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Surface Roughness Prediction for Steel 304 In Edm Using Response Graph Modeling

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Abstract

Electrical Discharge Machining (EDM) is a non-traditional cutting technique for metals removing which is relied upon the basic fact that negligible tool force is produced during the machining process. Also, electrical discharge machining is used in manufacturing very hard materials that are electrically conductive. Regarding the electrical discharge machining procedure, the most significant factor of the cutting parameter is the surface roughness (Ra). Conventional try and error method is time consuming as well as high cost. The purpose of the present research is to develop a mathematical model using response graph modeling (RGM). The impact of various parameters such as (current, pulsation on time and pulsation off time) are studied on the surface roughness in the present research. 27 samples were run by using CNC-EDM machine which used for cutting steel 304 with dielectric solution of gas oil by supplied DC current values (10, 20, and 30A). Voltage of (140V) uses to cut 1.7mm thickness of the steel and use the copper electrode. The result from this work is useful to be implemented in industry to reduce the time and cost of Ra prediction. It is observed from response table and response graph that the applied current and pulse on time have the most influence parameters of surface roughness while pulse off time has less influence parameter on it. The supreme and least surface roughness, which is achieved from all the 27 experiments is (4.02 and 2.12μm), respectively. The qualitative assessment reveals that the surface roughness increases as the applied current and pulse on time increases.

Keywords: *Electrical discharge machining, Graph Modeling, Response, Surface roughness.*

1. Introduction

Electrical discharge machining (EDM) is one of the most commonly used non-conventional machining operations that have been a large assistance to the industrialization and processing engineers to produce complex forms on any - conductive material or alloy. In this process we use thermal energy to machine electrically conductive materials. Likewise non-conductive materials can be succeeding in machined by using EDM technicality [1]. The principle of EDM is simple. The workpiece and tool are put in the working situation of working so it does not touch with each other, they are discrete by a hole that is full of with an insulate fluid. The cutting operations happen in a reservoir. The tool and workpiece are linked to a (DC) provenance through a cable. Material is taken away by overheating. Heat is inserting by the influx of electro among the workpiece and electrode in the shape of a spark. Material is put at dots akin between the electrode and workpiece, where the spark produce and terminated are heated to the point where the material evaporate. The electrode and workpiece are connected to a suitable power supply. The power supply generates an electrical potential between the two parts [2].

Ra (Surface Roughness) is extremely relies on the machining parameters which utilized for EDM of a specific workpiece material. Keeping in mind the end goal of maximizing the manufacturing operation a precise and efficient procedure should be built for the EDM procedure with an input machining parameters like the current, pulsation on Time and pulsation off Time so as the Ra is referred to the outcome variables. Experiments have been achieved in a view of measuring Ra based on response graph modeling (RGM) for three levels as well as three factors with a full factorial technique. After determining the significant coefficients, the final regression model is built for estimating the Ra parameter. Regarding to the regression model, the coefficient regression values clarify the impact of the controlled variables on the process response. The validity of the final regression model is further tested through utilizing the RGM model, which compares the measured and the predicted values.

The literature survey has revealed that several researchers attempted to get the relationships among inner and outer parameters in EDM operation by utilize soft computing technicality A hybrid artificial neural network and genetic algorithm methodology development and application for modeling and optimizing the EDM have been presented in [3]. In this work, the prognostic of the white layer surface roughness and the thickness has been obtained through utilizing adaptive neuro-fuzzy model.

An analysis of the efficient parameters on the material removal rate (MRR), surface roughness and electrode wear in EDM has been presented in [4]. This work evaluates the impact of the current, pulsation on-time and pulsation off-time on surface roughness, material removal rate and electrode wear at the finalizing period The proposed work demonstrates an appropriate second degree regression models for prognosticate surface roughness, material removal rate and electrode wear as well.

A developed surface roughness model for EDM has been proposed in [5]. In this technique, evaluation of different EDM variables likes current, pulsation on-time, and pulsation off-time and arc voltage on roughness value in accordance to the finishing and roughing machine steps through utilizing the genetic algorithm and Genetic Expression Programming (GEP) methods. The outcomes which have been achieved from the proposed work are compared with the roughness parameters that modeled via utilizing the genetic algorithm method with an error less than 10%.

An optimization strategy regarding the best process parameters selection of the EDM has been presented in [6]. The proposed work uses a normal cutting procedure. The cutting method is performed on die-sinking machine under various specifications and circumstances for the process variables. The proposed system model is accomplished by utilizing expansion resistance neural network and experiential data. This system model issued in order to jointly increase the MRR and increase the surface roughness via annealing scheme as well.

The impact of EDM variables on material removal rate (MRR) surface roughness, as well as electrode wear has been evaluated and presented in [7].

The proposed work develops a mathematical model relied on the predicted of surface roughness, MRR and electrode wear through changing the pulse on time, current and pulse voltage. It can be observe that an super fat of pulse on time causes an super fat in the MRR a bit unto it attain a value of 200µs subsequently the material removal rate start to diminishing again. The super fat in pulsation on time means enforce similar heating influx for a long time.

An operating parameters impact of the tungsten carbide on the machining characteristics has been studied in [8]. In particular, surface quality, material removal rate and electrode wear rate has been taken into account of this work. The proposed method is based on the basis of the required parameters likes pulse on time and pulse off time peak current and power supply voltage. This work investigates the surface quality via utilizing pertho-meter machine. In this work, Material removal rate and electrode wear are computed through a mathematical model.

A prediction of die-sinking EDM of aluminum alloy characteristics by using a developed mathematical model has been presented in [9]. In this work, the MRR, tool wear rate, the surface roughness and the hardness have been accomplished by utilizing fuzzy mathematical model. Multi-objective optimizations of EDM of mineral matrix composite use non- control sorting genetic algorithm. In this search, the influence of electrical discharge machining (EDM) on surface roughness and material removal rate (MRR) in metal matrix composite Al/SiC composite was scrupulous. By utilize experiential outcome analysis and mathematical modeling, the connation among four EDM conditions and operation outputs were deliberate. Four scrupulous EDM conditions inclusive pulsation on-time, pulsation peak current, average gap voltage and hundredth volumes fraction of SiC. To find the best conditions, outputs extracted from non-dominated sorting genetic algorithm led in attain convenient models. The optimization results point out proposition method has a high accomplishment in snags solving, were explained in [10].

An influence of input parameters on the EDM process such as pulse on-time and pulse current has been investigated in [11]. The proposed work is focusing on studying the process characteristics including the machining properties accolade material removal rate, tool wear ratio, and mathematical mean roughness. In addition, characteristics of the surface integrity including the thickness of the white layer and the profundity of the impacted heat zone of AISI H13 tool steel as workpiece have been considered in this work. The super fat in pulse on-time leads to the super fat in the material removal rate, surface roughness, likewise the white layer thickness and depth of heat an influenced area

EDM is the machining operation of controlled abrasion of electrically conductive materials by the spark among the tool (cathode) and the workpiece (anode) detached by submerged insulation fluid via the slight gap (close to 0.02 to 0.5) mm, and known as spark-gap. Therefore, the cutting instrument does not touch the workpiece, it is made-up of a soft readily worked material like copper, brass and graphite. The instrument works in a fluid like mineral oil or kerosene that is feed the work beneath pressure. The coolant usefulness as a dielectric, to wash away particles of eroded metal from the workpiece or instrument and to maintain a uniform resistance to current flow. The tank is filled with the dielectric fluid and the workpiece, and the electrode end is immersed an electrode, election relying on the shape of the cut, is positioned on the top of the workpiece leaving a small gap [12].

The aim search is to examine the effectiveness of machining parameters of EDM on surface roughness cutting of 304 SS workpiece using, copper electrode and gas oil dielectric solution, using DC current and low voltage (140V) to cut (1.7mm) thickness. The second orders develop a mathematical model using response graph modeling (RGM) on the basis of experimental results.

2. Experimental Work

The empirical test is accomplished by using a CHEMER EDM machine type (CM 323C), which is situated at the Machine Tool Laboratory in the University of Technology, as showed in Fig. 1. In this work, workpiece dimensions (40×30×1.7 mm) with a stainless steel (SS) 304, ASTM A 240 has been utilized. The chemical composition percentages of SS 304 a workpieces material was evaluated in the laboratories of (The State Company for Inspection and Engineering Rehabilitation) are illustrated in Table 1. Furthermore, the mechanical and physical properties of the SS 304 are portrayed in Table 2.A proper tool of copper with 99.74% Cu purity and diameter 5 mm has been used with a gas oil dielectric solutions well.

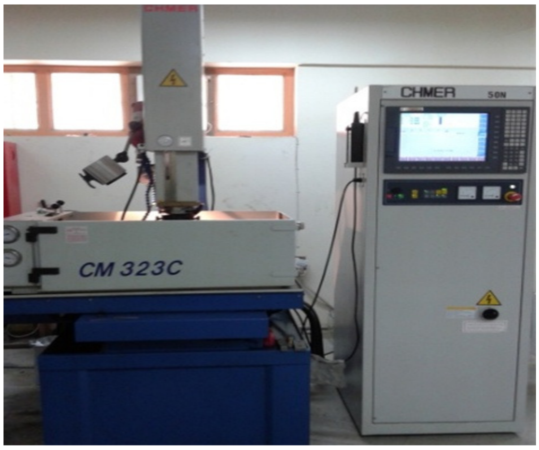


Fig. 1. EDM too model (CM 323C).

Table 1,
alchemical installation characteristics of SS 304 workpieces.

Material	%C	%Si	%Mn	%P	%S	%V	%Cr	%Mo	%Ni	%Fe
Used SS 304	0.055	0.58	1.08	0.03	0.02	0.142	19.4	0.24	8.95	equipoise
Standard SS 304 [13]	0.08 max.	0.75 max.	2.00 max.	0.045 max.	0.030 max.	-	18.00-20.00	-	8.00-12.00	equipoise

Table 2,
The mechanistic and physical characteristics of the SS 304 [14].

Hardness (Brinell)	170
Elongation (Percent in 50mm)	60
Tensile Strength (MPa)	600
Density (g/cm^3)	8.03
Melting Point (°C)	1400-1450

Experiments were done on EDM machine attached with a dielectric solution. The fundamental machining parameters for EDM shown in Schedule 3, which typical concatenation of machining regimes be used for the finishing phase of a non-conventional EDM second electrode operation.

Current, pulse on and pulse off time are considered to be the main variable of the machining process. The current discharge is specified within the ranges of 10, 20 and 30A.While the selection of the pulse on time and pulse off time round the ranges of 50, 60 and 70µs and 35, 45 and 55µs respectively, according to EDM machine᾽s parameters. However, the other parameters related to the electric impulse are held to be constant. In accordance to the manufactures specifications, the open gap voltage is indicated as 140V and the negative tool electrode polarity.

Table 3,
Machining characteristics for experiential work.

Working characteristics	**characterization**
Workpiece	SS 304 (40×30×1.7 mm)
instrument -electrode material	copper (5mm diameter)
instrument -electrode polarity	Negative (-)
Workpiece polarity	Positive (+)
Dielectric	Gas oil
Dielectric temperature	40-80°C
Inner voltage	380V (three phase) AC
Outer voltage	140V (two phase) DC
Current	20-30A

In light of view of the experiment implementation, a specimen's dimensions of (40×30×1.7 mm) are displayed of the EDM process under different cutting circumstances. According to equation (1), a27 numbers of cutting experiments have been performed based on three levels as well as three parameters (3^3). A full factorial design has been accomplished in order to obtain the surface roughness measurements. Current, Pulse on time (T_{ON}) and Pulse off time (T_{OFF}) are the main factors that considered in the experiment implementation. Finally, the investigated response is indicated by the surface roughness (Ra). Schedule 4. Illustrate the levels of the cutting parameters.

$$S_n = \ell^k = 3^3 = 27 \text{ experiments} \quad \ldots (2)$$

Where S_n = number of experiments, ℓ=number of levels, k = number of parameters.

Basically, an economical priced specified by Pocket-sized device is used to measure the surface roughness (Ra). In fact, a portable instrument can be used in the Production Engineering Department as well as Metallurgy laboratory due to its traceable performance of the surface roughness measurements with respect of a wide range of surfaces. The average surface roughness value is the average of three reading. Fig. 2. Depicts the implemented Surface roughness measuring device.

Table 4,
he levels of cutting parameters.

No	**Parameter**	**Unit**	**Levels Original**			**Coded**		
1	**Current (X_1)**	Amp	10	20	30	-1	0	1
2	**Pulse on time (X_2)**	μsec	50	60	70	-1	0	1
3	**Pulse off time(X_3)**	μsec	35	45	55	-1	0	1

Fig. 2. Surface roughness measuring device.

3. Results and Dissections

Regarding the experimental results which are portrayed in Table 5, the proposed (EDM) technique has been accomplished in order to develop the response graph modeling for predicting the surface roughness.

Table 5,
The experimental results for surface roughness.

Expt. No.	X_1	X_2	X_3	Current (Amp)	pulsation on time (μsec)	pulsation off time (μsec)	Average Surface roughness (μm)
1	-1	-1	-1	10	50	35	2.19
2	-1	-1	0	10	50	45	2.14
3	-1	-1	1	10	50	55	2.12
4	-1	0	-1	10	60	35	2.26
5	-1	0	0	10	60	45	2.25
6	-1	0	1	10	60	55	2.23
7	-1	1	-1	10	70	35	2.31
8	-1	1	0	10	70	45	2.29
9	-1	1	1	10	70	55	2.27
10	0	-1	-1	20	50	35	2.51
11	0	-1	0	20	50	45	2.49
12	0	-1	1	20	50	55	2.43
13	0	0	-1	20	60	35	2.62
14	0	0	0	20	60	45	2.56
15	0	0	1	20	60	55	2.52
16	0	1	-1	20	70	35	2.83
17	0	1	0	20	70	45	2.75
18	0	1	1	20	70	55	2.71
19	1	-1	-1	30	50	35	3.52
20	1	-1	0	30	50	45	3.49
21	1	-1	1	30	50	55	3.41
22	1	0	-1	30	60	35	3.87
23	1	0	0	30	60	45	3.81
24	1	0	1	30	60	55	3.73
25	1	1	-1	30	70	35	4.02
26	1	1	0	30	70	45	3.98
27	1	1	1	30	70	55	3.93

4. Response Graph Modeling
4.1 Response Table and Response Graph

According to the experiential results above, the impact of each factor on a response variable is indicated with respect to the factor state changing from low high level passing through its medium level. The parameters impact on surface roughness has been figured out through utilizing a complete response table according to a three levels, 27 runs full factorial design as illustrated in Table 6. The impact of each factor related to the response variable can be summarized as follow:

- If the factor impact is larger than zero then the intermediate response is high for higher level as compared with this factor at low level.
- If the factor impact is less than zero then the average response is high at low level as compared with this factor at high level.
- If factor impact is very small, then it's probably due to the random variation than a real factor impact.

The conjunction between the response graphs with the response which obtained from the table have been accomplished in order to identify a proper setting for EDM parameters as well as to minimize the average surface roughness. The impact of single factor and interaction factors are derived from the implemented response schedule which enable to evaluated by ($\ell_H - \ell_L$) so ℓ_H is the top level and ℓ_L is the least level with regard to factor and their interactions. The estimated effect graph is a fruitful tool to analyze the effect of the process variable which uses the absolute effect. The plot of the estimated effects of three control factors and their interactions for surface roughness as shown in Fig. 3. In accordance to the predestined impact graph for the surface roughness, the current (X_1) has the greatest effect on the measured surface roughness followed by pulse on time (X_2) (rank=2) and the pulse off time (X_3) has the lowest effect of the surface roughness. It will be pointed out that the statistical significance of the factor is straight linked to the length of the perpendicular line. Consequently, the dual action between the current and pulse on time (X_1X_2), and the dual action between the current and pulse off time (X_1X_3) have the greatest effect on surface roughness. The dual action between the pulsation on time and pulsation off time has the negligible effect of surface roughness.

4.2 Analysis of Disproportion for Surface Roughness

The experiential results were construing using analyses of disproportion (ANOVA), for characterize the factors that affecting on the surface roughness. The results of the ANOVA with the surface roughness are given in Table 7. The test was accomplished for a significance level of α=0.05, i.e. for a dependability level of 95%. The P-value less than 0.05 are considered to have a statistically significant. The exporter of disproportion is considered significant if it emphasize the status in equation 1:

$$F \geq F_{T\,(\alpha,\, v1,\, v2)} \quad \text{... (2)}$$

Where F is the calculated F-ratio of a given exporter of distinction as clarify in Table 6, and F_T is the tabulated F-ratio, α is the level of significance utilized in the test (α = 0.05), v_1 is the degree of freedom of a given exporter (v_1 =2) and v_2 is the degrees of freedom fault (v_2 = 8).

The tabulated F_T ratio for whole factors and dual action that determined on 5% level of significant and degree of freedom is {F_T (0.05, 2, 8) = 4.494}.

From these results it is clear that the applied current significantly affecting the surface roughness, which is highest among the contributions of the other parameters followed by pulse on time significantly affecting the surface roughness and the third order significant parameters the dual action between the current and pulse on time (X_1X_2). The last affected factor of the surface roughness was the pulse off time, as shown in Fig. 7.

Table 6,
Response table for mean surface roughness EDM machining.

No.	Ra μm	Odd action									Dual action								
		X_1			X_2			X_3			X_1X_2			X_1X_3			X_2X_3		
		-1	0	1	-1	0	1	-1	0	1	-1	0	1	-1	0	1	-1	0	1
1	2.19	2.19			2.19			2.19					2.19			2.19			2.19
2	2.14	2.14			2.14				2.14				2.14		2.14			2.14	
3	2.12	2.12			2.12					2.12			2.12	2.12			2.12		
4	2.26	2.26				2.26		2.26				2.26				2.26		2.26	
5	2.25	2.25				2.25			2.25			2.25			2.25			2.25	
6	2.23	2.23				2.23				2.23		2.23		2.23				2.23	
7	2.31	2.31					2.31	2.31			2.31					2.31	2.31		
8	2.29	2.29					2.29		2.29		2.29				2.29			2.29	
9	2.27	2.27					2.27			2.27	2.27			2.27					2.27
10	2.51		2.51		2.51			2.51				2.51			2.51				2.51
11	2.49		2.49		2.49				2.49			2.49			2.49			2.49	
12	2.43		2.43		2.43					2.43		2.43			2.43		2.43		
13	2.62		2.62			2.62		2.62				2.62			2.62			2.62	
14	2.56		2.56			2.56			2.56			2.56			2.56			2.56	
15	2.52		2.52			2.52				2.52		2.52			2.52			2.52	
16	2.83		2.83				2.83	2.83				2.83			2.83		2.83		
17	2.75		2.75				2.75		2.75			2.75			2.75			2.75	
18	2.71		2.71				2.71			2.71		2.71			2.71				2.71
19	3.52			3.52	3.52			3.52			3.52			3.52					3.52
20	3.49			3.49	3.49				3.49		3.49				3.49			3.49	
21	3.41			3.41	3.41					3.41	3.41					3.41	3.41		
22	3.87			3.87		3.87		3.87				3.87		3.87				3.87	
23	3.81			3.81		3.81			3.81			3.81			3.81			3.81	
24	3.73			3.73		3.73				3.73		3.73				3.73		3.73	
25	4.02			4.02			4.02	4.02					4.02	4.02			4.02		
26	3.98			3.98			3.98		3.98				3.98		3.98			3.98	
27	3.93			3.93			3.93			3.93			3.93			3.93			3.93
Total	77.24	20.1	23.4	33.8	24.3	25.8	27.1	26.1	25.7	25.4	17.3	41.6	18.4	18.0	41	17.8	17.1	43.0	17.1
Value	27	9	9	9	9	9	9	9	9	9	6	15	6	6	15	6	6	15	6
Avg.	2.86	2.23	2.60	3.75	2.7	2.87	3.01	2.90	2.86	2.82	2.88	2.77	3.06	3.01	2.76	2.97	2.85	2.87	2.86
Effect		1.52			0.31			0.08			0.29			0.25			0.02		

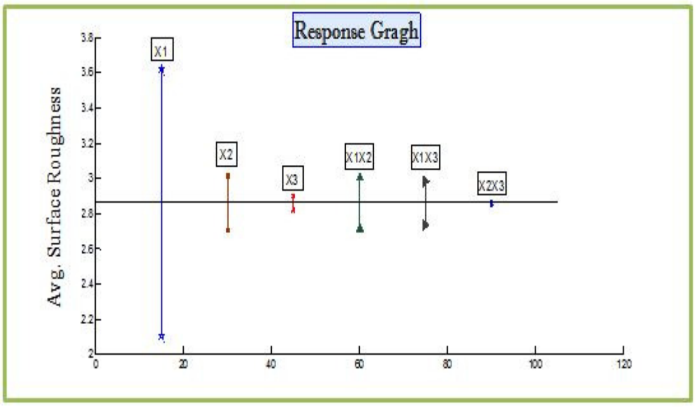


Fig. 3. The response graph of surface roughness.

Table 7,
Analysis of Variance for surface roughness.

Source	Sum Sq.	DOF	Mean Sq.	F	Prob>F
X_1	11.3295	2	5.66473	21849.66*	0*
X_2	0.4342	2	0.21711	837.44*	0*
X_3	0.0338	2	0.01691	65.24*	0*
X_1X_2	0.1178	4	0.02946	113.63*	0*
X_1X_3	0.0041	4	0.00103	3.96	0.0465
X_2X_3	0.0003	4	0.00006	0.25	0.9018
Error	0.0021	8	0.00026		
Total	11.9218	26			

$F_{T(0.05, 2, 8)}$ = 4.494 for odd and dual action parameters.

4.3 Interaction Effect Plot (IEP) for Surface Roughness

Influence happen when one factor does not make the same effect on the response at different levels of another factor. Therefore, if the direction of effect of two factors is equivalent there is no influence between them. On the contrary, when the direction of effect is a far from being parallel, the two factors are in interaction relation. The interaction effects of X_1X_2 seem to be significant to the surface roughness as concluded from ANOVA table. Table 8 and Fig.4represent the calculations interaction effect plot of the factors on surface roughness. From Fig.4, it is obviously noted that the current (X_1) and pulsation on time (X_2) have a significant interaction effect on surface roughness.

Fig. 5 showed the interaction effects plot for all factors on surface roughness.

Table 8,
Calculation for current (X_1) pulse on time (X_2) interaction.

		X_2	
		-1	1
X_1	-1	2.19	2.31
		2.14	2.29
		2.12	2.27
		2.15	2.29
	1	3.52	4.02
		3.49	3.98
		3.41	3.93
		3.47	3.98
	average	2.97	

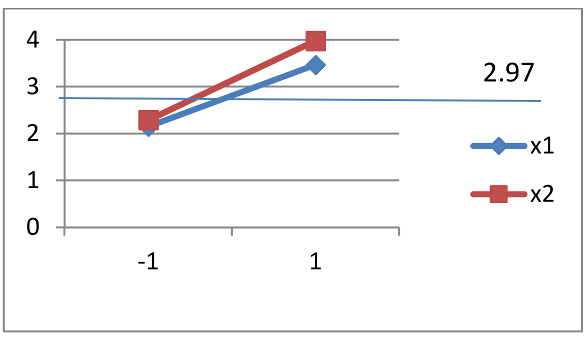


Fig. 4. Interaction effects plot for pair important factors on surface roughness.

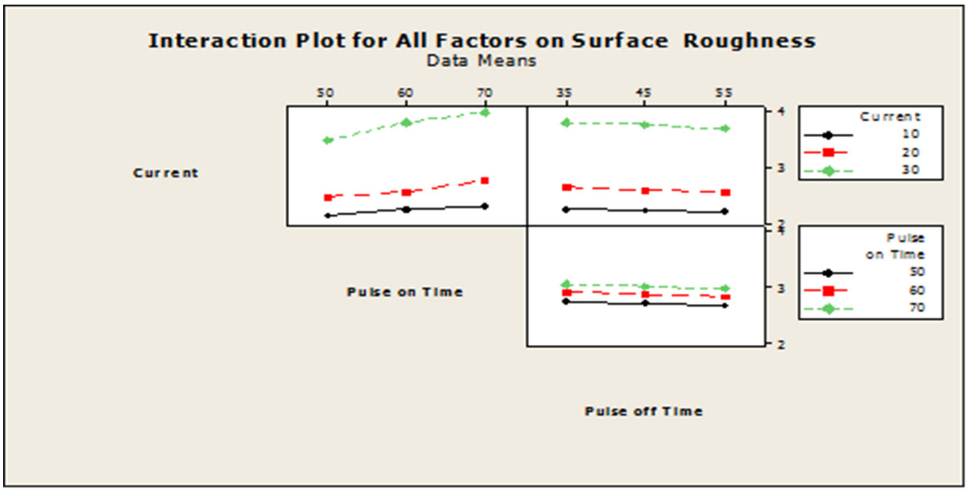
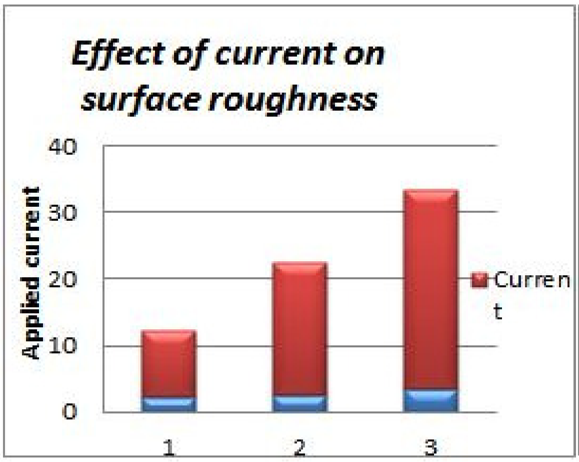
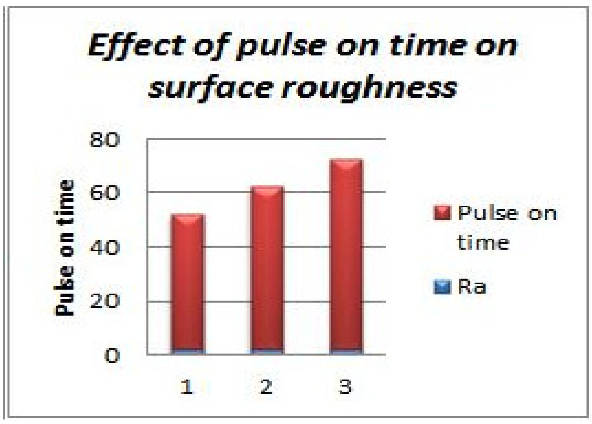


Fig. 5. Interaction plot for all factors on surface roughness.

The effects of current, pulsation on time and pulsation off time on surface roughness, as shown in Fig. 6, whereby observed the increases current and pulse on time leads to increase surface roughness while the increase pulse off time lead to decrease the surface roughness





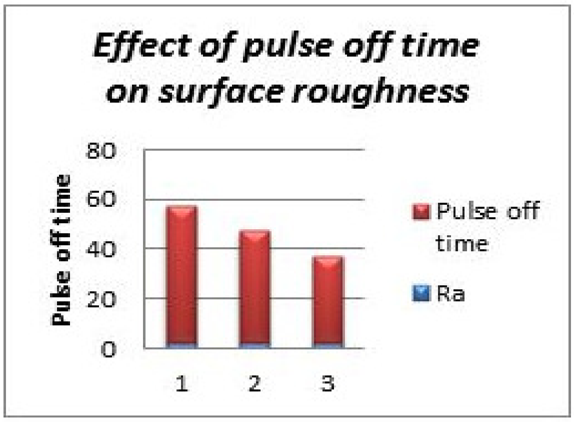


Fig. 6. Effect of surface roughness on current, pulsation on time and pulsation off time.

5. Conclusions

This search show that the effectiveness of several EDM parameters (current, pulsation on time and pulsation off time) on surface roughness for application of copper electrode to labor steel 304 has been scrupulous The surface roughness could be effectively by using current, pulse on time and pulse off time, and were the values in this work are about (2.12-4.02µm).

The ANOVA results show that the applied current and pulse on time are the most important factors affecting the surface roughness. It was observed that the augmentation in applied current and pulse on time cause a proportionate augmentation in the surface roughness and the applied current has large effective parameters on this response.

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التنبؤ بالخشونة السطحية للصلب ٣٠٤ بواسطة التشغيل بالشرارة الكهربائية بأستخدام استجابة رسم النماذج

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الخلاصة

عملية التشغيل بالشرارة الكهربائية هي عملية قطع غير تقليدية لإزالة المعادن استناداً إلى حقيقة أساسية هي أن قوة العدة التي تولد اثناء عملية التشغيل تهمل. أيضا، التشغيل بالشرارة الكهربائية يستخدم في تصنيع المواد الصلبة جداً التي تكون موصلة كهربائياً مضيعة للوقت وكذلك التكلفة العالية. البحث الحالي يهدف الى تطوير نموذج رياضي باستخدام نموذج مخطط الاستجابة.تأثير العوامل المختلفة (تيار، زيادة زمن النبضة وتقليل زمن النبضة) درست على الخشونة السطحية في هذا البحث.تم تشغيل ٢٧ عينة باستخدام ماكنة مبرمجة رقمية للتشغيل بالشرارة الكهربائية التي تستخدم لقطع فولاذ ٣٠٤ بمحلول عازل لزيت الغاز بتسليط تيار مستمر (١٠، ٢٠ و ٣٠). فولتية (١٤٠ فولت) استخدمت لقطع سمك ١,٧ ملم من الفولاذ واستخدمت قطباً من النحاس. النتيجة من هذا العمل مفيدة لتطبيقها في الصناعة لتقليل الزمن والكلفة في التنباء بالخشونة السطحية. يلاحظ من جدول الاستجابة ومخطط الاستجابة ان التيار المسلط وزمن استمرار النبضة اكثر العوامل المؤثرة على الخشونة السطحية حيث ان زمن توقف النبضة له تاثير اقل عليها. اعظم واقل خشونة سطحية والتي تحققت في ٢٧ تجربة هي (٤,٠٢ -٢,١٢ مايكرون) على التوالي. وان التقديرات النوعية تشير الى ان الخشونة السطحية تزداد بزيادة التيار المسلط وزيادة زمن استمرار النبضة.