An Investigation of the Impact of the EDM Parameters on the Process Characteristics of the A2 Tool Steel

Rasha Ramiz Elias
Production Engineering and Metallurgy Engineering Department, University of Technology-Iraq, Baghdad, Iraq
rasha.r.elias@uotechnology.edu.iq (corresponding author)

Qussay Salah Mahdi
Production Engineering and Metallurgy Engineering Department, University of Technology-Iraq, Baghdad, Iraq
qussay.s.mahdi@uotechnology.edu.iq

Mustafa Mohammed Abdulrazaq
Production Engineering and Metallurgy Engineering Department, University of Technology-Iraq, Baghdad, Iraq
mustafa.m.abdulrazaq@uetechnolgy.edu.iq

Received: 9 April 2025 | Revised: 13 May 2025 and 20 May 2025 | Accepted: 24 May 2025

ABSTRACT

The most popular nontraditional method for metal cutting is Electrical Discharge Machining (EDM), which offers advantages over conventional methods. The metal machining sector has benefited greatly from the increased accuracy and speed using EDM in both the subtractive and additive manufacturing processes. This study focused on examining the process parameters and their impact on the Tool Wear Rate (TWR), Material Removal Rate (MRR), and surface roughness (Ra) in the EDM of A2 Steel. The Taguchi's Design of Experiments (DOE) (L9) was adopted and machining experiments were performed at different levels of current, pulse-off time (T_{off}), and pulse-on time (T_{on}). Analysis of Variance (ANOVA) was used to analyze the experimental results to examine the process inputs and obtain performance measures that maximize the MRR and reduce the rates of TWR and Ra. All experiments were performed with a 2 mm depth cut. The results showed that the lowest Ra value was 2.604 at a current of 36 A, T_{on} of 250 µs, and T_{off} of 100 µs, whereas the highest MRR was 11.719 mm^3/min at a current of 48 A, T_{on} of 250 µs, and T_{off} of 75 µs. The minimum TWR was 0.296 mm^3/min at a current of 36 A, T_{on} of 200 µs, and T_{off} of 75 µs. According to the statistical analysis, the most significant element influencing both the multiple and individual responses was the current that maximized the MRR, Ra, and TWR. This improves the part quality and has favorable impacts on the productivity and sustainability of this process.

Keywords- electrical discharge machining; EDM; surface roughness; MRR; tool wear rate

I. INTRODUCTION

EDM has numerous applications, including in the aerospace sector. EDM is extensively utilized in various industries to cut complex shapes, microholes, grooving patterns, boring, and craters in alloys and superalloys, such as Inconel and Hastelloy. EDM can be defined as a non-contact metal removal method that operates on the basis of thermoelectrical erosion, which is regulated by high-frequency pulses produced in a dielectric medium [1, 2]. EDM causes vaporization, melting, and removal of the work material debris during normal operation by creating an important potential difference between an electrode (i.e., tool) and the workpiece [3-5], as shown in Figure 1 of [3]. EDM uses rapid, repeating spark discharges from a pulsing direct-current power supply between the workpiece and a submerged tool in a dielectric liquid [6, 7]. When cutting a material using EDM, several input parameters can be altered. Because the number of the input parameters leads to proportionately increasing experimental time and costs, it is difficult to examine all the parameters of the EDM process throughout the actual operation of machining [8-10]. The machining efficiency of an EDM operation was found to be significantly affected by several electrically controlled variables, including the cycle time, peak current, inter-electrode spacing, polarity, and gap voltage, and non-electrically regulated factors, including the electrode material, dielectric pressure, electrode rotation, and dielectric nature. In order to meet the requirements for better response outcomes, it is always preferable to operate an EDM machine by maintaining the optimal values of several input variables. A decrease in the machining time may lead to a higher production rate [11].

Authors in [12] assessed how the parameters of the EDM process, including the voltage, pulse on-time, flushing pressure, and peak current, affect the machining of aluminum 6061 that had been reinforced with 0.5 wt% SiC and 0.5 wt% graphene NPs. Al-based metal matrix composites were cast using stir casting or liquid processing. The impact of the process parameters on the machining properties of the produced composite, specifically the MRR and TWR, were assessed using Taguchi's Design of Experiments (DOE). According to the findings, the other parameters are less influential on the TWR and MRR than the peak current. Input variables, such as Ra, MRR, TWR, and machining time, with different input variables, such as T_{on}, gap voltage (V_g), peak current (IP), T_{off}, and depth of cut were investigated. The optimization values for MRR, Ra, machining time, and TWR were determined using Response Surface Methodology (RSM) [13]. Furthermore, the reactions of the material parameters were examined, and an Analysis of Variance (ANOVA) was performed to determine the degree of significance of the input parameters on the measured values. Applying the RSM approach, the purposeful responses were in good agreement with the expected outcomes. The high regression coefficients between the variables and responses of MRR, R, TWR, and time of machining demonstrate a superb evaluation of the empirical data using the 2nd-order polynomial abatement approach. In [14], the optimal EDM process parameters for a RENE-80 nickel superalloy electrode material were estimated. Several process parameters for the machining performance were studied. The input parameters were the current, T_{on}, and T_{off}, and their impacts on MRR, TWR, and Ra were investigated. The experimental layout was created using the Taguchi technique, and the optimal process parameters for EDM were determined by analyzing the impacts of the input process parameters on the machining properties. According to the findings of this study, choosing the appropriate input parameters for EDM has a significant influence on the process.

Authors in [15] performed experiments by selecting standard process parameters, like the T_{on}, T_{off}, pulse current, and gap voltage. For the EDM process with multiple responses, including MRR, EWR, and Ra, Taguchi-based Grey Relational Analysis (GRA) was deployed to determine the grey relational grade. The most significant parameters were the pulse current and T_{on}, according to ANOVA, depending on the grey relational grade that determined the relevance of the process parameters. In [16], the effects of the EDM machining parameters on the Ra, TWR, and MRR of a hybrid aluminum metal matrix composite were investigated. These variables were balanced by analyzing the T_{on}, voltage, current, and T_{off} using a combined optimization approach. The single responses were improved using RSM, whereas a hybrid approach incorporating the Taguchi method, Entropy Weight Method (EWM), GRA, and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was used for multi-response optimization. The parameter significance was evaluated using ANOVA, which showed significant effects on Ra, Electrode Wear Rate (EWR), and MRR.

Authors in [17] examined how the machining parameters, specifically the peak current, T_{on}, and duty factor, affected the MRR and Ra. Utilizing a copper electrode and employing a Box-Behnken design, the study found that increasing both the IP and T_{on} led to higher MRR and Ra values.

Authors in [18] examined the impact of the flushing pressure, peak current, and pulse time on EDM of the $AlSi_{10}Mg$ alloy reinforced with hybrid metal matrix composites including 9 wt% alumina and 3 wt% graphite. The machining properties of hybrid composites were examined utilizing a Taguchi DOE. The impact of the input process parameters on the MRR, Ra, and TWR was ascertained using ANOVA, as well as the signal-to-noise ratio. The ANOVA and signal to noise ratio showed that IP had the greatest impact on Ra, followed by the flushing pressure and T_{on}. The peak pressure, T_{on}, and MRR were the primary factors. T_{on} was the most significant TWR parameter, followed by the flushing pressure.

According to previous studies, the current was limited to ranges not exceeding 40 A, and the T_{on} did not exceed 200 μs. This study attempted to obtain higher values for these parameters. The present work investigates the limits beyond these values to explore their effects on the Ra, TWR, and MRR. The former aims to investigate the role of important machining parameters in the process characteristics while machining A2 tool steel.

II. EXPERIMENTAL PART

A. *Electrical Discharge Machine*

The experimental part of this work was conducted on the CHMER EDM model CM323+50 N, which is situated at the University of Technology's Workshops and Training Center, as depicted in Figure 1. The primary specifications of the EDM machine are listed in Table I. In this study, the electrode tool adopted a positive polarity, and the downward movement of the machine ram was controlled by a servo-head mechanism (i.e., constant gap). The dielectric fluid used was distilled water.

Fig. 1. EDM machine.

TABLE I. SPECIFICATIONS OF EDM MACHINE

Machine body	CM323C+50N
Table size (W x D)	500 x 350 mm
Table travel (X-Y)	300 x 200 mm
Ram travel (Z)	300 mm
Outside diemension	1200x1350x2250
Distance from platen to table	250-550 mm

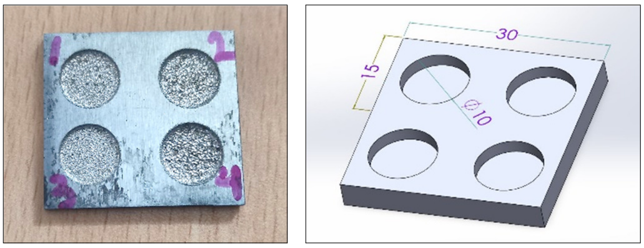
B. Workpiece Material

In the present study, AISI-A2 tool steel was used as the workpiece. Table II lists the chemical composition of the machined parts. The primary rationale for selecting A2-Tool steel is its suitability for cold-work tooling applications, which require a combination of toughness and wear resistance, such as blanking dies, thread-rolling dies, shears, punches, and forming dies.

TABLE II. CHEMICAL COMPOSITION OF A2 TOOL STEEL

Element	**C**	**Mn**	**P**	**Cr**	**S**
Weight %	1	0.60	0.030	5.0	0.03
Element	**Si**	**V**	**Mo**	**Fe**	
Weight %	0.30	0.350	1.10	Balance	

Additionally, it works well with plastic molds that must be extremely resistant to wear. The workpiece was square-shaped with dimensions of 30 mm × 30 mm × 4 mm, as shown in Figure 2.



(a) (b)

Fig. 2. Workpiece: (a) machined sample and (b) model showing the dimensions of the sample.

C. Tool Electrode

The wear resistance, corrosion resistance, good electrical conductivity, and high melting point are crucial factors to consider when selecting EDM copper tool electrodes. The cylindrical shaft that served as the tool electrode had a diameter of 10 mm and a length of 80 mm, as displayed in Figure 3. In the EDM machine, the copper tool electrode was connected to a negative-polarity terminal. Table III lists the physical and mechanical parameters of Cu electrodes.

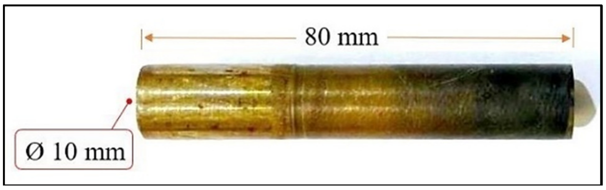


Fig. 3. Tool electrode.

TABLE III. PHYSICAL AND MECHANICAL PARAMETERS OF THE ELECTRODE

Thermal conductivity	391.1 W/m·K
Modulus of elasticity	117 GPa
Density	$8.94\text{x}10^3$ kg/m^3
Melting point	1356 K

D. Dielectric Fluid

The choice of fluid to serve as a dielectric medium is one of the most significant hurdles in the current research. For the EDM experiments, distilled water was chosen as the dielectric fluid because of its low cost, non-toxicity, non-conductivity, and low viscosity.

E. Selection of Controllable Parameters

Numerous factors affect the machining process performance, according to a literature review on EDM machining. Given that a high MRR has a considerable thermal impact on the integrity of the workpiece surface, the goal of EDM machining in this study was to minimize the machining time. Based on previous studies, the choice of machining parameters was considered with a small increase to work beyond their limits, as outlined in Table IV.

TABLE IV. PROCESS PARAMETERS AND THEIR LEVELS

Parameter	**Level (1)**	**Level (2)**	**Level (3)**
T_{on} (μs)	150	200	250
Current (A)	36	42	48
T_{off} (μs)	50	75	100

F. Design of Experiments

In the present study, the distribution of the three process parameters at three levels was considered. Since not all variable combinations were tested by orthogonal arrays, the effect of the interaction regarding process parameters was not taken into account for purposes of optimization. Therefore, the primary impact of each process parameter on EWR, MRR, and Ra was considered. For this investigation, an L9 (3^3) orthogonal array was chosen. Table V displays the experimental configuration of the EDM procedure using the L9 orthogonal array.

TABLE V. EXPERIMENTAL DESIGN MATRIX

No	**Coded values**			**Real values**		
	Current	**T_{on}**	**T_{off}**	**Current**	**T_{on}**	**T_{off}**
1	1	1	1	36	150	50
2	1	2	2	36	200	75
3	1	3	3	36	250	100
4	2	1	2	42	150	75
5	2	2	3	42	200	100
6	2	3	1	42	250	50
7	3	1	3	48	150	100
8	3	2	1	48	200	50
9	3	3	2	48	250	75

III. RESULTS AND DISCUSSION

This section provides an illustration of the findings from the experimental part of the EDM procedure of the current study, which are listed in Table VIII.

A. Results of Surface Roughness

Figure 4 shows that an increase in the current and T_{on} increases the pulse energy of the electric spark. Consequently, the longer the pulse duration is, the more material is melted, increasing the formation amplitude of the surface irregularities and ultimately leading to a high Ra. It is evident that when T_{off} increased, the electric spark's energy dropped. As a result, the longer the T_{off} is, the less molten material there is, and as a result, the distribution of irregularities decreases, producing a fine surface. The normal probability of the responses represented in Table VI was adopted to check the normality assumption and the normal distribution of errors. The model exhibited a good correlation between the observed and predicted values when the underlying error distribution was normal. Additionally, the relationship between the responses of the machining process and input parameters was identified and examined using ANOVA. In the regression analysis obtained using Minitab software, the relation that links the input parameters and the responses was regarded as a linear equation. The general linear model created by ANOVA, portrayed in Tables VI and VII, was used in this investigation. Mathematical models were developed utilizing experimental data. The regression equation is:

Ra = 3.0147 - 0.259 Current_36 - 0.057 Current_42 + 0.316 Current_48 - 0.297 PulseON_150 + 0.145 PulseON_200 + 0.152 PulseON_250 + 0.495 PulseOff_50 - 0.217 PulseOff_75 - 0.278 PulseOff_100

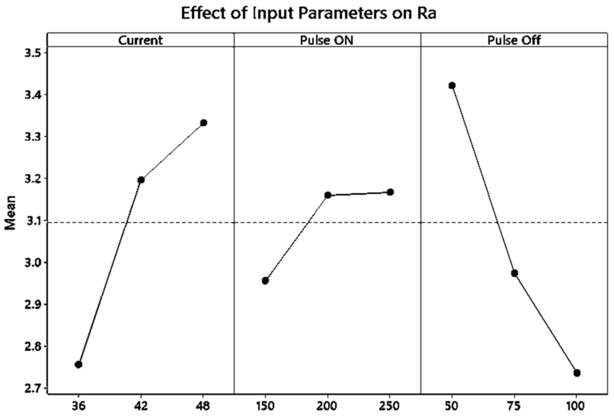


Fig. 4. Main effect plots of means for Ra.

TABLE VI. ANOVA FOR RA

Source	DF	Adj SS	Adj MS	F value
Current	2	0.508	0.254	4.59
T_{on}	2	0.316	0.158	2.86
T_{off}	2	1.024	0.512	9.24
Error	2	0.110	0.055	
Total	8	1.764		

TABLE VII. MODEL SUMMARY

S	R-sq	Rsq (adj)
0.2354	93.72%	74.87%

The model summary table (Table VII) elucidates the value of R-sq. The higher R-sq values indicate the high confidence/compliance of the theoretical results with the experimental outputs.

B. Results of MRR

One of the most important metrics for assessing the effectiveness of the EDM Process is MRR. The primary effect plot on the MRR is shown in Figure 5, where it is evident that T_{on}, the current, and T_{off} significantly affect the MRR, a finding corroborated by Tables IX and X. MRR is directly proportional to the current and pulse duration, as illustrated in Figure 5. The increase in the working current at constant T_{off} and T_{on} may increase the spark energy, which in turn produces a stronger spark with a high level of thermal energy. This energy is then transferred to the electrode tool and workpiece, and the introduction of a high impact force in the spark gap results in more molten material, which increases the MRR. The ANOVA results indicate that the MRR was most affected by the current, as shown from the high F-value of 28.97, and the least affecting parameter was T_{off} with an F-value equal to 3.63.

ANOVA was used to optimize and analyze the relationship between the chosen machining parameters and the features of the machining process. In the regression analysis, the correlation between the input parameters and responses was regarded as a linear equation. The general linear model, which was created by ANOVA and is displayed in Tables IX and X, was deployed in this investigation. Mathematical models were developed using experimental data.

TABLE VIII. EXPERIMENTAL RESULTS

No	Current	T_{on}	T_{off}	Ra	MRR	TWR	FITS-1	RESI-1	FITS-2	RESI-2	FITS-3	RESI-3
1	36	150	50	2.846	9.466	0.384	2.953	-0.107	9.162	0.303	0.358	0.025
2	36	200	75	2.816	8.289	0.296	2.682	0.133	8.388	-0.099	0.289	0.006
3	36	250	100	2.604	9.074	0.310	2.629	-0.025	9.277	-0.203	0.342	-0.03
4	42	150	50	3.118	9.986	0.431	3.156	-0.038	10.291	-0.305	0.479	-0.048
5	42	200	100	2.704	9.813	0.409	2.824	-0.120	9.611	0.201	0.399	0.009
6	42	250	50	3.764	11.275	0.622	3.604	0.159	11.171	0.103	0.583	0.038
7	48	150	100	2.903	10.836	0.582	2.756	0.146	10.834	0.002	0.559	0.022
8	48	200	50	3.958	11.584	0.702	3.970	-0.012	11.685	-0.101	0.718	-0.016
9	48	250	75	3.132	11.719	0.668	3.265	-0.133	11.619	0.099	0.674	-0.006

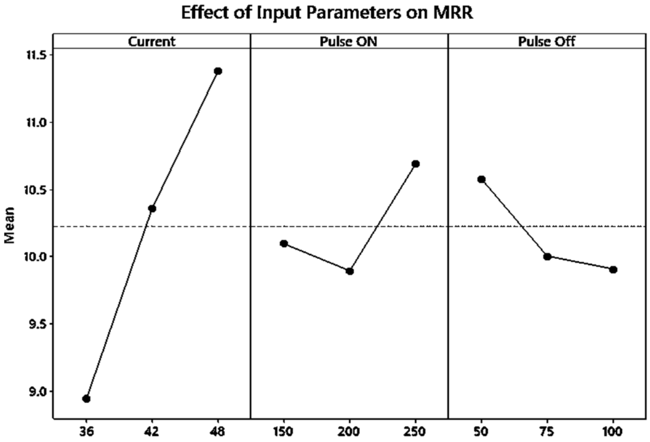


Fig. 5. Main effect plots of means for MRR.

TABLE IX. ANOVA FOR MRR

Source	DF	Adj SS	Adj MS	F value
Current	2	8.919	4.459	28.97
T_{on}	2	1.319	0.659	4.28
T_{off}	2	1.116	0.558	3.63
Error	2	0.307	0.153	
Total	8	11.430		

TABLE X. MODEL SUMMARY

S	R-sq	Rsq (adj)
0.392	97.31%	89.23%

The regression equation is:

MRR = 10.131 - 1.188 Current_36 - 0.060 Current_42 + 1.248 Current_48-0.322 PulseON_150- 0.236 PulseON_200 + 0.558 PulseON_250 + 0.542 PulseOff_50-0.318 Pulse Off_75-0.224 PulseOff_100

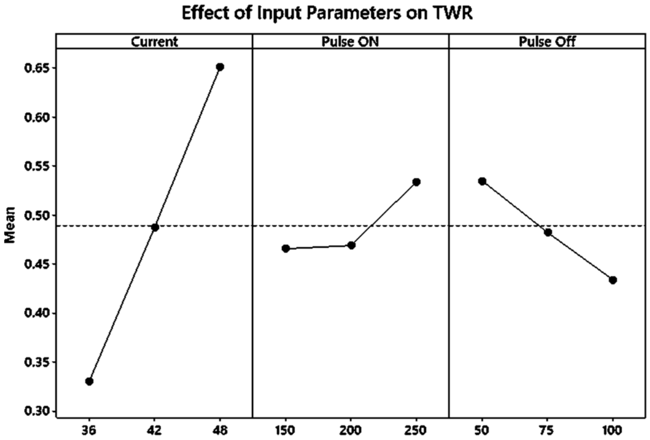


Fig. 6. Main effect plots of means for TWR.

Following the collection of experimental data for TWR, as depicted in Tables XI and XII and Figure 6, the TWR ANOVA findings demonstrated that TWR was significantly influenced by the current, as shown from the high F-value of 24.05. The parameter with the least contribution was the T_{off}. Figure 6 shows that TWR continues to increase as the current levels increase. According to Figure 6, the TWR has the largest value at higher current levels and the lowest value at lower current levels.

TABLE XI. ANOVA FOR TWR

Source	DF	Adj SS	Adj MS	F value
Current	2	0.156	0.078	24.05
T_{on}	2	0.014	0.007	2.21
T_{off}	2	0.024	0.012	3.73
Error	2	0.006	0.003	
Total	8	0.193		

TABLE XII. MODEL SUMMARY

S	R-sq	Rsq (adj)
0.057	96.64%	86.55%

The regression equation is:

TWR = 0.4773 - 0.1473 Current_36 - 0.0260 Current_42 + 0.1733 Current_48 - 0.0477 PulseON_150 - 0.0084 PulseON_200 + 0.0561 PulseON_250 + 0.0758 PulseOff_50 - 0.0322 PulseOff_75 - 0.0436 PulseOff_100

IV. CONCLUSIONS

The Electrical Discharge Machining (EDM) process offers the possibility of machining very hard materials with great potential for generating complex geometries. An attempt was made to reach higher values of machining factors than those in previous studies conducted on A2 tool steel. The limits beyond these values were investigated to explore their effect on surface roughness (Ra), Tool Wear Rate (TWR), and Material Removal Rate (MRR). Based on the experiments carried out using L9 the Taguchi's Design of Experiments (DOE), it can be concluded that the Ra increased with increasing pulse on time (T_{on}) and current, and decreased with increasing pulse-off time (T_{off}). Increasing the pulse duration increased the TWR. High levels of T_{off} reduce TWR. However, increasing the current increases the MRR of the machined parts.

The findings provide practical guidelines for maximizing the EDM performance when machining (A2) tool steel and cover a gap in previous research by describing the effects of intense process conditions on multiple outcomes.

REFERENCES

[1] M. Shabgard, M. Seyedzavvar, and S. N. B. Oliaei, "Influence of Input Parameters on the Characteristics of the EDM Process," *Journal of Mechanical Engineering*, vol. 57, no. 9, pp. 689–696, Sep. 2011, https://doi.org/10.5545/sv-jme.2011.035.

[2] J. E. A. Qudeiri, A. Zaiout, A.-H. I. Mourad, M. H. Abidi, and A. Elkaseer, "Principles and Characteristics of Different EDM Processes in Machining Tool and Die Steels," *Applied Sciences*, vol. 10, no. 6, Jan. 2020, Art. no. 2082, https://doi.org/10.3390/app10062082.

[3] S. K. Ghazi, M. A. Abdullah, and H. H. Abdulridha, "Investigating the Impact of EDM Parameters on Surface Roughness and Electrode Wear Rate in 7024 Aluminum Alloy," *Engineering, Technology & Applied Science Research*, vol. 15, no. 1, pp. 19401–19407, Feb. 2025, https://doi.org/10.48084/etasr.9252.

[4] Z. S. Ali, R. R. Elias, and Q. S. Mahdi, "Investigating affecting EDM process parameters on material removal rate, electrode wear rate and surface roughness of tool steel," *AIP Conference Proceedings*, vol. 2415, no. 1, Dec. 2022, Art. no. 060027, https://doi.org/10.1063/5.0092921.

[5] A. Kumar *et al.*, "Wire EDM process parameter optimization for D2 steel," *Materials Today: Proceedings*, vol. 37, no. part 2, pp. 2478–2482, Jan. 2021, https://doi.org/10.1016/j.matpr.2020.08.295.

[6] M. Patel Gowdru Chandrashekarappa, S. Kumar, Jagadish, D. Y. Pimenov, and K. Giasin, "Experimental Analysis and Optimization of EDM Parameters on HcHcr Steel in Context with Different Electrodes and Dielectric Fluids Using Hybrid Taguchi-Based PCA-Utility and CRITIC-Utility Approaches," *Metals*, vol. 11, no. 3, Mar. 2021, Art. no. 419, https://doi.org/10.3390/met11030419.

[7] A. Banu and M. Y. Ali, "Electrical Discharge Machining (EDM): A Review," *International Journal of Engineering Materials and Manufacture*, vol. 1, no. 1, pp. 3–10, Sep. 2016, https://doi.org/10.26776/ijemm.01.01.2016.02.

[8] T. P. T. Le, V. T. Dinh, T. Q. D. Nguyen, D. B. Vu, and T. T. Vu, "Application of the Multi-Criteria Decision Method to Find the Best Input Factors for Electrical Discharge Machining 90CrSi Tool Steel using Graphite Electrodes," *Engineering, Technology & Applied Science Research*, vol. 14, no. 6, pp. 18883–18888, Dec. 2024, https://doi.org/10.48084/etasr.9114.

[9] A. Gupta and H. Kumar, "Optimization of EDM Process Parameters: A Review of Technique, Process, and Outcome," in *Advances in Manufacturing and Industrial Engineering*, Singapore, 2021, pp. 981–996, https://doi.org/10.1007/978-981-15-8542-5_87.

[10] M. M. Abdulrazaq, M. M. H. AL-Khafaji, A. K. Salahaddin, S. Krinke, and H. Zeidler, "Out-Of-Position Bead Geometry Prediction in Wire Arc Additive Manufacturing (WAAM) Using Fuzzy Logic-Based System," *Management Systems in Production Engineering*, vol. 33, no. 1, pp. 46–53, Feb. 2025, https://doi.org/10.2478/mspe-2025-0005.

[11] W. S. Khudhir, M. Q. Abbood, and J. J. Shukur, "Multi-Criteria Decision Making of Abrasive Water Jet Machining Process for 2024-T3 Alloy Using Hybrid Approach," *Advances in Science and Technology. Research Journal*, vol. 16, no. 5, pp. 155–162, Nov. 2022, https://doi.org/10.12913/22998624/154040.

[12] S. Ammisetty, D. Ammisetti, K. Satyanarayana, S. Chitturi, and N. S. Naik, "Optimization of EDM Process Parameters on Machining Characteristics of SiC and Graphene Reinforced Al 6061-T6nano-Composites," *IOP Conference Series: Materials Science and Engineering*, vol. 1112, no. 1, Apr. 2021, Art. no. 012017, https://doi.org/10.1088/1757-899X/1112/1/012017.

[13] S. Zoalfakar, I. L-Batanony, M. Ghanem, and M. Gharib, "Multi-objective Optimization of Electrical Discharge Machining Process of Brass 35 Zn by Response Surface Methodology," *The Egyptian International Journal of Engineering Sciences and Technology*, vol. 28, pp. 22–32, Jul. 2019, https://doi.org/10.21608/eijest.2019.97298.

[14] S. Chandramouli, U. Shrinivas Balraj, and K. Eswaraiah, "Optimization of electrical discharge machining process parameters using Taguchi method," *International Journal of Advanced Mechanical Engineering*, vol. 4, no. 4, pp. 425–434, 2014.

[15] S. Gopalakannan, T. Senthilvelan, and S. Ranganathan, "Statistical optimization of EDM parameters on machining of aluminium Hybrid Metal Matrix composite by applying Taguchi based Grey analysis," *Journal of Scientific & Industrial Research*, vol. 72, no. 6, pp. 358–365, Jun. 2013.

[16] V. Mohankumar *et al.*, "Process parameters optimization of EDM for hybrid aluminum MMC using hybrid optimization technique," *Heliyon*, vol. 10, no. 15, Aug. 2024, Art. no. e35555, https://doi.org/10.1016/j.heliyon.2024.e35555.

[17] A. F. Ibrahim, A. H. Singal, and D. A. al kareem Noori, "Investigation of material removal rate and surface roughness during electrical discharge machining on Al (6061)-5%SiC-10%B_4C hybrid composite," *Metallurgical and Materials Engineering*, vol. 28, no. 1, pp. 47–60, Mar. 2022, https://doi.org/10.30544/798.

[18] N. Radhika, A. R. Sudhamshu, and G. Kishore Chandran, "Optimization of electrical discharge machining parameters of aluminium hybrid composites using Taguchi method," *Journal of Engineering Science and Technology*, vol. 9, no. 4, pp. 502–512, 2014.