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Investigation study of electrical discharge machining parameters on material removal rate for AISI M2 material

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ABSTRACT

EDM (Electrical Discharge Machining) is a common non-traditional machining technique for manufacturing geometry parts made of intricate or extremely rigid metals that are challenging to manufacture using conventional manufacturing techniques. Electrical discharge machining, by utilizing electrical discharge erosion, classifies the process of material removal (MR). The main objective of this paper is to discuss the ideal EDM parameters for using high-speed steel as workpiece AISI M2 and with using brass & copper as electrodes. Pulse on-time (100, 150, and 200 µs), current (10, 24, and 42 A) and pulse off-time (4, 12, and 25 µs) are the input parameters that affect the material removal rate (MRR) in the experimental work. The findings of the present study show that the highest MRR was achieved with copper & brass electrodes using a pulse on-time of 200 µs, pulse off-time of 12 µs, and a current of 42 A, resulting in rates of (0.31284 g/min and 0.18769) respectively. The lowest average value of the removed material was observed when evaluating a current of 10 A, pulse on-time of 100 µs, pulse off-time of 4 µs, resulting in rates of (0.05451g/min and 0.01898 g/min) respectively.

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1. Introduction

In general, electrical discharge machining (EDM) is an unconventional method for material removal, widely employed in industries [1]. The process involves a sequence of periodic, frequent electric sparks occurring between the electrode and the workpiece, while being separated by a liquid solution, to remove metal from the workpiece [2]. EDM is currently the most popular technique for achieving high accuracy in machining various conductive metals and alloys, regardless of their hardness. Furthermore, it finds applications in the agricultural, automotive, and aerospace industries [3]. In EDM, the two electrodes are spaced apart by a very small gap, typically ranging from 0.01 and 0.5 mm, and they are subjected to a sequence of voltage pulses with magnitudes ranging from approximately 20 to 120 V and frequencies on the order of 5 kHz [4]. The spark cycle time is shown in Fig. 1.

EDM machining has a high initial cost, but when the quality is improved and the ideal parameter levels are chosen, the waste and operational costs are reduced [5]. In a study by Jaspreer et al. [6], the parameters of EDM, such as Pulse on-Time (T_{on}), current (I), and Pulse off-Time (T_{off}), were investigated, along with their effect on the material removal rate (MRR) of stainless steel as the workpiece. The findings have been determined using response graphs and variance analysis. Through the study, in order to achieve a larger MRR and better surface roughness (Ra), it has been discovered that distinct collections of EDM machining parameters are desired. Srivastava & Pandey [7] studied the effects of the operation parameters of pulse on-time, duty cycle, current and voltage on response variables including tool wear rate, material removal rate, and surface roughness with the cryogenically treated electrode.

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Nomenclature:

T_{on}	Pulse on -time (µs)	*Subscripts*	
T_{off}	Pulse off -time (µs)	EDM	Electrical Discharge Machining
A	Current (I)	HSS	High-speed steel
Ra	Surface roughness (µs)		
MRR	material removal rate (g/min)		
EWR	electrode wear ratio (mm³/min)		

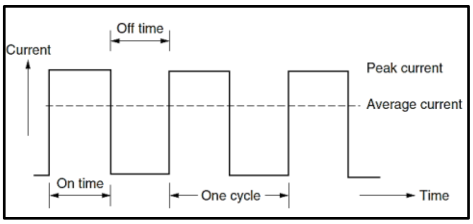

Figure 1. Typical EDM pulse current train for the controlled pulse generator.

They discovered that the three variables of current, pulse on-time, and duty cycle significantly affect the rate of material removal and wear of the tool. Chikalthankaret al., [8] investigated the influence of operations variables such as voltage, current, P_{on}, and P_{off} for the responses of MRR and Ra on the electrical discharge machining of tool steel (AISI D2) utilizing the material of copper. The study's discharge current parameters are the most useful ones for determining MRR and Ra. S. Chandramouliet al. [9] examined the best process parameters of electrical discharge machining on super alloy metal of nickel (RENE80) using aluminum (Al) as an electrode. P_{on}, P_{off} and *I* are utilized in experimental work to determine their effects on MRR and Ra and Tool Wear Rate. The findings of this research showed how important input parameter selection was to the success of EDM. Several factors that affect the rate of tool wear have been found by Shivendra Tiwari [10]. Copper was the material used to make the tools. According to the layout of the experiment table, three sets of experiments were carried out in this study. Based on the information gathered throughout the experiment, the material removal rate has been determined. In this paper, process parameter optimization was the main goal. The third set provided the highest rate of tool wear throughout the optimization of process parameters. Shashikant et al. [11] focused on the parametric and relationships interactions between the controllable and measurable parameters, and the effect on the rate of material removal (MRR) in the EDM of EN19 material. Four process variables were used to conduct the studies. Electrolytic copper was employed as the electrode material, and the following factors were considered: pulse off-time, current, pulse on-time, and voltage of gap. 31 tests in total were performed using various combinations of process parameters. The analysis of variance (ANOVA) was used to obtain the significant coefficients.

According to the analysis, the pulse on -time has a very small impact on the MRR, whereas the current of discharge, gap voltage, pulse off-time, and interaction terms are important. The model of sufficiency was found to be extremely satisfactory, and this methodology was determined to be very effective. Additionally, an effort has been made to optimize the rate of material removal in the research area. The difference between the experimental MRR value and the projected MRR value was found to be (1.45%). Analysis of grey relational and Taguchi approach combined by Tang & Du [12] to investigate the examine the problem of EDM variables optimization. Since tap water does not create any toxic gases while in use, it provides a good working environment. Gap voltage, discharge current, negative polarity, pulse duty factor, and lifting height are among the process parameters. As objective parameters, the electrode wear ratio (EWR), material removal rate (MRR), and surface roughness (Ra) are used to evaluate the total machining impacts. A confirmation experiment was used to confirm the results of the experiments that were based on Taguchi and Grey relational analysis. The MRR increased from 1.28 mm³/min to 2.38 mm³/min, EWR reduced from 0.14 to 0.10 mm³/min, and Ra fell from Ra 2.37 µm to Ra 1.93 µm when the machining parameters.

A1B1C3D2 were compared to A1B2C2D2. The following process variables are listed in order of relative importance: discharge current, lifting height, gap voltage, and the ratio of pulse width to pulse interval. The results indicate that Ti-6Al-4V material could be machined with tap water to achieve high MRR, lower machining costs, and have no negative effects on workers or the environment. This work studies the electrical discharge machining on machining HSS as a workpiece (AISI M2) with using brass and copper electrodes and the impact of process variables on the conditions for machining.

2. Experimental setup

Although many parameters might be taken into consideration for the electrical discharge machining process, in the current project work, discharge current, pulse on time, and pulse off-time are only three process parameters that are properly considered.

In this study, the optimal variables for maximizing MRR in the EDM operation are determined. Fig. 2 illustrates the work on the CM 323CEDM machine using oil as the dielectric solution. The electrodes used were copper and brass (ϕ 4mm), and their polarity was negative. This experiment uses nine specimens of HSS in AISI M2 size with (60 × 45 × 3 mm) plate that are conductive specimens. The chemical composition was tested in the State Company for engineering rehabilitation and testing. Tables 1 and 2 show the high-speed steel's chemical, physical, and mechanical properties, respectively.

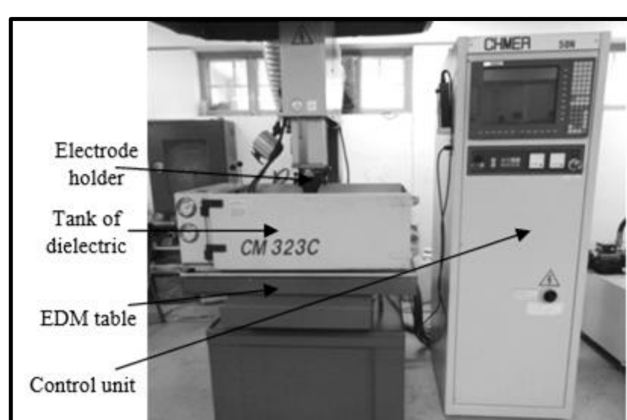

Figure 2. EDM CM323C CNC Machine.

Table 1. Chemical composition of the workpiece material (AISIM2).

Material	C	S	Mn	Si	P	Cr
Weight (%)	0.855	0.001	0.28	0.305	0.001	4.71
Material	Mo	W	Cu	Ni	V	Fe
Weight (%)	5.43	5.73	0.175	0.14	1.88	Balance*

Table 2. Physical and Mechanical properties of the workpiece [13].

Properties	AISIM2
Bending strength (MPa)	4700
Hardness (HRB)	65
Specific Heat Capacity (J/g-°C)	17.2×10^{-6}
Modulus of Elasticity (GPa)	207
Elastic modulus (GPa)	210

Brass and copper as tool electrodes with a size of ϕ4×100 mm were the materials employed in the experimental work. By dividing the workpiece's weight after (W_{before}) and weight before (W_{after}) against the accomplished machining time (T), the MRR of the operation is calculated in Eq. 1 [14].

$$MRR = \frac{W_{before} - W_{after}}{T} (g / \min) \quad (1)$$

The experiment design for the EDM technique is displayed in Table 3. The experiments were designed and analysed by Factorial design within the Minitab program, as shown in Table 4.

Table 3. Experiments design.

Consideration factors	Symbol	Values		
		1	2	3
Pulse off-time (μs)	T_{off}	4	12	25
Pulse on-time (μs)	T_{on}	100	150	200
Current (A)	I	10	24	42

3. Results and discussions

The results achieved from the experiments are illustrated in Table 4. Figs. 2–5 illustrate the major effect of the process parameters (T_{on}, T_{off}, and current) on the rate of material removal of the copper electrode. The range of MMR for copper electrode is 27.391 to 84.355 g/min, with a current range of 10 to 42 A, T_{on} range of 100 to 200 μs, and T_{off} range of 4 to 25 μs. The highest MRR of 84.355 g/min was achieved with a current of 42 A, T_{on} of 100 μs, and T_{off} of 25 μs. Similarly, for the brass electrode, the MRR ranged from 18.034 to 43.243 g/min, with a current range of 10 to 42 A, T_{on} range of 100 to 200 μs, and T_{off} range of 4 to 25 μs. The highest MRR of 43.243 g/min was achieved with a current of 42 A, T_{on} of 100 μs, and T_{off} of 25 μs.

Figs. 3 and 4 illustrate the relationship between the current values and the rate of material removal by changing the pulse-on-time values of the copper and brass electrodes. It can be observed that the relationship is direct, but the copper electrode exhibits better performance compared to the brass electrode. Figs. 5 and 6 illustrate the relationships between the pulse on-time values and the rate of the material removal by changing the current values of the copper and brass electrodes. It can be observed that the relationship is direct and slightly variable, with the copper electrode exhibiting better performance compared to the brass electrode.

Table 4. Experimental result of machining variables.

No. of Exp.	I (A)	T_{on} (μs)	T_{off} (μs)	MRR (g/min) (Copper)	MRR (g/min) (Brass)
1	10	100	4	0.05451	0.01898
2	10	150	12	0.07072	0.01903
3	10	200	25	0.08365	0.02252
4	24	100	12	0.14884	0.07035
5	24	150	25	0.16887	0.08157
6	24	200	4	0.19183	0.10812
7	42	100	25	0.25435	0.14324
8	42	150	4	0.28739	0.16756
9	42	200	12	0.31284	0.18769

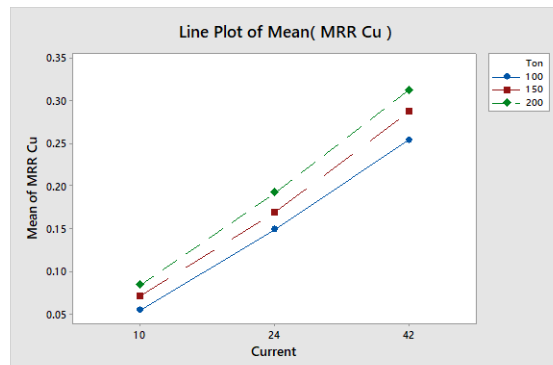

Figure 3. Show MRR of main effect curve with current and pulse on-time at the electrode of copper.

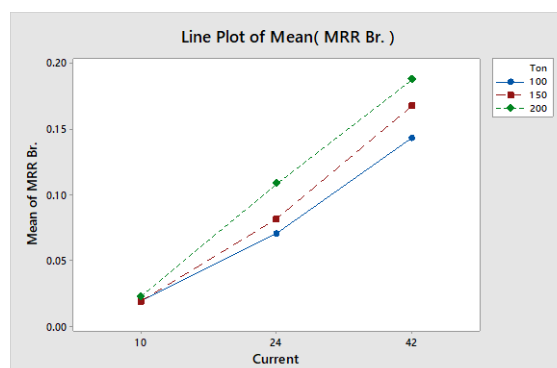

Figure 4. Show MRR Main effect curve with current and pulse on-time with the electrode of brass.

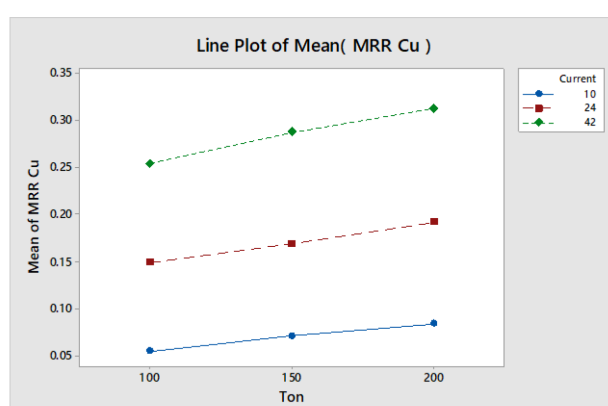

Figure 5. Show MRR Main effect curve on pulse on-time and current with using the copper electrode.

Figs. 7 and 8 show the relationships between the pulse off-time values and the rate of the material removal by change the current values of the copper and brass electrodes. It can be observed that the relationship varies between increase and decrease, with the copper electrode exhibiting better performance compared to the brass electrode. Figs. 9, 10, and 11 show the comparisons between the values of the material removal rate with respect to the current, pulse on-time and pulse off-time for the copper and brass electrodes. We observe that the values of the copper electrode are better and greater than those of the brass electrode.

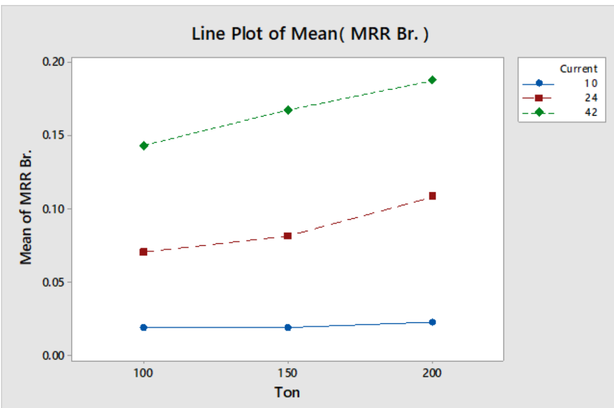

Figure 6. Show MRR Main effect curve on pulse on-time and current with using brass electrode.

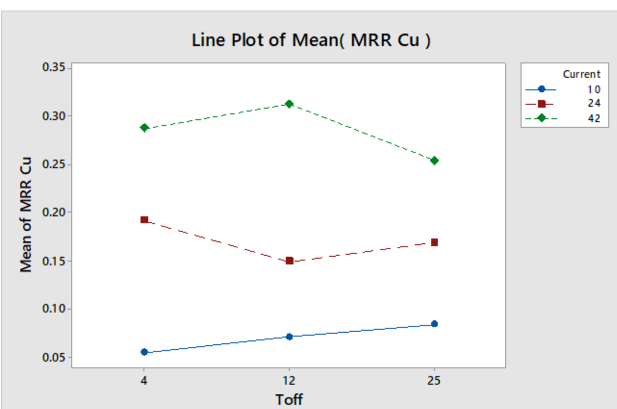

Figure 7. Show MRR Main effect curve on pulse off-time and current with using copper electrode.

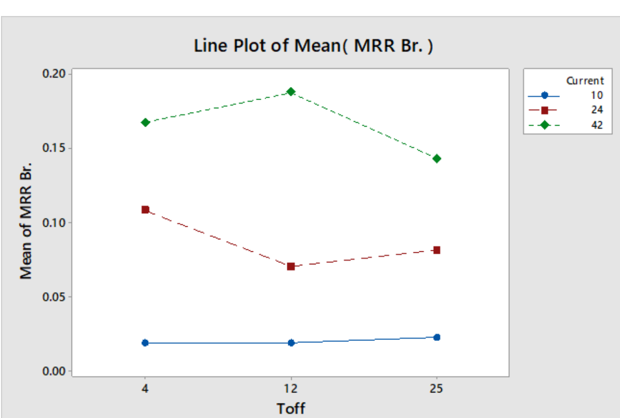

Figure 8. Show MRR Main effect curve on pulse off-time and current with using the brass electrode.

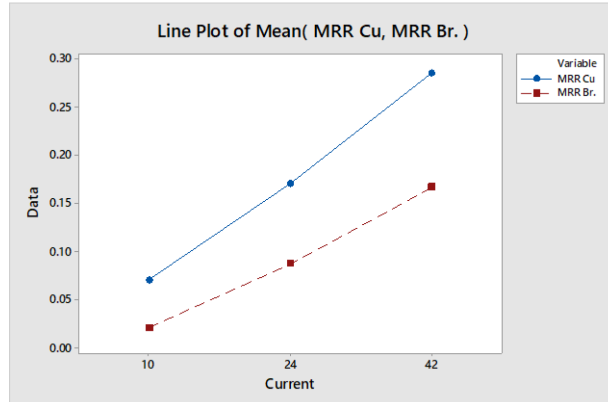

Figure 9. Comparison influences plot of MRR mean value on current with using copper and brass electrodes.

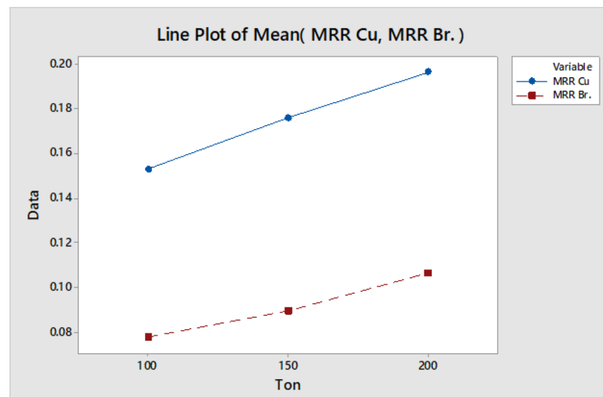

Figure 10. Comparison influences plot of MRR mean value on T_{on} with using copper and brass electrodes.

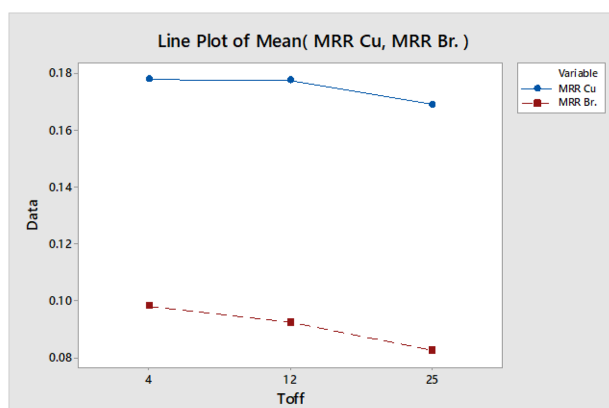

Figure 11. Comparison influences plot of MRR mean value on T_{off} with using brass and copper electrodes.

4. Conclusions

This study utilized EDM tests to examine the effects of machining parameters on the MRR of the HSS workpiece (AISI M2) using brass and copper as tool electrodes. The focus of the study was to investigate the improvement of MRR. The study concluded that several parameters, including pulse on-time, pulse off-time, and current, have significant effects on the experiment, as follows:

1. The material removal rate (MRR) of Electric Discharge Machining can

be improved by optimizing various factors such as current, T_{on}, and T_{off}, as determined within this work.

2. For the brass and copper electrodes, the current has the highest effect on the MRR, followed by pulse on-time has a moderate effect, and pulse off-time which has minimal effect.
3. The optimal process parameters can be observed from the table, where the current is 42 A, T_{off} 12 µs, and T_{on} 200 µs, resulting in a MRR of 0.31284 g/min for copper electrode and 0.18769 g/min for brass electrodes.
4. During applied experiments, we found that using a copper electrode results in a higher MRR compared to using a brass electrode.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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