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Effect of Voltage on Electrode Wear Rate (EWR) in the Electrical Discharge Machining (EDM) for Stainless Steel AISI 444

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HIGHLIGHTS

- Using low levels of machining parameters (voltage, Ip and Ton) to achieve low EWR.
- According to Factorial Design, model fits the data was 97.65% and 97.83% for 140 and 240 V, respectively.
- Mathematical relationship between the input parameters and EWR has been gained for correlating EWR.

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ABSTRACT

Electrical Discharge Machining process (EDM) is a nontraditional metal removal technique that uses thermal energy to erode the workpiece without generating any physical forces of cutting between the tool and the machining part. It is used to cutting of hard and electrical conductivity materials and product intricate shapes of products. The aim of this work is to study the effect of changing voltage values on electrode wear rate (EWR). The machining parameters includes voltage (V), peak current (Ip), pulse duration (Ton) and finally, pulse interval (Toff). The results show that the EWR was increase with rising in voltage, peak current and pulse duration values but when the pulse interval value rises, the electrode wear rate reduce. The best (EWR) value was (0.093507) mm3/min that obtained at voltage (140) V, Ip (12) A, Ton (400) µs and Toff (12) µs.

1. Introduction

Electrical Discharge Machining (EDM) is a nontraditional high-precision removal of metal technique that uses thermal energy to erode the workpiece. Between the tool and the workpiece, there are not found of any physical forces of cutting process [1]. History of EDM technique can be traced back to 1770, when the Joseph Priestley and who is English chemist scientist discovered the effect of corrosive of the sparks [2,3]. EDM was underutilized. Even in 1943, when two Russian scientists N.I. Lazarenko and B.R. Lazarenko discovered and improved how the effects of corrosive of this technique could be managed and used for machining purposes [4], by contrived the Relaxation Circuit (RC) they used a servo controller to keep the distance (gap) between the electrode and the workpiece constant, minimize arcing, and make EDM more profitable [5]. The EDM operation is depended on energy and it is called the thermos-electric energy produced in the gap between the workpiece and electrode as Figure 1 [6]. This gap is small and separates between the workpiece and electrode, and it is named with a spark gap [7].

Owing to the rise in temperature of the sparks, cause the workpiece material melts and vaporizes [8], and also material of the electrode melts and vaporizes, resulting what is called with electrode wear (EW) [9]. The electrode loses its dimensions due to the EW, which affects the accuracy of the cavities produced as Figure 2 [10]. As the electrode wears, the requisite geometrical characteristics of the electrode will not be replicated on the workpiece. The EWR is the ratio of the electrode weight difference before and after machining with EDM process to the time of machining [11,12].

It is represent the general equation of EWR in the unit of (gram), and can be divided on the (T_m) and (ρ) of the electrode to calculate the EWR in (mm^3/min)

So, EWR can be calculated according to final form, as in Eq. (2):

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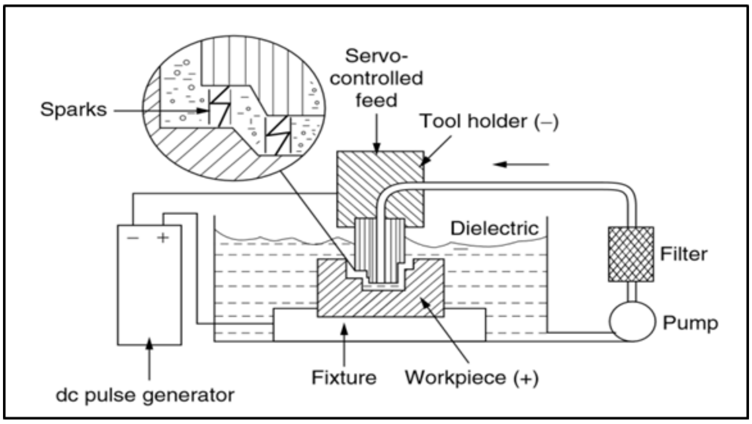

Figure 1: DM schematic

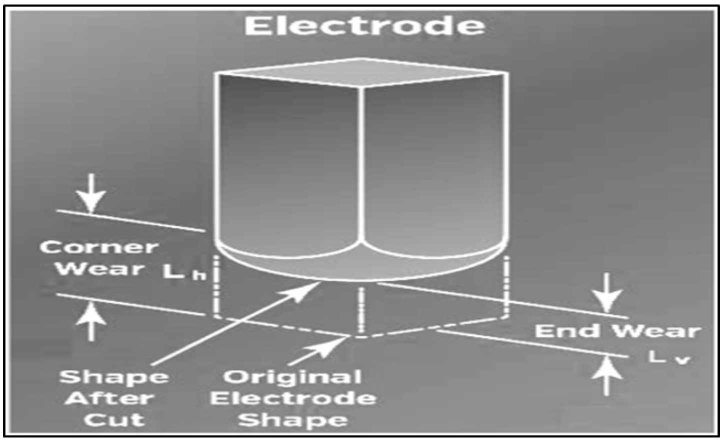

Figure 2: Electrode wear rate in EDM

$$EWR = W_b - W_a \quad (1)$$

$$EWR = \frac{W_b - W_a}{T_m * \rho} \quad (2)$$

Where: EWR = Electrode wear rate in (mm^3/min), W_b = Electrode weight before cutting in (g), W_a = Electrode weight after cutting in (g), T_m = Time of machining (min) and ρ = Electrode density in (g/cm^3)

The purpose of this experiment is to study the influence of input parameters specially voltage on EWR that produced in each experiment comparison between the values. Finally, determination the optimal parameters that give lowest EWR value. Therefore, several studies have been conducted in this field, P. M. George, et al. (2004) It is found that the EWR reduces of (89.28)%, if the parameters like voltage, current and pulse on time are set at their lowest values [13]. S. Daneshmand, et al. (2013) show that with the increase of pulse on time up to (50) µs, EWR increases. The increase of pulse off time causes the reduction of EWR. The increase of voltage leads to the increase of EWR [14]. K. G. Maniyar, et al. (2016) show that the pulse current was the more efficacious on EWR, pursued by voltage and pulse on time. Low pulse off time, pulse current, and voltage values achieve low values of EWR [15]. k. Kakkar, et al. (2018) show that the increase in voltage, current and pulse on time lead to increase the values of EWR [16]. A. A. Khleif and O. S. Sabbar (2019) the study results show that EWR increase when the voltage and current are increase. EWR ascends with abatement in the pulse duration values and ascends with expanding the pulse off time values [17]. S. M. Basha, et al. (2020) it is found that the EWR increase when the current, voltage, and pulse in time increase. While it is decrease when decreasing in pulse of time [18]. D. W. Jung (2021) show that the lower EWR obtained when the current, gap voltage and pulse on time are setting at lower values [19].

2. Experimental Procedure

The design of experiment was done by Minitab 19 software and full factorial design to select the number of experiments in this study. The design involve inter the number parameters (3) and levels (3) for each parameter and inter the levels values. So, there are (27) experiment in this study. The cutting procedure was carried out with cutting (1) mm depth from the workpieces, depended on machine fixed parameters as Table 1. The cutting process was done in two levels and each level applied in different side of workpieces and different voltage values, these levels are described as Table 2.

The practical experiments were carried out on a die sinking EDM system named CHMER of model (CM 323C) at the University of Technology/ Baghdad's Training and Workshop Center, as shown in Figure 3.

3. Work piece Material

Material of work piece that used in this study made of stainless steel AISI 444 with dimensions 40 x 30 x 2 mm^3.

4. Electrode Material

Material of electrode that used in this study made of pure copper with dimensions 82 x 40 x 5 mm^3, as Figures 4 and 5. Tables 3 and 4 show the chemical composition of work piece and electrode, respectively.

Table 1: EDM machine's fixed parameters

Machining parameters	Fixed value
Polarity of workpiece	Negative
Polarity of electrode	Positive
Dielectric liquid	Transformer oil
S code	20
Gap code	9
Jumping time	0.8 s
Servo feed	0.75
Working time	0.6 s
Depth of cut	1 mm

Table 2: Machining parameters levels

parameters	Units	Levels		
		Level 1	Level 2	Level 3
Voltage	V	140	240	
Peak current	A	12	24	50
Pulse duration (pulse on time)	μs	100	200	400
Pulse interval (pulse off time)	μs	3	6.5	12

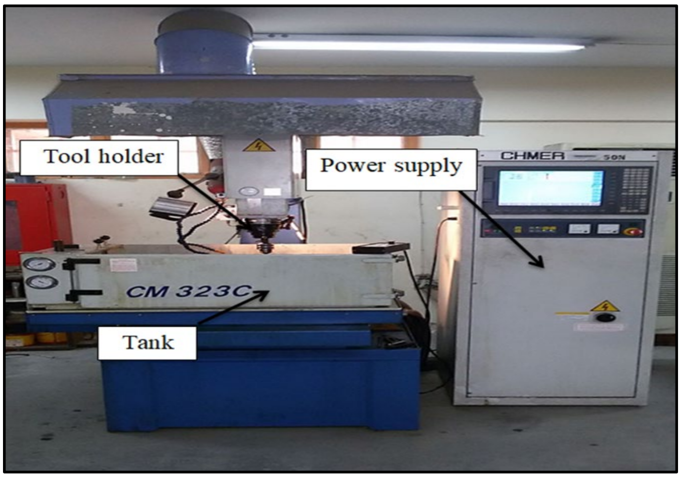

Figure 3: EDM machine at U. O. T

Table 3: Work piece chemical composition

Element	Sn	Fe	Zn	Mn	Pb	P	S
Weight %	0.0015	0.0182	0.003<	0.0004<	0.00057	0.0132	0.001
Element	**Ni**	**Si**	**As**	**Sb**	**Al**	**Cu**	
Weight %	0.00044	<0.0008	0.00062	0.0048	<0.0005	99.9	

Table 4: Electrode chemical composition

Element	C	Si	Mn	P	S	Cr
Weight %	0.0237	0.340	0.206	0.0247	< 0.0005	19.08
Element	**Ti**	**Al**	**Cu**	**Ni**	**Mo**	**Fe**
Weight %	0.237	0.0056	0.121	0.252	< 0.002	Bal.

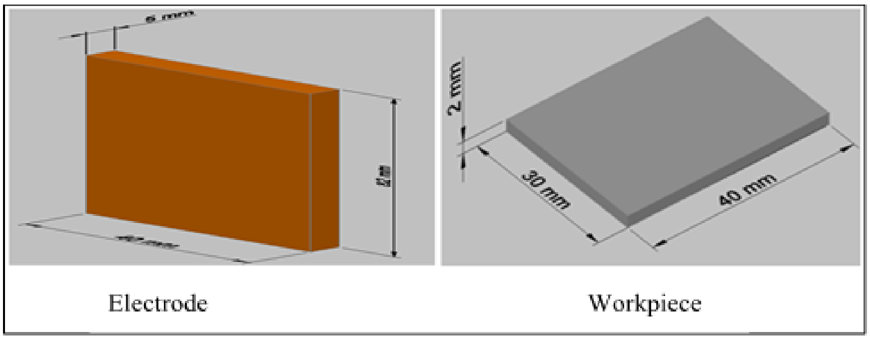

Figure 4: Electrode and workpiece material

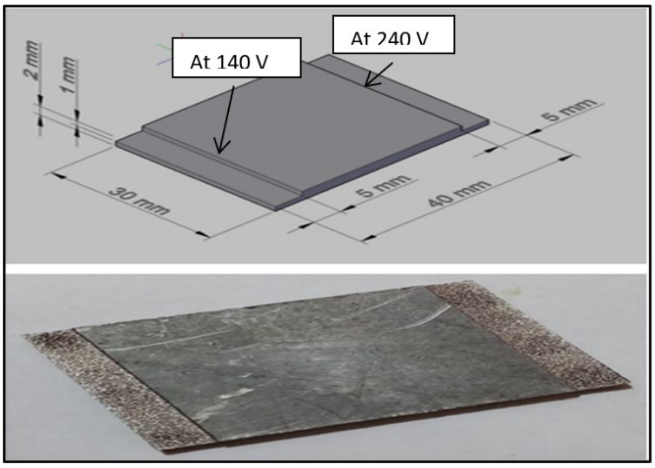

Figure 5: workpiece after EDM process

Table 5: Experimental results for EWR

No. of sample	I_p (A)	T_{on} (µs)	T_{off} (µs)	EWR (mm^3/min) for 140 (V)	240 (V)
1	12	100	3	0.120626	0.138896
2	12	100	6.5	0.111543	0.124054
3	12	100	12	0.093507	0.106529
4	12	200	3	0.135657	0.149455
5	12	200	6.5	0.121237	0.137774
6	12	200	12	0.109098	0.122345
7	12	400	3	0.142643	0.151573
8	12	400	6.5	0.125651	0.14622
9	12	400	12	0.112121	0.139918
10	24	100	3	0.157435	0.166509
11	24	100	6.5	0.155999	0.159037
12	24	100	12	0.150054	0.157544
13	24	200	3	0.166565	0.178009
14	24	200	6.5	0.126578	0.160003
15	24	200	12	0.100345	0.158556
16	24	400	3	0.18546	0.196221
17	24	400	6.5	0.178122	0.185033
18	24	400	12	0.171235	0.177994
19	50	100	3	0.194638	0.25729
20	50	100	6.5	0.179941	0.218295
21	50	100	12	0.16773	0.18404
22	50	200	3	0.199094	0.269462
23	50	200	6.5	0.184539	0.23431
24	50	200	12	0.17073	0.219809
25	50	400	3	0.256574	0.270633
26	50	400	6.5	0.240518	0.266751
27	50	400	12	0.23519	0.247767

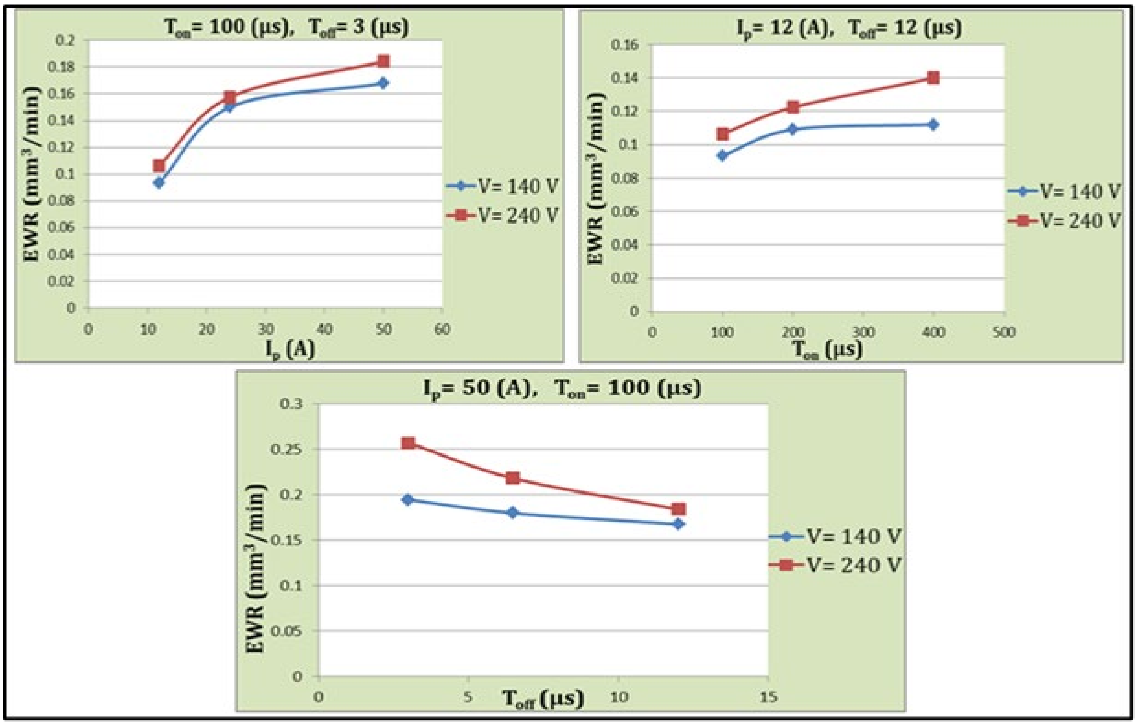

Figure 6: Influence of machining parameters on EWR

5. Results and Discussion

The results of experiment of this study for all voltage values are explained as Table 4.

The effect of input parameters on EWR as Figure 6. It can see that the EWR was increase with increasing in voltage (5) and I_p, from (140 to 240) V and (12 to 50) A, respectively. The explanation for this is that there are more electron collisions and a stronger spark, which results in a higher temperature between the electrode and the work piece, causing the electrode to melt and vaporize in addition to the material. Also, EWR increase when T_{on} increase from (100 to 400) µs. Since the energy of the discharge for the plasma channel is increasing, the time it takes for this energy to be transformed into the electrodes is also increasing. Further, EWR decreases with increasing T_{off} from (3 to 12) µs, due to the plasma channel is smaller and the spark discharge time and strength are reduced. The maximum EWR is (0.270633) mm^3/min at T_{off} (3) µs and highest both of voltage (240) V, I_p (50) A and T_{on} (400) µs.

6. Analysis of EWR

The electrode wear rate comparison as in Figure 7. Is pretend that the minimum values of EWR are achieved with used voltage of (140) V. But the maximum EWR values are obtained when machined with (240) V.

Tables 5 and 6 show the results of analysis of variance (ANOVA) for voltages of (140) V and (240) V, respectively. Can be show that the current parameter is most influence on EWR and involves all sources of variance to see if the variables are significantly related to the production. There is variation anytime that all of the data values are not identical. This variation can come from different sources such as the model or the factor and machine vibration. There is always the left over variation that cannot be explained by any of the other sources. This source is called the error

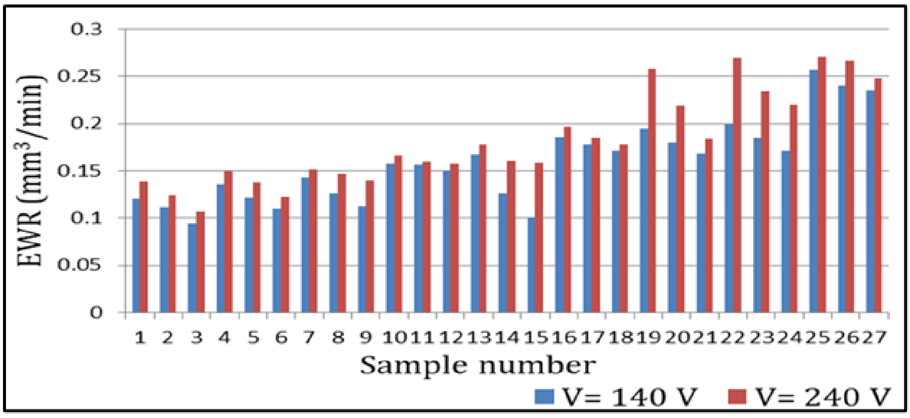

Figure 7: Electrode wear rate comparison

Table 6: ANOVA table for EWR for 140 V

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	0.046933	0.004693	66.57	0.000
Linear	6	0.043359	0.007226	102.49	0.000
I_p	2	0.032081	0.016040	227.50	0.000
T_{on}	2	0.007834	0.003917	55.56	0.000
T_{off}	2	0.003443	0.001722	24.42	0.000
2-Way Interactions	4	0.003575	0.000894	12.67	0.013
I_p*T_{on}	4	0.003575	0.000894	12.67	0.013
Error	16	0.001128	0.000071		
Total	26	0.048061			

Table 7: ANOVA table for EWR for 240 V

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	0.060922	0.006092	72.29	0.000
Linear	6	0.060001	0.010000	118.66	0.000
Ip	2	0.052056	0.026028	308.85	0.000
Ton	2	0.004070	0.002035	24.15	0.000
Toff	2	0.003875	0.001937	22.99	0.000
2-Way Interactions	4	0.000921	0.000230	2.73	0.066
Ip*Toff	4	0.000921	0.000230	2.73	0.066
Error	16	0.001348	0.000084		
Total	26	0.062270			

Develop the mathematical model requires use of these coefficients, In regression equations for (140 and 240) V, the mathematical relationship between the input parameters and EWR has been gained for correlating EWR, as shown in equations (2) and (3).

$$EWR140V = 0.1449 + 0.00289\ Ip - 0.000360\ Ton - 0.00689\ Toff - 0.000029\ (Ip)\ 2 + 0.000001\ (Ton)\ 2 + 0.000218\ (Toff)2 + 0.000004\ Ip * Ton + 0.000010\ Ip * Toff + 0.000001\ Ton * Toff \quad (2)$$

$$EWR_{240V} = 0.1075 + 0.003455\ I_p + 0.00076\ T_{on} - 0.00644\ T_{off} - 0.000008\ (I_p)^2 + 0.000254\ (T_{off})^2 + 0.000002\ I_p * T_{on} - 0.000082\ I_p * T_{off} + 0.000007\ T_{on} * T_{off} \quad (3)$$

7. Conclusions

The following points can be deduced from this experiments:

1) EWR rises as voltage (V), current (Ip), and pulse on time rise (Ton).
2) EWR decreases as pulse off time increases (Toff).
3) At Toff (3) µs and the highest voltage (240) V, Ip (50) A, and Ton (400) µs, EWR reaches (0.270633) mm3/min.
4) At Toff (12) µs, voltage (140) V, Ip (12) A, and Ton (400) µs, EWR is (0.093507) mm3/min.

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Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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