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Optimization the Effect of Electrode Material Change on EDM Process Performance Using Taguchi Method

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Abstract

Electrical Discharge Machining (EDM) is a widespread Nontraditional Machining (NTM) processes for manufacturing of a complicated geometry or very hard metals parts that are difficult to machine by traditional machining operations. Electrical discharge machining is a material removal (MR) process characterized by using electrical discharge erosion. This paper discusses the optimal parameters of EDM on high-speed steel (HSS) AISI M2 as a workpiece using copper and brass as an electrode. The input parameters used for experimental work are current (10, 24 and 42 A), pulse on time (100, 150 and 200 µs), and pulse off time (4, 12 and 25 µs) that have effect on the material removal rate (MRR), electrode wear rate (EWR) and wear ratio (WR). A Minitab software environment was used to adopt Taguchi method to analyze the effect of input on output parameters of EDM. The results of the present work showed that the best of MRR in copper and brass electrodes with (current 42 A, pulse on time 100 µs and pulse off time 25 µs) are (84.355×10^{-3} g/min) and (43.243×10^{-3} g/min) respectively, and the MRR predicted by Taguchi are (86.1751×10^{-3} g/min) in copper electrode by using the parameters with (current 10 A, pulse on time 200 µs and pulse off time 25 µs) and (43.2979×10^{-3} g/min) in brass electrode at current 42 A, pulse on time 100 µs, and pulse off time 25 µs. The lowest EWR occurs with a value of (1.4510×10^{-3} g/min) with (current 10 A, pulse on time 100 µs, pulse off time 4 µs) variables when using a copper electrode. The highest WR (2.602508) was found for the brass electrode with (current 24 A, pulse on time 200 µs, pulse off time 4 µs) variables.

Keywords: *EDM, taguchi method, material removal rate, electrode wear rate, wear ratio.*

1. Introduction

One of the non-conventional material removal processes is an electrical discharge machining (EDM), which is widely used in industry [1]. Metals are taken away from the piece by a series of frequent periodic electric spark between electrode and workpiece separate by a liquid solution [2].

At present, EDM is the most widely used technique for high – precision machining of all types of conductive metals, alloy irrespective of hardness. It is also used in Automobile industry, aerospace and in farm industry [3].

An initial cost of EDM machining is high but with a selection of optimal parameter's levels, its wastage, operating cost decreases with quality improvements [4].

In tested the influence of the electrical discharge machining parameters like, Pulse on Time (Ton), Pulse off Time (Toff), and Current (I) on Material Removal Rate (MRR) for stainless steel, the results were resolved by using variance analysis and response graphs, it has been different collections of EDM process parameters are obtain higher MRR and better surface roughness (Ra) [5].

Srivastava & Pandey [6] conducted an experiment with the process parameters like a pulse on time, current, duty cycle and voltage on response factors like tool wear rate, material removal rate and surface roughness with the cryogenically treated electrode. They revealed that current, pulse on time and duty cycle have a significant effect on tool wear and material removal rate. Shukry et al. [7] studied the effect of EDM parameters such as current, pulsation on time and pulsation off time on surface roughness of steel 304 with dielectric solution of gas oil by supplied DC current values (10, 20, and 30A). The voltage of (140V) uses to cut 1.7mm thickness of the steel and use the copper electrode. They found that the parameters of current and pulsation on time affected the surface roughness (Ra) directly.

Discharge current was the most effective parameter on the MRR & Ra when using the copper material as voltage, current, Pon and Poff for responses of surface roughness and material removal rate on the EDM of tool steel (AISI D2) [8].

Selection of input parameter played a great property of EDM on nickel superalloy material (RENE80) with aluminum (Al) as an electrode. That the input parameters considered are I; Pon and Poff are used for Experimental Work and their effect on MRR, Tool Wear Rate, and Ra [9].

2. Objectives

Although various parameters could be considered for electrical discharge machining process, but in the present work, three process parameters namely discharge current, pulse-on-time, and pulse-off time are considered.

To find out the optimal factors of maximization for MRR in EDM process, Taguchi technique is used. The works have been done with oil as dielectric solution on (CM 323C EDM machine), as shown in Fig. 1. High-speed steel AISI M2 size 60×45×3mm plate is chosen for conductive experiment with nine specimens. The chemical, mechanical, and physical properties of the high-speed steel are given in table 1, and table 2, respectively.

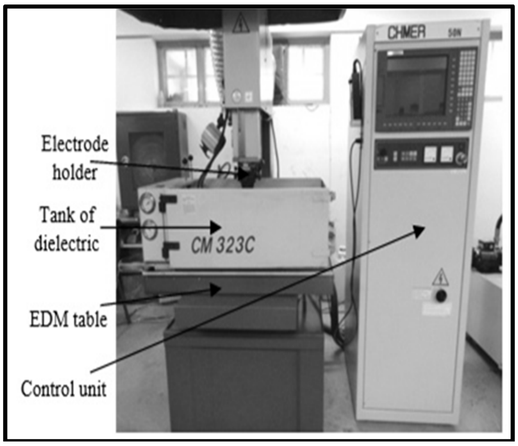

Fig. 1. EDM CM323C CNC Machine.

Table 1,
Chemical composition of AISIM2 works material.

Material	Weigh t (%)	Material	Weight (%)
C	0.855	Mo	5.83
Si	0.305	Ni	0.14
Mn	0.28	Cu	0.175
P	0.001	V	1.88
S	0.001	W	5.73
Cr	4.71	Co	0.045
Sn	0.001	Fe	Balance

Table 2,
Mechanical and Physical properties of high speed steel.

properties	AISI M2 (%)
Modulus of Elasticity (GPa)	207
Specific Heat Capacity (J/g-	0.46
Thermal conductivity (W/m-	19
Electrical Resistivity (ohm-	54x10-6
Density (g/cm3)	8.14
Hardness (HRC)	61-66
Chirpy Impact (J)	31.2-38
Poisson's ratio	0.30

The tool electrodes’ material that are used in the experimental work are copper and brass electrodes (ϕ4×100 mm) with negative polarity, as shown in Fig. 2 (a- copper electrode and b- brass electrode).

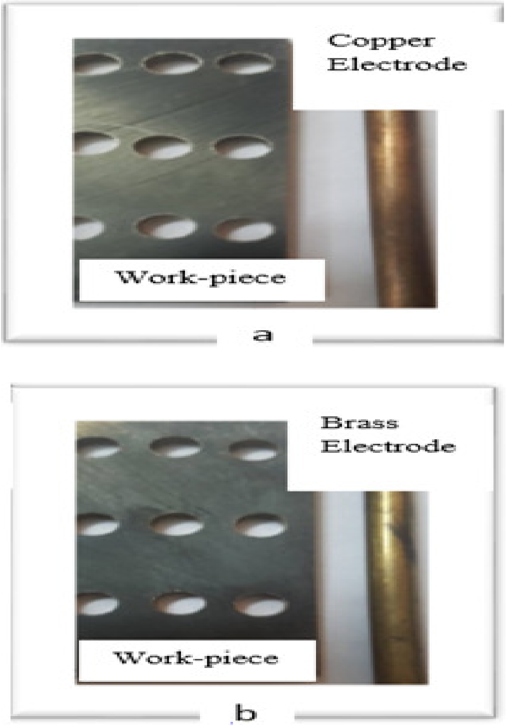

Fig. 2. The high-speed steel (HSS) AISI M2 as a workpieces and electrodes (a) Copper electrode, (b) Brass electrode.

By using three sets of experiments (Peak Current (Ip), Pulse on time (Ton), Gap Voltage (Vg)) to find tool wear rate, experiments showed that the optimization of process parameters, the third set gave the maximum tool wear rate when using the copper as a tool material and the aim was to optimize set of process parameters [10].

Variables on the material removal rate (MRR) in die-sinking EDM of EN19 material for four processes (Pulse on time, pulse off time, discharge current and gap voltage) with electrolytic copper use as the electrode material. The different combinations of process parameters and by analysis of variance (ANOVA) found that pulse off time, discharge current, gap voltage and the interaction terms are significant whereas the pulse on time has almost negligible effect on MRR 1.45% is the error between the predicted and experimental MRR value was found to be very effective as shown in this studied [11].

This work studies the optimization of EDM process parameters on machining per for using high-speed steel AISI M2 as a workpiece and copper and brass as an electrode.

The material removal rate of the process obtained by the formula [12]:

$$MRR = \frac{\text{Wbm}-\text{Wam}}{M_t} \quad \ldots(1)$$

MRR= Material removal rate in (g/min).
Mt = Machining time in (min).
Wbm= Weight workpiece before machining in (g).
Wam= Weight after workpiece machining in (g).

The electrode wear rate of the process obtained by the formula [12]:

$$EWR = \frac{\text{Ebm}-\text{Eam}}{M.} \quad \ldots(2)$$

Where:
EWR= Electrode wear rate in (g/min).
Mt = Machining time in (min).
Ebm= Weight electrode before machining in (g).
Eam= Weight electrode after machining in (g).

The wear ratio of the process obtained by used the formula [13]:

$$WR = \frac{\text{EWR}}{MRR} \quad \ldots(3)$$

Where:
WR= Wear ratio.
EWR= Electrode wear rate in (g/min).
MRR= Material removal rate in (g/min).

3. Taguchi Method

To find out the best machining parameters of maximization for MRR in EDM process, Taguchi analysis is used. This method can identify the main effective parameters with embedded sub-level parameters.

This method is used to loss function parameters diverge from the required values into a Signal to Noise (S/N) ratio to three types mainly as follows:-
(1) Larger-The-Better
(2) Nominal-The-Better
(3) Smaller-The-Better

The characteristic of higher value represents better machining performance. For example, material removal rate is termed as Larger-the-better. Characteristics of lower value appear for best machining interpretation. Hence it is concluded that for material removal rate "larger-is –better" were selected for finding optimum machining parameters. The overcut of (S/N) ratio is calculated by [14]:

$$\frac{S}{N} = -10\log(\sum Y_i)\wedge 2/n \quad \ldots(4)$$

Where the Yi is ith observed value of the response and n: number of observations. The design and levels parameters of the study experiments at different factors of consideration (current, pulse on time and pulse on time) are shown in table 3. MINITAB 17 Software is used for the design of the experiment in Taguchi analysis. A number from ordinary orthogonal array has been created to ease of experimental designing. Table 4 shows the Taguchi matrix method of the experiment at a different number of experiments with machining parameters grades.

Table 3,
Design of experiments.

factors of consideration	code	grade 1	2	3
Current(A)	I	10	24	42
PULSE ON TIME(µs)	Ton	100	150	200
PULSE OFF TIME(µs)	Toff	4	12	25

Table 4,
Taguchi matrix ((3-grades design)).

No. of Experiments	Machining parameters grades I Current(A)	Ton Pulse On Time(µs)	Toff Pulse Off Time(µs)
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. Results and Discussion

The obtained experimental results are shown in the tables (5-13), respectively. MRR, EWR and WR were analyzed in accordance with the input parameters i.e. current, Ton and Toff. Nine experiments were conducted according to the Tables (5-7) and the average of the three was taken for the analysis purpose. In order to investigate the effect of three parameters i.e. I. Ton and Toff on the MRR, EWR and WR experiments were conducted using L9 Orthogonal array along with the S/N ratio by used Taguchi design method of experiment at a different number of experiments with machining parameters grades. According to Taguchi method of the experiment, the better quality characteristics for material removal rate, electrode wear rate and wear ratio by use copper and brass electrodes. The ideal conditions for MRR required is current 42 A, Ton 100 µs and Toff 25 µs of copper electrode. The required EWR is current 10 A, Ton 100 µs and Toff 4 µs of copper electrode, and the required WR is current 10 A, Ton 100 µs and Toff 4 µs of copper electrode. The optimal process parameters combination for max. MRR is found to be current at the highest level, pulse on time at the lowest level, and pulse off time at the highest level of the copper electrode, max. EWR is found to be current at the highest level, pulse on time at the lowest level, and pulse off time at the highest level of the brass electrode, and max. WR is found to be current at a moderate level, pulse on time at the highest level, and pulse off time at lowest level of brass electrode.

Figs. (3-4) show the main effect of machining variables (I, Ton and Toff) on the MRR of copper electrode in rang (27.391-84.355×10-3 g/min) with current (10-42 A), pulse on time (100-200 µs), and pulse off time (4-25 µs) and obtained high MRR (84.355×10-3 g/min) with current (42 A), Ton (100 µs), and Toff (25 µs) and the MRR of brass electrode in rang (18.034-43.243×10-3 g/min) with current (10-42 A), Ton (100-200 µs), and Toff (4-25 µs). High MRR of (43.243×10-3 g/min) was obtained with current (42 A), Ton (100 µs), and Toff (25 µs).

Figs. (5-6) show the main effect of machining variables (I, Ton and Toff) on the EWR of copper electrode in rang (1.451-25.0716×10-3 g/min) with current (10-42 A), pulse on time (100-200 µs), and pulse off time (4-25 µs) and obtained low EWR (1.451×10-3 g/min) with current (10 A), Ton (100 µs), and Toff (4 µs) and the EWR of brass electrode in rang (25.8523-91.4651×10-3 g/min) with current (10-42 A), Ton (100-200 µs), and Toff (4-25 µs).Low EWR of (25.8523×10-3 g/min) was obtained with current (10 A), Ton (150 µs), and Toff (12 µs).

Figs. (7-8) show the main effect of machining variables (I, Ton and Toff) on the WR of copper electrode in rang (0.026619-0.297215) with current (10-42 A), pulse on time (100-200 µs), and pulse off time (4-25 µs). High WR of (0.297215) was obtained with current (42 A), Ton (100 µs), and Toff (25 µs) and the WR of brass electrode in rang (1.38796-2.60258) with current (10-42 A), Ton (100-200 µs), and Toff (4-25 µs) and obtained high WR (2.60258) with current (24 A), Ton (200 µs), and Toff (4 µs).

The response tables for MRR, EWR and WR are given in Tables (8-13). It is verified from Table 8 that Toff has the maximum effect as compared to the I and Ton of the copper electrode. The ranks on the process parameters clarify this. Delta values are the difference between the maximum and minimum values from level 1 to level 3. As MRR is the higher, the better type performance characteristics, so Table 8 gives the optimal setting of process parameters. From Table 8 and Fig. 3, it has been envisaged that (I) 2 (Ton) 3 (Toff) 1 gives the maximum MRR of copper electrode.

Same condition as the rest of the tables (9-13). From Table 9 and Fig. 5 it has been envisaged that (I) 2 (Ton) 3 (Toff) 1 gives the maximum MRR of copper electrode.

Figs. (9-14) shows the main effect curve of MRR on current and pulse on at copper and brass electrodes.

It has been noted from 3D figures influence that whenever current and pulse on-time increases the material removal rate increases. The MRR, EWR and WR increase with the increase in I and Ton. The reason exists behind this was the high value of spark-energy. As Ton is the time for which the current pulse in a circuit remains active. A large value of Ton depicts the large current value and this current value is the reason for spark. So, a high Ton value correspondingly enhances the spark energy. This spark energy removes the material from the work-piece. High Ton value removes a large amount of material as compared to the low Ton value. The values of MRR, EWR and WR found to be decreased with the increases in Toff value. This was due to the low value of spark-energy in the circuit. As Toff is the time gap between two successive pulses in a circuit, so if the time gap between two successive pulses decreased, then the value of current within a specified time period also decreases. This would reduce the intensity of the spark in the circuit.

Table 5,
Result machining variables experimental of MRR with Taguchi design.

No. of Experiments	I Current (A)	T_{on} (µs)	T_{off} (µs)	MRR 10^{-3} (g/min.) (Copper)	$PMEAN_2$	MRR 10^{-3}(g/min.) (Brass)	$PMEAN_3$
1	10	100	4	54.510	58.2514	18.982	18.8696
2	10	150	12	70.072	63.8051	18.034	18.0889
3	10	200	25	83.652	86.1751	22.252	22.3096
4	24	100	12	48.840	51.3654	30.030	30.0876
5	24	150	25	68.876	72.6174	30.157	30.0446
6	24	200	4	31.833	25.5661	18.129	18.1839
7	42	100	25	84.355	78.0881	43.243	43.2979
8	42	150	4	27.391	29.9164	27.116	27.1736
9	42	200	12	32.849	36.5904	30.769	30.6566

Table 6,
Result machining variables experimental of EWR with Taguchi design.

No. of Experiments	I Current (A)	T_{on} (µs)	T_{off} (µs)	EWR 10^{-3} (g/min.)	$PMEAN_2$	EWR 10^{-3}(g/min.) (Brass)	$PMEAN_3$
1	10	100	4	1.4510	1.4311	32.7528	32.6525
2	10	150	12	3.8702	3.8708	28.8523	28.8513
3	10	200	25	3.9706	3.9706	30.8768	30.8771
4	24	100	12	13.4573	13.4673	58.9802	58.9502
5	24	150	25	10.9633	10.9333	59.5285	59.5235
6	24	200	4	1.4791	1.4721	48.4499	48.4139
7	42	100	25	25.0716	25.2716	91.4651	91.4651
8	42	150	4	7.074	7.0584	66.8264	66.7263
9	42	200	12	5.9832	5.7822	71.7554	71.7253

Table 7,
Result machining variables experimental of WR with Taguchi design.

No. of Experiments	I Current (A)	T_{on} (µs)	T_{off} (µs)	WR (Copper)	$PMEAN_2$	WR (Brass)	$PMEAN_3$
1	10	100	4	0.026619	0.026531	1.725466	1.72547
2	10	150	12	0.055232	0.056252	1.599883	1.59988
3	10	200	25	0.047465	0.049462	1.387596	1.38760
4	24	100	12	0.275538	0.275732	1.464042	1.46404
5	24	150	25	0.159174	0.158175	1.973953	1.97395
6	24	200	4	0.046464	0.048465	2.602508	2.60251
7	42	100	25	0.297215	0.299213	2.115143	2.11514
8	42	150	4	0.258238	0.254233	2.464463	2.46446
9	42	200	12	0.182142	0.186143	2.332068	2.33207

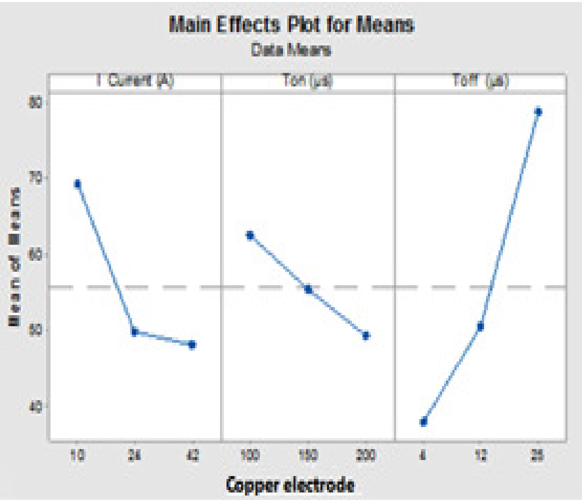

Fig. 3. Main effects plot of the mean value for MRR of the copper electrode.

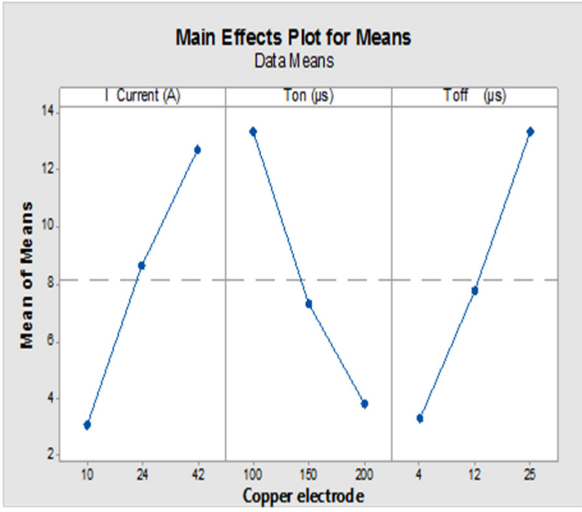

Fig. 5. Main effects plot of the mean value for EWR of the copper electrode.

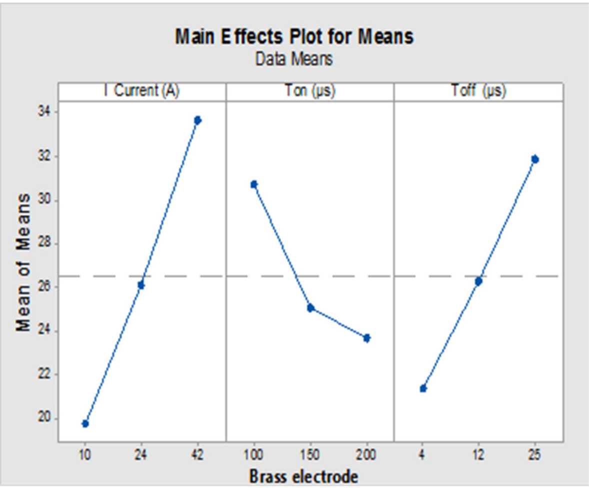

Fig. 4. Main effects plot of the mean value for MRR of the brass electrode.

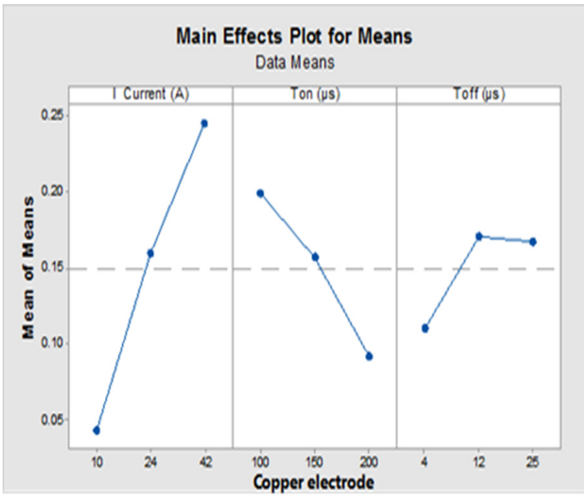

Fig. 6. Main effects plot of the mean value for EWR of the brass electrode.

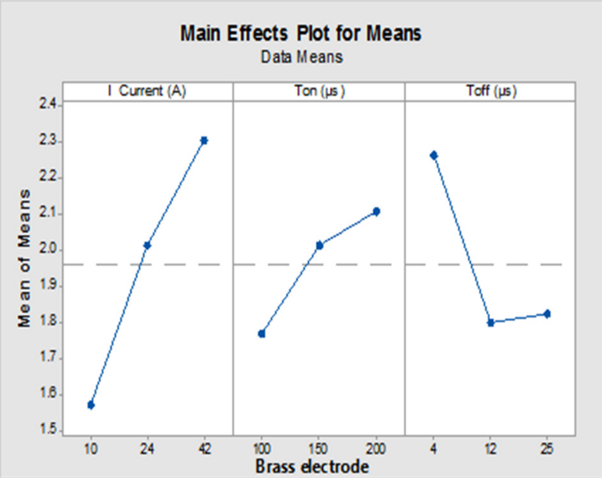

Fig. 7. Main effects plot of mean value for WR of copper electrode.

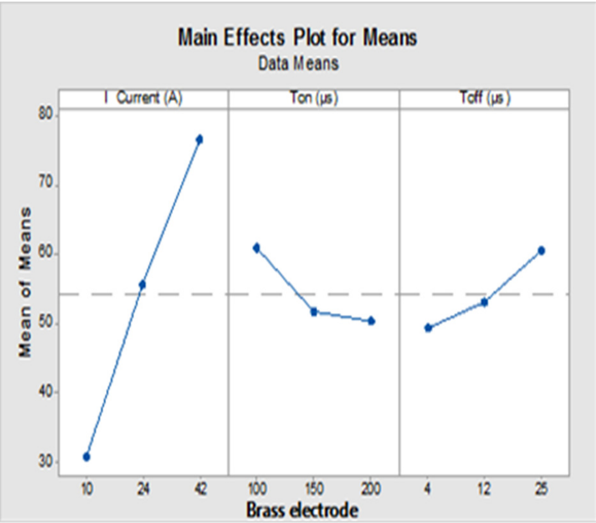

Fig. 8. Main effects plot of the mean value for WR of the brass electrode.

Table 8,
Response Table for Means of the copper electrode (MRR).

Level	I (A)	T_{on} (µs)	T_{off} (µs)
1	69.41	62.57	37.91
2	49.85	55.45	50.59
3	48.20	49.44	78.96
Delta	21.21	13.12	41.05
Rank	2	3	1

Table 9,
Response Table for means of brass electrode (MRR).

Level	I (A)	T_{on} (µs)	T_{off} (µs)
1	19.76	30.75	21.41
2	26.11	25.10	26.28
3	33.71	23.72	31.88
Delta	13.95	7.03	10.47
Rank	1	3	2

Table 10,
Response Table for means of copper electrode (EWR).

Level	I (A)	T_{on} (µs)	T_{off} (µs)
1	3.097	13.327	3.335
2	8.633	7.302	7.770
3	12.710	3.811	13.335
Delta	9.612	9.516	10.000
Rank	2	3	1

Table 11,
Response Table for means of brass electrode (EWR).

Level	I (A)	T_{on} (µs)	T_{off} (µs)
1	30.83	61.07	30.83
2	55.65	51.74	53.20
3	76.68	50.36	60.62
Delta	45.86	10.71	11.28
Rank	1	3	2

Table 12,
Response Table for means of copper electrode (WR).

Level	I (A)	T_{on} (µs)	T_{off} (µs)
1	0.04311	0.19979	0.11044
2	0.16039	0.15755	0.17097
3	0.24587	0.09202	0.16795
Delta	0.20276	0.10777	0.06053
Rank	1	2	3

Table 13,
Response Table for means of brass electrode (WR).

Level	I (A)	T_{on} (µs)	T_{off} (µs)
1	1.571	1.768	2.264
2	2.014	2.013	1.799
3	2.304	2.107	1.826
Delta	0.733	0.339	0.465
Rank	1	3	2

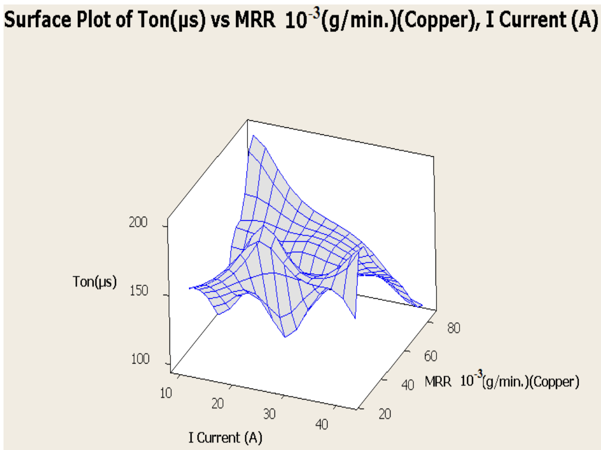

Fig. 9. Show Main effect curve of MRR on current and pulse on of copper electrode.

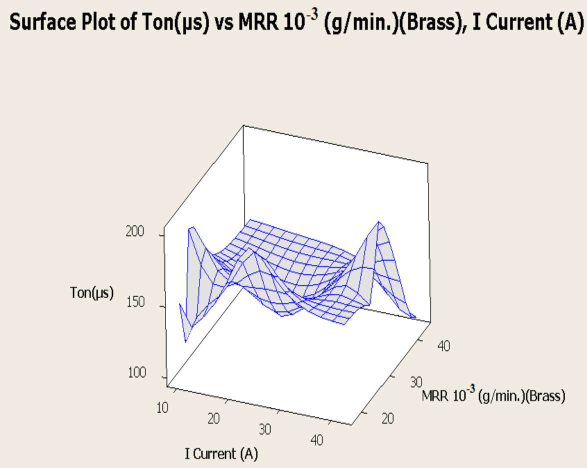

Fig. 10. Show Main effect curve of MRR on current and pulse on of brass electrode.

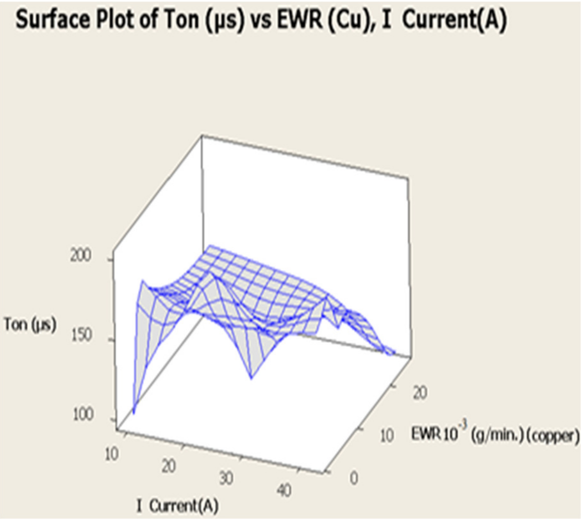

Fig. 11. Show Main effect curve of EWR on current and pulse on of copper electrode.

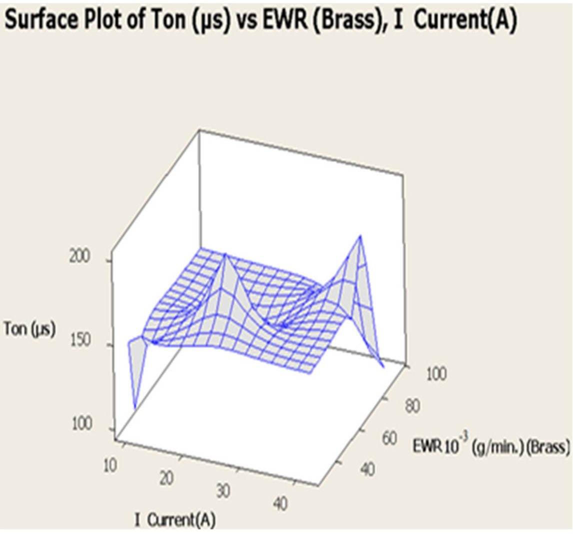

Fig. 12. Show Main effect curve of EWR on current and pulse on of brass electrode.

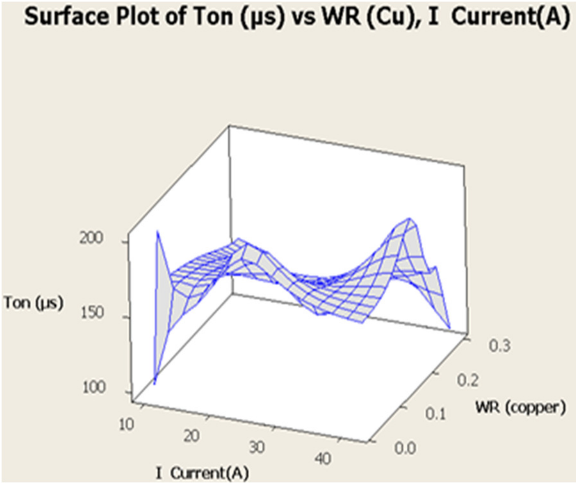

Fig. 13. Show Main effect curve of WR on current and pulse on of copper electrode.

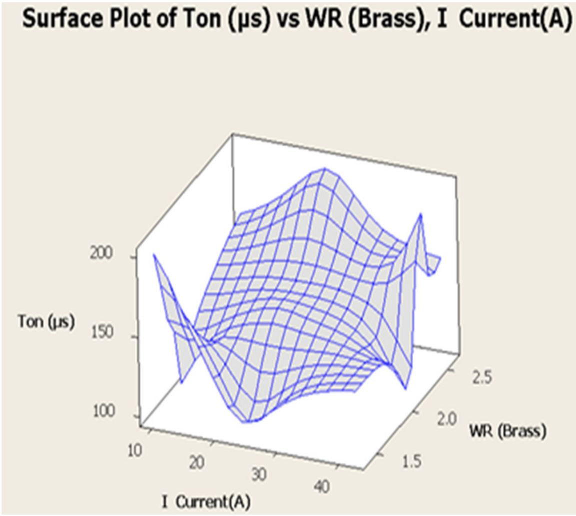

Fig. 14. Show Main effect curve of WR on current and pulse on of brass electrode.

5. Conclusions

In this investigation, experiments on Electrical Discharge Machining were conducted to examine the influence of machining output possessed for idea are MRR, EWR and WR of the high speed steel AISI M2 workpiece using copper and brass electrodes tool by Taguchi design method. Improvement of MRR, EWR and WR have been also investigated. The experiment depends on various parameters namely (I), (T_{on}), and (T_{off}) which has been selected. This experiment is based on L9 orthogonal array by Taguchi design, was conducted and Minitab 17 software was used for this experiment. The major conclusions of this work are as follows:

1- Current has most significant parameters on MRR, EWR and WR but T_{on} moderately affects the MRR, EWR and WR while T_{off} has the least significant influence on MRR, EWR and WR for two electrodes copper and brass.
2- The best operation parameters, as shown in the observation table, are current 42 A, T_{on} 100 µs, and T_{off} 25 µs, for both copper and brass electrodes.
3- Through practical experiments, it has been noted that the use of a copper electrode is better than the electrode of the brass in terms of the MRR, EWR, and WR.

Notation

EDM	Electrical Discharge Machining
EWR	Electrode wear rate
HSS	High speed steel
I	Current
Ip	Peak Current
MR	Material removal
MRR	Material removal rate
M_t	Machining time
N	Number of observations
NTM	Nontraditional machining
Poff	Pulse off Time
Pon	Pulse on Time
Ra	Surface roughness
S/N	Signal to Noise Ratio
T_{off}	Pulse off Time
T_{on}	Pulse on Time
Vg	Gap Voltage
WR	Wear ratio
W_{am}	Weight after machining
W_{bm}	Weight before machining
Yi	ith observed value of the response

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أمثلية تاثير تغير مادة القطب على اداء عملية التشغيل بالشرارة الكهربائية (EDM) باستخدام طريقة تاكوشي

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الخلاصة

تعتبر عملية التفريغ الكهربائي (EDM) عمليات تصنيع غير تقليدية واسعة النطاق (NTM) لتصنيع هندسة معقدة أو أجزاء معدنية صلبة للغاية يصعب تشغيلها بواسطة عمليات التشغيل التقليدية. آلتشغيل بالتفريغ الكهربائي هي عملية لإزالة المواد (MR) تتميز باستخدام تآكل التفريغ الكهربائي. تناقش هذه الورقة المحددات المثلى لـEDM على الصلب AISI (HSS) عالي السرعة M2 باعتبارها القطعة المشغلة واستخدم النحاس والبراص كأقطاب. محددات الإدخال المستخدمة في العمل التجريبي الحالية (24,10، ٤٢ A) ، وقت نبضة التشغيل (١٠٠ ، ١٥٠ و ٢٠٠)مايكروثانية ووقت نبضة التوقف (٤ و ١٢ و ٢٥) مايكروثانية والتي تؤثر على معدل إزالة المواد (MRR)، معدل بلى الاقطاب (EWR) ونسبة البلى (WR). استخدام برنامج ميني تاب باعتماد طريقة تاكوشي لتحليل تأثير المدخلات على مخرجات المحددات من الEDM. أظهرت نتائج هذا العمل أن أفضل معدل إزالة المواد في أقطاب النحاس والبراص مع (لتيار ٤٢ A ، وقت نبضة التشغيل ١٠٠ مايكرو ثانية ووقت نبضة التوقف ٢٥ مايكرو ثانية) (84.355 × ١٠$^{-٣}$غرام/دقيقة) و (٤٣,٢٤٣ × ١٠$^{-٣}$ غرام/دقيقة) على التوالي ، ومعدل إزالة المواد التي تنبأت عن تاكوشي هي (٨٦,١٧٥١ × ١٠$^{-٣}$ غرام/دقيقة) في القطب النحاسي باستخدام المتغيرات (التيار ١٠ A ، وقت نبضة التشغيل ٢٠٠ مايكرو ثانية ووقت نبضة التوقف ٢٥ مايكرو ثانية) و (٤٣,٢٩٧٩ × ١٠$^{-٣}$ غرام/دقيقة) في القطب النحاسي في التيار ٤٢ A ، وقت نبضة التشغيل ١٠٠ مايكرو ثانية ، ووقت نبضة التوقف ٢٥ مايكرو ثانية. يحدث أدنى معدل بلى الاقطاب بقيمة (١,٤٥١٠×١٠$^{-٣}$ غرام / دقيقة) مع متغيرات (التيار ١٠ A، نبضة التشغيل ١٠٠ مايكرو ثانية ، ووقت نبضة التوقف ٤ مايكرو ثانية) عند استخدام القطب النحاس. تم العثور على أعلى نسبة البلى (2.602508) للإلكترود النحاسي مع المتغيرات (التيار ٢٤ A ، نبضة التشغيل ٢٠٠ مايكرو ثانية ، ووقت نبضة التوقف ٤ مايكرو ثانية).