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The Effect of Electrode Material on High Speed EDM Process on Product Quality

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ABSTRACT

Electric Discharge Machining (EDM) is a non-traditional machining process that involved a transient spark discharges through the fluid due to the potential difference between the electrode and the work piece. In this experiment, EDM process on mild steel work piece was conducted using EDM Die Sinking Neu-ar. The electrodes used were copper, brass and graphite. This project is to be conducted using Taguchi method L4 orthogonal array. The parameters to be studied are peak current (12A and 21A), discharge ON time (10µs and 45 µs) and pumping direction (B0 and B1). This research aims to study the factors that influence the machining of different electrodes in electrical discharge machining (EDM) process. Surface roughness was measured using surface roughness tester (SJ-301). Material removal rate (MRR) and electrode wear ratio were determined based on weighting the work piece and electrode using digital weight scale. Then, the result of the experiment was analysed using EXCEL. The higher material removal rate in the EDM machine, the better the machining performance is, while the lower electrodes wear ratio in the EDM machine, the better and accurate performance characteristic is. The results show that copper electrode gives higher material removal rate which is 0.411 g/min than brass and graphite. Brass electrode gives better surface finishing which is 15 µm and graphite electrodes give the better electrode wear rate which is 0.53 among two electrodes.

Introduction

EDM machining process is widely used to manufacture moulds, dies and aerospace parts using EDM machine as this machine can cut complex shapes such as sharp ending shape and pointed corners. According to Ho et al. (2003), EDM is used to produce critical parts and components for the aerospace, electronics and medical industries. The impact of EDM on the dies and moulds making industry has been especially profound.

However, there is insufficient information regarding the methods of testing and evaluation of metal cutting experimental data. The demand for high quality products is focused on the product surface finish, especially because of its effect on product appearance, functionality and capability. Therefore, it is important to ensure the tolerance and surface finish is consistent.

EDM technology is commonly used in dies, moulds and industrial equipment which required high precision, complex shapes and good surface finish. It is difficult to cut with accuracy by using conventional machining processes. However, problem such as high wear on the electrode occurs when using an electrical discharge machine (EDM). Wear ratio is defined as the loss of metal volume from the electrodes divided by the volume of metal removed from the work piece. If wear rate is high on the electrode, this means that the electrode material is not suitable to be used for cutting purposes.

This project evaluated the effects of electrode materials on the EDM die sinker such as the material removal rate (MRR), electrode wear rate (EWR) and surface roughness. The work piece material is mild steel and using three different materials as electrodes which are copper, brass and graphite. The best machining performance of electrical discharge machining (EDM) can be determined by knowing the responses from these materials. Khan et al. (2009) states that the performance of EDM is usually evaluated by the output parameters namely material removal rate (MRR), electrode wear rate (EWR), wear ratio (WR) and machined surface roughness. However, there is insufficient information from the electrical discharge machining (EDM) especially in the case of pulse discharge energy and the selection of the electrodes, since the energy is not only used to machine the work piece, but also influence electrode wear (Lin and Lin 2002).

The objectives of this research are:

i. To study the influence of the electrode material on surface finish in high speed EDM.

ii. To compare the performance of graphite, brass and copper as EDM electrodes material in high speed EDM.

iii. To evaluate the effect of machining parameter (peak current (L), discharge time adjustment (ON time) and pumping direction) on material removal rate (MRR), electrode wear rate (EWR) and surface finish.

Yan Cherng et al. (2009) discussed about EDM machining process and the parameters effect on MRR and surface roughness by using ZrO2 and steel. The experiment was carried out by using a copper electrode and the effect of two levels of peak current and pulse ON-time to MRR and surface roughness.

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They found that during the experiment, MRR and surface roughness increased with peak current and pulse duration.

The effects of EDM current, pulse ON-time and flushing pressure on MRR, TWR, taper and surface roughness when machining cast Al-MMC with 10% SiCp were investigated by Narender Singh et al. (2004). They show the correlations between the MRR, EWR, taper and surface roughness with the parameters of the EDM process. The results showed that with the combination of these parameters, the MRR increased with an increase in peak current and pulse ON-time.

Prajapati et al. (2012) found that, the surface roughness is the general quality of a product surface, measured using surface roughness tester, and measured as the arithmetic average Ra (µm). He investigated the performance of different electrode which was brass, copper and graphite materials in EDM in MRR and surface roughness. He found that a brass electrode gives better surface roughness when peak current increased.

According to the experiments done by Prajapati et al. (2013), it showed that the surface roughness was mainly affected by the peak current and pulse on time. The higher value of the current causes the more surface roughness and will affect the finishing of surface quality on the machining performances.

The research from Khan et al. (2009) found that the increase of current will increase the surface roughness due to stronger spark that makes a crater of higher depth. He studied of electrode shape configuration on the performance of die sinking EDM. The experiment was carried out by using mild steel as a work piece and different shape of copper electrode such as round, square, triangular and diamond. Three current values of 2.5, 3.5 and 6.5 A are used to investigate the surface roughness and MRR and he reported that not give any influence to the surface roughness of the shape of the electrodes.

2. Experimental Setup

The procedure begins with the design of experiments bases on Taguchi methods and data analysis using EXCEL. There are divided into three main parts:

i. Work piece and electrode materials
ii. Equipment
iii. Data sources and data analysis.

2.1 Selection of work piece and electrode material

2.1.1 Selection of work piece

The mild steel bar of dimension of 80mm x 50 mm x 30 mm is used as a work piece material, having the typical composition shown in Table 2.1. It is softer and more easily shaped and also bends instead of breaking. Mild steel can be machined, and can be hardened with carburizing. It is the cheapest type of steels and most versatile widely used in industry.

Table 2.1. Specification Properties of Mild Steel

Element	Composition
C	1%
Mn	1.65%
Cu	0.6%
Si	0.6%
P	0.4%
S	0.05%

2.1.2 Selection of electrode material

In this experiment, the electrode materials used are copper, brass and graphite with dimension that use is 25mm x 25mm x 40mm. After undergo finishing process, the result was taken and being analysed using the selected method in term of to evaluate the performance of EDM Die Sinking on mild steel with selected various input parameters. Figure 2.1 showed the electrodes and workpiece materials.

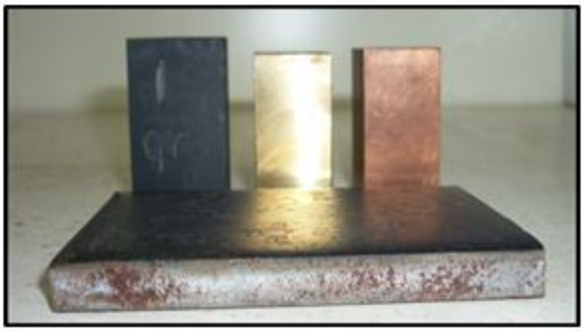

Figure 2.1: Electrodes and workpiece materials.

A copper (Cu) is being selected for the machining because it is a highly conductive tool, low cost, low wear ratio, good machinability and finishing (Roger 2008). Copper is a reddish-yellow material and is extremely ductile. Copper has a face-centered-cubic crystal structure and has the second best electrical conductivity of the metals, second only to silver compared to which it has a conductivity of 97%. The thermal conductivity of copper is very high falling in between silver and gold. There are almost 400 different copper alloys depending on the commercial product made which are rods, plates, sheets, strips, tubes, pipes, extrusions, foils, forgings, wires and castings from foundries.

Graphite is the preferred electrode material for 90% of all sinker EDM applications. It has an extremely high melting point at 3490 K which is higher than copper and brass therefore it does not melt at all, but sublimes directly from a solid to a gas. This made the graphite electrode an ideal electrode material to be selected.

Brass is proportion of zinc and copper. Some types of brasses are called bronzes and it is a substitutional alloy. It is used for embellishment for its bright gold-like appearance and also for applications where low friction is required such as locks, gears, bearings, ammunition, and valves for plumbing and electrical applications. Table 2.2 shows the specification properties of copper, brass and graphite.

Table 2.2. Specification properties of copper, brass and graphite.

Property	Copper	Brass	Graphite
Thermal conductivity (W/m.K)	390	159	80
Melting point ^{o}C	1082	990	3490
Electrical resistivity (Ω.m)	5.01	4.7	$6310\ 10^{-8}$
Specific heat capacity (J/kg.K)	388	0.38	1423

2.2 Equipment Used

The equipment used to carry out the EDM experiments is divided by two categories which are:

i. Machine preparation
ii. Measurement equipment

2.2.1 Machine Preparation

2.2.1.1 Die Sinker machining (EDM)

The type of machine that is used in this experiment is EDM die sinker Neu-ar (CNC- A50). Dielectric fluid is commercial kerosene and this EDM machine features with 3-axis linear motor with the highly responsive servo system. EDM die sinking Neu-ar (CNC-A50) has high speed with up to dynamic response, cooling system, ceramic table, linear motor for the X, Y and Z axes and also has an automatic fire extinguisher. Figure 2.2 shows the EDM die sinker that will be used along the experiment.

The descriptions about EDM die sinking Neu-air (CNC-A50) are shown in Tables 2.3 and 2.4 below.

Table 2.3. Process parameters and range.

Dielectric used	Commercial grade EDM oil
Work material polarity	Negative
Speed	100%
Servo	50%
Gap	55V

Table 2.4. Machining Specification.

Item	Specification
Work tank dimensions	940 mm x 550 mm x 350 mm
Work table dimensions	630 mm x 360 mm
XYZ axis travel	400 mm x 300 mm x 300 mm
Distance from main axis to table	410 mm
Maximum work piece weight	500 kg
Maximum electrode weight	50 kg
Maximum capacity of dielectric	300 liters
Maximum machining speed	420 mm^3/min
Minimum wear rate	< 0.1%
Best surface finish	< Ra 0.12 µm
Maximum output current	50 A
Input power	3.3 kVA
Machining dimensions (L x W x H)	155 mm x 140 mm x 225 mm
Total weight of machine	1370 kg

2.3Measure Equipment

Figure 2.2. Die Sinker Machine (EDM).

2.3.1 Surface roughness testing tool.

In this experiment, surface roughness tester model SJ-301 is used to measure the surface roughness of the work piece. The surface roughness is measured by central line average (Ra) in order to assess the quality of the machine surface quantitatively. The measurements are taken for three times at various positions of work piece based on depth. The surface roughness is measured by setting the surface roughness tester on a workpiece and press the key at the display of the screen. The detector traverses, performing measurement. A bar is displayed indicating the measurement is in progress. After the measurement has been completed, the measured results will be displayed on the touch panel. Figure 2.3 shows the model of surface roughness tester that is used to measure surface roughness during the experiment. The calibration can be performed by simply inputting and measuring the Ra value inscribed on the roughness reference specimen.

The resulting measurement is within a 3% tolerance of the measurement on the specimen label.

If the measurement is out of tolerance, the detector and/or the precision roughness specimen may need to be replaced due to wear.

Figure 2.3. Surfaces Roughness Tester, SJ-301.

2.3.2 Weight scale

This equipment is used to scale the electrode wear rate and material removal before and after the experiment. In this experiment, it will measure output response which is a material removal rate and tool wear ratio. The material removal rate of the work piece was measured by dividing the weight of work piece before and after machining (found by weighing method using weight scale) against the machining time that was achieved. After completion of each machining process, the work piece was blown by compressed air using air gun to ensure no debris and dielectrics were present. A weight scale was used to measure the weight of the work piece required. Similar procedure for measuring the weight of work piece was used to determine the weight of the electrode before and after machining.

The higher material removal rate in the EDM machine, the better is the machining performance. While, the lower electrode wear ratio in the EDM machine shows the better and accurate performance characteristic. From the result, the best electrode material for EDM machining process can be determined.

Figure 2.4. Weight scale, AM-300X.

3. Experiment Result

3.1 Material Removal Rate

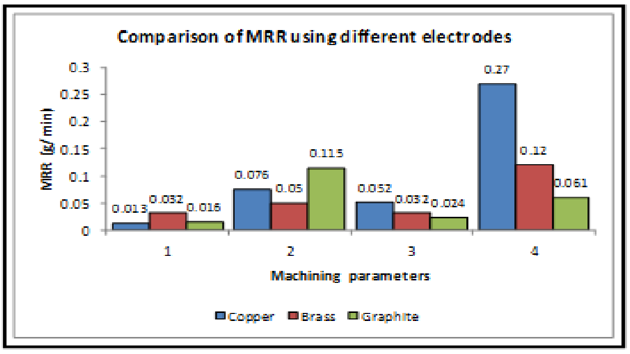

Figure 3.1 Comparison of MRR using different electrodes

Figure 3.1 shows the material removal rate of three electrode materials which are copper, brass and graphite when machining using mild steel as a workpiece. This experiment used different peak current, discharge on time and pumping direction. It has been found that MRR increases with increase in discharge on time for copper and brass electrodes. However, in the case of graphite, it decreases with increasing the discharge on time. It is presumed that spark energy released into inter electrode gap acts as an instantaneous disc heat source at low discharge durations, incident thermal energy does not penetrate deep into work material, which produces shallow craters, therefore low material removal rate. Copper shows good response in material removal rate toward high values of peak current and discharge current. The higher material removal rate can be seen in the experiment 4 which is copper electrodes due to increase the peak current and discharge on time. This may have happened because of the increase in thermal and electrical conductivity. The thermal conductivity and the melting point of the electrodes and workpiece materials play an important role in EDM performance. Thermal conductivity of graphite (80 W/m-K) is lower as compared to brass (109 W/m-K) and copper (401 W/m-K) which creates substantial amount of heat in the inter electrode gap, due to which material removal rate of graphite is higher in up to 10A gap current. In addition, the effect of arching dominates the removal of material from workpiece due to insufficient spark interval. The different percentage between the highest and lower is 30%. The calculation of the different percentage between the highest and the lowest is shown below:

Total material removal rate using copper, brass and graphite 0.861g/min.

The highest material removal rate (copper): 0.27g/min

The lower material removal rate (copper): 0.013g/min

Percentage of the highest material removal rate: (0.27/0.861) x100= 31.4%

Percentage of the lower material removal rate: (0.013/0.861) x 100= 1.5%

The different percentage: 31.4- 1.5 = 30%.

The effect of different electrode materials on MRR was previously observed by Choudhary et al. (2010) in their study on analysis and evaluation of heat affected zones in electric discharge machining of EN-31 die steel. Their results showed that the peak current and discharge on time influence more significantly to the electrode material. Another result from Kansal et al. (2005) evaluated the effect of material removal rate tends to increase considerably with increase in peak current.

3.2 Electrode Wear Rate

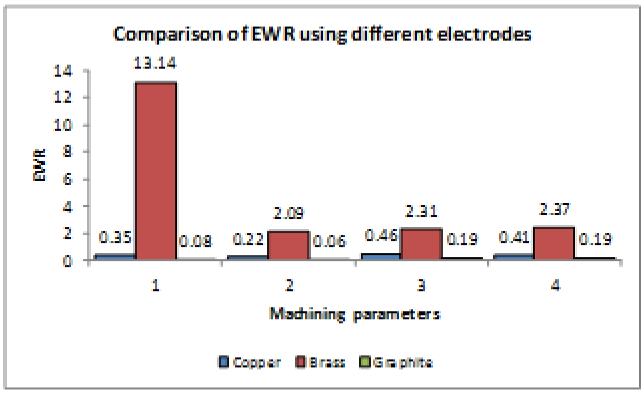

Figure 3.2. Comparison of EWR using different electrodes.

Figure 3.2, shows the comparison of EWR using three different electrodes which are copper, brass and graphite. Regarding this graph, it can be seen that the brass electrode gives the higher electrode wear rate in all experiments which is 96.8% compared to copper 2.6% and graphite only 0.6%. Higher wear rate of brass electrodes is associated with the lower melting point of brass. The electrode particles eroding at a lower temperature require less energy. These phenomena are also was observed by Khan (2008) who machine in steel workpiece by using brass electrode that has a low thermal conductivity coupled with high melting temperature resulted in poor MRR which led to increased EWR.

3.3 Analysis of surface roughness.

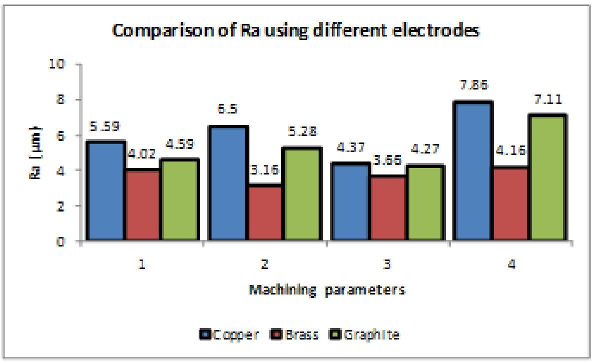

Figure 3.3. Comparison of surface roughness using different electrodes

Figure 3.3 shows the result of surface roughness when machining of three electrode material which are copper, brass and graphite. It can be clearly seen that the surface roughness increases with increasing discharge on time by using copper and graphite electrode. Regarding this graph, the highest of surface roughness when doing machining using is a copper electrode which is 7.86 μm in experiment 4 due to the higher material removal rate reached for that material and the lower is brass from experiment 2 which is recommended for high surface finish of the work piece material after machining. The electric-discharge machined surface consists of a multitude of overlapping craters that are formed by spark discharges. The size of these craters depends on the discharge energy and duration. The more the peak current and discharge on time, the larger are the craters resulting in more surface roughness. This means that larger and deeper craters were made in the work piece surface using copper electrode.

4. Discussion

The selection of the most appropriate EDM electrode material is a major decision in machining performance in EDM due to the material properties itself. In EDM, the result of machining characteristics such as material removal rate, electrode wear rate and surface roughness significantly influenced by the properties of material such as electrical conductivity, boiling point, melting point, structural conductivity, mechanical properties, manufacturability and cost. Therefore, in this experiment three materials have been selected which were copper, brass and graphite. These materials gave the different value of material removal rate, electrode wear rate and surface roughness due to their properties as evident in Table 4.1.

Table 4.1: The properties of copper, brass and graphite.

Material	Electrical conductivity (W/m-K)	Boiling point (K)	Melting point (K)
Copper	401	2835.15	1357.77
Brass	109	2624	900
Graphite	80	4098	3490

4.1: The influence of the electrode material on surface finish in high speed EDM.

From the theory, the material with high electrical conductivity will give effect by increasing the material removal rate. Regarding to the Table 4.1, the copper material has high conductivity compared to the brass and graphite material. Therefore, the highest electrical conductivity will give the influence of the surface finish on the work piece due to high energy generate to impact on the work piece. Hence, the material which has higher electrical conductivity will make the machining run effectively and fast due to more spark that discharges energy. In previous studies, it also found that an electrode material wear less with higher melting point by Bhogal et al. (2011). Referred to the Table 4.1, the melting point of graphite is higher than copper and brass, so it will give less tool wear to graphite but poor in surface roughness.

4.2: The comparison of performance of graphite, brass and copper.

This research investigation concentrates on the comparison of performance of different material which is graphite, brass and copper using EDM. The selection of material electrode will give the high expectation and important indicator of the EDM machine efficiency. For that reason, the best machining performance of electrical discharge machining can be determined by knowing the responses from these materials. Usually, EDM performance will be measured by material removal rate, electrode wear rate and surface roughness of the material. Many journals said that copper will give the higher material removal rate, followed by brass and graphite due to the high electrical conductivity but this property will give the lower surface roughness, for example journal from Bhougal et al. (2011) and Choudhary et al. (2010). They reported that the material removal rate will increase when the peak current increases.

For electrode wear rate, the graphite gives the lowest electrode wear rate value which means higher melting point will give lower electrode wear rate due to its properties. It can remove material better than copper and the ability to reduce electrode wear as the discharge increases. It does not melt but sublimes at a very high temperature (3,400ºC), and finally, its density is low (five times less than copper) which means lighter electrodes. Therefore, graphite has been matched for the machining of large electrodes since working with a high current concentration delivers decreased roughing time.

Referred to the machined surface roughness point of view, the brass is categorized as the best electrode and followed by graphite and copper. These experiments are proven by other researchers such as Amin et al. (2002) and Payal et al. (2008).

4.3: Evaluation on the effect of machining parameter (peak current (L), discharge time adjustment (ON time) and pumping direction) on the material removal rate (MRR), electrode wear rate (EWR) and surface finish.

The part that the industries must consider most is the production rate which means the rate or time taken to manufacture the product. If the production rate is slow, the profit flow is also slow otherwise if the production rate is high, the more profit can gain. The most important performance measured in EDM is the material removal rate. To increase the production rate, the industry needs to increase the material removal rate. When the material removal rate is higher, the production runs faster.

Table 4.2 shows the effect of electrode material on material removal rate using three different materials for the work piece material.

The best material removal rate is from the copper electrode with the increase in peak current, discharge current and pumping direction, followed by graphite and brass give the poor material removal rate. This condition occurs when the current increases the material removal rate will also increase due to higher in spark energy. The material removal rate is also controlled by the frequency of the sparks. It is observed that low discharge currents and higher frequencies correspond to low stock removal. Therefore, effective machining rates with graphite electrode could not be achieved because the graphite has low electrical conductivity.

Table 4.2. Comparison MRR result with journal

Experiment	MRR	Journal
Copper	Best	Copper
Brass	Average	Brass
Graphite	Poor	Graphite

The other problem in industry in selecting electrode material in EDM machining is the high rate of tool wear because it will be costly to be produced. In industries, they are trying to improve this factor to make sure no waste happens and reduce the purchase of material with high wear. Essentially, the definition of wear rate is the different work piece removal weight divided by the different electrode wear weight depending on the tool and work materials used. If the rate of tool wear is high, it means that the material is easy to wear and not good for machining performance.

Table 4.3 shows that the graphite electrode is the best in electrode wear rate. Brass and copper show a significant decrease in the electrode wear with the increase in the peak current, discharge on time and pumping direction. In other words, the electrode wear rate will become less for electrode material with high boiling point, high melting point and low electrical conductivity.

Table 4.3. Comparison EWR result with journal

Experiment	EWR	Journal
Graphite	Best	Graphite
Copper	Average	Copper
Brass	Poor	Brass

The surface produced by the EDM process consists of a large a number of craters that are formed from the discharge energy. The quality of surface mainly depends upon the energy per spark. The increases of peak current, discharge on time can cause a rougher form on the surface materials. Table 4.4 shows that the brass electrode is the best in surface roughness, followed by graphite and copper. Surface roughness for brass is low at low peak current and discharge on time compared to graphite and brass. This situation gives the same results for all parameters used in machining. Studies by Amin and Sarder (2002) on input parameter which are peak current and gap voltage indicate that the brass gives good surface roughness. Choudhary et al.(2010) also gives the same result when analysis and evaluate the heat affected zones in electrical discharge machining of EN-31 die steel. They found brass produce high surface roughness at high values of discharge current.

Table 4.4. Comparison Ra result with journal.

Experiment	Ra	Journal
Brass	Best	Brass
Graphite	Average	Graphite
Copper	Poor	Copper

5.0 Conclusion

This research investigation focuses on the performance EDM process by using different parameters such as peak current, pulse on time and pumping direction.

In this case, three different electrodes which are copper, brass and graphite were analysed to get the effect of machining parameters for material removal rate, electrode wear rate and surface roughness. An analysis has also been performed on the comparative performance of copper, brass and graphite electrode.

There are many factors that influence the machining process in electric discharge machine (EDM) especially in material removal rate, electrode wear ratio and surface roughness. This characteristic mostly depends on the material properties like electrical conductivity, melting point and others. Furthermore, it has been found from the experimental analysis that in the case of material removal rate and electrical conductivity are the major influencing factors. Instead, higher electrical conductivity is useful to raise the temperature of the work piece above the melting point in a short time. These are the reasons why copper electrode material provides higher material removal rate in the finishing.

Moreover, the electrode wear rate of an electrode intensely depends on the melting point properties material and it has been found from the literature that the electrode wear ratio is almost in reverse as compared to the melting point of the electrode material.

In order to have a better surface roughness, it depends on electrical conductivity and also the melting point properties of materials. The lower electrical conductivity and melting point are the better surface roughness it will be. Besides that, the discharge on time machining may be done at low value to get a better surface roughness.

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