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Performance Prediction in EDM Process for Al 6061 Alloy Using Response Surface Methodology and Genetic Algorithm

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Abstract

The Electric Discharge (EDM) method is a novel thermoelectric manufacturing technique in which materials are removed by a controlled spark erosion process between two electrodes immersed in a dielectric medium. Because of the difficulties of EDM, determining the optimum cutting parameters to improve cutting performance is extremely tough. As a result, optimizing operating parameters is a critical processing step, particularly for non-traditional machining process like EDM. Adequate selection of processing parameters for the EDM process does not provide ideal conditions, due to the unpredictable processing time required for a given function. Models of Multiple Regression and Genetic Algorithm are considered as effective methods for determining the optimal processing variables of Electrical Discharge Machining.

The material removal rate (MRR) and tool wear (Tw) were investigated using the process variables of pulse on time *(Ton)*, pulse off time *(Toff)*, and current intensity *(Ip)*. The established empirical models were used to perform Genetic Algorithm (GA) to maximize (MRR) and minimize (Tw). The optimization results were utilized to establish machining conditions, validate empirical models, and obtain optimization outcomes. The optimal result that appears in this work was the pulse on (176.261 μ s), pulse off (39.42 μ s), and current intensity (23.62 Amp.) to maximize the MRR to (0.78391 g/min) and reduce tool wear to (0.0451 g/min).

Keywords: *Electro Discharge Machining, Genetic Algorithm, MRR, Tool Wear.*

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1. Introduction

Machining Aluminum alloy using traditional machining technologies has problems such as high cutting temperatures and a high tool wear ratio. Aluminum is employed in a variety of industries, including automobiles, and aerospace. Aluminum alloy, on the other hand, has some advantages due to its low cost, low density, availability, and manufacturability [1].

AA 6061 Aluminum alloy is a precipitation-hardened variant of the 6000 series Al alloys that are widely used. It's a heat-treatable extruded alloy with medium to high strength properties [2]. Electrical discharge machining (EDM) is a non-traditional machining technique that is commonly used to machine die surfaces [3]. EDM is a popular production technique for difficult-to-machine materials and complex geometries. Wire and electrode EDM are the two primary types of EDM processes. The manufacturing process setup includes the electrode material, the geometry of wire diameter or the electrode, and the energy transfer parameters of voltage V with its polarity, pulse current intensity I, and pulse on time *(Ton)* and pulse off time *(Toff)* [4][5]. Several authors attempted to machine several materials by utilizing the electrical discharge machining process. S. Ranjith et al. [6] examined the influence of EDM machining variables (pulse-on duration, current, pulse-off duration, and spark gap voltage) on MRR and Tw of silicon nitride–titanium nitride ceramic composites with the copper electrode. From the results, it has been shown that the current is a highly important factor among other parameters on both MRR and TWR. Higher material removal rate is obtained when pulse-on time and current is higher, whereas lower EWR result from high gap voltage and low current. Huu-Phan et al. [7] applied Multi-response optimization based on Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to examine the impact of low-frequency vibration on material removal rate MRR and Surface Roughness Ra in EDM process. From the experimental results, in the low-frequency vibration aided EDM technique, the process performance accuracy has been enhanced to around 86.6 percent. By enhancing the quality of the machining surfaces, TOPSIS was able to improve the low-frequency vibration-assisted EDM process' performance. The material removal rate can be increased with low-frequency vibration due to the controlled spark energy. Mandeep and Sthitapragyan [8] examined the effects of machining parameters such as pulse-on time (T-on), pulse-off time (T-off), current (I), and voltage (V) on the MRR of Aluminum based composite material. The aluminum metal matrix composite was cast with 200 mesh size (Avg. size 75 mm) particles (20 percent SiCp and 8% Grp). Response surface methodology RSM created the design matrix and mathematical models. The experimental results indicate that the pulse-on time and current are both major factors that directly affected (increased) the material removal rate, according to the analysis. Finally, at a high level of "pulse-off time," the MRR is minimal, but "voltage" has no significant effect on MRR. Mandeep et al. [9] determined the optimum process parameters (Peak current (I), voltage (V), Ton, and tool material) that affect the MRR and Ra of EDM during the machining of a new hybrid aluminum metal matrix composite. From the analysis of variance (ANOVA), the MRR increased as the Ton and pulse current increased, however, the MRR declined as the voltage increased. Reduced Ra, on the other hand, could only be achieved with low I, V, and pulse length. It was also revealed that the electrodes used in EDM had a substantial impact on MRR and surface roughness. Chinmayee et al. [10] investigated the influence of input parameters (discharge current, pulse-on-time, and open circuit voltage) on MRR, Tw and radial overcut of AA 7075 aluminum- 6% red mud metal matrix composites (AMMC) in the EDM process. From the results, it has been observed that pulse on-time and discharge current have a crucial influence on machinability characteristics of (AMMC) by providing useful information with less deviation to improve the accuracy of the EDM parts. Ramanuj et al. [11] carried out an experimental investigation to study the effect of (voltage, pulse on time, and current) on the (Ra) and (MRR) of Ti-6Al-4V ELI using EDM. Multi response Grey Relation Analysis (GRA) technique has been utilized for optimizing the machining parameters. From the results, it has been presented that the MRR and Ra were directly proportional to discharge current. Sagar and Pravin [12] provided an experimental investigation on the effect of (pulse on duration, discharge voltage, capacitance, and electrode rotation speed) on side gap width, MRR, and taper ratio when drilling Titanium alloy (Ti6Al4V) with copper tungsten (CuW) electrode. The experimental results demonstrate that capacitance, discharge voltage, and electrode rotation speed all have an impact on MRR parameters, whereas pulse on time, capacitance, and electrode rotation speed influence side gap width. On the other hand, capacitance and pulse on duration were the affecting parameters on the taper ratio. R.Rajesh and M. Dev Anand [13] calculated the optimum operating parameters namely; working voltage, oil pressure, spark gap, Pulse On Time, and Pulse Off Time, affecting the MRR by developing genetic algorithm and multiple regression models with an empirical model by conducting experiments based on the Grey Relational Analysis, which were used to obtain the greatest value for MRR in electric discharge machine. Tzeng et al. [14] analyzed MRR, electrode wear ratio, and workpiece surface finish on process parameters during the manufacture of SKD61 by electrical discharge machining (EDM). A hybrid method including a back-propagation neural network (BPNN), a genetic algorithm (GA), and response surface methodology (RSM) were proposed to determine optimal parameter settings of the EDM process.

In this paper, the influence of EDM parameters (pulse on time Ton (µs), pulse off time Toff (µs) and current intensity Ip (A)) was studied to determine their influence on the Material Removal Rate (MRR) and Tool Wear Rate (Tw) values based on Response Surface Methodology (RSM) and Genetic algorithm.

2. Experimental Work

A CHEMER EDM machine model (CM-323 C) as shown in Figure 1, is used to implement the experimental work.

Fig. 1. EDM Tool Model CM 323C

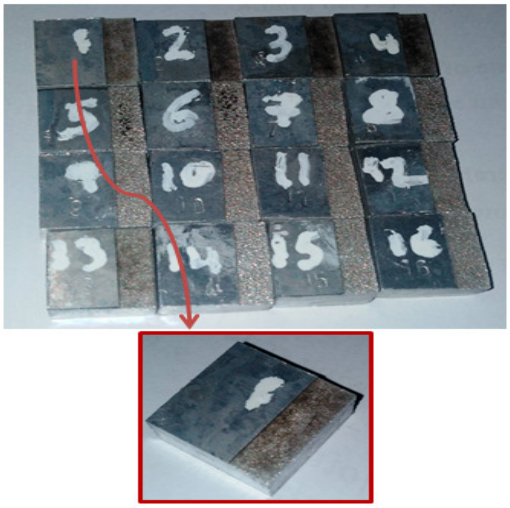

Fig. 2. Work piece Samples of Al-6061 Alloy

2.1 Work piece material

For evaluating the optimum values of process variables, a Copper electrode was used to Machine twenty samples of AA 6061 Aluminum alloy with dimensions (15×15×5mm) as shown in Figure 2. Table 1 illustrates the Chemical Composition of AA 6061 Alloy.

Table 1,
Al-6061 Alloy Chemical Composition

Sample	Workpiece material
Cu %	0.388
Fe %	0.195
Si%	0.49
Mg %	1.07
Mn %	0.068
Zn %	0.003
Cr%	0.243
Ti%	0.019
Al%	Balance

2.2 Selection parameters and their levels

Process variables are the parameters that influence Material Removal Rate (MRR) and Tool Wear Rate (Tw) of machined surface and include the current intensity (Ip), pulse on time (*Ton*), and pulse off time (*Toff*). Table 2 shows the parameters values and their levels that were used in the experiments.

Table 2,
parameters values and the levels used

Process Parameters		pulse on time Ton (μs)	pulse off time Toff (μs)	current intensity Ip (Amp.)
Levels	Low	100	25	8
	Medium	150	37	16
	High	200	50	24

2.3 Design and Analysis of Experimental Work

To find which input parameters generate the optimum output and to identify the influence of input parameters that enhance the developed qualities of the part above the obtained qualities, RSM was adopted to in this study to develop statistical and mathematical models due to its reliable performance [15, 16]. The central composite design is the most frequent way of building a quadratic model of a response surface (CCD). Experiments are conducted with RSM and a Central Composite Design (CCD) matrix with Two-level factorial (full factorial) where it consists of 8 cube points, 6 center points, and 6 axial points with α=1.68179.

Experimental design is an important stage in creating a response surface model using MINITAB software[15]. Material Removal Rate (MRR) and Tool Wear Rate (Tw) are calculated from equations (1,2) [17, 18] after experimentation, as shown in Table 3.

$$\mathrm{MRR} = \frac{weight\ reduction\ \ on\ workpiece}{Time\ taken\ in\ machining} \quad \dots (1)$$

$$\mathrm{T}w = \frac{weight\ reduction\ on\ tool}{Time\ taken\ in\ machining} \quad \dots (2)$$

Table 3,
Experimental results of (MRR), (Tw)

No.	Ton	Toff	Ip	MRR (g/min)	Tw (g/min)
1	100	25	8	0.0790	0.0024
2	200	25	8	0.0820	0.0023
3	100	50	8	0.0700	0.0013
4	200	50	8	0.0760	0.0010
5	100	25	24	0.5040	0.0100
6	200	25	24	0.6890	0.0130
7	100	50	24	0.4952	0.0048
8	200	50	24	0.5300	0.0231
9	100	37	16	0.3050	0.0065
10	200	37	16	0.4160	0.0069
11	150	25	16	0.3845	0.0130
12	150	50	16	0.3540	0.0130
13	150	37	8	0.0810	0.0015
14	150	37	24	0.6300	0.0120
15	150	37	16	0.3800	0.0069
16	150	37	16	0.3800	0.0069
17	150	37	16	0.3800	0.0069
18	150	37	16	0.3800	0.0069
19	150	37	16	0.3800	0.0069
20	150	37	16	0.3800	0.0069

3. Results and Discussion

3.1. Analysis of Variance

On the basis of Table 3's experimental findings, the impact of the input variables *(Ton), (Toff),* and *(Ip)* on the outputs (MRR and Tw), is investigated using MINITAB 17 software and Analyses of Variance (ANOVA). The significance of the model is determined using ANOVA. The ANOVA results for MRR and Tw are shown in Tables 4-5, respectively.

Table 4,
ANOVA of MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.648477	0.072053	118.07	0.000
Linear	3	0.620442	0.206814	338.91	0.000
Ton	1	0.011445	0.011445	18.75	0.001
Toff	1	0.004550	0.004550	7.46	0.021
Ip	1	0.604448	0.604448	990.51	0.000
Square	3	0.015405	0.005135	8.41	0.004
Ton*Ton	1	0.001454	0.001454	2.38	0.154
Toff*Toff	1	0.000493	0.000493	0.81	0.390
Ip*Ip	1	0.002155	0.002155	3.53	0.090
2-Way Interaction	3	0.011331	0.003777	6.19	0.012
Ton*Toff	1	0.002771	0.002771	4.54	0.059
Ton*Ip	1	0.005555	0.005555	9.10	0.013
Toff*Ip	1	0.003005	0.003005	4.92	0.051
Error	10	0.006102	0.000610		
Lack-of-Fit	5	0.006102	0.001220	*	*
Pure Error	5	0.000000	0.000000		
Total	19	0.654580			

S = 0.0247030, R-sq = 99.07%, R-sq(adj) = 98.23%, R-sq(pred) = 85.78%

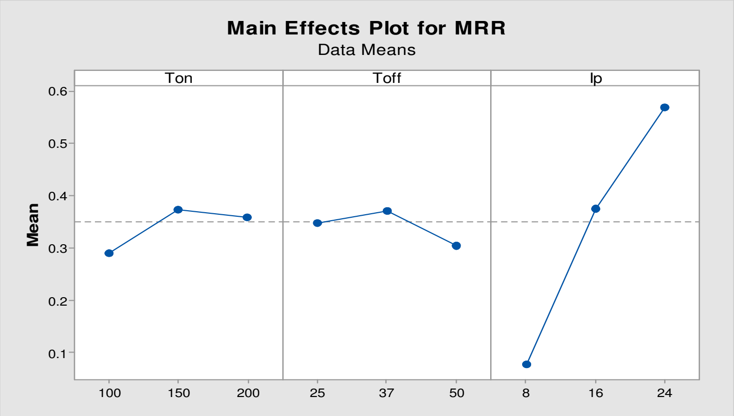

Fig. 3. MRR Main Effects Plot.

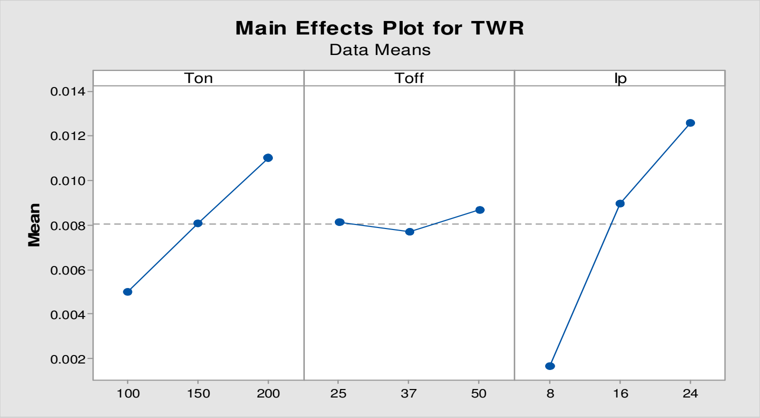

Fig. 4. Tw Main Effects Plot

It is clear from the main effects plot of Figure 3 that the material removal rate highly increases with the increase of current intensity, and decreases with the increase in pulse on time and pulse off time, the reason behind this is that the discharge energy increases with the increase of pulse on time and peak current leading to a faster cutting rate. With the decrease in the pulse off time, the number of discharges within a given period becomes more which leads to a higher material removal rate.

To depict the input variables relationship between (Ton, Toff, and Ip) and the output (MRR), Material Removal Rate mathematical model is established as in equation 3.

MRR = -0.714 + 0.00350 Ton + 0.01230 Toff + 0.04211 Ip - 0.000009 Ton*Ton - 0.000086 Toff*Toff - 0.000437 Ip*Ip - 0.000030 Ton*Toff + 0.000066 Ton*Ip - 0.000194 Toff*Ip

… (3)

Table 4 shows the overall significance of the mathematical model, with (R-Sq) determining the fit value between predicted and experimental findings. The (R-Sq(adj)) value indicates that the independent variables (Ton, Toff, and Ip) recorded (98.23) percent of the variance in the dependent variable (Y), with the remainder due to random error.

Table 5,
ANOVA of Tw

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.000522	0.000058	7.41	0.002
Linear	3	0.000388	0.000129	16.52	0.000
Ton	1	0.000091	0.000091	11.61	0.007
Toff	1	0.000001	0.000001	0.08	0.783
Ip	1	0.000297	0.000297	37.88	0.000
Square	3	0.000042	0.000014	1.79	0.213
Ton*Ton	1	0.000001	0.000001	0.13	0.730
Toff*Toff	1	0.000018	0.000018	2.26	0.163
Ip*Ip	1	0.000038	0.000038	4.81	0.053
2-Way Interaction	3	0.000094	0.000031	3.98	0.042
Ton*Toff	1	0.000028	0.000028	3.58	0.088
Ton*Ip	1	0.000059	0.000059	7.52	0.021
Toff*Ip	1	0.000007	0.000007	0.85	0.377
Error	10	0.000078	0.000008		
Lack-of-Fit	5	0.000078	0.000016	*	*
Pure Error	5	0.000000	0.000000		
Total	19	0.000600			

S = 0.0027986, R-sq = 86.96% , R-sq(adj) = 75.22%, R-sq(pred) = 0.00%

It is also clear from the main effects plot of Figure 4 that the most influencing factor on tool wear rate is the peak current; tool wear rate is minimum at lower currents.

To depict the input parameters relationship between (Ton, Toff, and Ip) and the output (Tw), Tool Wear Rate mathematical model is established as in equation 4.

Tw = 0.0397 - 0.000232 Ton - 0.001797 Toff + 0.001171 Ip + 0.000000 Ton*Ton + 0.000016 Toff*Toff - 0.000058 Ip*Ip + 0.000003 Ton*Toff + 0.000007 Ton*Ip + 0.000009 Toff*Ip

… (4)

Table 5 shows the overall significance of the mathematical model, with (R-Sq) determining the fit value between predicted and experimental findings. The (R-Sq(adj)) value indicates that the independent variables (Ton, Toff, and Ip) recorded (75.22) percent of the variance in the dependent variable (Y), with the remainder due to random error. Figure 4 shows the Tw Main Effects Plot.

3.2 GA Results

Genetic algorithm is a probabilistic search technique that generates a new population from an iterative collection (called a population) of mathematical objects (typically fixed-length binary character Strings), each with a fitness value [19]. The genetic algorithm analyzes the experimental and expected values by using the intersection technique and the best value is supplied in the schedule below.

Genetic Algorithm Input

Population size=50
Population type=double vector
No. of generations = 50
No. of generations chosen = 15
Fitness Function =Rank scaling
Cross function = Two-point
Cross over Fraction of = 0.8
Mutation Function = adaptable Feasible

The best results were obtained after choosing the fitness function for a total length of the string of 18 and then transferring the results to MATLAB after setting up GA parameters and presenting them in Table 6.

Table 6,
GA that results for MRR, tool wear

No.	Ton	Toff	Ip	MRR	Tw	Rank
1	100.231	25.263	9.41	0.063425	0.0025	1
2	123.451	29.421	13.44	0.0736586	0.0031	1
3	110.275	35.781	17.23	0.0208128	0.0071	1
4	133.651	38.621	16.42	0.3721823	0.0097	1
5	144.573	38.689	18.931	0.46217	0.0187	1
6	176.261	39.42	23.623	0.78391	0.0451	1
7	157.621	33.465	12.217	0.11327	0.0037	1
8	167.951	43.26	19.425	0.53217	0.02321	1
9	172.651	46.72	15.621	0.27218	0.0110	1
10	155.621	35.621	17.631	0.43218	0.0132	1
11	143.679	42.631	18.965	0.49265	0.0211	1
12	175.692	47.345	22.31	0.61329	0.032	1
13	199.200	37.625	16.781	0.39781	0.0197	1
14	184.222	48.681	19.678	0.59232	0.0232	1
15	137.437	28.42	14.597	0.21379	0.0111	1

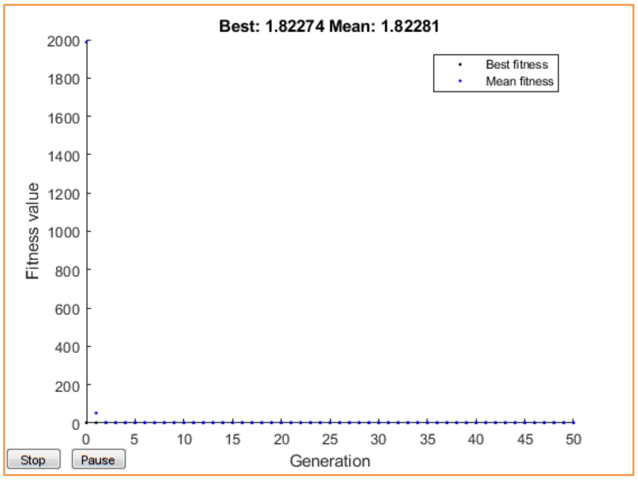

Fig. 5. The implemented data on GA

Table 7,
The optimum solution for several values of GA parameters

Number of iteration	crossover	Mutation	Optimal solution	
			Best	mean
1	0.6	0.04	1.356321	1.356453
2	0.6	0.05	1.366012	1.367432
3	0.6	0.06	1.369412	1.373211
4	0.6	0.07	1.477213	1.477631
5	0.6	0.08	1.478231	1.478912
6	0.75	0.04	1.565221	1.566321
7	0.75	0.05	1.572132	1.572322
8	0.75	0.06	1.575423	1.576421
9	0.75	0.07	1.579543	1.582311
10	0.75	0.08	1.594352	1.596432
11	0.8	0.04	1.653211	1.662132
12	0.8	0.05	1.663214	1.673421
13	0.8	0.06	1.594231	1.594326
14	0.8	0.07	1.694325	1.694321
15	0.8	0.08	1.82274	1.82281

Providing better reproductive opportunities through offspring gives more possible solutions so Table 7 shows that the increase in the crossover value caused improvement in the results until it reaches the optimal values, where reading No (15) in table 7 showed the best fitness (1.82274) and mean fitness (1.82281) which was evident in the Figure 5 that represents the implementation of the program.

The pulse on time, pulse off time, and current intensity were all optimized. The aim here is to reduce tool wear while increasing the rate of material removal. The following are the boundary conditions for the decision variables pulse on time, pulse off time, and current intensity:

Pulse on time *(Ton)* = (100 to 200 μ s)
Pulse off time *(Toff)* = (25 to 50 μ s)
Current intensity *(Ip)* = (8 to 24 Amp.)

Figures 6-7 illustrate the effect of *(Toff)* on MRR and tool wear, where its increase in Toff led to an increase in MRR to optimal value (0.78391 g/min) at Toff (39.42 μ s) with a decrease in tool wear by (0.0451 g/min), while figures 8-9 indicate the effect of current intensity on MRR and Tw, respectively the optimal values was at Ip (23.623 Amp.).

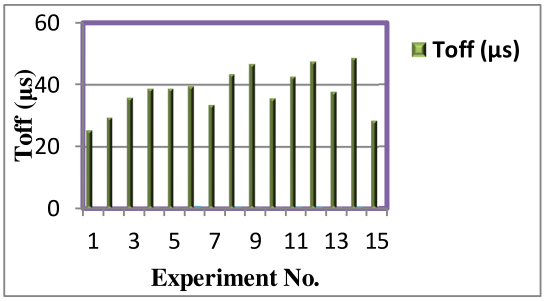

Fig. 6. Effect of pulse off time on MRR.

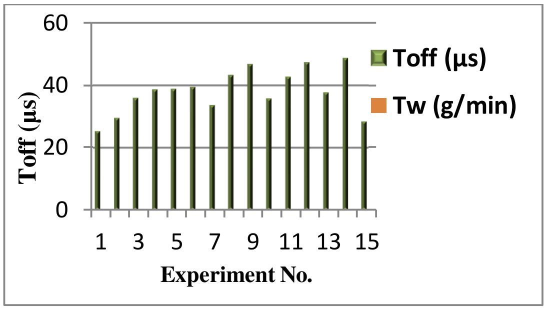

Fig. 7. Effect of pulse off time on Tw.

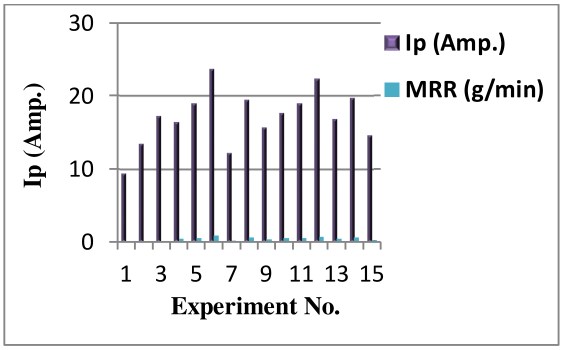

Fig. 8. Effect of current intensity on MRR.

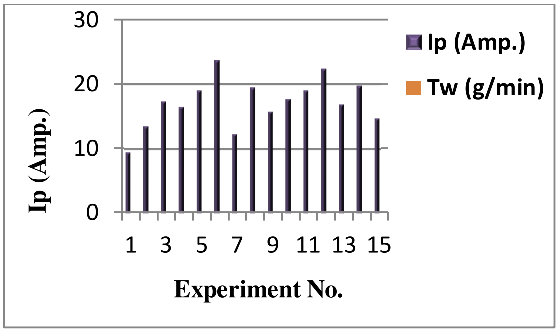

Fig. 9. Effect of current intensity on Tw.

4. Conclusions

This research presents a realistic method for optimizing EDM cutting parameters based on GA. The machining parameters included pulse on, pulse off, and current intensity Ip. The EDM method yields results such as metal removal rate and tool wear.

The response surface method (RSM) uses statistical and mathematical methods for issue modeling and analysis to locate the input variables that generate the optimum response. Finally, GA was able to determine the best circumstances. That is, between experimental data, pulse on (176.261 μ s), pulse off (39.42 μ s), current intensity (23.62 Amp.) to maximize the MRR to (0.78391 g/min) and reduce tool wear to (0.0451 g/min). The machining current of the EDM process is the most influential factor revealed by the response table.

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تقنية الخوارزمية الجينية مع منهجية سطح الاستجابة للتنبؤ بمعدل ازالة المعدن وتأكل الاداة في عملية التشغيل بالشرارة الكهربائية

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الخلاصة

طريقة التشغيل بالشرارة الكهربائية (EDM) هي تقنية تصنيع كهر وحرارية جديدة يتم فيها إزالة المواد عن طريق عملية تكوين شرارة متحكم بها بين قطبين مغمسين في وسط عازل. بسبب صعوبات عمليةEDM ، فإن تحديد أفضل متغيرات القطع لتحسين أداء القطع أمر صعب للغاية. نتيجة لذلك، يعد إيجاد امثل متغيرات التشغيل خطوة حاسمة، خاصة لعمليات التشغيل الغير التقليدية مثل EDM . إن التحديد المناسب لمتغيرات هذه العملية ربما لا يعطي الظروف المثلى نظرا لصعوبة التنبؤ بوقت المعالجة المطلوب للمهمة المعطاة. تم إنشاء نماذج الانحدار المتعدد والخوارزمية الجينية كطرق فعالة لتحديد متغيرات المعالجة المثلى في معالجة التفريغ الكهربائي لحل هذه المشكلة. تم التحقق من معدل إزالة المواد (MRR) ومعدل بليان الأداة (Tw) باستخدام متغيرات العملية وهي: زمن تشغيل النبضة (Ton)، وزمن إطفاء النبضة (Toff)، وشدة التيار (Ip). تم استخدام النماذج التجريبية المحددة لأداء التحسين متعدد الأهداف المستند إلى الخوارزمية الجينية (GA) لتعظيم (MRR) وتقليل (Tw). تم استخدام نتائج الأمثلية لإنشاء ظروف التشغيل الآلي، والتحقق من صحة النماذج التجريبية، والحصول على المخرجات المثلى. أظهرت النتائج ان الظروف المثلى: زمن تشغيل النبضة (µs١٧٦,٢٦١)، زمن إطفاء النبضة (µs ٣٩,٤٢)، وشدة التيار (.Amp ٢٣,٦٢) أدت للحصول على أعلى معدل إزالة مواد (g/min ٠,٧٨٣٩١) واقل معدل بليان أداة (g/min ٠,٠٤٥١).