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Optimization of MRR and Surface Roughness for 7024 AL-alloy in EDM Process

Abstract- *Electro discharge machining is major non-traditional operations for cutting the materials due to its suitability and benefits. The experimental work of this paper deals with electrico discharge machining (EDM). A system for machining in this process has been developed. Many parameters are studied such as current, time on and time off. Different current rates are used ranging from (30, 36 and 42) Amp, found that low current gives less material removal rates and good surface roughness. The results showing that maximum MRR is achieved (0.525) mm3/min when machining current (42), time on (150), and time off (50) while good surface roughness (2.11 µm) when machining current (30), time on (50), and time off (25).The level of importance of the machining parameters for surface roughness and material removal rate is determined by using Taguchi design experiments and analysis of variance (ANOVA).*

Keywords- *Taguchi method, EDM, surface roughness, Material removal rate.*

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1. Introduction

Electrical discharge machining (EDM) is a non-traditional cutting process for metals machining based upon the fundamental fact that negligible force of the tool is generated during the cutting process. The metals removal in the process is characterized by the erosive effects by a series of electrical sparks that generate between tool and workpiece materials through a steady electric field that emerge in dielectric environment. EDM process is typically utilized for made-up the cutting tools, punch dies, beside to other parts that difficult-to-cut. EDM process is one of the amongst the most broadly utilized non-traditional material removal operations. Its extraordinary feature of using the thermal energy for electrical machining the conductive parts regardless of hardness has been its distinctive advantage in the manufacture of die, mould, surgical components, automotive, and aerospace. Besides, the EDM process doesn't has a direct contact between the work piece and the electrode getting rid of the mechanical stresses, and vibration troubles over machining [1]. Since the electrode doesn't reach the work piece, it is made of a delicate, easily worked matal such as copper. The tool is working in a fluid such as kerosene or mineral oil, which is feeding the work under pressure. The coolant role is a dielectric for the process, to wash away the eroded metal particles of from the workpiece or tool, and keeping a regular resistance to the flow of the current. The dielectric fluid filling the tank, the end of electrode and the work piece are having sunk in the tank. The selection of the electrodes depends on the shape of cutting that placed on the top of the work piece making a small gap [2]. After linking the electrode with the positive charge, erosion of spark occurred, making a "miniature thunderstorm" between them. Flashing or "lightning" in rapid series occur. The rate of metal removal measures the work capacity of the traditional EDM machine. The EDM process uses electro discharges to remove material from the workpiece, with each spark producing a temperature of 10000C° to 20000C°. Consequently, the workpiece undergoes to a heat affected zone (HAZ) the upper layer of which cover the recast material or white layer [3].
Saifuddin and Khan [4] have studied comparative analysis of the behavior of aluminum and copper electrodes for cutting the carbide and stainless steel. They found that MRR (material removal rate) increased by increasing the current and voltage, but MRR is less during machining of carbide than that of stainless steel. During cutting the stainless steel, electrode wear and corner wear were less than those during cutting carbide. The wear of aluminum electrodes was higher than that of copper electrodes.
Seong et al. [5] demonstrated the effecting of pulse condition for EDM on the micro EDM properties. Current, voltage, and time on/off of the pulse were chosen as experimental variables through a simple formula for the metal removal rate. The pulse variables is particularly concentrated on the duration of pulse and the off-time to on-time ratio, and the cutting properties are reported on tool wear, metal removal rates, and cutting accuracy. The experimental outcome shows that the current and voltage of the pulse exert strong influence on the cutting properties

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and the shorter pulse of EDM is more effective to make an accurate part with a larger metal removal rates.

Habib [6] suggested comprehensive mathematical models for higher order influences and correlating the interactive of various electrical discharge machining factors through (RSM), utilizing relevant experiment data. The adequacy of the models has been tested through the analysis of variance (ANOVA).

Medfai et al. [7] studied the mathematical representation development for the influence of machining parameters on cutting by EDM process. This paper studies the effect of the machining conditions on cutting by electrical erosion of steel 42CD4-42CrMo4 on the quality of parts surface. The study results show that the electrode nature used and the variety grades of the machined materials by EDM influence frequently the material removal volume and the quality of surface for the machined parts.

Nguyen et al. [8] studied the electro chemical reaction in micro EDM- die sinking that used deionized water as dielectric fluid by using short voltage pulse. The metal removal rate of micro-EDM in deionized water is greater than in hydrocarbon oil. Utilizing short duration pulse and large frequency will minimize MRR. That leads to the unpredictable additional metal removal from the work piece which influence on the quality and cutting shape.

Paramjit and Singh [9] studied the effects of electrical discharge machining (EDM) parameters on surface roughness experimentally. He used (H 13 steel) as work material. Experiments are conducted using Taguchi methodology to determine the effects of EDM process parameter. Polarity, peak current, pulse on time, duty cycle, gap voltage and concentration of abrasives powder in dielectric fluid are taken as process input parameters.

2. Theory of Taguchi Method

Taguchi discovers a novel conception for the quality control method named as (Taguchi parameter design) [5]. The method stated that the quality of manufactured part must be computed by the deviation amount from the required value. He takes into consideration not only the operation mean, but also the variation magnitude or (noise) created with manipulating the inputs parameters or operation variables. The technique is focus on two major groups; a unique matrix type called orthogonal array (OA), all the columns include number of experiment depending on the level number for the control factor, in addition to (signal to noise ratio) S/N [6]. The concept (S) indicates to require amount of the outputs characteristics and concept (N) indicates for unrequired amount (standard deviations). The calculation of (*S*/*N*) is varying regard to outer functions, i.e., characteristics values. Two characteristics value “Smaller is Better (SB)” and “Larger is Better (LB)” [10]. Design the experimental parameter using MINITAB 16 program as follow:

STAT ⟹DOE ⟹Taguchi ⟹Create Taguchi design

3. Analysis of Variance

The experiential works tested use variance method (ANOVA) show figure out of effecting the machining variables on the surface roughness and (MRR) that depend on machining variables T_{on},T_{off} and SF while others are independent variables. (%) percent is refer to influence rate of operation variables to (Ra) and (MRR) [8].

4. Experimental Work

EDM machine is available in training and workshop Center University of technology. With workpiece dimension (30 x 40) mm and thick (5) mm. This operation needs some accessories and experimental setup, the main elements that must be used in EDM can be divided into the following elements.

I-EDM Machine

The experiments have been conducted on Electric Discharge Machine model CM 323+50N (CHMBER EDM), which is available at the University of Technology, Baghdad. A photograph of the machine is shown in Figure 1. The machine specifications are shown in Table 1.

Figure 1: EDM Machine used for the experimentation

Table 1: Machine specifications

Specification	Dimensions
Machine body	CM 323C+50N
Table travel (X,Y)	(300×200) mm
Max workpiece weight	500 kg
Outside dimensions	(1200×1350×2250) mm
Weight	1000 kg
Ram travel(Z1)	300 mm
Dielectric tank	D323
Machine body	CM 323C+50N
Table size(W×D)	(500×350) mm
Work tank size	(820×500×300) mm

II-Work-Holding Assembly

The work-holding assembly consists of work-table with X-Y coordinate base Figure 2. The work piece is fitted on the work-holding assembly with the help of jaws, bolt or special work-holding fixture. In addition, the ED machine contains other components like Machine control unit, Dielectric tank, Filter and Resin reservior.

III-Cutting Tool

The tool electrode should be easily machined, but has higher thermal conductivity, density and melting point. It does not undergo surface wear when it is affected by the positive ions in the process. The heat rise has to be less when localized on the surface of the tool. In this work, the copper is selected as tool electrode material because it possesses the good characteristics efficiently as shown in Figure 3.

IV- Work Piece

Al-alloy 7024 use as workpiece. The composition of the Al-alloy 7024 listed in Table (2) which is checked in the central organization for standardization and quality control

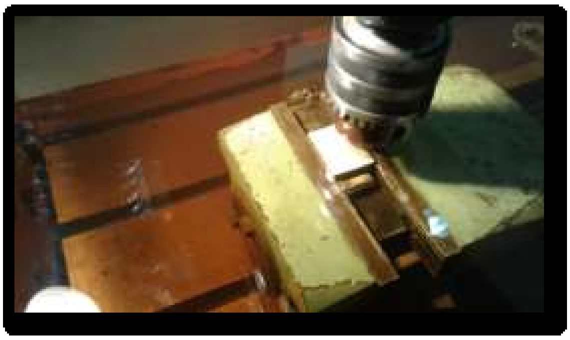

Figure 2: Work-Holding Assembly

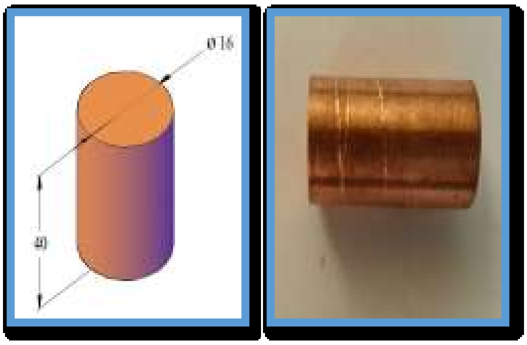

Figure 3: Cutting tool dimensions

Table 2: Chemical composition of Aluminum 7024

Element	Wt%
Si%	0.163
Fe%	0.422
Cu%	2.14
Mn%	0.216
Mg%	1.55
Cr%	0.090
Ni%	0.012
Zn%	4.93
Ti%	0.038
Ga%	0.010
V%	0.007
Pb%	0.071
Other%	0.132
AL%	90.219

V- Design of Experiments

The cutting work with total number are (nine) with (3) levels and (3) parameters as (27 test) . A paritial design was done for studying the effects of parameter on material removal rates and surfaces roughnes value. The variables: Ton, TOFF, SF. as table (3).Gap = 7 mm

- Water pressure (WP) = 1 Pascal
- voltage (Sv) = 25 Volt
- The final levels and the experiments distribution are clarified in Table 4) using the theories of Taguchi designing method:

VI- Machining Using WEDM

In fig (6) the nine specimens machining by EDM process using cutting conditions depending on linear interpolation.

Table 3: Cutting conditions

No	Parameter	Symbol	Level 1	Level 2	Level 3	Units
1	Current	curr	30	36	42	Amp
2	Pulse on time	T_{ON}	50	100	150	μsec
3	Pulse off time	T_{OFF}	25	50	75	μsec

Table 4: Experimental design for the work

No	T off	Ton	Current
١	٢٥	٥٠	٣٠
٢	٥٠	١٠٠	٣٠
٣	٧٥	١٥٠	٣٠
٤	٥٠	٥٠	٣٦
٥	٧٥	١٠٠	٣٦
٦	٢٥	١٥٠	٣٦
٧	٧٥	٥٠	٤٢
٨	٢٥	١٠٠	٤٢
٩	٥٠	١٥٠	٤٢

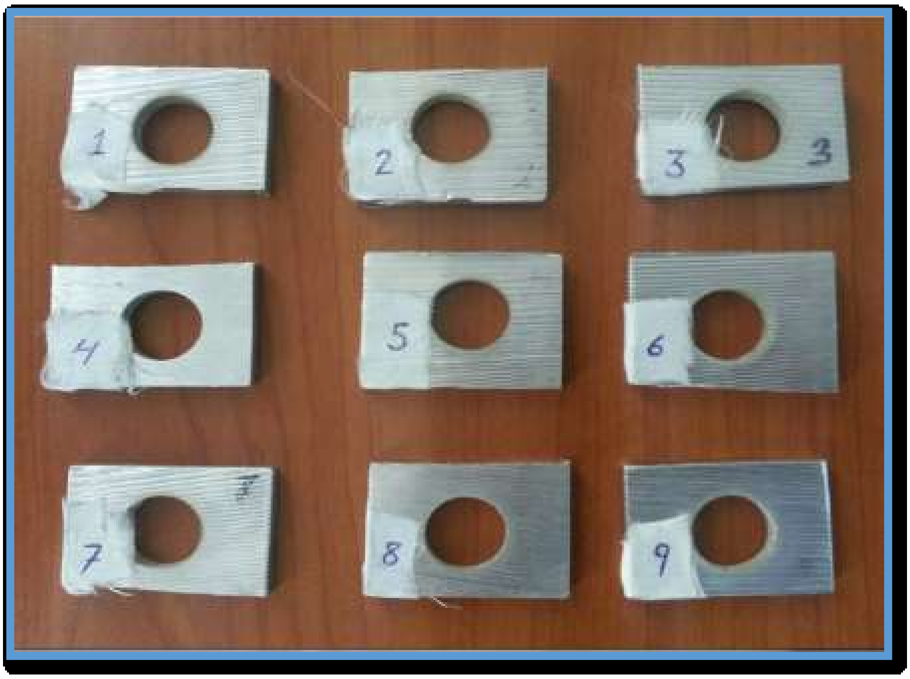

Figure 4: specimens after machining

VII- Surface Roughness Test

The portable gauge of surfaces roughnes Mehr Federal is available at measurement lab / prodection and metalurgy engineering Department/UOT, and shown in Figure (7).The probe has three levels of the distance to give reading (1, 3 and 5 mm).

Figure 5: The Pocket Surf gage

Table 5: Specifications of Pocket Surf

Overall Dimension	140 mm x 75 mm x 26 mm
Weight	436 g
Measuring Range	Ra (0.03-6.36 μm), Ry (0.225 μm)
Display Resolution	0.01 μm

The process of measurement of the surface roughness is use special holder to give the Pocket Surf more freedom in measuring as shown figure (6).

Figure 6: Pocket Surf holder for the proposed work

VIII-MMR Calculations

Material removal rate measure used the equation bellow

$$MRR = \frac{Initial\ weight - Final\ weight}{Machining\ time} \ (mm^3/min) \quad (1)$$

5. Results and Discussion

I- Effect of Pulse on Time and current on the MRR

Figure (7) shows the effecting of TON on MRR at constant current. It obviously noted that the raise in TON leading to raise the material removal rate. That because of the high energy generated through the machining leading to higher melting. Also, the raise in current leads to raise MRR but this raise in MRR leads to raise in Ra because of the high energy that generate from machining.

Table 6: Experimental work readings Material removal rate

No	Current	Ton	Toff	Initial weights	Final weights	Time	Material removal rate	
							MRR1	MRR2
1	٣٠	٥٠	٢٥	14.58	11.95	9.40	0.279	0.222
2	٣٠	١٠٠	٥٠	15.24	12.61	7.07	0.371	0.390
3	٣٠	١٥٠	٧٥	15.24	12.37	6.43	0.446	0.432
4	٣٦	٥٠	٥٠	13.30	10.84	7.14	0.344	0.356
5	٣٦	١٠٠	٧٥	14.80	12.33	5.09	0.485	0.500
6	٣٦	١٥٠	٢٥	15.91	13.25	6.18	0.430	0.426
7	٤٢	٥٠	٧٥	13.18	10.68	7.25	0.344	0.366
8	٤٢	١٠٠	٢٥	12	9.91	5.03	0.415	0.410
9	٤٢	١٥٠	٥٠	12.2	9.97	4.24	0.525	0.503

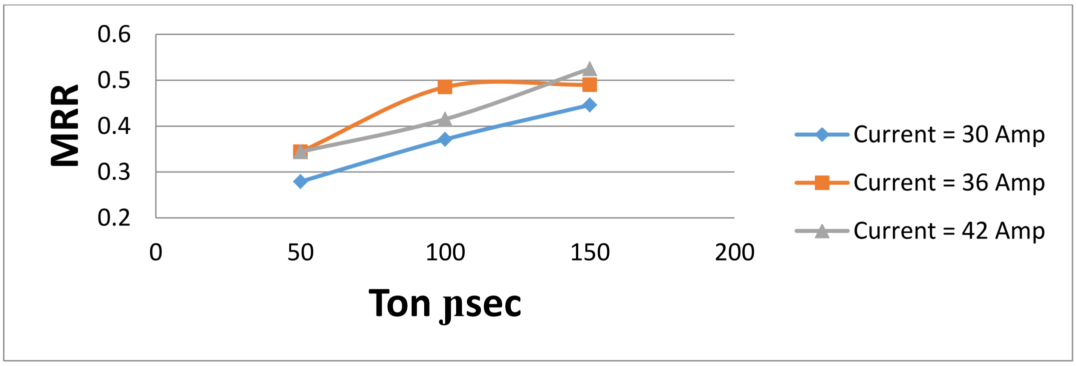

Figure 7: Effect of Pulse on Time and current on the MRR

II-Variance Analysis

The outcomes are utilizing the variance (ANOVA) for determining the effects of cutting variables on the MRR as the output, TON, TOFF and current as input.

The F ratio value of 9.44 the TON is (see Table 8).Therefore, TON (69.73%) which is about four times of the current (14.57%). The TOFF has a small influence with 8.74%. Through analyzing, F- ratio is the mean square error ratio to residual, and its conventionally utilized to compute the importance of factors.

III-Optimal Design Conditions for MRR

The major effecting plots are utilized for calculating the optimum design conditions for giving the optimal MRR and so that the better cutting condition utilizing (SPSS) program. Figure (10) clarify effecting of MRR with inputs process. This figure explains differences for the responding of the (3) variables, i.e. Current, TON and TOFF separatly. The result shows the optimum variables giving the higher material removal rates were: current at level-3(42 Amp), TON at level-3(150 µs), and TOFF at level-2(50 µs).

Table 7: ANOVA for the material removal rate

Source of variance	DOF	SS	V	F ratio	P (%)
Current	2	0.006	0.003	1.714286	14.57
Pulse on time, T_{on}	2	0.0330	0.016535	9.448571	69.73
Pulse off time, T_{off}	2	0.004	0.00208	1.188571	8.74
Error ,e	2	0.003	0.00175		7.3
Total	8	0.0476			100

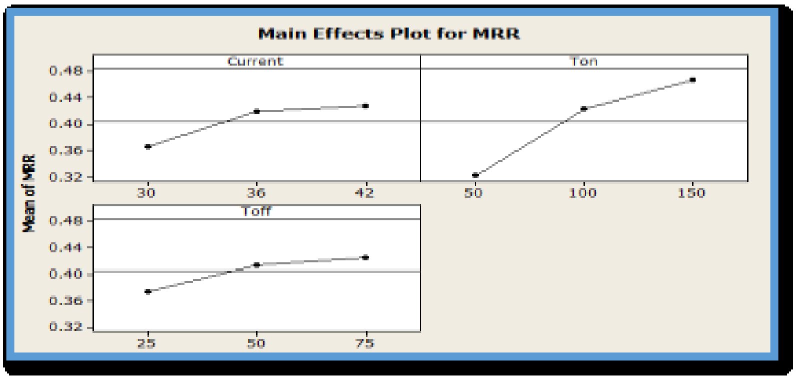

Figure 8: Feed on the MRR

IV-Effect of Pulse on Time and Pulse off Time on the Surface roughness

Figure 9 shows the effect of T_{ON} on Surface roughness while maintaining current constant. From these figures, it can be seen, that the increasing in T_{ON} leads to increasing Surface roughness, and the increasing the current leading to raise the Surface roughness. That because of low rates of melting at high values of current while Toff gives a little influence on Surface roughness as shown Table 8.

Table 8: Experimental work readings Surface roughness

No	Current	Ton	Toff	Surface roughness	
				Ra1	Ra2
1	٣٠	٥٠	٢٥	2.11	2.57
2	٣٠	١٠٠	٥٠	2.98	2.66
3	٣٠	١٥٠	٧٥	3.10	2.99
4	٣٦	٥٠	٥٠	3.12	3.56
5	٣٦	١٠٠	٧٥	3.36	4.1
6	٣٦	١٥٠	٢٥	3.25	3.21
7	٤٢	٥٠	٧٥	4.68	5.10
8	٤٢	١٠٠	٢٥	6.20	6.11
9	٤٢	١٥٠	٥٠	6.32	5.99

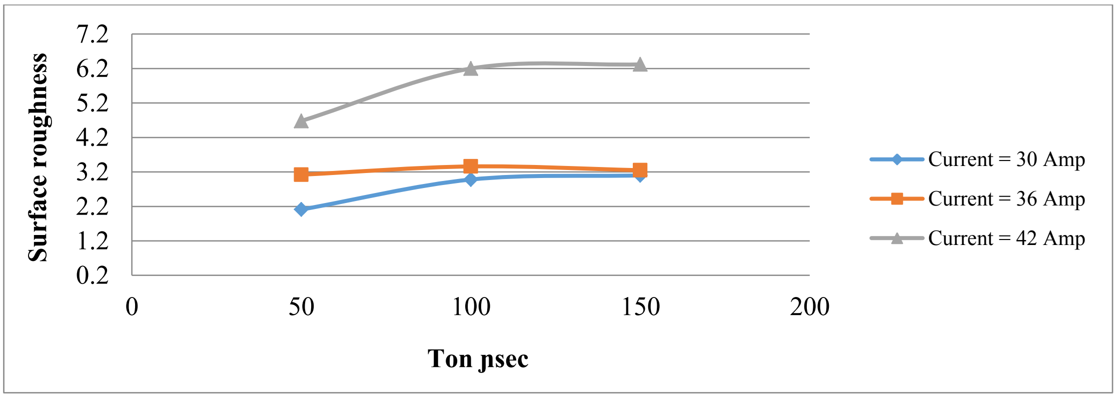

Figure 9: Effect of Pulse on Time and current on the Surface roughness

V-Analysis of Variance

The outcomes are utilizing the variance (ANOVA) for determining the effects of machining variables on the surface roughness as the output, TON, TOFF and current as input.

The F ratio value of 40.322 for the current is greater among the parameters (see Table 9).Therefore, the most influential parameter is Current (87.14%) which is about several times of the TON (9.1%). The TOFF has a less influence with 1.6%. Through analyzing, F- ratio is the mean square error ratio to residual, and its conventionally utilized to compute the importance of factors.

VI-Optimal Design Conditions for Surface roughness

The major effecting plots are utilized for calculating the optimum design conditions for giving the optimal surface roughness and so that the better cutting condition utilizing (SPSS) program. Figure (13) clarify effecting of MRR with inputs process. This figure explains differences for the responding of the (3) variables, i.e. Current, TON and TOFF separately. The results show the optimal conditions for minimum surface roughness were: current at level-1(30 Amp), TON at level-1(50 µs), and TOFF at level-1(25µs).

Table 9: ANOVA of Surface Roughness

Source of variance	DOF	Sum of squares	Variance, V	F ratio	P (%)
Current	2	15.484	7.742	40.322	87.14
Pulse on time, T_{on}	2	1.62	0.81	4.218	9.1
Pulse off time, T_{off}	2	0.28	0.14	0.729	1.6
Error ,e	2	0.384	0.192		2.16
Total	8	17.768			100

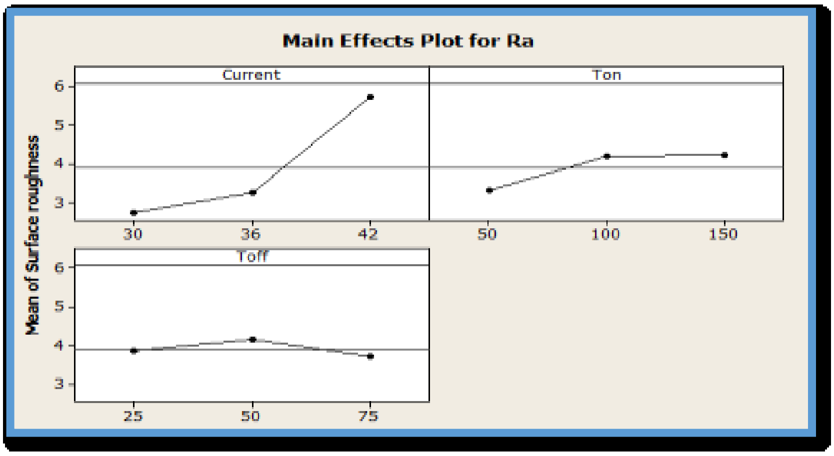

Figure 10: Mean effects plot for Surface roughness

After analyzing the results and making the prediction procedures for the best parameters that gave the best metal removal rate and surface roughness. These variables were as the following:

1- The largest metal removal rate is (0.511) mm^3/min achieved with the values (42 Amp), (150µs), and (50µs) for the current, Ton, and Toff respectively.
2 - The best surface roughness is (2.232) achieved with the values (30 Amp), (50 µs), and 25 µs) for the current, Ton, and Toff respectively.
After that, two samples were run optimal parameters that have been prediction and the results were as follows (0.499) to the metal removal rate (2.211) of the surface roughness.

6. Conclusions

The main conclusions which can be deduced from this work can be summarized as: At low current supplied (30 Amp) we get more accurate machining but max machining time (9min) using copper electrode and workpiece of 5mm thickness, the MRR is less, while this process gives best surface roughness. The error between the predicted and experimental values at the optimum combination of variables characteristics for MRR, and surface roughness lies within 1.1544% and 2.122% respectively. Obviously, this confirms excellent reproducibility of the experimental conclusion.

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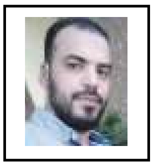

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