Introduction

Electrical discharge machining (EDM) is an unconventional process, that been utilized to cut out metal by numbers of individual electrical sparks. The discharges created during electrical energy take place between tool named electrode and the workpiece at attend of fine layer of liquid called the dielectric fluid. The electrical energy will transform in to thermal energy that ionize the dielectric fluid and cut out the metal from both the electrode and workpiece; there is no connection between the two electrodes. It is usually utilize to make prototypes for the aerospace and electronics markets, produce molds and dies, to drill small and flawless holes. In this work, micro-holes fabricated on copper alloys by utilizing EDM [1,2]. EDM is a machining processes usually utilized for hardened metals or metals that would be difficult to cut out at the micro system with conventional process for manufacturing the automotive engines as well as sports, medical and surgical parts [3]. EDM have single disadvantage, is that electrical discharge machining only suitable for manufacturing of limited quantities although some specific bulk manufacturing process due to low material removal rate. EDM is greatly suitable for machining complicated figuration or hard hollows that would be hard to manufacture with grinder, an end mill or other cutting tools, from the development of new materials that are hard and difficult-to-machine such as tool steels, composites, ceramics, super alloys, hast alloy, nitralloy, waspalloy, nemonics, carbides, stainless steels, heat resistant steel, etc. [4,5]. This paper attempted to study the influence of different EDM parameters using three types of electrode, the copper, aluminum and brass and with using kerosene dielectric for AISI 304 stainless steel as workpiece material. The response used to design the experimental work matrices for all electrodes materials. The analysis of variance (ANOVA) models are used to predict the material removal rate and electrode wear rate and to developing models for three groups of experiments in order to improve the machining efficiency and the machining durations.

Literature Review

The literature survey has revealed that several researchers attempted to find the widely interested through the EDM specifications such as the electrodes material, discharge current, applied Vol.tage, pulse on time, pulse off time, duty cycle, etc. and in what way these conditions will bring the production up such as material removal rate (MRR), electrodes wear rate (EWR), surface roughness (SR) and hardness. Reddy et al. [6] investigated in EDM by using four parameters configuration like current, servo control, duty cycle and open circuit Vol.tage on the outputs on MRR, EWR, SR and hardness on the diesinker electrical discharge machining of processing AISI 304 Stainless steel. They worked on design of experiments (DOE) technique with mixed level configuration and evaluation for producing small quantities of jobs. They
concluded that for high value material removal rate, the current, servo and duty cycle should be constant as elevated standard and 95% deduction standard with dropping level given electrode wear rate with constant parameters.

Rajmohan et al. [7] analyzed utilizing design of experiment method under L9 orthogonal array configuration and analyze the influence of processing conditions of electrical discharge machining like pulse on time, pulse off time, current and Vol.tage on material removal rate in processing of AISI 304 stainless steel. For development had been utilized signal to noise ratio and analysis of variance to estimate the influence of the specifications on material removal rate and develop the machining conditions.

Singh and Singh [8] investigated the effect of different electrode materials in electrical discharge machining for cutting Inconel 600 as a workpiece. Brass, copper and copper-tungsten utilized as electrodes. The results analyzed using the Taguchi method to inspect the effects of electrodes material, pulse on time, peak current and gap Vol.tage on the material removal rate, electrode wear and surface roughness in order to select the optimum machining parameters.

Khan and Saifuddin [9] deliberated the effect of copper and aluminum electrodes material on wear features while machining electrical discharge machining of stainless steel 304 as workpiece materials. Aluminum electrodes provide better surface finish but also appear elevated electrode wear rate analyze to copper electrodes while machining the workpiece materials.

Khan [10] investigated the EW while electrical discharge machining of mild steel and aluminum using brass and copper were use as cutting tools. They concluded that the EW raised and MRR rose up clearly with raise in Vol.tage and current.

Arunkumar et al. [11] studied the influence of EDM specifications for processing of EN31 by electrical discharge machining. Copper, aluminum and EN24 utilized as cutting tool. It realized that the small EWR, elevated MRR and small tapper magnitude found while utilizing copper.

Sharma et al. [12] concentrated on the influence of copper and brass EDM tools on AISI 329 stainless steel. The copper tool gives excellent hole characteristics and display excellent productivity than brass tool. Brass tool provide elevated electrode wear.

Reman and singla [13] investigated the influence of different electrodes used in EDM for En-31 workpiece. Copper, aluminum and brass used as electrodes material to determine the best material removal rate and electrode wear rate.

3. Taguchi Orthogonal Array

Taguchi method is robust design technique based on orthogonal array (OA), which shows an easy method to construct an adapted and money saving analysis [14,15]. Increasing the ability to eliminate the total of traditional test charge by utilizing design factors (control parameters) in column and standard magnitudes (levels) in row projected and approved. The achievement magnitude, signal to noise ratio (S/N) projected by Taguchi is utilize to achieve the maximum specifications connections [16]. The L9 orthogonal array with 3-columns and 9-rows utilized in this investigation for the process conditions. This orthogonal array construct of 3-adimistrate parameters and 3-levels for material removal rate and electrode wear rate present in the table (1). In this experiment, the MRR and EWR were evaluation by highest and lowest magnitudes. Therefore, by Taguchi technique “maximum is excellent” accepted for material removal rate, and “minimum is excellent” for electrode wear rate. The determinations examined on S/N ratio and analysis of variance (ANOVA) that depending on orthogonal array. ANOVA is the analytical technique largely utilized for the production of the investigations to calculate the portion quantity of individual parameter. The signal to noise ratio calculated from applying equation (1) and equation (2) [17].

For the “maximum is excellent” feature specifications, the mathematical statement is:

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

(1)

For the “minimum is excellent” feature specifications, the equation is:

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

(2)

Where:

$\frac{S}{N}$ = the signal to noise ratio.

n = the number of observations.

$y_i$ = the observed data.

| Table 1: Machining parameters and their levels |
|---------------------------------------------|
| Experiment number | Parameter level combination |
| | A | B | C |
| | Electrodes material | Current (ampere) | Thickness (mm) |
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 1 | 3 | 3 |
| 4 | 2 | 1 | 2 |
4. Experimental Materials
The investigations attended by utilizing a computer numerical control (CNC) electrical discharge device, series CM323C produced by CHMER. Economic kerosene flows as the dielectric liquid in the container. The schematic diagram of EDM machine utilize in the experiment present in Figure 1.

The workpiece material that used for the performing experimental is AISI 304 stainless steel with dimensions (40×40 mm) with three dissimilar dimensions (1, 1.5 and 2 mm) thickness. Table 2 shows the chemical composition of the workpiece material. It is usually the maximum applied metal in widely production processes and utilized for approximately fifty percent of the earth’s stainless steel productions and constructions. Seeing its attractive appearance in architecture constructions, advance mechanical and physical features, resisted to corrosion and chemicals, weldability, it belong to the wildly preferable metal.

In the experiment, nine samples were used under three different current values (50, 100 and 150 A) and machined by three different electrode materials. Copper, aluminum and brass used as electrodes material with diameter (Ø 8 mm). Table 3 and 4 show the physical and mechanical characteristics of electrodes material respectively. The electrode produced by a lathe turret device to achieve the final diameter dimensions and cut out the melted tip from the produced tool electrode by facing process.

During experiment, there were some parameters, which kept constant throughout, and some parameters were variables. Fixed specifications displayed in Table 5 and changing specifications selected according to Taguchi design three factors with three levels displayed in Table 6.

| Components | weight% | Components | weight% |
|------------|---------|------------|---------|
| C%         | 0.048   | Ti%        | 0.009   |
| Si%        | 0.438   | V%         | 0.093   |
| Mn%        | 1.450   | W%         | 0.033   |
| P%         | 0.032   | Pb%        | 0.001   |
| S%         | 0.002   | Sn%        | 0.010   |
| Cr%        | 18.0    | B%         | 0.001   |
| Mo%        | 1.186   | Ca%        | 0.007   |
| Ni%        | 8.38    | Se%        | 0.004   |
| Al%        | 0.111   | Sb%        | 0.003   |
| Co%        | 0.121   | Ta%        | 0.010   |
| Cu%        | 0.202   | Others%    | 0.056   |
| Nb%        | 0.007   | Fe%        | Balance |

| Physical properties | Copper | Aluminum | Brass |
|---------------------|--------|----------|-------|
| Electrical conductivity [10.E-6 Siemens/m] | 58.5 | 35 | 15.9 |
| Electrical resistivity [10.E-8 Ohm.m] | 1.7 | 2.82 | 6.3 |
| Thermal conductivity [W/m.K] | 401 | 130 | 150 |
| Thermal expansion coef. [10.E-6 (1/°C)] | 17.3 | 24 | 20 |
| Specific heat capacity [J/Kg.k] | 335 | 207 | 375 |
| Density [g/cm3] | 8.89 | 2.7 | 8.5 |
| Melting point [°C] | 920-1000 | 660 | 900 |

| Mechanical properties | Copper | Aluminum | Brass |
|-----------------------|--------|----------|-------|
| Tensile strength [MPa] | 220 | 131 | 350 |
| Hardness Brinell | 80 | 80 | 75-110 |
| Elongation percent 50mm | 20% | 3% | 53% |
| Modulus of elasticity [GPa] | 117 | 69 | 96 |

| Table 2: Chemical composition of AISI 304 stainless steel workpiece |
|--------------------------|---------|---------|
| Table 3: Physical properties of electrodes material. |
| Table 4: Mechanical properties of electrodes material |
| Table 5: fixed machining specifications |
MRR calculated according to the equation (3), which depends on the difference of weight of the workpiece before and after machining to the machining time and density of the material.

\[
MRR = \frac{W_{\text{bm}} - W_{\text{am}}}{t \times \rho}
\]  

(3)

MRR = material removal rate (mm³/min).
Wbm = Weight of workpiece before machining (g).
Wam = Weight of workpiece after machining (g).

The experimental results displayed in Table 7 for ANOVA analysis and for plotting various graphs.

Table 8: Investigated magnitudes and S/N ratios of EDM output

| No. of runs | Electrodes material | Current (ampere) | Thickness (mm) | MRR  | SNRA | MEAN | EWR  | SNRA | MEAN |
|-------------|---------------------|-----------------|----------------|------|------|------|------|------|------|
| 1           | Copper              | 50              | 1              | 43.6512 | 32.7999 | 43.6511 | 7.1385 | -17.072 | 7.1385 |
| 2           | Copper              | 100             | 1.5            | 38.3091 | 31.6660 | 38.3091 | 7.0903 | -17.013 | 7.09034 |
| 3           | Copper              | 150             | 2              | 26.5881 | 28.4937 | 26.5880 | 2.2497 | -7.0425 | 2.24971 |
| 4           | Aluminum            | 50              | 1.5            | 15.4586 | 23.7833 | 15.4585 | 8.6352 | -18.725 | 8.63522 |
| 5           | Aluminum            | 100             | 2              | 13.1579 | 22.3837 | 13.1579 | 9.3282 | -19.395 | 9.32818 |
| 6           | Aluminum            | 150             | 1              | 11.5295 | 21.2361 | 11.5294 | 13.0159 | -22.289 | 13.0158 |

5. Completed Orthogonal Array and Results

During the assembling of the information in order to determine the S/N ratio magnitude for material removal rate and EWR. With help of data shown in Table 7, the intermediate influence reactions of basic information estimated for material removal rate and EWR is displayed in Table 8 and intermediate influence reactions of S/N ratio is estimated for material removal rate and EWR displayed in Table 9. The main target of ANOVA, calculate which process specifications greatly influence on the material removal rate and EWR, as displayed in Table 10. Columns labeled Sum of Squares (SS), Mean Square (MS) degrees of freedom (DF), the F-ratio is a measure of the size of the effects (F-ratio) and The (F) magnitude analysis the null hypothesis that information from all data collected from population along equal mean.
Table 9: Reaction of S/N for EDM

| Level | Electrodes material | Current (ampere) | Thickness (mm) | Main effect for S/N ratio for MRR | Electrodes material | Current (ampere) | Thickness (mm) |
|-------|---------------------|------------------|----------------|----------------------------------|---------------------|------------------|----------------|
| 1     | Brass 50            | 2                | 2.0268         | 6.13613                          | Brass 100           | 1                | 6.6704         |
| 2     | Brass 100           | 1                | 6.6704         | 16.4830                          | Brass 150           | 1.5              | 3.5424         |
| 3     | Brass 150           | 1.5              | 3.5424         | 10.9858                          | Brass 50            | 2                | 2.0267         |
| Delta | 1                   | 3                | 2              |                                  | 1                   | 3                | 2              |

Table 10: ANOVA table for MRR and EWR

| Source for MRR | DF | SS   | MS  | F-ratio | P  |
|----------------|----|------|-----|---------|----|
| Electrode material | 2  | 1637.01 | 818.5 | 67.8 | 0.015 |
| Current (ampere)    | 2  | 73.32  | 36.66 | 3.04  | 0.248 |
| Thickness (mm)      | 2  | 73.91  | 36.95 | 3.06  | 0.246 |
| Error               | 2  | 24.14  | 12.07 |       |    |
| Total               | 8  | 1808.37 |      |       |    |

| Source for EWR | DF | SS   | MS  | F-ratio | P  |
|----------------|----|------|-----|---------|----|
| Electrode material | 2  | 46.914 | 23.4568 | 5.59  | 0.152 |
| Current (ampere)    | 2  | 1.533 | 0.7664 | 0.18  | 0.846 |
| Thickness (mm)      | 2  | 19.37 | 9.6849 | 2.31  | 0.302 |
| Error               | 2  | 8.392 | 4.1958 |       |    |
| Total               | 8  | 76.208 |      |       |    |

The graphs that show the main effect for both MRR with mean of means of MRR and MRR with S/N of MRR can be presented as shown in figure (2) and figure (3) respectively. The graphs that show the main effect for both EWR with mean of means of EWR and EWR with S/N of EWR can be presented as shown in figure (4) and figure (5) respectively.
Electrode material, workpiece thickness and current are determined in order 1, 2, and 3 accordingly conform to their bigger magnitude of data. Order 1 provides maximum contribution factor for the material removal rate or EWR and order 3 provides smallest contribution factor for material removal rate or EWR. From Figure 2, copper electrode has highest MRR and Brass have lowest MRR value. From the Figure 4, it analyzed that the aluminum tool has maximum electrode wear rate and copper has lowest electrode wear rate. It conforms that copper is best EDM tool. For current, 100 A the MRR and EWR are higher than other values 50 A and 150 A. For workpiece thickness 1 mm has MRR and EWR higher than other values 1.5 mm and 2 mm.

6. Conclusion
In the attendant investigation, for EDM machining technique the influence of electrode material (copper, aluminum and brass), current and workpiece thickness reviewed. The influence of machining parameters on EDM responding such as MRR and electrode wear rate were analyzed for workpiece material AISI 304 stainless steel. L9 orthogonal array utilizing Taguchi architect and analysis of variance where the performance for investigated the development.
1. For the material removal rate, EDM tool metal has great effective instrument and then workpiece thickness and current at the end.
2. Copper EDM tool displays the biggest material removal rate at current 50 A with 1 mm workpiece thickness when the brass EDM tool displays the lowest material removal rate at current 150 A with 2 mm workpiece thickness.
3. For electrode wear, the EDM tool metal is biggest effecting parameters and workpiece thickness and the final is current. EWR is preferable with smaller magnitude of current.
4. Copper electrode displayed the lowest electrode wear rate at current 50 A with 2 mm workpiece thickness while the aluminum electrode shows the highest electrode wear rate as comparative to copper and brass at current 150 A with 1 mm workpiece thickness. For current 100 A, the EWR is highest which is not preferable.
5. The machining period increased when the workpiece thickness increased.

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Figure 5: Parameter response plot for EWR
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