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MULTI-OPTIMIZATION METHOD FOR NEW DESIGN OF ANGLED ELECTRODES AND PERFORMANCE ENHANCEMENT USING ALLOY STEEL (X210)

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Abstract:
Electrical Discharge Machining (EDM) process is considered as one of the ultimate famously process used in the components production like tools of surgical, dies, punch and aerospace. The EDM technique perform on the control of loss metal principle according to power as thermal-electric through the electrode and blank piece. Alloy steel (X210) was selected as a workpiece, whereas copper electrodes selected by in different angled electrodes (0°, 22.5°, 45°, 67.5°, and 90°). The technique of composite design (CCD) was applied in this work and accomplish (ANOVA) was concluded to consider the highly important variables. The experimental results show that the material removal rate is accelerate at highest value using Angle of Electrode (E A 67.5°) and (I 30A). Electrode Wear Rate (EWR) can be attained using (E A 22.5°) and (I 20A).Thickness of White Layer (WLT) is increased at (E A 22.5°) with enlarge current at maximum magnitude (30 A), minimize WLT is obviously at (E A 45°) and current is (15A). An optimization technique was utilize to conclude of optimal parameters at maximize MRR and consequently reduce EWR. The optimum values for the responses such as MRR and EWR with optimum value are gained with the following parameters: (E A 22.5°), (I 27), (P-on299) and (P-off 50).

Key words: *Electrical Discharge Machining, Multi-Optimization Method, MRR, EWR. WLT*

INTRODUCTION

Materials machining of complex and tough with traditional approach might be a not appropriate and wasting the time. moreover, quality of surface of the polished components with usual methods is compact [1, 2]. Machining by Electrical Discharge plays on the role of metal diminish by thermal energy between the electrode and workpiece [3]. The industry field fronts a difficulty whenever it should make holes and slots in hard materials while sustain a high measure of dimensional accuracy. The presence of under-cuts in EDM is one of the biggest essential matter, which finally has an influence on the precision of geometrical. undercut has been certain, notably in case of dies manufacturing according by EDM [4], is so complicated to explain the relation between wear of electrode, the diameter of electrode, and the rest of parameters. This can be exceptionally suitable when increasing of undercut according of tool wear [5, 6].

Ahsan Khan et al. [7] studied the impact of electrode form on some parameters of steel, copper electrode material was used. The shapes of tool electrode were, diamond, square, triangle and round. Round geometry electrode was the better in MRR and other geometries were followed. Diamond shape revealed the best in MRR and EWR.

Jitendra, et al. [8] studied a new electrode shape to improve the efficient of EDM. Zircaloy_2 is utilized of Cu tool by changing rake angle with (0°- 45°- and 60°), by development of angle, MRR is improved. Nadeem, et al. [9] investigated by applying a traditional electrode with adding the relief angles in electrodes. Cu and WC were the electrode and work piece. By using this electrodes a 49% minimized with time machining.

Hanan, et al. [10] studied the effect of angle tip and copper electrode radius with several criterions like current and P_{on} for tool alloy (AISI-D2). Conical geometry electrode with radius 1 mm offers maximum MRR and the minimum EWR changed into conical shape with radius 0 mm in comparison with the alternative electrodes, the effects have indicated that the White Layer Thickness (WLT) will increase with rise in angle of electrode tip. N. Pellicer et al. [11] investigated multi geometry of electrodes, square and rectangle shape exhibit increasing of groove accuracy, hence of increasing in EWR. Triangular tool is not better enough because the triangular edges shape is wears quickly.

Rahul Davis, et al. [12] investigated solid and hollow electrodes. MRR is increasing with raising factor of duty and current for two kinds of geometries. Decreasing in roughness was with conical tool as hollow electrodes. Tool wear is increased with hollow shape comparing to solid electrode. Smrutirekha and Masanta [13] investigated of hexagonal form electrode. Al alloy (A6063) material was the work piece. Big large holes are generated by increasing of high current and power with increasing of MRR. Mahesh and Tajane [14] reported that circular shape of electrode increasing MRR and decreasing of electrode wear, round shape deliver smooth surface then square electrode.

Kamlesh et al. [15] studied the influence of electrode shape on surface status and MRR. The most factor that impact on the responses was the electrode geometry.

The goal of this experimental study objective to apply EDM to analysis and evaluate the quality of Alloy tool steel (X210) using EDM copper electrode. The results of the experiments have been investigated and evaluated and factors could be analysed for better input process. The response surface approach generated the primary experiments' design matrix.

There is a poor of literatures sign on machining of alloy tool steels (X210) with new electrode using EDM. Thus, there is need to investigate the impact of progressive electrode design on output parameters (MRR, TWR, and White layer thickness) of machining. In this work, Alloy (X210) is machined with EDM using Cu progressive electrode of different electrode angle (0°, 22.5°, 45°, 67.5° and 90°).

The Novelty of this Investigation

A number of contribution has been found that clear in new electrode design (22.5° and 67.5°) including a side flushing hole with alloy tool steel workpiece.

Methods and Materials

(X210) tool steel Alloy specimens are cut by WEDM (dk7740) with dimensions (15 × 15 × 10 mm). Spectrometer ARL approach applying to find composition (wt. %) as listed in Table 1.

Table 1

Composition percentage of Alloy tool steel (X-210)

Factors	C.	Mo	Sn	Cr	Zn	Mn	Cu	Fe
wt percentage (%)	1.99	0.24	2.22	11.71	0.15	0.49	0.36	Rest

In the current experimental work, decisions have been made on the four process variables, each of which has five levels. In order to capture the real function of the studied results parameters, it is preferable to have five distinct levels of process settings. The factors, currently referred to as process parameters, are listed in the following column. Tables 2 numerous of various for the factors of process and parameters. As factors in the current study, various electrode angles were used. An electrode of cylindrical geometry in conventional EDM fabricated to machining blind shape of holes.

Table 2

Parameters with levels

Symbols	Parameters.	The Levels				
		1	2	3	4	5
A	Angle of Electrode (deg).	0.0°	22.5°	45°	67.5°	90°
B	current (Amp).	15.0	20.0	25.0	30.0	35.0
C	Pon (µs).	75.0	150.0	225.0	300.0	375.0
D	Poff (µs).	20.0	50.0	80.0	110.0	140.0

This analyzing design was used to alter by modify some design category, particularly by developing angled of electrodes [16]. Fig. 1 shows the shape of electrodes with determined angles.

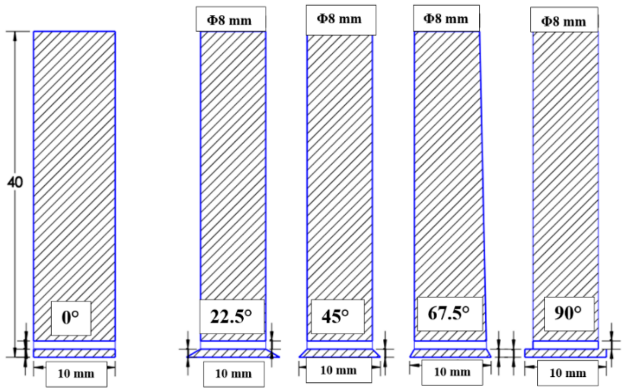

Fig. 1 different angles of Electrodes

The fabrication of copper electrode and obtained of 10.0 mm rod shape with area of sparking 40mm length with a side flushing hole. DEDM machine sinking (323,50 N) was used to create hole of 10 mm in the specimens.

Because the machining was done in a single step using EDM, the weight of the tool both before and after machining was determined using a digital scale (model JM-B) and the total TWR was computed. The purpose of the experiments is to determine how the electrode angle geometry affects response metrics. Table 3 displays all other parameters, which were taken into consideration as constants and include the voltage value, polarity, and type of dielectric.

Table 3

Fixed parameters

No	Machining model	Value
1	Voltage	240 V
2	Polarity	Direct
3	Dielectric Type	transforming oil

Fig. 2 displays an actual image of the Cu tool, and Table 4 provides a detailed description of each tool. Following EDM machining, response parameters (MRR, TWR, and WLT) are examined. MRR is calculated using Equation 1 [17].

Fig. 2 Electrodes angle with produced by WEDM

Table 4
Design of practical study

No	Electrode Angle-(deg)	I_p (amp)	P_{-on} (µs.)	P_{-off} (µs.)
1	22.5°	20.00	150	50.0
2	67.5°	20.00	150	50.0
3	22.5°	30.00	150	50.0
4	67.5°	30.00	150	50.0
5	22.5°	20.00	375	50.0
6	67.5°	20.00	375	50.0
7	22.5°	30.00	375	50.0
8	67.5°	30.00	375	50.0
9	22.5°	20.00	150	110.0
10	67.5°	20.00	150	110.0
11	22.5°	30.00	150	110.0
12	67.5°	30.00	150	110.0
13	22.5°	20.00	375	110.0
14	67.5°	20.00	375	110.0
15	22.5°	30.00	375	110.0
16	60°	30.00	375	110.0
17	0°	25.00	225	80.0
18	90°	25.00	225	80.0
19	45°	15.00	225	80.0
20	45°	35.00	225	80.0
21	45°	25.00	75	80.0
22	45°	25.00	300	80.0
23	45°	25.00	225	20.0
24	45°	25.00	225	140.0
25	45°	25.00	225	80.0
26	45°	25.00	225	80.0
27	45°	25.00	225	80.0
28	45°	25.00	225	80.0
29	45°	25.00	225	80.0
30	45°	25.00	225	80.0

$$\mathrm{MRR} = \frac{\mathrm{W_i} - \mathrm{W_f}}{\mathrm{t}\,.\rho} \tag{1}$$

where:
W_i = "before weight machining",
W_f = "After weight machining",
t = time of machining,
ρ = density of material.

The workpiece was substituted with the electrode, similar to the methodology employed in the Material Removal Rate (MRR) technique. The equation representing the Electrode Wear Ratio (EWR) is formulated by Equation 2 [17].

$$\mathrm{EWR} = \frac{\mathrm{W}_{ie} - \mathrm{W}_{fe}}{\rho_e \mathrm{t}} \tag{2}$$

where:
W_{ie} = weight of tool (before) (gm.),
W_{fe} = weight of tool (after) (gm.),
t = fabricating time",
ρ_e = Density of electrode (gm/mm^3).

It is an important to make many experimental work as a research fulfilments. Taguchi's analysis and response surface methodology (RSM) in (DOE) support the study of the effect of different parameters on effective method [100]. Central composite design (CCD) is the common statistical method and used design of statistics by Design of expert (DOE) software. Figure 3 illustrated a photo of 30 samples for DOE techniques.

Fig. 3 Alloy steel 30 Workpieces (X210) after machining

RESULTS AND DISCUSSION

Material Removal rate (MRR)

In this work, tool steel (X210) was machined using EDM process, and the effect of progressive electrodes (Angled electrode, peak current, pulse on, and pulse off) were taken into account to assess machining response i.e. MRR, TWR, and calculating WLT according to the SEM images. Material removal rate (MRR) can be improved by using new electrode with angle. The amount of weight that the material is assessed in prior and following to the runs by a weight digital-balance. Table 5, shows results of Material Removal Rate (MRR) for the thirty runs.

Table 5
Results of MRR

Run	E. Angle (Deg)	Current (Amp)	$P_{on.}$ (µs)	$P_{off.}$ (µs)	MRR real mm^3/min)	MRR před (mm^3/min)	Act/Pred
1	45	25	375	80	6.244	6.4123	0.974
2	45	25	225	80	5.545	5.2459	1.057
3	22.5	20	300	110	5.511	5.3884	1.023
4	45	25	225	80	4.924	5.0853	0.968
5	45	25	225	140	5.708	5.0853	1.122
6	67.5	20	150	50	4.641	4.7177	0.984
7	22.5	20	150	50	4.027	4.3240	0.931
8	45	35	225	80	6.141	5.8236	1.054
9	90	25	225	80	5.499	5.6787	0.968
10	22.5	30	300	110	6.077	5.8022	1.047

11	45	25	225	20	5.051	5.4090	0.934
12	45	25	225	80	5.558	5.2459	1.059
13	45	15	225	80	4.55	4.1534	1.095
14	67.5	30	150	50	5.121	4.8427	1.057
15	0	25	225	80	4.879	4.5749	1.066
16	67.5	20	300	110	5.332	5.0578	1.054
17	45	25	75	80	3.797	3.9586	0.959
18	67.5	30	300	50	5.91	5.7943	1.020
19	22.5	30	150	110	5.297	4.5939	1.153
20	45	25	225	80	5.35	4.8231	1.109
21	22.5	20	150	110	4.616	3.9409	1.171
22	22.5	30	150	50	5.149	4.5939	1.121
23	67.5	20	300	50	5.473	5.0578	1.082
24	67.5	20	150	110	4.887	4.1716	1.172
25	45	25	225	80	4.822	4.8231	1.000
26	22.5	30	300	50	5.637	5.5219	1.021
27	67.5	30	150	110	5.603	4.8427	1.157
28	22.5	20	300	50	5.242	4.8036	1.091
29	67.5	30	300	110	6.465	5.7943	1.116
30	45	25	225	80	4.853	4.8231	1.006
					The Mean		**1.052**
					Stand. Deviation.		**0.070**
					C. Variation		**0.066**

Analysis of-variance (ANOVA) results for the material-removal rate (MRR) are shows in Table 6.

Table 6
ANOVA of Material removal rate

The Source	Sum of Squares	Df	Mean of Square	Fishe value	p-value	
Model	0.4557	4	0.1139	37.30	< 0.0001	affected
AE angle	0.0197	1	0.0197	6.44	0.0177	
B. Current	0.1501	1	0.1501	49.15	< 0.0001	
C. Pulse-on	0.2559	1	0.2559	83.80	< 0.0001	
D. Pulse-off	0.0300	1	0.0300	9.82	0.0044	
Residual	0.0763	25	0.0031			
Lack of Fit	0.0471	20	0.0024	0.4037	0.9332	not affected
Pure of Error	0.0292	5.0	0.0058			
Cor of Total	0.5320	29.0				
Stand. Dev.	0.0553					
The Mean	2.29					
% C.V.	2.41					
R^2	0.8565					
Adjusted of R^2	0.8335					
Predicted of R^2	0.8043					
Adeq of Precision	21.8368					

The computed of Fisher-value for the expectance MRR model is 37.3, presenting statistically that the model is significant. The noise only accounts for 0.01% of greater Fisher-values. In this instance, the terms EA, Ip, Pon, and Poff have been identified as statistically evident (P-value smaller than 0.05). The Fisher-value as the (lack of-fit) is 0.40, which means it does not meet the criteria for statistical significance when compared to error.

Value of R^2 expected of 0.8043 exhibits an acceptable degree of accordance with Adjusted R^2 value of 0.8335, as the variance between the two measures is lower than 0.2. Adeq Precision estimates the ratio of S/N. A ratio exceeding 4 is considered desirable. Previously value of 21,837 refer to suitable signal. Regression approach is utilized to build a regression equation for the material removal rate (MRR). In regression analysis, the parameters with not important P -value (larger than 0.05) are frequently eliminate from calculations. The model of mathematical regression for material removal rate (MRR) is provided in Eq. 3.

Regression model of MRR

$$1.43369 + 0.00127249 \times \mathit{lectrode} - \mathit{angle} + 0.0158167 \times \mathit{max\ current} + 0.00137682 \times P - on + 0.00117802 \times P - off \quad (3)$$

Residual approach had been utilised to evaluate the efficiency of the MRR model of regression that has been created. Plots of the normal probability vs externally of residuals studentized and actual versus anticipated MRR are shown in Figures 4 and 5, individually.

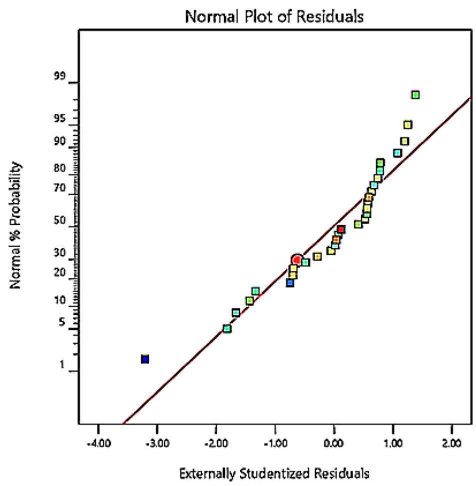

Fig. 4 Externally Studentized residuals versus Normal

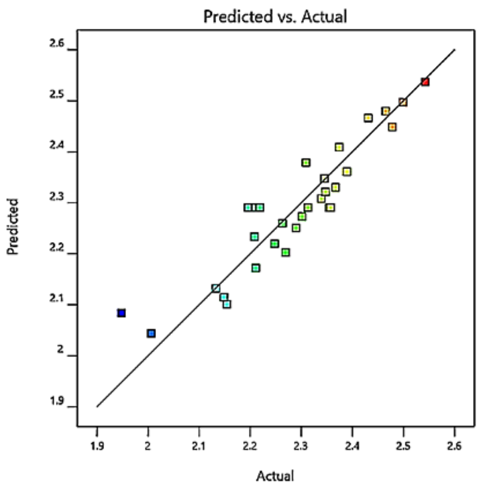

Fig. 5 Predication versus Act MRR

A linear correlation between the plotted actual MRR and predicted MRR data suggests that the two values correspond well. Therefore, the MRR model that was proposed is quite significant.

MRR can be obtained through three-dimensional response Contour diagrams. By response surface methodology (RSM), this study explores the impact of electrode angle on the maximum (MRR). As a result of an increase in current at 35 Ampere and P_{on} at max value, there is a continuous increase in MRR at maximum value. The observed enhancement in MRR resulting from the rise in peak current can be explained by the possibility of a higher level of discharge energy within the sparking area. This increased energy availability facilitates the processes of work material melting and vaporization at a constant value; E.A = 67.5° and default value P_{off} at = 110 µs as in Figure 6. The influence of electrode angle (EA) in 45° on MRR at minimum value, while keeping the level of P_{off} = 80 µs at default value clearly demonstrated in Figure 7 as a 3D Contour diagram. At a minimum set of current (15 A) and P_{on} 75 µs, there is a continuous decrease in MRR at minimum value.

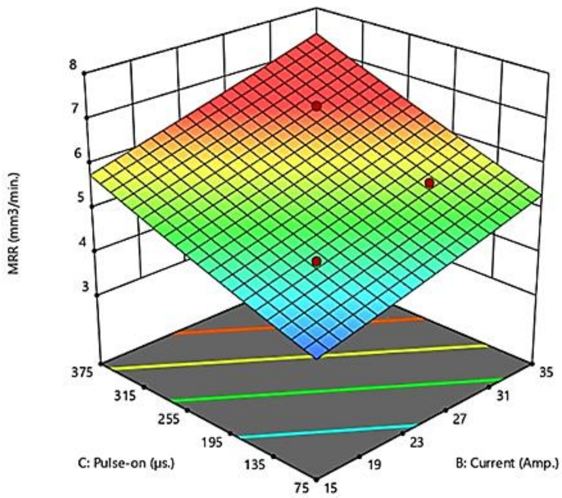

Fig. 6 Max MRR vs. Pulse-on and current

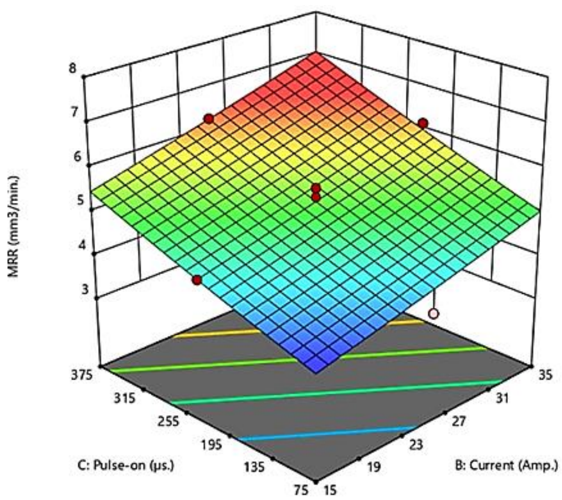

Fig. 7 Min MRR vs. Pulse on and current

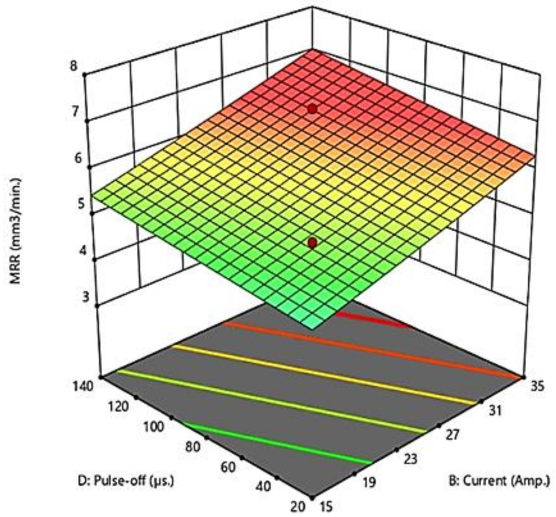

Fig. 8 Max MRR versus. P-$_{off}$ and max current

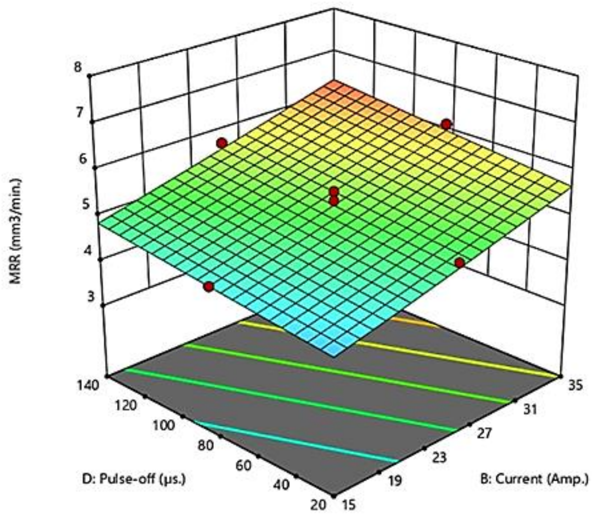

Fig. 9 Minimum MRR versus. P-$_{off}$ and max current

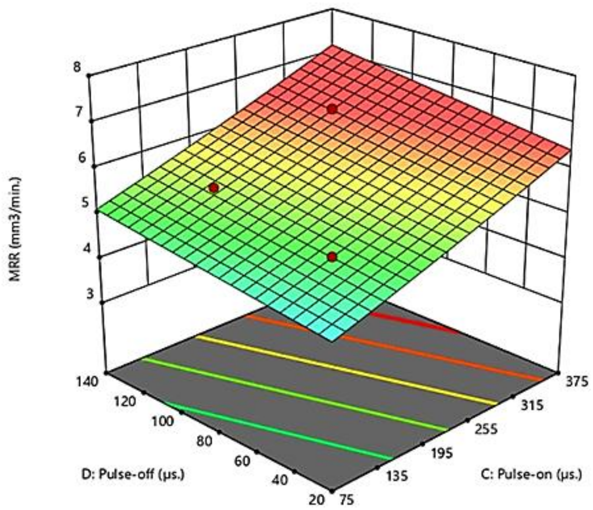

Fig. 10 Max MRR vs. P_{off} and P_{on}

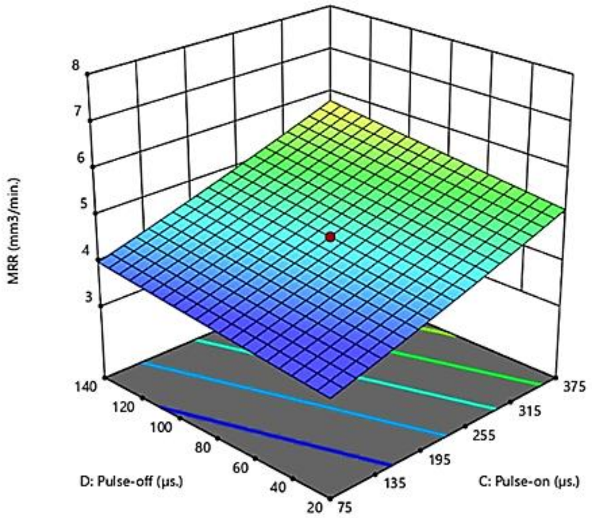

Fig. 11 Min MRR vs. P_{off} and P_{on}

Figure 8 shows a 3D Contour diagram of Max MRR versus P_{off} and current, while keeping EA = 67.5° and P_{on} = 300 µs constant, with increase current from 15 to 35 A, MRR at the maximum value is continuously rising. The observed enhancement in MRR as the current increased can be related to providing a constant heating temperature, which leads to longer pulse durations and, thus, a greater amount of energy. Therefore, MRR increases when a high current and maximum P_{off} are applied within the same machining duration.

Without changing the; EA = 45° and P_{on} = 225 µs in Figure 9 as a 3D diagram of contour. It's been indicated at for a decrease in P_{off} at min value, with peak current at min value, there is continuous decrease in MRR at minimum value. This decreasing in MRR with the decrease in P_{off} is due to for a longer period of time. The effect of P_{off} and P_{on} on Max MRR, without changing the; EA = 67.5° and current = 30 A are illustrated in Figure 10, There is a continuous increase in MRR at max value. The observed enhancement in MRR as the P_{off} increases can be explained by the longer duration of the heating pulse, resulting in a more significant amount of energy being available for the process. Therefore, it can be noted that there is an increase in the MRR when a longer P_{off} is used during the machining process while keeping the duration of the machining same.

Likewise, The impact of P_{off} and P_{on} with Min MRR, without changing the other two variables; EA = 45° and Ip = 15 ampere are illustrated in Figure 11. Based on the evidence presented, it can be stated that that for a decreasing in P_{off} from 140 to 20, there is an ongoing decrease in MRR at Min value. Additionally, an enhancement in MRR was seen as the P_{on} increased, MRR is increasing at P_{off} increased at the same level.

Tool Wear Rate (TWR)

The achievement of an optimal tool wear rate (TWR) is a desired result in terms of surface modification processes performed using (EDM) [18, 19]. The high TWR is caused by introducing a significant quantity of Powder pieces are put into the space between the electrodes. The existence of an excessive amount of powder particles will lead to a deterioration in machining performance as a result of arcing. Electrodes have been designed to reduce tool wear and modifications work material with good machining efficiency. The response surface methodology was used in planning and performing the experiments.

Measures such as sum squares, fit lack test, and the mode summary statistics were used to ensure the proposed model was adequate. ANOVA can be used to determine the degree to which each parameter contributes to minimizing TWR. The development of Contour diagrams in three dimensions was performed to investigate the influence of parameters on the Tool wear rate (TWR). Table 7 presents the results related to the tool wear rate.

Table 7
Results of TWR

Runs	**Electrode Angle (deg)**	**Max current (Amp)**	**P-on (µs)**	**P-off (µs)**	**TWR act (mm^3/min)**	**TWR predict (mm^3/min)**	**Act/predict**
1	45	25	375	80	0.2790	0.2432	1.1471
2	45	25	225	80	0.2813	0.6614	0.4254
3	22.5	20	300	110	0.7383	0.6148	1.2007
4	45	25	225	80	0.7830	0.6614	1.1839
5	45	25	225	140	0.9874	1.0798	0.9145
6	67.5	20	150	50	0.8119	1.1399	0.7122
7	22.5	20	150	50	0.9490	0.7715	1.2301
8	45	35	225	80	0.9783	1.0647	0.9189
9	90	25	225	80	1.2457	1.0052	1.2393
10	22.5	30	300	110	0.8949	1.0054	0.8901
11	45	25	225	20	0.6846	0.3450	1.9841
12	45	25	225	80	1.1186	0.6614	1.6913
13	45	15	225	80	0.4237	0.3537	1.1981
14	67.5	30	150	50	1.4944	1.6544	0.9033
15	0	25	225	80	0.3356	0.3893	0.8620
16	67.5	20	300	110	1.0461	0.9476	1.1039
17	45	25	75	80	1.0676	1.2845	0.8311
18	67.5	30	300	50	0.2237	0.2728	0.8201
19	22.5	30	150	110	1.1186	0.7725	1.4479
20	45	25	225	80	0.8819	0.6614	1.3334
21	22.5	20	150	110	0.2237	0.4361	0.5130
22	22.5	30	150	50	1.1196	1.2032	0.9305
23	67.5	20	300	50	0.0224	0.0922	0.2425
24	67.5	20	150	110	0.7237	0.7220	1.0024
25	45	25	225	80	0.5593	0.6614	0.8456
26	22.5	30	300	50	0.0559	0.1109	0.5045
27	67.5	30	150	110	1.4112	1.1412	1.2366
28	22.5	20	300	50	0.0112	0.0131	0.8548
29	67.5	30	300	110	1.2125	1.4209	0.8534
30	45	25	225	80	0.8119	0.6614	1.2275
					The Mean		1.00828
					Stand. Deva.		0.03683
					C, of V		0.15787

The outcomes of analysis of-variance (ANOVA) for TWR mode are showing in the Table 8.

The obtained Fisher-value for the expectance MRR mode is 23.98, imply that mathematical mode is important statistically. Possible of greater Fisher-value to noisy is possible with a 0.01. In case of, EA, I_p, P_{on}, P_{off}, ($I_p \times P_{on}$) and ($P_{on} \times P_{off}$) are observed to be statistically important have P-values less 0.05.The Fisher-value of "lack fit" is 0.4333, the lack fit is not statistically important comparing to the pure of error.

The expected R^2 of 0.7528 is quite comparable to the adjusted R^2 of 0.7985, and the difference is under 0.2. Adeq Precision calculates the signal-to-noise ratio. A number of more than 4 is preferable. A ratio larger than 4 is acceptable. In this case 19.2987 shows a sufficient signal.

Table 8
ANOVA of Tool Wear Result

The Source	Sum Squares	D.f	Mean Square	Fisher value	P-value	
Model	2.21	5	0.4421	23.98	< 0.0001	important
A,E-angle	0.2151	1	0.2151	11.67	0.0023	
B, Current	0.2866	1	0.2866	15.55	0.0006	
C, Pulse-on	0.6148	1	0.6148	33.35	< 0.0001	
D, Pulse-off	0.3061	1	0.3061	16.60	0.0004	
C-D	0.7880	1	0.7880	42.74	< 0.0001	
Residual	0.4425	24	0.0184			
Lack of Fit	0.2753	19	0.0145	0.4333	0.9152	not important
Pure of Errors	0.1672	5	0.0334			
Total cor	2.65	29				
Stad.Deviation	0.1358					
The Mean	0.8133					
C of V. %	16.70					
R^2	0.8332					
Adjusted of R^2	0.7985					
Predicted of R^2	0.7528					
Adq-Precision	19.2987					

The use of regression analysis has been employed to construct a regression mathematical model for the tool wear rate (TWR). In the regression of analysis, expressions with non-important P-value (larger than 0.05) are frequently eliminate. Eq. 4 provide the regression model of mathematical for TWR.

Regression mathematical model of TWR

$$2.0319 + 0.00420735 \times \text{Electrode} - \text{angle} + 0.0218567 \times \text{max Current} - 0.0100247 \times \text{P} - \text{on} + -0.018428 \times \text{P} - \text{off} + 9.86334\text{e}^{-5} \times \text{Pulse} - \text{on} \times \text{Pulse} - \text{off} \quad (4)$$

The residual method had been utilized by evaluate the accuracy of the builds regression mode of tool wear rate (TWR). The relation of normal-probability versus externally-studentized at Figure 12 and relation of actual versus projected TWR Figure 13. The plot shows that the data distribution for the actual TWR versus the predicted TWR is approximately linear, indicating high agreement between individual values. The significance of the proposed TWR model can therefore be presented.

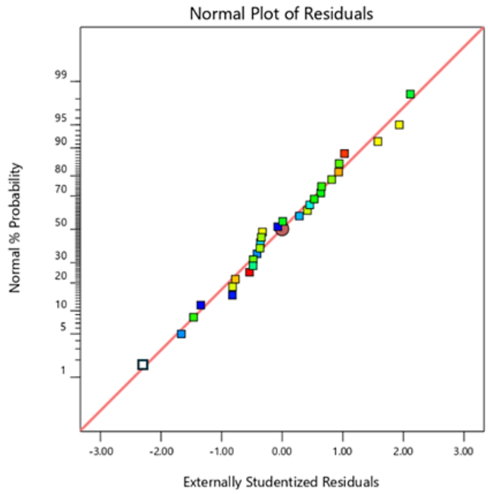

Fig. 12 Normal versus the externally residuals

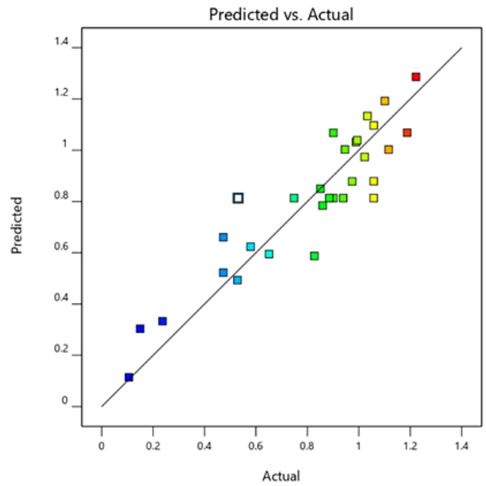

Fig. 13 Predict vs. Act TWR

The effects of electrode angle on TWR are illustrated as a 3D Contour diagram in Figure 14 using (RSM), keeping the level of default P_{off} = 50 µs. Max

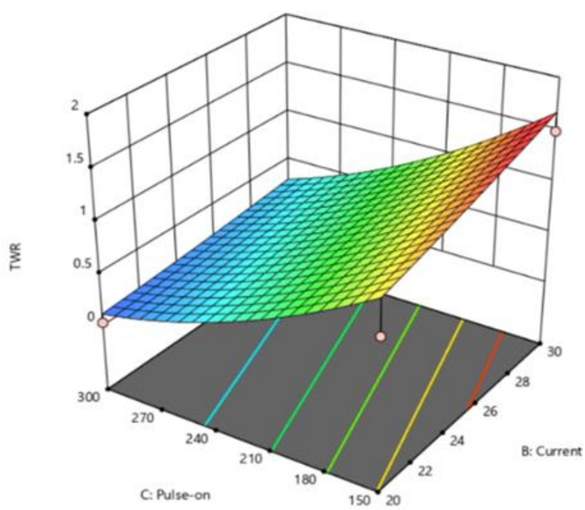

Fig. 14 Max TWR vs. P_{off} and Current

TWR was shown to vary with electrode angle 67.5°, leading to the assumption that a steady rise in TWR can be expected for a given peak current value. The observed increase in (TWR) with elevated max current is often related to the greater expelling energy available during longer pulses, which promotes the melting and vaporization of materials and tool materials inside the ignition region. The area with a significant peak current exhibits the highest discharge energy value.

Low TWR has been observed with decreasing in current (EA at 22.5° and P_{off} 50 µs is shown in Figure 15.

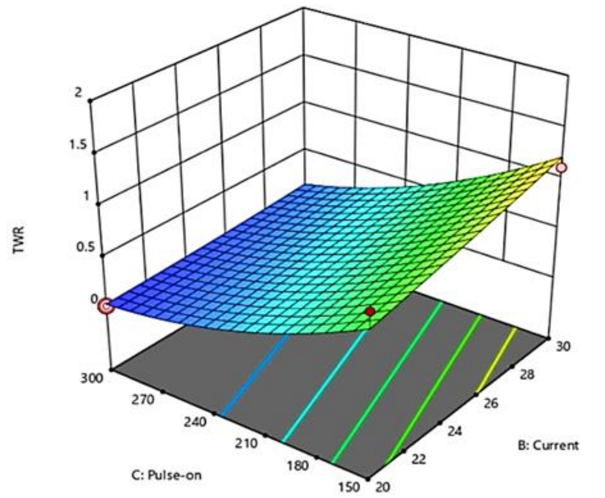

Fig. 15 Min TWR vs. P_{on} and Current

This low TWR value (while current at 20 ampere) may be explained by mentioning that a decreasing in heating energy generated, therefore additionally decrease electrode material melted and vaporization as well. Therefore, it is desirable to have a reduced amount of maximum current in order to keep a lesser TWR with electrode angle 22.5°. The effect of EA at 67.5° on the maximum (TWR) and keeping a default pulse level of 150 µs is illustrated in Figure 16, Observing the variations in maximum (TWR) with a 67.5° EA has been described.

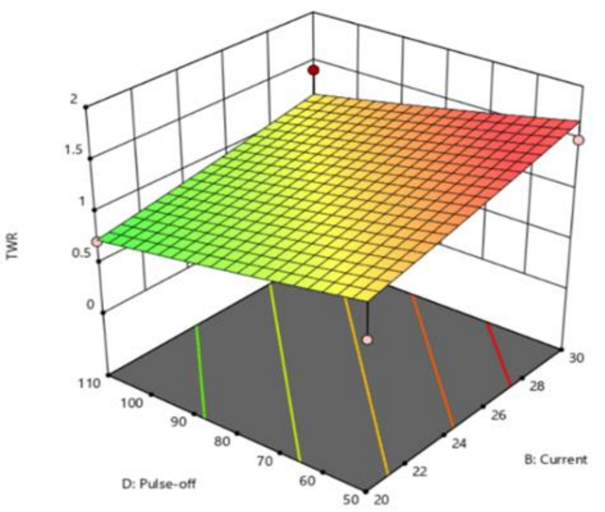

Fig. 16 Max TWR vs. P_{off} and Current

A rise in (TWR) has been noted when current and P_{off} levels increase while keeping the P_{on} constant. The observed increase in (TWR) can be explained by the larger surface area of the EA as the degree of inclination increases., In Figure 17, shows the influence of EA 22.5° on TWR while keeping P_{on} = 300 µs values. The relationship between TWR and current has been examined, there is a decrease in TWR with a 22.5° for recent reduction at the lowest value with the most downward P_{off}. The shorter pulse duration at lower current levels is responsible for this reduction in TWR. Therefore, a less-long pulse is produced when a lower current is selected. As a result, the machined area has less time to absorb the same amount of heat energy.

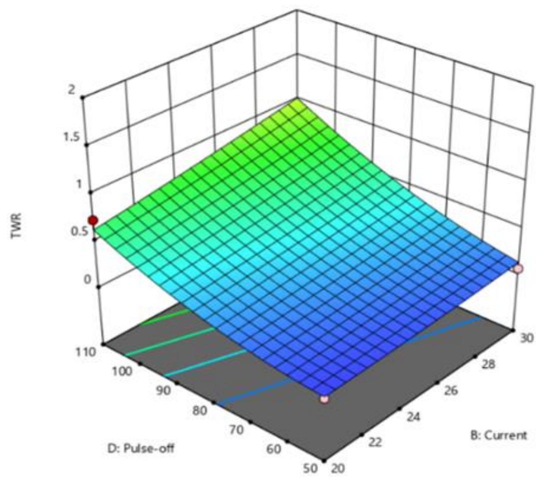

Fig. 17 Min TWR vs. P_{off} and Current

Moreover, the impact of EA at 67.5° on P_{off} and P_{on} on max TWR, while keeping current fixed can be seen in Figure 18. It has been observed that TWR changes with P_{on} and P_{off}, and it has been determined that with a decrease in Poff and a high current level, there is a continual increase in max TWR. This rise in TWR with a low value of P_{off}, as regards of the prolonged keeping of a continuous heating temperature. As a result, a raise in TWR has been seen with a short P_{on}. TWR increased even more at an elevated amount, there is a surge in current caused by the high discharging energy.

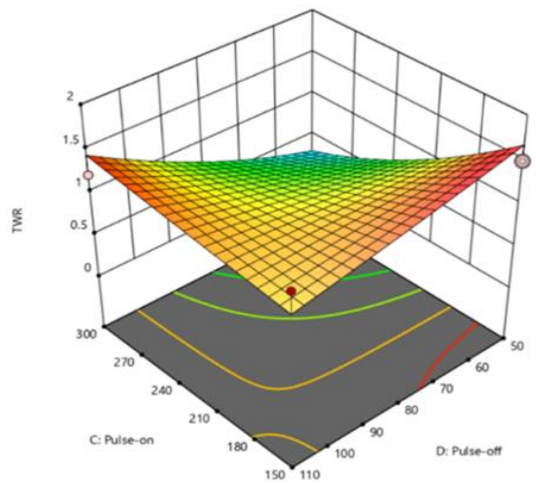

Fig. 18 Max TWR vs. P_{on} and P_{off}

Likewise, the effect of EA at 22.5° on P_{off} and P_{on} on min TWR, while keeping of max current is seen in Figure 19. The modification of TWR with P_{off} been illustrated and It had been determined for a decrease in P_{off} at lower value, there is a continuous decrease in TWR.

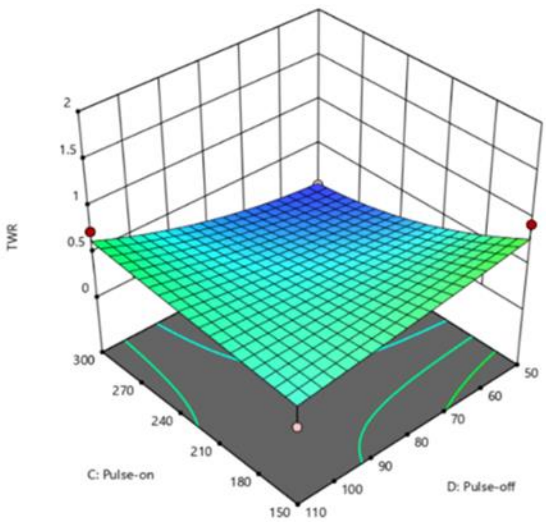

Fig. 19 Min TWR vs. P_{on} and P_{off}

White Layer Thickness (WLT)

The thickness of the white layer is influenced by the heat transfer to the workpiece and the resulting microstructural modifications that occur during the (EDM) process. The heat transfer process depends on the quantity of heat being transferred through energy transfer. Ip and P_{on} have determined the craters' length, width, and depth resulting from the sparking. The reduction in heat leads to a decrease in the phenomenon known as WLT. However, if the P_{off} is increased, which refers to the duration between the last of a spark and the beginning of the second spark, it will enable the workpiece to effectively disperse heat, thus reducing the workpiece's (WLT).

Figures 20 and 21 illustrate the SEM of the surface obtained through (EDM). A 1000x magnification was used to obtain the photographs.

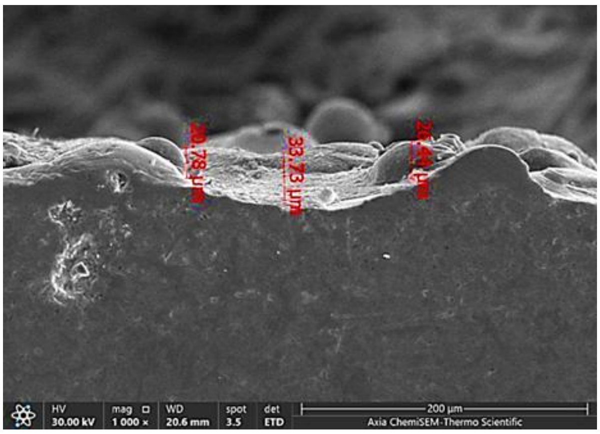

Fig. 20 EA = 22.5°, I_p = 20 A, P_{on} = 120 µs and P_{off} = 50 µs

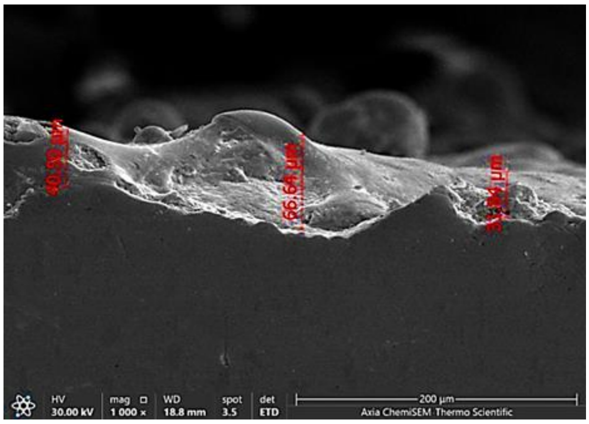

Fig. 21 EA = 22.5°, I_p = 30 A, P_{on} = 120 µs and P_{off} = 50 µs

WLT as the peak current is adjusted from 20 A in Fig 20 to 30 A at Fig 21 while keeping the EA constant, Average WLTs of these micrographs are 26.98 µm and 46.32 µm correspondingly, these are displaying the increasing in WLT with the increasing of current in same electrode geometry. The increasing in average WLT may also be clearly observed by transforming of EA in Figures 20 and 22, from 22.5° to 67.5°, Average WLTS of these micrographs are 26.98 µm and 30.85 µm.

Images were captured by a SEM for I_p at 20 Amp and 30 Amp is shown in Figures 22, and 23, keeping EA at 67.5° with other parameters in same values.

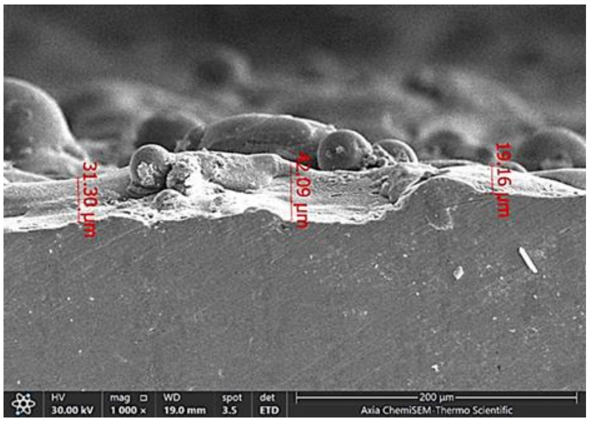

Fig. 22 EA = 67.5°, I_p = 20 A, P_{on} = 120 µs and P_{off} = 110 µs

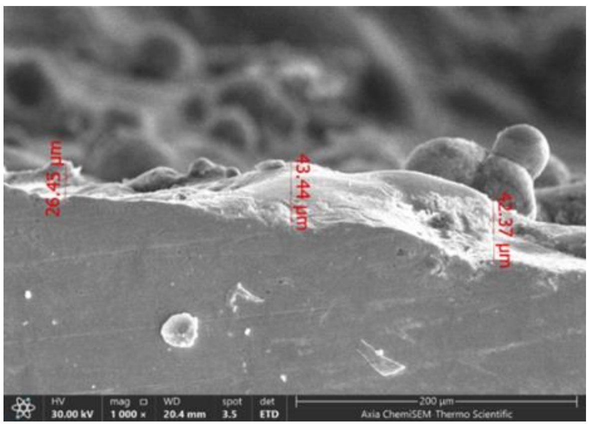

Fig. 23 EA = 67.5°, I_p = 30 A, P_{on} = 120 µs and P_{off} = 110 µs

The respective average WLTs are 30.85 µm, and 37.42 µm, the qualitative visualization of the raising in WLT could be observed from the SEM images that have been given. The temp degree of the machining surface increases significantly when subjected to high discharge current, resulting in a more significant amount of molten metal being generated more efficiently.
Likeness, with transforming in angled electrode from 0° to 90° and keeping other parameters are constant, the SEM micrographs are presented in Figures 24 and 25 respectively, the corresponding WLTS are 30.85 µm, and 36.33 µm.

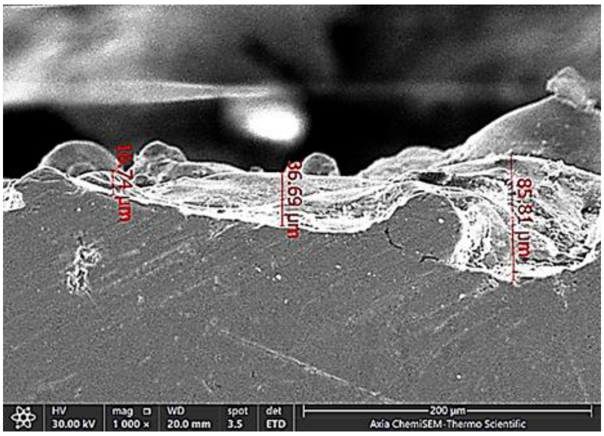

Fig. 24 EA = 0°, I_p = 20 A, P_{on} = 180 µs and P_{off} = 80 µs

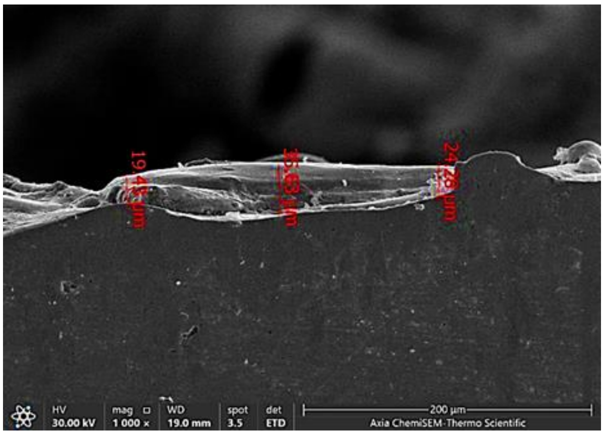

Fig. 25 EA = 90°, I_p = 20 A, P_{on} = 180 µs and P_{off} = 80 µs

WLT increases clearly with increase in angled electrode, for the same other parameters. The respective average WLTS in Figures 26 and 27 are 17.62 µm, and 43.88 µm, the qualitative visualization of the rise in WLT can be observed from the SEM micrographs that have been provided. Peak current has a great effect in 45° with low value, whereas keeping other parameters in constant. When the discharge current is high, the machined surface heats up, resulting in more easily melted metal.

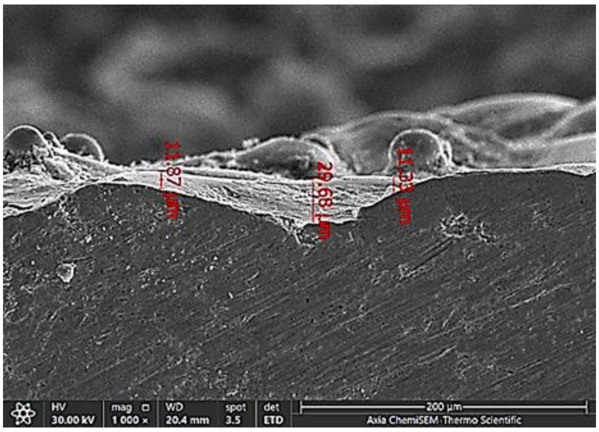

Fig. 26 EA = 45°, I_p = 15 A, P_{on} = 180 µs and P_{off} = 80 µs

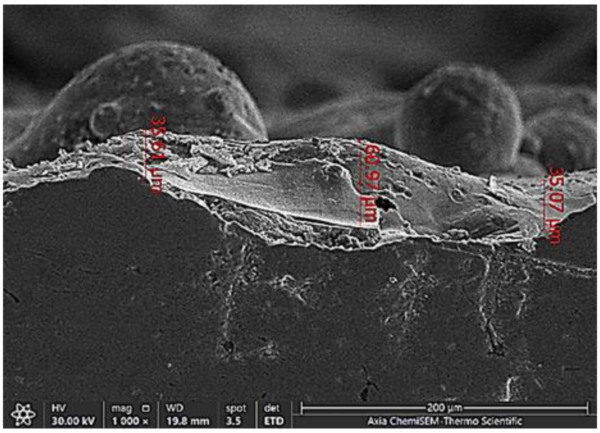

Fig. 27 EA = 90°, I_p = 25 A, P_{on} = 180 µs and P_{off} = 80 µs

MRR and TWR Optimization

The objectives and space of several factors to consider, including (EA), (I_p), (P_{on}), and (P_{off}), along in accordance with the characteristics of the responses MRR and TWR, are shown in Table 9. The two of responses, (MRR) and (TWR), were actually attributed equal range of importance, which is 3.

Table 9
Input parameters with responses (MRR and TWR)

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:E-angle	is in range	22.5	67.5	1	1	3
B:Current	is in range	20	30	1	1	3
C:Pulse-on	is in range	150	300	1	1	3
D:Pulse-off	is in range	50	110	1	1	3
(MRR)	maximize	1.94859	2.54264	1	1	3
TWR	minimize	0.0111857	1.49441	1	1	3

The most desirable combination of process parameters is chosen among the four possible results as the most effective approach to achieving the goal. Table 10 presents a comprehensive overview of the optimal input process parameters, together with the corresponding desirability levels necessary to provide an optimal combination of answers within specified limitations.

Table 10

Comprehensive overview of the optimal parameters of the input process along with the corresponding levels of desirability

No	**EA**	**Current**	**P_{on}**	**P_{off}**	**MRR**	**TWR**	**Desirability**	
1	22.501	29.999	300	70.556	2.433	0.011	0.903	Selected
2	22.732	30.000	300	70.179	2.433	0.011	0.903	
3	22.500	30.000	299	70.061	2.432	0.011	0.902	
4	24.750	30.000	299	67.064	2.432	0.011	0.902	

CONCLUSIONS

In the present study work, the fabrication, efficiency of (X-210) steel parts using electrodes which made from copper material in the shape of different angles of electrode with horizontal hole have been studied for EDM process. The influence of different parameters called electrode angle, max current, P-on-time and P-off-time (P_{off}) was studied by response surface methodology (RSM). Results (MRR, EWR, and WLT) were analyzed using RSM. An outline of the essential results derived from the experimental study and the results gained:

1. The use of Angled electrodes can enhance the performance of Electrical Discharge Machining (EDM) by significantly increasing the Material Removal Rate (MRR) of the machined surface.
2. The experiment obtained a maximum MRR value of 6.465 mm^3/min under the following conditions: Angle electrode of 67.5°, peak current of 30A, P-on time (300 µs), and P-off time (110 µs). Based on results mentioned above, it can be observed that in order to get the highest material removal rate (MRR) using an electrode inclined at 67.5°, it is preferable to select both a greater peak current value and pulse on time.
3. The lowest EWR value obtained in an experiment with an inclined electrode of 22.5°, a max of current 20A, a P-on-time (300 µs), & a P-off the duration of 50 µs is 0.0112 mm^3/min. The EWR can be reduced by using a 22.5° electrode and a minimum peak current value.
4. Electrode angle with 45° and 15 A had the minimum WLT, whereas electrode with 22.5° angle and 30 A had the maximum WLT.

Recommendations

1. Multiple powder compositions and particle sizes can be used to investigate the influence of different compacted pressures and annealing temperatures on surface characteristics.
2. It would be possible to investigate the role and impact of the side flushing mechanism and how it impacts the horizontal hole in the flushing operation on the surface modification procedure.

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