Performance of Electroplated Copper Coating on Graphite Electrode in EDM Process

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Abstract

Electrical Discharge Machining (EDM) is a nonconventional manufacturing process whereby a desired shape is obtained by using electrical discharges. Material is removed from the workpiece by current discharges between tool-electrode and workpiece, separated by a dielectric liquid. Copper electroplating is the process to produce a layer of copper on the surface of the substrate in this research was used graphite which is the tool-electrode. The study aims to investigate the performance of EDM product which used graphite coated with the copper layer. The experiment designed by using Taguchi-grey relational approach based multi-response optimization to find the optimal electroplating parameters. The considered electroplating parameters including 3 parameters 2 levels, current density 3.7 A/dm2 and 5.4 A/dm2, electrolyte concentration 0.1 mol and 1.0 mol, plating time 3 hours and 5 hours. The electrode's machining performance of the surface roughness (SR) of workpiece, tool wear rate (TWR) and material removal rate (MRR) will be investigated and compared with the conventional copper electrode.

Keywords: Copper electroplating, graphite electrode, EDM process, surface quality, wear rate

I. INTRODUCTION

Electrical Discharge Machining (EDM) is a non-traditional machining process which using electrical discharges or spark erosion through the electrode to remove material from work piece under the dielectric fluid [1]. When considering tool-electrode for using in EDM, there are various material properties of tool-electrode to be considered such as electric conductivity, thermal expansion, particle size etc. The mostly used material for tool-electrode is copper and graphite. For copper, due to its electric conductivity is high, it mostly be used in rough and finishing surface, also it can be finished mirror like surface as well. However due to its thermal expansion is also high as well, it least used in more complex work piece. For graphite, due to its electric conductivity is almost at the same level as copper, it can be used as alternative material for copper. More over its thermal expansion is also low, its mostly be used to produce more complex work piece [2]. However it cannot achieve the true mirror like finish surface just like copper. In order to obtain tool-electrode which had low thermal expansion and high electric conductivity and can be used in finishing complex work piece. The composite material of copper and graphite is selected. However, method of powder metallurgy for graphite and copper is expensive. The affordable and easier method such as copper electroplating is selected. The copper electroplating method is a process for coating copper onto the desired surface or work piece. By using electrochemical reaction of copper and copper (II) sulfate was shown in (1) and (2) for anode and cathode respectively.

$$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^{-} \quad (1)$$

$$Cu^{2+}(aq) + 2e^{-} \longrightarrow Cu(s) \quad (2)$$

The good performance of tool-electrode is to having high material removal rate (MRR) and low tool wear rate (TWR) and low Surface roughness (SR) [3]-[4]. In this study aim to optimize the performance of tool-electrode through the copper electroplating process using Taguchi Grey relational analysis.

II. MATERIALS AND METHODS

A. Materials and tools

Copper and graphite used in this study are pure copper 99% and graphite's specification was POCO EDM3 and the electrolyte for electroplating was copper(II) sulfate supplied by Chemipan store (Chemical products and tools store) and power supply for electroplating was UNI-T regulated DC power supply 30V 3A and was using XFK magnetic mixer while electroplating as shown in Figure 1.

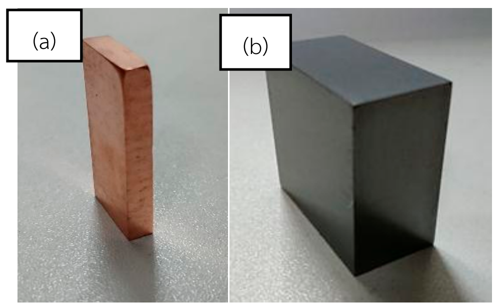


Figure 1 EDM tool electrode, (a) Copper electrode and (b) Graphite before preparation

The EDM machine was Mitsubishi's EA8 and Surface roughness testing machine was Mitutoyo's surface roughness testing machine.

B. Methods

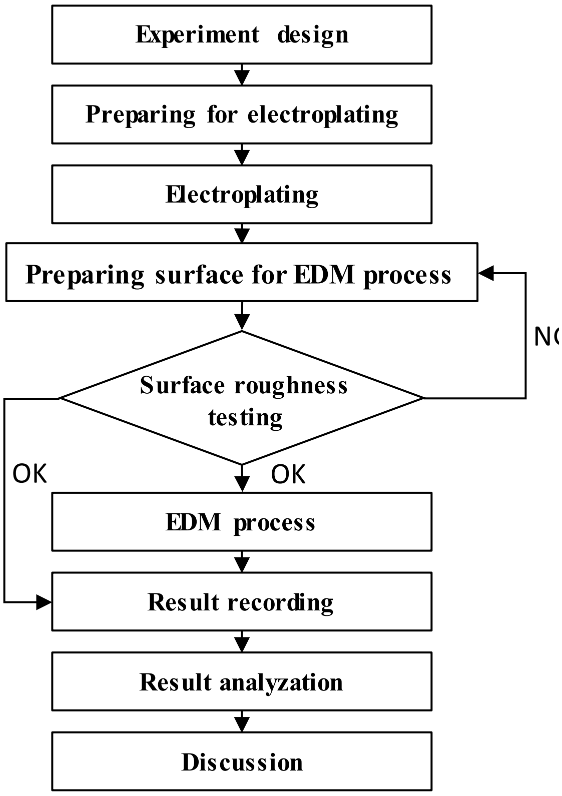


Figure 2 Diagram of the experiment

In this study, the concerned parameters for electroplating are current density (A/dm2), electrolyte concentration (Mol) and electroplating time (hours). Dues to nature of EDM process, TGRA is also a good choice for experiment with the uncertain nature of result or reducing experiment number [5]-[10]. The experiment will be conducted with 2-levels 3-parameters of electroplating from the mentioned parameters as shown in Table 1.

Table 1 Electroplating parameters

Plating parameters	Levels	
	1	2
Plating time (hours)	3	5
Electrolyte concentration (Mol)	0.5	1
Current density (A/dm2)	3.7	5.4

The graphite electrode specimens were prepared for each conditions by cutting into the dimension of 32x17x5 mm and sanding the surfaces. After surfaces were prepared, performing the electroplating process by each condition with the electroplating setup (As shown in Figure 3).

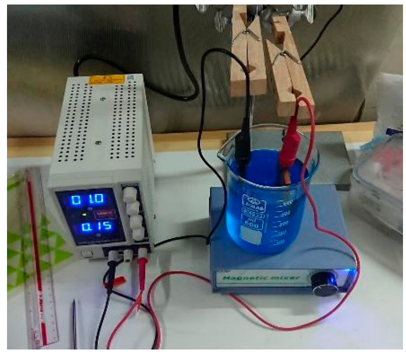


Figure 3 Electroplating setup

After copper electroplated graphite electrode (As shown in Figure 4), all specimen's copper surfaces were sanded for preparing the capable surface for using in glossy mirror EDM process. Then the dimension, weight before EDM for each specimen will be recorded for comparison with after EDM. Then, all sample will be used in EDM by testing with EDM machine in the same machining condition of EDM input for the S50C workpiece within the ESPER program for searching E-conditions pack in the Mitsubishi's EDM EA-8 as shown in Table 2.

Figure 4 Sample of copper electroplated graphite electrode

Table 2 ESPER input setting for search condition in EDM machine

Condition	Parameters
Machining type	Cavity
Material	Cu-St, Gr-St
Surface roughness(Ra)	0.6
Finishing Process	Glossy mirror
Fluid	Emission
Contact area (mm^2)	75
Initial Machining	ON
Undersize	0.12
Orbital pattern	200
Priority	wear rate

After obtains the Workpiece's surface roughness will be recorded by Mitutoyo's SV-3100 surface testing machine (Shown in Figure 5),

Figure 5 Mitutoyo's surface testing machine

Workpiece's weight and electrode's dimension and weight after tested was recorded and be used to analyze with TGRA for the electrode performance of SR,MMR and TWR respectively.

After analyzed with TGRA the optimal electroplating condition and predicted result could be obtained, the confirmation for the optimal condition was conducted and the result was recorded for compared with predicted result and used in discussion for performance when comparing with copper electrode.

III. RESULTS AND DISCUSSION

A. Experiment results

The result of EDM process from all the electroplating condition was recorded and can be summarized as shown in Table 3 and the workpiece surfaces can be shown as Figure 6.

Table 3 EDM process experiment result

Condition	Surface roughness (µm)	Material Removal Rate (mm3/min)	Tool Wear Rate (mm3/min)
1	0.171	$8.012x10^{-08}$	0.770
2	0.257	$5.383x10^{-07}$	0.792
3	0.277	$4.451x10^{-07}$	0.783
4	0.203	$1.322x10^{-07}$	0.785

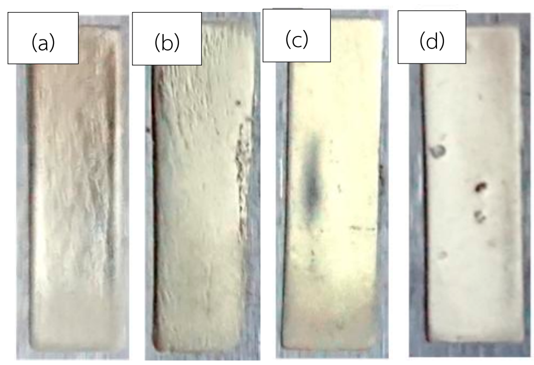


Figure 6 Workpieces surfaces after EDM process by using copper plated graphite electrode with a). Condition 1, b). Condition 2, c). Condition 3, d). Condition 4.

For each condition, surface profile has a mirror like reflection. The surface roughness is low and causing the mirror like reflection, however the profile of the surface is not uniformly flat. The reason for this might be from copper's layer changed its surface profile due to thermal expansion. For condition 4, there's a hole on the surface which it might has air bubble in the copper layer when electroplating.

B. Taguchi-Grey relational analysis

Using Taguchi method to find Signal-Noise ratio (S/N ratio) on the EDM process results by using (3) for Smaller-the-better analysis of SR, TWR and (4) for Larger-the-better analysis of MMR [11].

$$\frac{S}{N} = -10 * \log\left(\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{Y_i^2}\right)\right) \quad (3)$$

$$\frac{S}{N} = -10 * \log\left(\frac{1}{n}\sum_{i=1}^{n}(Y_i^2)\right) \quad (4)$$

Where Yi is the response result for each experiment condition and n is the number of experiment. Signal-Noise ratio for each condition results are as shown in Table 4.

Table 4 S/N ratio

Condition	Surface roughness (dB)	Material Removal Rate (dB)	Tool Wear Rate (dB)
1	15.340	-2.275	138.345
2	11.801	-2.030	122.643
3	11.150	-2.120	124.317
4	13.850	-2.104	133.965

The S/N ratio result will be normalized for being use in the grey relational analysis by using (5) and (6) for smaller-the-better of SR,TWR analysis and larger-the-better of MMR analysis respectively.

$$x_i^*(k) = \frac{maxy_i(k) - y_i(k)}{maxy_i(k) - miny_i(k)} \quad (5)$$

$$x_i^*(k) = \frac{y_i(k) - miny_i(k)}{maxy_i(k) - miny_i(k)} \quad (6)$$

Where xi*(k), is normalized S/N ratio, yi(k) is the S/N ratio obtained from the Taguchi analysis. The min yi(k) and max yi(k) are minimum and maximum values of S/N ratio respectively. The normalized S/N ratio is shown in Table 5.

Table 5 Normalized S/N ratio

Condition	Surface roughness	Material Removal Rate	Tool Wear Rate
1	0.000	0.000	0.000
2	0.845	1.000	1.000
3	1.000	0.893	0.636
4	0.356	0.279	0.698

The normalized S/N ratio will then be used to determined deviation sequence using (7)

$$\Delta_{0i}(k) = |x_0^*(k) - x_i^*(k)| \quad (7)$$

Where $\Delta_{0i}(k)$, $x_0*(k)$, $x_i*(k)$, are the deviation, reference and comparability sequences respectively. The determined deviation sequences are shown in Table 6.

Table 6 Deviation sequence

Condition	Surface roughness	Material Removal Rate	Tool Wear Rate
1	1.000	1.000	1.000
2	0.155	0.000	0.000
3	0.000	0.107	0.364
4	0.644	0.721	0.302

The grey relational coefficient (GRC) is determined using (8)

$$\xi_i(k) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{0i}(k) + \xi\Delta_{max}} \quad (8)$$

Where ξ_i (k) represents the GRC of individual response variables computed as a function of Δmin and Δmax, the minimum and maximum deviations of each response variable and ξ is the distinguishing or identification coefficient, defined in the range from 0 to 1, it is generally set at 0.5 to allocate equal weights to every parameter. The GRC for each condition's response are shown in Table 7.

Table 7 Grey Relational Coefficient

Condition	Surface roughness	Material Removal Rate	Tool Wear Rate
1	0.333	0.333	0.333
2	0.763	1.000	1.000
3	1.000	0.824	0.578
4	0.437	0.409	0.624

Grey relational grade (GRG), is then computed by averaging the GRC of each response variable using (9)

$$\gamma_i = \frac{1}{n}\sum_{i=1}^{n} \xi_i(k) \tag{9}$$

Where γ_i represents the value of GRG determined for the ith experiment, n being the aggregate count of performance characteristics. The rank for each parameter and condition could be determined. By using the GRG ranking from the highest to lowest. The determined GRG, condition ranking are shown in Table 8.

Table 8 Grey Relational Grade & Rank

Condition	GRG	Rank
1	0.333	4
2	0.921	1
3	0.801	2
4	0.490	3

C. *Optimal parameter and confirmation*

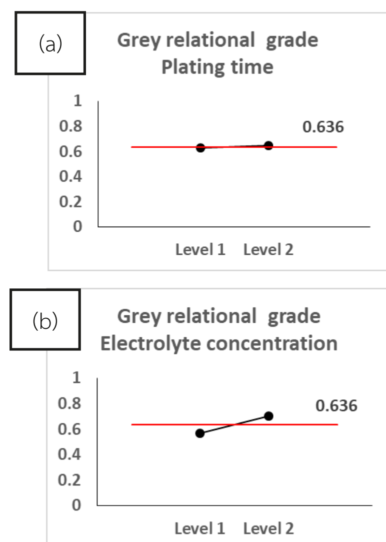
The optimal parameter will then be determined by using (10)

$$L_i = \frac{1}{n}\sum_{i=1}^{n} \gamma_i \tag{10}$$

Where L_i is the average of GRG for the ith level of those parameters. The main effect for each parameter can be determine by using the difference of maximum and minimum of those parameters average GRG and can be ranking from the highest to lowest. The average of GRG for each level of parameters, the optimal level of parameter for the copper electroplating and the main effect with ranking can be summarised as shown in Table 9 and Figure 6.

Table 9 Average GRG

Parameters	GRG		Main Effect	Rank
	Level 1	Level 2	(Max-Min)	
Plating time	0.627	0.646	0.018	3
Electrolyte concentration	0.567	0.706	0.138	2
Current density	0.412	0.861	0.449	1



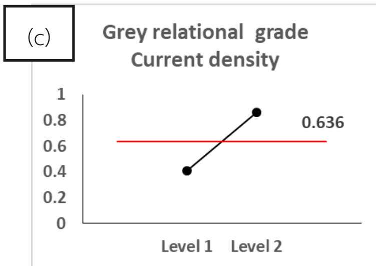


Figure 6 GRG plot for each level of a). Plating time, b). Electrolyte concentration, c). Current density

After optimal condition of copper electroplating was obtained, which is plating time level2 (5 hours), electrolyte concentration level2 (1 Mol) and current density level2 (5.4 A/dm2). The predicted GRG can be calculated by using (11)

$$\gamma_{predicted} = \gamma_m + \sum_{i=1}^{q} \gamma_o - \gamma_m \qquad (11)$$

Where $\gamma_{predicted}$ is the predicted GRG, γ_m is the mean GRG, γ_o is the maximum of average GRG and q is number of factors affecting response values. Then the confirmation of the predicted optimal parameter was conducted and compared with the condition that given the best result in the experiment. The confirmation test result is as shown in Table 10.

Table 10 Predicted GRG &confirmation test result

	Best of experiments	Predict	Difference
	Level 2-1-2	Level 2-2-2	
GRG	0.819	0.904	**10.46%**
SR	0.277	0.191	**31.05%**
TWR	1.322×10^{-7}	2.126×10^{-7}	**-60.82%**
MRR	0.783	0.78	**-0.45%**

From the confirmation testing result, the predict condition of plating time level 2 (5 hours), electrolyte concentration level 2 (1 Mol) and current density level2 (5.4 A/dm2) given the better result of surface roughness than the best result of the experiment from the condition of plating time level 2 (5 hours), electrolyte concentration level 1 (0.5 Mol) and current density level 2 (5.4 A/dm2), even though the result of TWR and MMR still inferior than the best result of experiment. The difference in the TWR and MMR's results are small and can be negligible. In order to confirm the result the optimal condition copper electroplating graphite electrode. The testing with the same EDM condition by using copper electrode was conducted and the result was compared with the optimal condition as shown in Table 11.

Table 11 Performance comparison

Mean	Optimal	Cu 100%
SR(μm)	0.191	0.197
TWR(mm3/min)	2.126×10^{-7}	1.580×10^{-7}
MRR(mm3/min)	0.780	0.85

From the result of performance for the optimal condition when comparing with copper electrode. It can be said that the performance in surface roughness of copper electroplating graphite electrode is on the same level as the copper electrode, however the tool wear rate and material removal rate is still inferior to the copper which the reason might be from the electrolyte using in the electroplating process which contain H2 O. While electroplating, H2 O receiving electrons producing H2 and OH as shown in (12) [12], causing air gap in the copper layer, resulted in poor electric conductivity and structure for the electrode.

$$2H_2O + 2e^- \longrightarrow H_2 + 2OH^- \qquad (12)$$

IV. CONCLUSION

The optimal condition of 5 hours in electroplating time, 1 mol of electrolyte concentration and current density of 5.4 A/dm^2. The optimal condition's copper electroplating graphite electrodes were successfully in producing workpiece's surface roughness of 0.191 μm in the same level as copper electrode of 0.197 μm in glossy mirror EDM process. However there's still the room for the improvement in the tool wear rate and material removal rate which in this experiment result can be consider inferior from the level of copper electrode. The author suggests in changing copper electroplating method from using copper (II) sulfate which contain 5 atoms of H_2O to other solution of copper which doesn't contain H_2O or the substance that could be resulted in the increasing of electric resistivity or causing the irregularity in the electroplating process. Furthermore, considering the alternate electrode quality check process such as testing electrical conductivity due to material conductivity's affect the quality of electrode in the EDM process.

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