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Analysis of the Influence of Different EDM Parameters Using Taguchi Technique

Abstract- *Electrical discharge machining (EDM) is a non-traditional material removal process developed in late 1940s has now become the most important technology in manufacturing industries. Taguchi technique has been applied for design of experiments with three input factors and their trinity levels utilizing L9 orthogonal array. The nine specimens were machined with different electrodes material where AISI 304 stainless steel had been used as a workpiece with kerosene as dielectric fluid. The major aim of this study is the evaluation to choice the principle specifications of electrical discharge machining with the assist of Taguchi technique and utilizing Minitab program in condition of material removal rate and electrode wear rate. The variance conditions examined during production the research on electrical discharge machining would be the electrodes material, current and workpiece thickness. The effect of each parameters and excellent performance variables will be achieve by means of ANOVA examination and conformed by investigation to enhance method.*

Keywords-*Electrical Discharge Machining; Electrode Material; Taguchi Technique.*

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1. 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 utilized 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 ate and electrode wear rate and to developing models for three groups of experiments in order to improve the machining efficiency and the machining durations.

2. 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

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concluded that for high value material removal ate, 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-31workpiece. 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-admiistrate 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:

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

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

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

Where:

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

n = the number of observations.

y_i = the observed data.

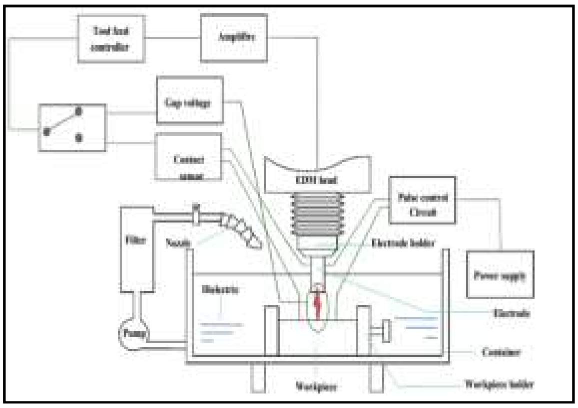
Table 1: Machining parameters and their levels

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

5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	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.



Figurer 1: Schematic diagram of experimental setup

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.

Table 2: Chemical composition of AISI 304 stainless steel workpiece

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%	0.186	Ca%	0.007
Ni%	8.38	Se%	0.004
Al%	0.011	Sb%	0.003
Co%	0.121	Ta%	0.010
Cu%	0.202	Others%	0.056
Nb%	0.007	Fe%	Balance

Table 3: Physical properties of electrodes material.

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

Table 4: Mechanical properties of electrodes material

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 5: fixed machining specifications

Fixed specifications	Specifications magnitude
Polarity of the electrode	Negative
Polarity of workpiece	Positive
Pulse on (Ton)	150 µs
Pulse off (Toff)	75 µs
High Vol.tage	2٤0 V
Gap Vol.tage	7
Servo feed (SVO)	75.0 %
Working time (WT)	1.6 sec
Jumping time (JT)	1.2 mm
Dielectric fluid	Kerosene oil

Table 6: Changing specifications (factors) and their levels

Factors	Levels			Observed values
	Level (1)	Level (2)	Level (3)	1- material removal rate (mm^3/min) 2- electrode wear rate (mm^3/min)
Electrodes material	Copper	Aluminum	Brass	
Current (ampere)	50	100	150	
Thickness (mm)	1	1.5	2	

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.

$$\mathbf{MRR} = \frac{\mathbf{Wbm-Wam}}{\mathbf{t\times\rho}}$$

(3)

MRR = material removal rate (mm^3/min).
Wbm= Weight of workpiece before machining (g).
Wam = Weight of workpiece after machining (g).
t = processing period (min).
ρ = Density of workpiece material (g/mm^3) [4].
EWR displayed as the percentage of the change of weight of the Ebm and Eam the processing period and density of the electrode material.

$$\mathbf{EWR} = \frac{\mathbf{Ebm-Eam}}{\mathbf{t\times\rho}}$$

(4)

EWR = electrode wear rate (mm^3/min).
Ebm = Weight of electrode before machining (g).
Eam = Weight of electrode after machining (g).
t = processing period (min).
ρ = Density of electrode material (g/mm^3) [4].
The electrode and workpiece in all investigations weighted before and after processing by utilizing sensitive balance device (DENEVER INSTRUMENT 4Dig). The experimental results presented in table (7). These results have been used to analyze the MRR and EWR by using Taguchi method constructed in Minitab (version 17) for ANOVA analysis and for plotting various graphs.

Table 7: Design matrix and Observation

Sample	Experimental conditions			Weight of Workpiece (g)		Weight of electrode (g)	
	Electrodes material A	Current (Ampere) B	Thickness (mm) C	Before machining	After machining	Before machining	After machining
S_1	Copper	50	1	11.185	10.825	25.363	25.297
S_2	Copper	100	1.5	21.202	20.561	24.488	24.355
S_3	Copper	150	2	26.448	25.573	21.877	21.794
S_4	Aluminum	50	1.5	18.293	17.62	5.185	5.057
S_5	Aluminum	100	2	27.268	26.427	4.444	4.241
S_6	Aluminum	150	1	10.805	10.485	7.691	7.568
S_7	Brass	50	2	26.369	25.756	16.853	15.427
S_8	Brass	100	1	11.045	10.698	24.066	23.698
S_9	Brass	150	1.5	18.723	18.105	21.088	20.074

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 (P) magnitude analysis the null hypothesis that information from all data collected from population along equal mean.

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	7.13853
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

7	Brass	50	2	2.0268	6.13613	2.0267	4.3987	-12.866	4.39865
8	Brass	100	1	6.6704	16.4830	6.67040	6.5997	-16.390	6.59971
9	Brass	150	1.5	3.5424	10.9858	3.54235	5.4225	-14.683	5.42246

Table 9: Reaction of S/N for EDM

	Major influence for S/N ratio for MRR			Main effect for S/N ratio for EWR		
Level	Electrodes material	Current (ampere)	Thickness (mm)	Electrodes material	Current (ampere)	Thickness (mm)
1	22.47	20.91	23.51	-20.14	-16.22	-18.58
2	11.2	23.51	22.15	-14.65	-17.6	-16.81
3	30.99	20.24	19.0	-13.71	-14.67	-13.1
Delta	19.78	3.27	4.5	6.43	2.93	5.48
Rank	1	3	2	1	3	2

Table 10: ANOVA table for MRR and EWR

	Source	DF	SS	MS	F-ratio	P
ANOVA for MRR	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			
ANOVA for EWR	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.

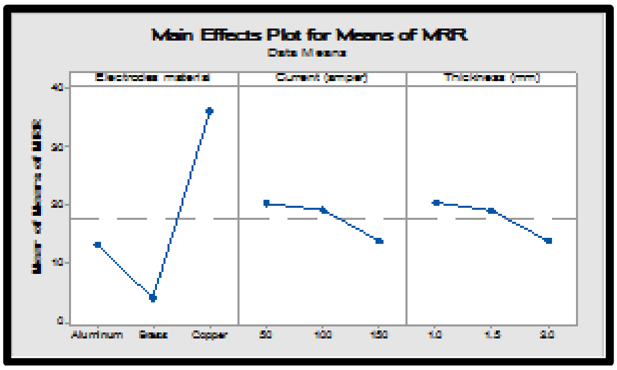


Figure 2: Plot for mean of MRR

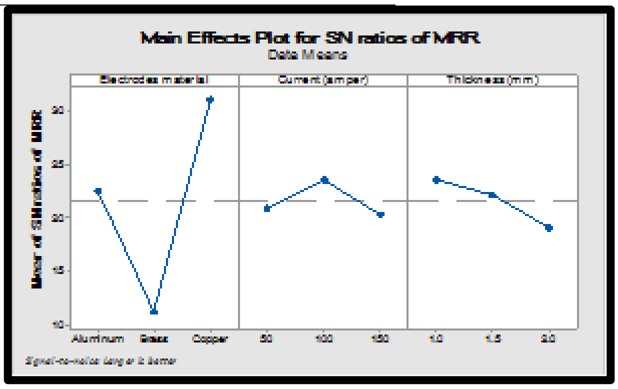


Figure 3: Parameter response plot for MRR

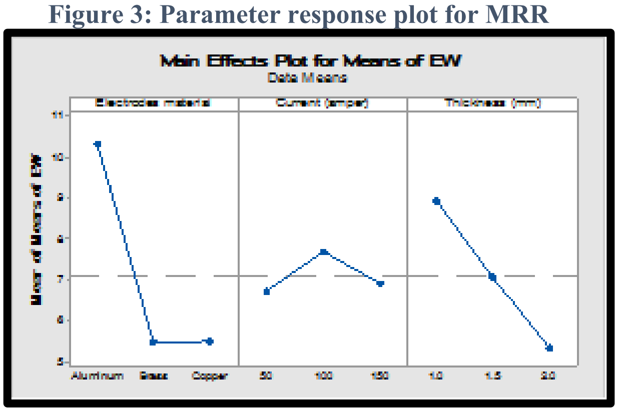


Figure 4: Plot for mean of EWR

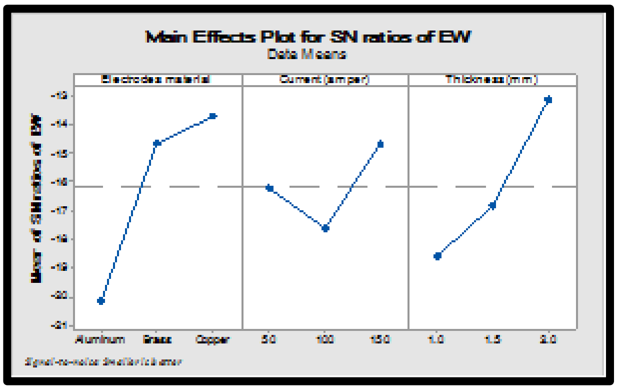


Figure 5: Parameter response plot for EWR

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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