for the response variables studied in this work which is EW. The EW study have been made using the statistical techniques of design of experiments (DOE) and multiple linear regression analysis. The design of experiments (DOE) technique allows us to model and analyse the influence of determined process variables over other specified variables which are response variables (Puertas et al., 2005). The response variables chosen are amongst variables that are very important in studying EDM process besides surface roughness. Equation 1 show how to measure response variables of EW.

EW=Volume of material removed from electrode/Volume of material removed from part - (1)

Although other ways of measuring EW do exist, in this work the material removal rate and electrode wear rate have been calculated by the weight difference of the sample and electrode before and after undergoing the EDM process (Luis et al., 2005).

## Results and Discussion

The data obtained from the experiment was analysed using Minitab software. The machining parameter studied were the polarity, pulse on time, current and voltage whilst the machining characteristic evaluate was machined electrode wear rate. Table 1 shows the result of the experiments.

Table 1: Results of the experiment

| RUN ORDER | POLARITY | PULSE ON TIME | CURRENT | VOLTAGE | EW (%) |
|---|---|---|---|---|---|
| 1 | +VE | 50 | 20 | 120 | 37.24 |
| 2 | +VE | 50 | 20 | 200 | 40.05 |
| 3 | +VE | 50 | 64 | 120 | 45.69 |
| 4 | -VE | 50 | 20 | 120 | 77.90 |
| 5 | -VE | 300 | 64 | 200 | 25.79 |
| 6 | +VE | 300 | 64 | 120 | 14.29 |
| 7 | +VE | 50 | 64 | 120 | 46.26 |
| 8 | +VE | 300 | 20 | 120 | 13.24 |
| 9 | -VE | 50 | 20 | 200 | 78.47 |
| 10 | +VE | 300 | 20 | 200 | 15.36 |
| 11 | +VE | 300 | 64 | 200 | 12.85 |
| 12 | -VE | 300 | 20 | 120 | 114.80 |
| 13 | -VE | 50 | 64 | 120 | 50.69 |
| 14 | +VE | 300 | 64 | 200 | 12.21 |
| 15 | +VE | 300 | 20 | 120 | 13.50 |
| 16 | -VE | 50 | 64 | 200 | 57.28 |
| 17 | +VE | 300 | 20 | 200 | 13.22 |
| 18 | -VE | 300 | 20 | 200 | 120.07 |
| 19 | +VE | 50 | 64 | 200 | 46.38 |
| 20 | +VE | 50 | 20 | 120 | 43.13 |
| 21 | -VE | 50 | 20 | 120 | 75.58 |
| 22 | +VE | 300 | 64 | 120 | 14.36 |
| 23 | -VE | 300 | 64 | 200 | 29.55 |
| 24 | -VE | 300 | 20 | 200 | 118.34 |
| 25 | +VE | 50 | 20 | 200 | 40.06 |
| 26 | -VE | 50 | 64 | 200 | 52.83 |
| 27 | -VE | 300 | 64 | 120 | 26.63 |
| 28 | +VE | 50 | 64 | 200 | 41.09 |
| 29 | -VE | 50 | 20 | 200 | 76.08 |
| 30 | -VE | 300 | 20 | 120 | 118.53 |
| 31 | -VE | 300 | 64 | 120 | 30.00 |
| 32 | -VE | 50 | 64 | 120 | 52.06 |

## Analysis of Electrode Wear (EW)

Figure 1 shows the normal probability plot of the standardized effect of electrode wear rate (EW). It is observed that the factors A(polarity), B(pulse on time), C(current), interaction between AC, AB, BC and ABC are statistically significant at 95% confidence level. In other words, these factors have large impact on the electrode wear of graphite electrode when machining copper beryllium alloy.

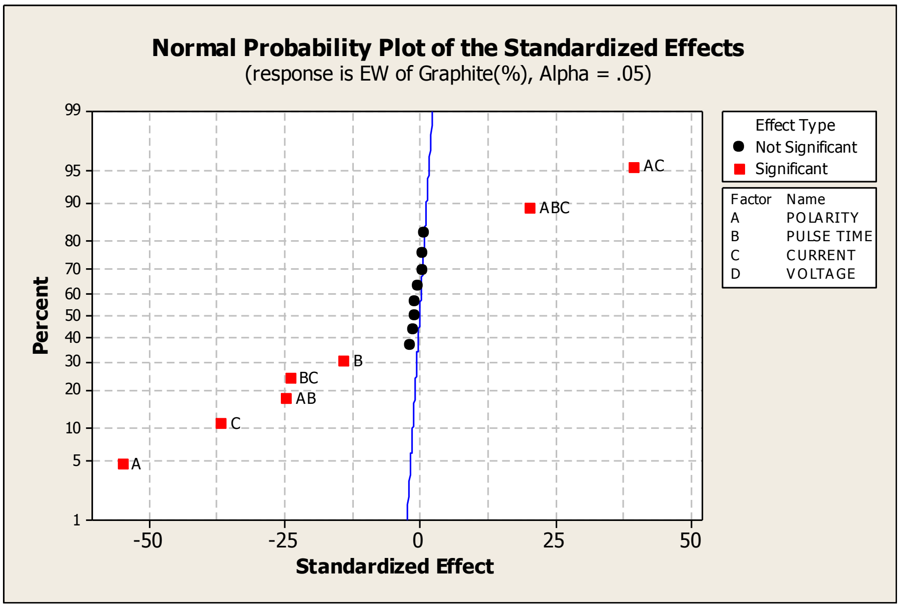


Figure 1: Normal probability plot of the Standardized Effect for EW

Figure 2 shows the pareto of the standardized effect for EW. As can be clearly seen that all the bars of the diagram which go beyond the reference line (2.12) are statistically significant for a confidence level of 95%. The significant factors arranged in order of important are: polarity, interaction between polarity and current, current, interaction between polarity and pulse on time, interaction between pulse on time and current, interaction between polarity, pulse on time and current and lastly pulse on time. The rest of the factors or interactions have very little effect or even no effect to the EW.

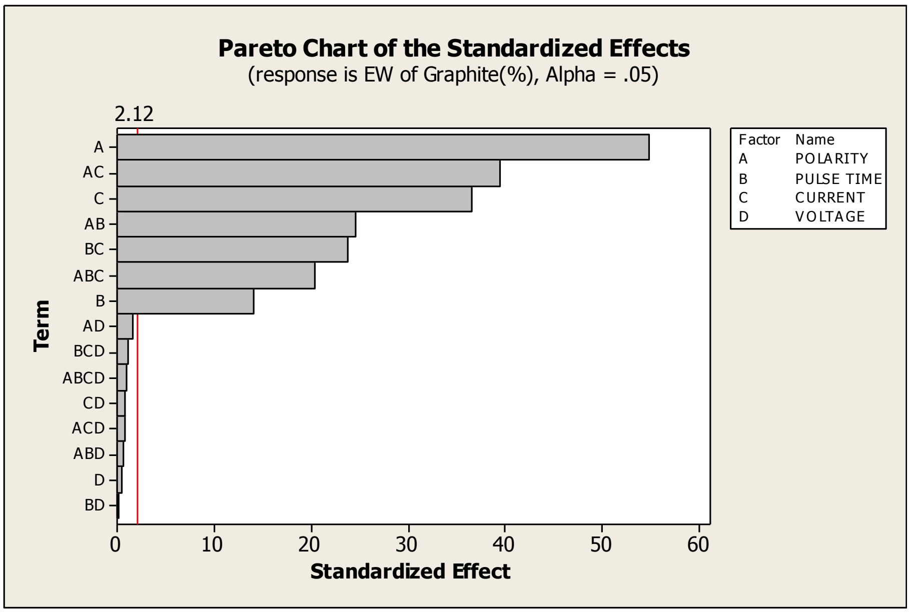


Figure 2: Pareto chart of Standard Effect for EW

Figure 3 shows the main effect plot for EW. As can be seen in the graph, the value of EW decreases significantly with the change of polarity and with the increase of current. The EW also tends to decrease with the increasing of pulse on time. Factor of voltage does not being significant at confidence level of 95%.

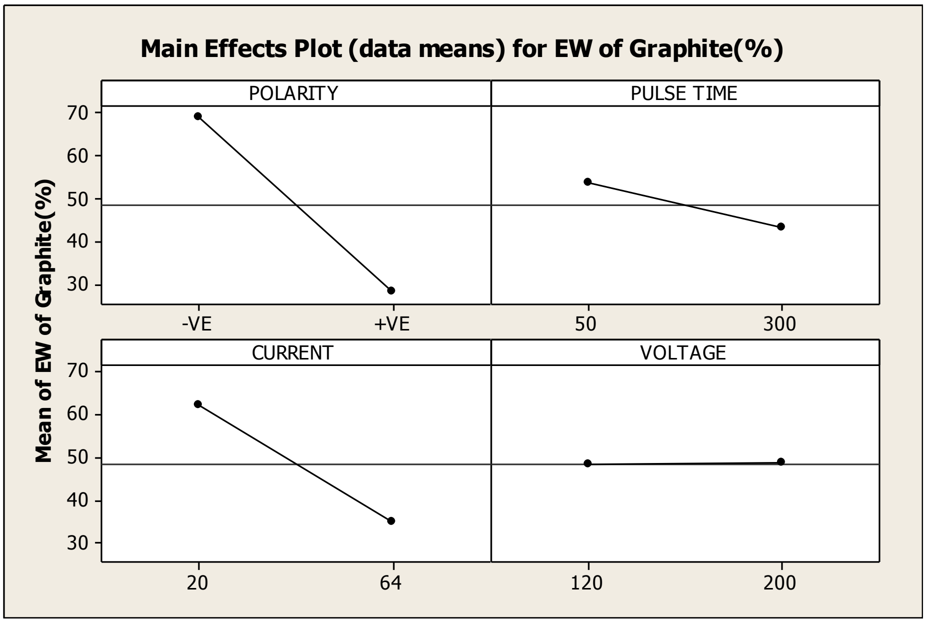


Figure 3: Main effect plot for EW

From the figure 4, it shows that for high level of pulse on time, EW is much lower at the high level of current than at the low level of current. For low level of pulse on time, the results are quite same. The EW is slightly lower at high current than for low current. The interaction between pulse on time and current shows that to get low EW rate of graphite electrode, pulse on time and current must be at high level. The interaction graph between polarity and pulse on time indicates that to obtain less EW during machining, the polarity must be positive and pulse on time at high level. From the interaction between polarity and current, it could be understood that to obtain low EW during machining, current must be at low level and positive polarity of electrode.

.

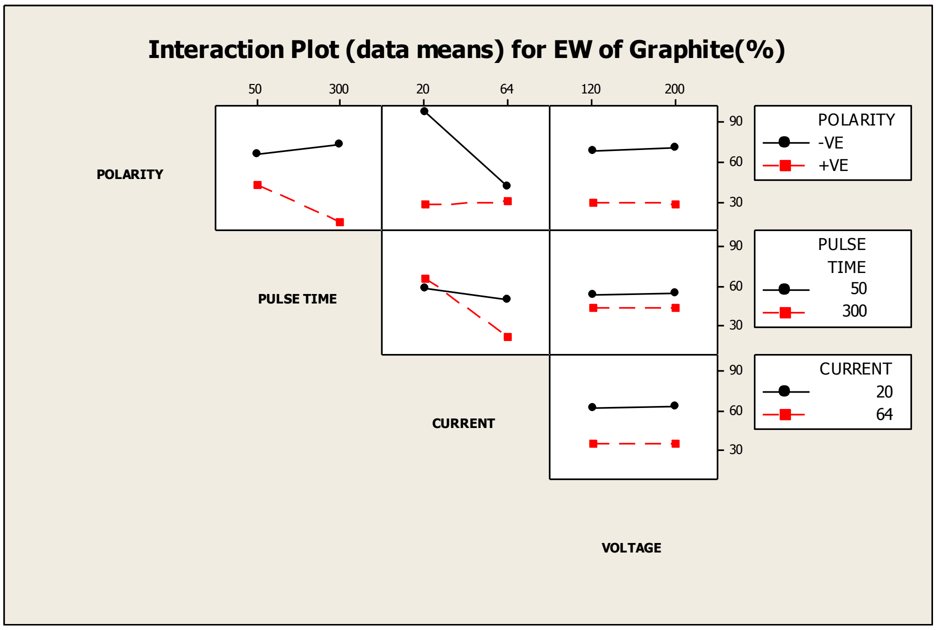


Figure 4: Interaction plot for EW

### Mathematical model development for EW

Table 2 shows the result of the estimated effects and coefficient for MRR (uncoded units). The effects of various machining process variables, e.g. Polarity ($X_1$), Pulse on time ($X_2$) and Current ($X_3$) on EW (Y) has been evaluated by utilising the relevant experimental data from Table 1.The mathematical relationship for correlating the EW and the considered machining process parameters is obtained as follows:

$$Y(EW) = 59.49780 - 17.86730X_1 + 0.06926X_2 - 0.10959X_3 - 0.17567X_1X_2 + 0.33097X_1X_3 - 0.00261X_2X_3 + 0.00225X_1X_2X_3$$

This mathematical model can be used to analyse the effects of the machining parameters considered on EW in EDM process for machining the Copper Beryllium alloy.

Table 2 : Estimated effects and coefficients for EW (uncoded units)

| Term | Estimates of effects | Coefficients |
|---|---|---|
| Constant | | 59.4978 |
| Polarity ($X_1$) | -40.98 | -17.8673 |
| Pulse on time ($X_2$) | -10.50 | 0.0692527 |
| Current ($X_3$) | -27.35 | -0.109591 |
| Polarity* Pulse on time ($X_1X_2$) | -18.36 | -0.175672 |
| Polarity* Current ($X_1X_3$) | 29.52 | 0.330966 |
| Pulse on time* Current ($X_2X_3$) | -17.82 | -0.00260989 |
| Polarity* Pulse on time* Current ($X_1 X_2X_3$) | 15.25 | 0.00225284 |

## Conclusion

In this work, a study on the influence of the most relevant EDM operating parameters over electrode wear (EW) has been carried out. The study has been made for copper beryllium alloy on rough machining using graphite electrode. In order to achieve this, DOE has been used to analyse all response variables.

The following conclusions can be drawn from the analysis of the results:

i) It is observed from the analysis that polarity, pulse on time, current and interaction between each other have large impact on EW of graphite when machining copper beryllium alloy.
ii) Polarity, contributed the most effects to the EW of graphite electrode when machining copper beryllium alloy.
iii) To get low EW rate of graphite electrode, the polarity must be positive, pulse on time and current at high level during machining process.

## References


Amorim, F.L., & Weingaertner, W.L.(2007). The Behavior of Graphite and Copper Electrodes on the Finish Die-Sinking Electrical Discharge Machining (EDM) of AISI P20 Tool Steel, *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, Vol XXVI, No. 4 366-371.

Amorim, F.L., & Weingaertner, W.L. (2004). Die-sinking electrical discharge machining of a high-strength copper-based alloy for injection molds, *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, Vol XXVI, No. 2 137-144.

Bhattacharyya, B. , Gangopadhyay, S. , & Sarkar, B.R. (2007). Modelling and analysis of EDMed job surface integrity, *Journal of Materials Processing Technology,* 189, 169–177.

Elman, C.J. (2001). Electrical Discharge Machining, *Society of Manufacturing Engineers Dearborn*, Michigan. USA

Guha, A. , Smyers, S., Rajurkar, K.P., Garinella, P.S. , & R. Konda. (1995). Optimal parameters in electrical discharge machining of copper beryllium alloys, *Proceedings of the International Symposium for Electro-machining*, ISEM XI, April 17-21, EPFL, Lausanne, Switzerland, pp. 217-224.

Luis, C.J. , Puertas, I. , & Villa, G. (2005). Material removal rate and electrode wear study on the EDM of silicon carbide, *Journal of Materials Processing Technology,* 164-165, 889-896.

Puertas, I. ,Luis, C.J., & Villa, G. (2005). Spacing roughness parameter study on the EDM of silicon carbide, *Journal of Materials Processing Technology,* 164-165 ,1590-1596.

Ramasawmy, H., & Blunt, L. (2004). Effect of EDM process parameters on 3D surface topography, *Journal of Materials Processing Technology*, 148, 155–164.

Rebelo, J.C., Morao Dias, A., Mesquita, R., Vassalo, P., & Santos, M. (2000). An experimental study on electro-discharge machining and polishing of high strength copper beryllium alloys, *Journal Of Materials Processing Technology*,103, 389-397.

Singh, S., Maheshwari, S., & Pandey, P.C.(2004). Some investigations into the electric discharge machining of hardened tool steel using different electrode materials, *Journal of Materials Processing Technology*, 149, 272-277.