Investigation of Surface Roughness and Material Removal Rate (MRR) on Tool Steel Using Brass and Copper Electrode for Electrical Discharge Grinding (EDG) Process

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Abstract

This paper presents the investigation on surface roughness and material removal rate (MRR) of tool steel machined with brass and copper electrode for Electrical Discharge Grinding (EDG) process. The machining parameter include pulse ON time, pulse OFF time, peak current and capacitance. Analysis of variance (ANOVA) with Taguchi method is used to investigate the significant effect on the performance characteristic and the optimal cutting parameters of EDG. The result shows that, the surface roughness value when using of both tool materials are mostly influenced by pulse ON time and peak current. The capacitance parameter in both experiments was not giving any significant effect. The significant factors for the material removal rate due to the machining parameter are peak current parameter and ON time parameter but it also can increase the machining time

Keywords: Electrical Discharge Grinding (EDG), Tool steel, Surface roughness, Material removal rate.

1. INTRODUCTION

Electrical Discharge Machining (EDM) is a high precision metal removal process using thermal energy by generating a spark to erode the workpiece. In the EDM process, the workpiece must be a conductive electricity material which is submerges into the dielectric fluid for better erosion. EDM machine has wide application in production of die cavity with large component, deep small diameter hole and various intricate shaped.

A.B.M.A. Asad et al [1] recommended that for hard-to-machine workpiece materials, it should be machined very precisely in 3-dimensional forms in the micron range for microinjection. For the fabrication of complex 3-dimensional molds using very tough die materials, EDM is one of the alternative machining processes that can be used successfully. EDM can machine almost every conductive material, regardless of its stiffness. Using a very thin electrode with control of the EDM contour, micro-molds can be produced successfully. Although these methods cannot reach the dimensional magnitudes of photo-fabrication techniques, such magnitudes are not required in many cases.

Chris J. Morgan et al [2] provides an overview of several approaches to micro-machining by mechanical and electro-discharge method of material removal. Each of these mechanical machining methods can be combined with EDM to achieve a customizable surface finish and feature accuracy. Trade-offs such as tool wear, Material Removal Rate (MRR) and machining time are discussed with several examples. Electrical discharge grinding (EDG) is a "non-conventional" machining technique which make possible to achieve precision machining of micro shafts and a variety of complex shapes. EDG use the same principle as EDM in removing a material from workpiece, through the erosive action by control the electrical discharges (sparks) between a tool and workpiece electrode. The difference only on the workpiece, its circular shape rotates at constant speed. Heat is introduced by the electricity flow between the tool and workpiece in the form of spark. Material at the closest points between the tool and workpiece, where the sparks originates

and terminates, are heated until the material vaporizes.

EDG differs from most chip-making machining operations where the electrode does not make physical contact with the workpiece for material removal. Since the tool does not contact with the workpiece, there are no tool force introduced. The tool always spaced away from the workpiece by the distance required for sparking, known as sparking gap. If tool contacts with the workpiece, spark will cease and no material will be removed. Sparking occurs in the frequency from 2000 to 50000 sparks per second causing a lot of sparks simultaneously. EDG process can be done by using a stationary sacrificial block, rotating sacrificial disk or guided running wire or using a wire - EDG (WEDG) [1]. Currently, there are lots of studies being conducted on EDG machining [3, 4]. E. Uhlmann, et al [5], studies on the case of micro-electrical discharge grinding with a micro-profiled disk electrode for producing micro-channels. The machining process was done by transferring the geometry of the rotating disk electrode to the rotating workpiece by a linear feed. An investigation into micro-EDG was carried out on the basis of the machining planar workpieces for fabrication micro-channels. Then WEDG process is used as a third process variant.

R. S. Hung et al [6] investigate the electrical discharge grinding (EDG) using a rotary disk electrode. The optimal machining parameters are found through ANOVA analysis. The experimental results show that both the lower electrode wear rate and the higher materials removal rate are obtained when a rotary disk electrode with positive polarity is conducted on EDG. T.Wada, et al [7], carried out a work on producing a micro shaft using Wire electro-discharge grinding (WEDG). A typical tungsten micro shaft produced with WEDG; the diameter and length are approximately 50 μm and 1.5 mm, respectively. These fabricated shafts are used in microstructure application as tools in subsequent micro fabrication processes. For instance, micro shafts produced with WEDG were recently used to drill micro holes in silicon.

N. Tosun et. al [8], identified the machining parameter that effect on the kerfs width and material removal rate that being produce in the EDM. The experiment was conducted according to the open circuit voltage, wire speed and dielectric pressure. To examine the result of the parameters, the Taguchi

L934 orthogonal array experimental design was used in the parameter design. The main objective in this work is to find the optimum machining parameter that can minimize the value of the kerfs together with material removal rates. Based on the ANOVA method, the highly effecting parameters were found as open circuit voltages and the pulse duration times, where the speed of wire and dielectric flushing pressure were less effecting factors. At the end, a mathematical model was developed to relate the machining parameter characteristic and the performance characteristics.

Y.S.Liao et al [9] carried out an investigation of the machining parameter that effect on the material removal rate. The objective in this work is to obtain an optimize value of the EDM machining parameter. The machining parameter includes table feed, pulse ON time, pulse OFF time, peak current and flushing pressure. An approach to determine parameters setting is proposed and based on the Taguchi quality design method and the analysis of variance (ANOVA). According to the Taguchi method and quantity of the parameter, the L18 mixed orthogonal array was used in this experiment. The optimum conditions in each factor are located and being related to minimize the value of the MRR. In the result, table feed and pulse ON time have a significant influence on the metal removal rate, the gap voltage and the total discharge frequency, whilst the gap width and the surface roughness are mainly influenced by the pulse ON time. It is recommended to build an expert system of EDM for machining parameter selection with the goal of automation cutting.

J.S. Soni and G. Chakravertib [10], present the Scanning Electron Microscopic (SEM) investigation on changes in chemical composition of resolidified layers on the tools and the workpieces as well as debris. An investigation has also been made on variation of micro-hardness, depth of resolidified layer and heat affected zone (HAZ) with pulse current and electrode rotation. This change in chemical composition occurs due to migration of material from either of the electrodes during electro-discharge machining of high carbon high chromium die steel with rotating copper-tungsten tool electrode.

Optimization analysis of machining process are usually based on either machining process, production cost, maximizing production rate or obtaining the fitness possible surface quality by using empirical relationships between tool life and the optimum operating parameters[11]. Currently, no systematic study on the effect of machining parameters on the EDG performances has been reported in public domain [12].

This work will reveal the main effects of machining parameters on surface roughness and material removal rate (MRR). These machining performances are greatly influenced by the machining parameters. Therefore, there is a need to identify the optimal machining parameters on achieving the desired machining performance characteristics. The machining characteristics of the material depend on the various machining parameters such as discharge current, pulse duration, voltage and electrode materials. The rotation of electrode during machining also contributes towards these. The experiments were conducted to study the effect of these parameters on electrode and workpiece surfaces. The objective of this study is to determine and analyze the operating parameter that influences the material removal rate and surface roughness. Analysis of variance with Taguchi method is used to investigate the significant effects of the performance characteristic and the optimal cutting parameters of EDG are determined.

2. EXPERIMENTAL DESIGN

2.1 EDM Machine

The EDG experiment was performed with Fine Sodick A30R EDM Machine equipped with rotating spindle. Figure 1 illustrates the placement of the tool and workpiece on EDM machine. Workpiece was place on the EDM spindle head and electrode was clamped using a vise and place on the top of EDM machine table. During the process, both tool and electrode were submerged into a dielectric fluid to increase spark generation. The generator circuit for Sodick A30R EDM machine contains subassembly for the DC power supply, servo voltage, AC electric power distribution and DC arc protection. In operating the experiments, all the parameters are conducted using the C370 machining which suitable for machining of tool steel and copper or brass as electrode.

2.2 Parameter consideration Figures

There are many parameter can be controlled by using Sodick A30R EDM machine. But there are only four machining parameter that been use to set up the experiment, which is Pulse duration, Current peak, Servo reference voltage, electrode and tool material. From previous researches, these parameters will give large influences on the surface roughness and MRR in EDG process. Pulse duration is the duration of the EDM sparks that strikes the closes surface of material and to have the next spark to occur. There are two different type of pulse; pulse ON time; time that taken the spark strike the work piece, and spark OFF time; the time that the voltage been charge. The current peak controls the amount of applied amperage (current). The servo reference voltage is used to set the distance at which discharge occurs. The large the set value, the higher the average machining voltage applied, making machining more stable, however the machining speed is lowered as the gap increase. The rotation speed of workpiece is rotates constantly at 50 revolutions per minute. The EDG process was perform to reduce tool steel round workpiece diameter from 6.0 mm to 5.5mm. Tool steel is a material that is usually used as a puncher in die fabrication for sheet metal working process. This material is suitable for blanking and punching process of sheet metal parts because of its hardness.
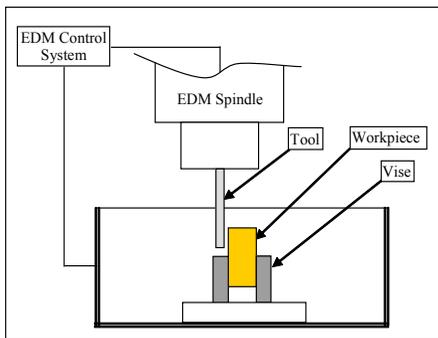

Figure 1 Basics of EDG process

Brass and copper are well-known material that can be use as electrode for EDM processes. Therefore work will also use brass and copper as electrode material to study the effect on EDG process. The size of these electrodes block is 40mm x 40mm x 12mm. The density and melting point for the copper and brass electrode is shown in the table 1.

Material	Density ($\times 1000$ kg/m³)	Melting Point (°C)
Copper	8.94	1085
Brass	8.4 - 8.75	930

Table 1: Density and melting point for copper and brass.

The performance of each experiment have been calculated and measured in term of surface roughness and material removal rate. In order to measure the quality of surface finish on the machined surface, Mahr Pethometer PFK Model M4Pi with a flexible surface texture profiler styles was used. The surface roughness is a term to describe the geometry quality of a mechanical surface. The quality of the surface roughness is important in the evaluation of the machined surface. There are two methods in measuring the surface roughness of material which is the arithmetic mean value and the root mean square value. Only the Arithmetical Mean Roughness, Ra parameter is selected to measure the surface roughness. The arithmetic mean value (Ra) is an average or center line average of value. It is based on the schematic illustration of a rough surface. The arithmetic mean value is defined as:

$$R_a = (a+b+c+d+.......+n) / N \qquad (1)$$

Where all coordinate, a,b,c,…..,n are absolute value, and the N is the number of reading. For the weight measurement in calculating the material removal rate, the Analytical Balance Model: Precisa 220A was used. The material removal rate is based on the erosion effect in the electric spark when it occurred between the electrode and the workpiece. Amount of material removal rate (MRR) in EDM process are depend largely on the amount of the machine current and the spark ON time in the cutting process [13]. The speed of the material removal rate is specified on the rate the material that has being removed. The MRR are influenced by the melting temperature of the workpiece, the lower melting temperature will gave faster MRR. To calculate the material removal rates, following equation are been used:

$$MRR = \frac{\text{Weight before machining - weight after machining}}{\text{time of machining}} \qquad (2)$$

2.3 Design of experiment for EDG

In this work, analysis of variance (ANOVA) with Taguchi method is used to investigate the significant

effects of the performance characteristic and the optimal cutting parameters of EDG. Surface roughness and material removal rate are obtained from the experiment using the calculation and measurement device and then collected based on Taguchi optimization methodology. Four factors are chosen as machining parameter and these factors is assigned to orthogonal arrays for each workpiece. The controlled factor and level unit of experiment for pulse ON time, pulse OFF time, peak current and capacitance is shown in table 2.

The experiment was design with 4 factors at 3 levels each; the fractional factorial design used is $L_9 3^4$ orthogonal array. There are 9 trials in the control factor array and each row of the matrix represents one trial. This orthogonal array is use due to its simplicity and versatile for data analysis. The design of the $L_9 3^4$ orthogonal array of EDG is shown in table 3. The selection of level for this experiment is good since certain unique features. If closely observed, the levels of various factors are balanced between one another. This makes the orthogonal arrays a balanced matrix of levels and factors, without any interruptions from other factors that will affected the outcome or response of the experiment. In other words, the effects of one factors is not confused with any effects of other levels or factors. Analysis of variance is a method of partitioning variability into identifiable sources of variation and the associated degrees of freedom in an experiment. In this work, the ANOVA is conducted for TPM analysis [14].

EXP	Pulse ON Time (µs)	Pulse OFF Time (µs)	Peak Current (A)	Capacitance (C)
1	008	008	002	03
2	008	016	004	05
3	008	032	007	06
4	012	008	004	06
5	012	016	007	03
6	012	032	002	05
7	018	008	007	05
8	018	016	002	06
9	018	032	004	03

Table 3: The L_9 (3^4) Orthogonal Array with value shown in each factor

3. RESULT AND DISCUSSION

This section presents the data and analysis collected from the experiment. Table 4 shows the collected data for surface roughness and material removal rate of EDG machining using the copper and brass electrode. Each experiment was repeated 3 times for better surface roughness and MRR result. Based on the result, the values are used in calculation the ANOVA analysis in the direction find the corresponding factor on affecting of the surface roughness and MRR

The example figures from experiment 6 and 7 of workpiece tool machined with brass are shown in figure 2 and 3. With 40x and 100x magnification the roughness of tool steel workpiece surface can be clearly seen. The machined tool steel using EDG processes are shown in figure 4. The wear on copper and brass electrode after the process are shown in figure 5.
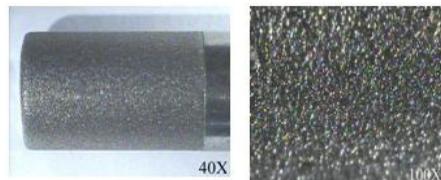
Control	Description	Level 1	Level 2	Level 3
A	Pulse on time	8µs	12µs	18µs
B	Pulse off time	8µs	16µs	32µs
C	Peak Current	2A	4A	7A
D	Capacitance	3C	5C	6C

Table 2: Controlled factor and level unit of experiment

Figure 2: Machined tool steel from experiment 6
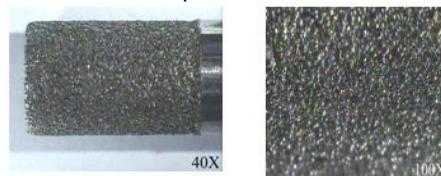
Figure 3: Machined tool steel from experiment 7

Exp				Copper			Brass		
	A	B	C	D	TPM (Ra,μm)	TPM (MRR)	Time (min)	TPM (Ra,μm)	TPM (MRR)	Time (min)
1	1	1	1	1	1.122	0.0010522	122.5	3.6386	0,0010537	100.03
2	1	2	2	2	1.7436	0.0009114	69.78	3.7406	0,0008682	62.43
3	1	3	3	3	3.163	0.0026139	19.09	6.1012	0,0025353	11.32
4	2	1	2	3	2.9006	0.0011673	134.67	4.8478	0,0014433	80.65
5	2	2	3	1	3.3896	0.0041085	79.98	7.5608	0,0043400	65.53
6	2	3	1	2	2.5046	0.0002705	78.19	3.9923	0,0001755	66.67
7	3	1	3	2	4.1836	0.0067027	37.88	7.6218	0,0076943	30.23
8	3	2	1	3	2.7228	0.0011511	106.68	4.2666	0,0011984	84.53
9	3	3	2	1	4.6942	0.0029525	77.63	8.3827	0,0030681	60.07

Table 4: $L_9(3^4)$ Orthogonal Array for surface roughness, MRR and machining time of Copper and Brass (Electrode)

Figure 4: the machined tool steel using EDG processes

Figure 5: wear on copper and brass electrode after the EDG process

3.1 Surface Roughness

Result of surface roughness using copper and brass electrode shown in table 4. The lowest value of the surface roughness measured on tool steel workpiece using copper electrode is from experiment 1 while the highest value is from experiment 5. For EDG process using brass as electrode, the lowest value of the surface roughness attain on from experiment 8, while the highest value is from experiment 2.

From the response graph in figure 6, it can be identified the best combination of condition to get low value of surface roughness which response to the smaller the better value. All the level and its value are shown below subjected to the optimum condition to find the low value of surface roughness.
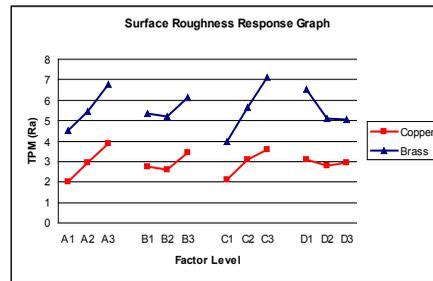

Figure 6: Response graph of TPM surface roughness level analysis

Based on the result, ANOVA analysis in direction to find the corresponding factor on affecting of the final result and the contribution factor is shown in figure 7. By using ANOVA analysis, where copper as electrode and the best significant factors are chosen based of the large value. The ON time, OFF time and peak current factor gives cumulatively contributes factor about 97.46% for surface roughness. It is suggested that servo voltage pulse ON time (factor A) had a largest of significant effect on surface roughness which give of 52.02% effect, and follow by the capacitance (factor C) 33.48% and pulse OFF time (factor B) by 11.95%, the other factor (factor D) can be ignored or known as error in the experiment which is contribute only 2.54% of factor effect. For the EDG using brass as electrode, from ANOVA analysis, the best significant factors are ON time, peak current and capacitance factor gives cumulatively contributes factor about 85.83% for surface roughness. It is suggested that capacitance (factor C) had the largest on significant effect on surface roughness which give of 49.44% effect, and follow by the pulse ON time (factor A) 24.64% and capacitance (factor D) by 11.75%, the other factor (factor B) can be ignored or known as error being pool to create error of experiment which is contribute of 25.92% factor effect.
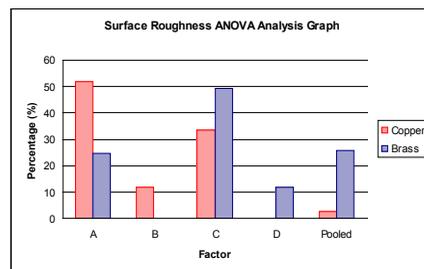

Figure 7: ANOVA graph contribution of factor (%) for surface roughness

It is suggested to use minimum of discharge time (ON time), the lowest value of ON time parameter will give lowest rate energy to generate in each repetition cycle. When the time is decreasing in each spark, the surface roughness of material is also decrease due to the lowest heat affected zone (HAZ). In a charging time parameter (OFF time), reducing a value of OFF time will lowered the value of surface roughness, it is because the time provided in each cycle spark is more longer so the surface of the material will became more stable and the HAZ in surface will decrease. From the result from the figure 4.3 and 4.7, in peak current parameter, when the peak current is lower, it suddenly decreases the value of surface roughness on the surface.

3.2 Material removal rate (MRR)

Referring to table 4, the result of MRR using copper electrode, the lowest value of the MRR is attained from experiment 6 while the highest value is experiment 7. The same result achieve or EDG process using brass electrode. From the graph in figure 8, it can be identified the best combination of condition to get high value of MRR which response to the larger the better value. All the level and its value are shown below subjected to the optimum condition to find the high value of MRR in 6mm diameter of tool steel material.
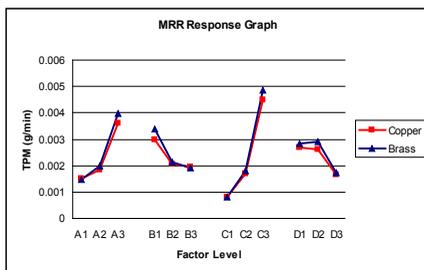

Figure 8: Response graph of TPM MRR level analysis

Based on the result, ANOVA analysis in direction to find the corresponding factor on affecting of the final result and thecontribution factor is shown in figure 9. By using the ANOVA analysis, for brass as electrode, the best significant

factors are chosen based of the large value which are pulse ON time, pulse OFF time and capacitance factor gives cumulatively contributes factor about 85.68% for MRR. It is suggested that peak current (factor C) had a largest of effect of 62.69% on the material removal rate, and follow by the pulse ON time (factor A) 19.57% and capacitance (factor D) by 3.42%, the other factor (factor B) can be ignored or known as error being pool to create percentage error in the experiment which is contribute 14.31% of factor effect.

For the EDG using copper as electrode, by using the ANOVA analysis, the best significant factors are pulse ON time, pulse OFF time and peak current factor gives cumulatively contributes factor about 79.31% for MRR. It is suggested that peak current (factor C) had the largest of effect of 58.24% on the material removal rate, and follow by the pulse ON time (factor A) 21.08 % and pulse OFF time (factor B) by 3.42%, the other factor (factor D) can be ignored or known as error being pool to create percentage error in the experiment which is contribute 20.69% of factor effect.
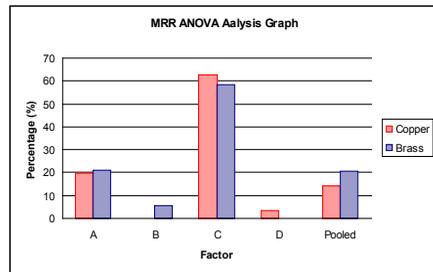

Figure 9: ANOVA graph contribution of factor (%) for MRR

It is suggested to use of larger of discharge time (ON time), the highest value will increase the energy rate in each repetition cycle. When the time is increasing in each spark, the more material will remove from the material properties so the MRR will higher. In the charging time parameter (OFF time), the smallest value of OFF time can give the high value of material removal rate, it is because the time provided in each cycle spark is more less so the machining time will decrease that will give the high value of MRR. In the peak current parameter, it observed that as the peak current value increase, it lead to increasing the value of MRR. This is because with the increasing of current, the cutting process time can be faster and more material removes per unit second.

4. CONCLUSION

In this work, analysis of variance (ANOVA) with Taguchi method is used to investigate the significant effects on the performance characteristic and the optimal machining parameter of EDG process. Based on the objectives of the study, several conclusions can be made in term of the surface roughness and material removal rate:

1. The surface roughness value for both electrode materials are mostly influenced by ON time parameter, and then followed by the peak current parameter. The capacitance parameter in the both experiment was not giving any significant factor of any effect. From result these experiment, both tool material that used give almost given the same factor that affect the experiment.

2. The significant factor for the material removal rate due to the machining parameter are on the peak current parameter, and ON time parameter but it also can increase the machining time.

3. The material type also influences the experiment result. For the copper tool give the lower of Ra values compare to the brass tool. It is because this result of the EDG depends on the melting point not the hardness of material.

4. In the pulse ON time parameter, it had been concluding that the increasing the value of discharge time it will increase the value of surface roughness of the material, but it will help to large the MRR value of material.

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