Al-Khwarizmi Engineering Journal,Vol. 11, No. 3, P.P. 20-36 (2015)

Al-Khwarizmi Engineering Journal

Studying and Modeling the Effect of Graphite Powder Mixing Electrical Discharge Machining on the Main Process Characteristics

Ahmed N. Al-Khazraji* **Samir A. Amin **** **Saad M. Ali *****

**, ** Department of Mechanical Engineering / University of Technology*

**** Department of Mechanical Engineering / University of Karbala*

*Email: dr_ahmed53 @yahoo.com

**Email: alrabiee2002@yahoo.com

***Email: smaengg@yahoo.com

(Received 1 February 2015 ; accepted 11 May 2015)

Abstract

This paper concerned with study the effect of a graphite micro powder mixed in the kerosene dielectric fluid during powder mixing electric discharge machining (PMEDM) of high carbon high chromium AISI D2 steel. The type of electrode (copper and graphite), the pulse current and the pulse-on time and mixing powder in kerosene dielectric fluid are taken as the process main input parameters. The material removal rate MRR, the tool wear ratio TWR and the work piece surface roughness (SR) are taken as output parameters to measure the process performance. The experiments are planned using response surface methodology (RSM) design procedure. Empirical models are developed for MRR, TWR and SR, using the analysis of variance (ANOVA).The best results for the productivity of the process (MRR) obtained when using the graphite electrodes, the pulse current (22 A), the pulse on duration (120 µs) and using the graphite powder mixing in kerosene dielectric reaches (82.84mm³/min). The result gives an improvement in material removal rate of (274%) with respect to the corresponding value obtained when copper electrodes with kerosene dielectric alone. The best results for the tool wear ratio (TWR) of the process obtained when using the copper electrodes, the pulse current (8 A), the pulse on duration (120 µs) and using the kerosene dielectric alone reaches (0.31 %). The use of graphite electrodes, the kerosene dielectric with 5g/l graphite powder mixing, the pulse current (8 A), the pulse on duration (40 µs) give the best surface roughness of a value (2.77 µm).This result yields an improvement in SR by (141%) with respect to the corresponding value obtained when using copper electrodes and the kerosene dielectric alone with the same other parameters and machining conditions.

Keywords: *EDM, RSM, MRR, TWR, SR, AISI D2die steel, graphite powder mixing.*

1. Introduction

EDM process is useful for the machining of high-value components, such as mould tools and dies as well as aerospace engine components. The process is particularly advantageous when compared to conventional mechanical cutting operations, since strength and toughness of the work piece are not factors in its machinability, and instead the thermal and electrical properties determine the ability for a material to be cut [1,2]. EDM is known to significantly affect the surface of cut materials compared to many other manufacturing processes, such as milling, grinding or electrochemical machining, and the reduced potential fatigue life of EDM components [3].

AISI D2 cold work tool steels of series D, also known as die steels, is one of the most popular high-chromium and high-carbon steels and it is characterized by its high compressive strength and wear resistance, good through-hardening properties, high stability in hardening and good resistance to tempering-back. AISI D2is a high alloy steels Fe-Cr-C-base. This alloy has the ability to preserve its desirable mechanical properties intact upon cycling over a range of temperatures, which can be an advantage for applications including, piercing and blanking dies, punches, shear blades, spinning tools, slitting cutters, as well as variety of higher-end wood working tools [4]

EDM process is very demanding but the mechanism of process is complex and far from completely understood. Therefore, it is hard to establish a model that can accurately predict the response (productivity, surface quality etc.) by correlating the process parameter, though several attempts have been made [5]. Since it is a very costly process, optimal setting of the process parameters are up most important to reduce the machining time to enhance the productivity [6]. Improving the MRR and surface quality are still challenging problems that restrict the expanded application of the technology [7].

Among several attempts, RSM was employed by N. S. Khundrakpam et al [8], have been used a Central Composite Design (CCD) for combination of variables and Response Surface Method (RSM) to explore the influence of process parameters, such as peak current, powder concentration and tool diameter on the Material Removal Rate (MRR) on EN-8 steel. Analysis of Variance (ANOVA) was performed to obtain the significant coefficients. Pradhan and Biswas [9], investigated the influence of processing variables on the responses MRR and SR. Ranganathan and Senthivelan [10], used powder mixing for optimization of SR, TWR and MRR. Pradhan and Biswas [11], have established empirical models variables with MRR and SR. J. Lin and C. Lin [12], optimized the machining parameters with responses MRR, SR, and electrode wear ratio using of orthogonal array. Singh et al. [13], optimized MRR, TWR, SR on EDM. Reddy and Rao [14], obtained the optimal levels of process in drilling of aluminum 6061 alloy using design of experiments based grey relational analysis. Saurav and Sankar [15], studied the effect of parametric influence of wire EDM on MRR, SR and width of cut to establish mathematical models and simulation. B. Reddy et al. [16], studied the effect of fine metal powders, such as aluminum and copper are mixed to the dielectric fluid, during Electric Discharge Machining (EDM) of AISI D3 Steel and EN-31 steel. Material removal rate and Surface Roughness are taken as output parameters to measure the process performance. The obtained outcomes of experiments indicated that the addition of metal powders in dielectric fluid increases the material removal rate and improves the surface quality.

This paper attempted to study the effect of graphite powder mixed to the dielectric fluid with other input parameters like, peak current and pulse on time, during Electric Discharge Machining (EDM) of AISI D2die steel. Material removal rate, electrodes wear rates and surfaces roughnesses are taken as output parameters to measure the EDM and PMEDM process performance. This paper is also attempted to develop models for SR, MRR and TWR by using the response surface methodology (RSM) technique. Two sets of experiments are designed for performing the experiments in pure kerosene dielectric for the first set, while the second is the addition of abrasives graphite powders mixed with dielectric fluid in order to improve the process productivity, efficiency and the workpiece surface quality.

2. Experimental Work

The selected AISI D2 die steel workpiece material, was tested firstly for chemical composition examination. Three samples were tested by using the AMETEXSPECTRO MAX material analyzer. The results with the equivalent values according to ASTM A 681-76 standard specification for alloy and die steels [17] are listed in table (1).

Four specimens were prepared for tensile tests on the bases on ASTM-77 steel standards for flatwork piece [18]. The same specimens were tested for Rockwell hardness tests. The tests results are given in table (2).

Two types of electrodes materials, copper and graphite were selected. The electrodes were manufactured with a square cross-section of 24 mm and 30 mm lengths, with a quantity of 24 pieces for each type, as shown in figure (1).

The main designed EDM parameters are the gap voltage Vp (140 V), the pulse current Ip (8 and 22 A), the pulse on time duration period time Ton (40 and 120 µs), the pulse off time duration period Toff (14 and 40 µs), the graphite powder concentration (0 and 5g/l), the kerosene dielectric adjusted from both sides of the w/p with a flashing pressure = 0.73 bar (10.3 PSI) and the electrode polarity (+). The EDM experiments were done on ACRACNC-EB EDM machine with all the manufactured attachments shown in figure (2). A stainless steel container (of about 30 liters volume and dimensions 400 mm hight, 300mm length, 230 mm width and plate thickness 3 mm) was manufactured. It contains of a special kerosene dielectric pump, an electric motor (300 RPM) connected to a mixture contains a stainless steel impellers, a workpiece clamping fixture, valves and pipe accessories. For the power supply, an

AC/DC converter for driving the special kerosene pump was attached in an electrical board. This board contains also a pressure gauge (one bar capacity), wiring, switches and piping accessories. The manufacturing of the stainless steel container were completed by using the TIG argon inert gas welding process, as shown in figure (2).

The graphite powders substances were tested for chemical compositions by using the X-Ray diffraction apparatus, and then the powder was tested to measure its grains sizes using the laser diffraction particle size analyzer. The average grain size is (44,866 µm) for graphite powder as given in the test certificates. The surface roughness for each work piece and electrode (copper and graphite) were measured before and after EDM and PMEDM machining by using the portable surface roughness tester. All the w/p specimens and electrodes are weighed before and after EDM machining too by using the electronic weighting balance with accuracy of (0.0001g).

Fig. 1. The copper and graphite electrodes and workpieces PMEDM processes.

Fig. 2. The (CNC) EDM machine with all the manufactured accessories designed for the implementation the PMEDM experiments.

Table 1,
The chemical compositions for the selected workpiece material and the equivalent given by the standard for AISI D2die steel.

SAMPLE	C%	Si %	Mn %	P %	S %	Cr %	Mo%	Ni %	Co %	Cu%	V %	Fe%
Tested samples	1.51	0.174	0.264	0.014	0.003	12.71	0.555	0.158	0.0137	0.099	0.306	Bal.
Standard AISI D2 [17]	1.40 to 1.60	0.60 max.	0.60 max.	0.03 max.	0.03 max.	11.00 to 13.00	0.70 to 1.20	-	1.00 Max.	-	1.10 Max.	Bal.

Table 2,
The mechanical properties for the selected materials.

	Ultimate Tensile stress (N/mm^2)	Yield strength (N/mm^2)	Elongation (%)	Hardness (HRB)
Average	704.25	415.25	18.125	90.25

3. Results and Discussions

3.1 Modeling of Material Removal Rate (MRR) Using Copper and Graphite Electrodes

In this paper, to study the performance characteristics of the process , two groups of experiments are designed using the kerosene dielectric alone or with graphite powder mixing, each contains (22) experiments for comparing the results produced by EDM and PMEDM machining. Each group was divided in two subgroups. The first subgroup used the copper electrodes, while the graphite electrodes were used in the second subgroup. A new set of w/p and electrode was using in each experiment. The surface roughness (SR), the material removal rate (MRR) and the tool wear ratio (TWR), which are experimentally measured and calculated after EDM and PMEDM machining with the input parameters are modeled by using the response surface methodology (RSM) and the two level factorial (2^3) design for both experimental groups. The input EDM parameters and their levels are given in table (3), while the output process responses are given in table (4).

The designed EDM experimental matrix in a random manner with the selected actual factors and the experimental response results for the both groups using the kerosene dielectric or the kerosene dielectric with graphite powder mixing with copper and graphite electrodes are collected in one matrix as given in table (5). The two level factors (2^3) full factorial design (FFD) was used to set the necessary number of experiments to fit the model. The ANOVA technique was used to analyze the significance of EDM process parameters, where the F-test ratio is calculated for a 95% level of confidence. The ANOVA functions then run in order to assess the results for the material removal rate (MRR) response which are given in table (6) using the two levels and three factor for backward Partial sum of squares transform model for lower the p-value. The Model F-value of 107.11implies the model is significant. Values of "Prob> F" less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, BC, BD, CD are significant model terms.

The predicted final empirical equation is:

Material removal rate (MMR) = + 1.88640- 4.63234 * A + 0.66256 * B - 0.12830* C - 12.03147*D + 0.49159*A*B + 0.018299* B*C+0.79800*B*D+0.078758*C*D …(1)

The three dimensional (3D) graphs given in figures (3-6) are used to interpret and evaluate the model for the experimental groups. These figures show the influence of the EDM and PMEDM parameters on the material removal rate. All figures indicated that material removal rate is increasing with increasing the pulse current (up to 22 A) and the pulse on duration (up to120 µs). Figure (3) and table (5) indicated that when using these levels of parameters with the copper electrodes, MRR reaches theoretically (28.2177 mm^3/min), and experimentally (30.2452 mm^3/min). When using the graphite powder mixing in kerosene dielectric, MRR reaches the value (58.1689 mm^3/min), as shown in figure (5) and the experimental value is (58.0063 mm^3/min). This means that the process removal rate increase by (206 %) when using the graphite powder compared with when using the kerosene dielectric alone. The same results obtained when working with graphite electrodes and kerosene dielectric alone, where the maximum productivity of the process obtained reaches a value (40.5832 mm^3/min) as shown in figure (4), whereas the experimental value is (37.4865 mm^3/min). The predicted MRR reaches a value of (70.5344 mm^3/min) with the same previous parameters and using the graphite powder mixing in kerosene dielectric as shown in figure (6) and the experimental value is (82.8404 mm^3/min), i.e., the predicted MRR process improved by (174 %) and experimentally by (221 %). The total predicted improvement of the MRR process is (250 %); experimentally by (274 %) with respect to using the graphite electrode with graphite powder mixing and compared with the case when using the copper electrodes and the kerosene dielectric alone.

This means that productivity increases with the pulse current and pulse on duration time, especially when using the graphite electrodes and graphite powder mixing. The amount of thermal energy generated would be great and it is working to increase the melting and abrasive processing to remove successive more layers of workpiece surface. This energy will increase with increasing the pulse current period, especially when using the graphite powder mixed in kerosene dielectric, which owns high level of hardness and abrasiveness and working to increase the removal property of the process. The high thermal conductivity of the graphite electrode and the graphite powder also works to increase the amount of thermal energy transformed to the workpiece surface, thereby improving removal and productivity efficiency. The high electrical conductivity of the graphite powder is working to increase the electrical conductivity of the kerosene dielectric and this will improve the discharge characteristics of the process by increase and intensify the arrangement and intensity of discharge energy bands consequently improved the material removal rates.

3.1.1. Numerical Optimization of Material Removal Rate Results

For optimization and to development of the predicted model with the best EDM and PMEDM parameters, a set of new goals for the MRR response will be conducted to generate the optimal combination conditions for these parameters. The new objective function named the desirability will allow evaluating the goals by a proper combining.

The main goals are to maximize the values of response with the same ranges of the selected EDM parameters and electrodes types as mentioned in table (7). The best three solutions found from the desirability process shows that the optimum predicted values of the MRR obtained when using the graphite electrodes with pulse current about (22 A), pulse of duration about (120 µs) and using the graphite mixed powder gives the best maximum predicted MRR of (70.534mm³/min) with a maximum desirability ratio (0.839) as shown in table (8). The desirability process shows that the best predicting response values are approximately the same with the obtained values by experiments as indicated in table (5), experiments number (28) and (35) with the same input parameters where the experimentally values of MRR obtained are (82.8404) and (74.1234) mm³/min respectively and this confirmation the theoretical results of the present work.

Table 3,
The input EDM parameters and their levels for both groups.

Fac.	Name	Units	Min.	Max.	Coded Values		Levels
A	Pulse current (Ip)	(A)	8	22	-1	+1	2
B	Pulse on duration (Ton)	(µs)	40	120	-1	+1	2
C	Graphite powder mixed in kerosene dielectric	g/l	0	5	-1	+1	2

Table 4,
The EDM process responses, MRR, TWR and SR.

Response	Name	Units	Minimum	Maximum	Trans	Model
R1	Material removal rate(MMR)	mm³/min	6.1696	82.8404	None	R2FI
R2	Tool wear ratio(EWR)	%	0.4168	12.8845	None	R3FI
R3	Surface roughness (SR)	µm	2.77	6.32	Inverse	R3FI

Table 5,
The designed experimental matrix for Group (1) using copper electrodes.

		Input factors(Actual)				Responses		
		X1	X2	X3	X4			
Block No.	Run No.	A: type of electrode	B: Pulse current (Ip) (A)	C: Pulse on duration (Ton) (μs)	D:Graphite powder mixed in kerosene dielectric (g/l)	Material removal rate (MMR) (mm^3/min)	Tool wear ratio (EWR) (%)	Surface roughness (SR) (μm)
1	1	Copper	22	120	0	26.7538	1.898	5.65
1	2	Graphite	8	40	5	7.9017	12.8845	2.78
1	3	Graphite	8	120	0	7.2612	3.0141	4.75
1	4	Graphite	22	120	0	35.6832	1.5401	5.31
1	5	Graphite	8	120	5	7.4974	11.3743	5.36
1	6	Graphite	22	40	5	37.1668	4.9357	4.63
1	7	Graphite	8	40	0	8.5929	7.0756	2.87
1	8	Copper	8	120	0	9.3969	0.4168	3.91
1	9	Copper	8	40	5	9.4955	4.396	3.77
1	10	Graphite	22	120	5	74.062	1.7828	6.28
1	11	Copper	22	40	5	29.5841	5.0271	5.24
1	12	Copper	22	40	0	15.9392	6.0467	4.84
1	13	Copper	8	120	5	14.2975	1.582	4.88
1	14	Copper	22	120	5	55.0778	1.6091	6.19
1	15	Copper	8	40	0	6.2369	3.1489	4.05
2	16	Copper	22	40	0	15.8625	5.9988	4.85
2	17	Graphite	22	120	0	37.4865	1.0934	6.26
2	18	Copper	22	120	0	25.8697	1.9535	5.63
2	19	Copper	22	120	5	58.0663	1.7499	6.21
2	20	Graphite	8	40	0	7.1359	7.0756	2.9
2	21	Graphite	22	40	0	29.1021	3.1563	3.78
2	22	Copper	8	120	5	14.0783	1.5006	4.92
2	23	Graphite	8	40	5	8.1076	12.1329	2.77
2	24	Copper	8	40	0	6.8461	2.764	4.07
2	25	Graphite	8	120	5	9.0389	8.9295	5.32
2	26	Graphite	8	120	0	6.8553	2.9656	4.73
2	27	Copper	8	120	0	8.4774	0.5054	3.94
2	28	Graphite	22	120	5	82.8404	1.6076	6.32
2	29	Copper	8	40	5	7.1469	4.5038	3.81
3	30	Graphite	22	40	5	31.4558	5.8591	4.46
3	31	Graphite	22	40	0	29.1021	3.1563	3.78
3	32	Graphite	8	120	0	6.1696	2.9883	4.77
3	33	Copper	8	40	0	7.4271	2.7986	4.09
3	34	Copper	8	120	0	9.2215	0.4273	3.94
3	35	Graphite	22	120	5	74.1234	1.6262	6.3
3	36	Graphite	8	40	0	12.1531	5.7332	2.81
3	37	Copper	8	120	5	9.7263	1.5738	4.9
3	38	Copper	22	40	5	30.343	5.0822	5.25
3	39	Copper	22	120	5	55.9944	1.5594	6.17
3	40	Graphite	8	120	5	10.277	8.9295	5.34
3	41	Graphite	22	120	0	36.3096	1.376	6.24
3	42	Copper	22	120	0	30.2452	1.9765	5.61
3	43	Copper	8	40	5	9.6572	4.05	3.79

Table 6,
The (ANOVA) analysis for material removal rate (MRR) after the EDM.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Block	52.40	2	26.20			
Model	17331.15	8	2166.39	107.11	< 0.0001	significant
A-type of electrode	171.34	1	171.34	8.47	0.0065	
B-Pulse current (Ip)	161.21	1	161.21	7.97	0.0081	
C-Pulse on duration (Ton)	209.58	1	209.58	10.36	0.0029	
D-graphite powder mixed in kerosene dielectric	667.47	1	667.47	33.00	< 0.0001	
AB	500.48	1	500.48	24.75	< 0.0001	
BC	1089.99	1	1089.99	53.89	< 0.0001	
BD	1299.28	1	1299.28	64.24	< 0.0001	
CD	412.07	1	412.07	20.37	< 0.0001	
Residual	647.20	32	20.23			
Cor Total	18030.76	42				

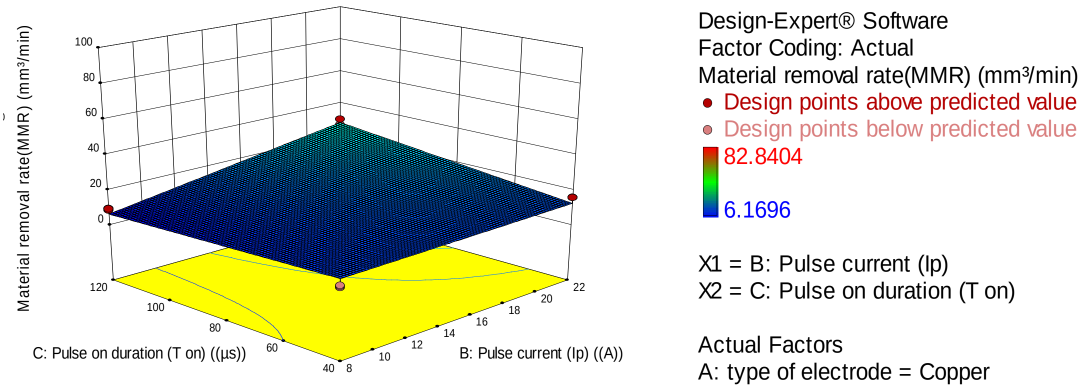

Fig. 3. The 3D graphs for MRR using kerosene dielectric alone and copper electrodes

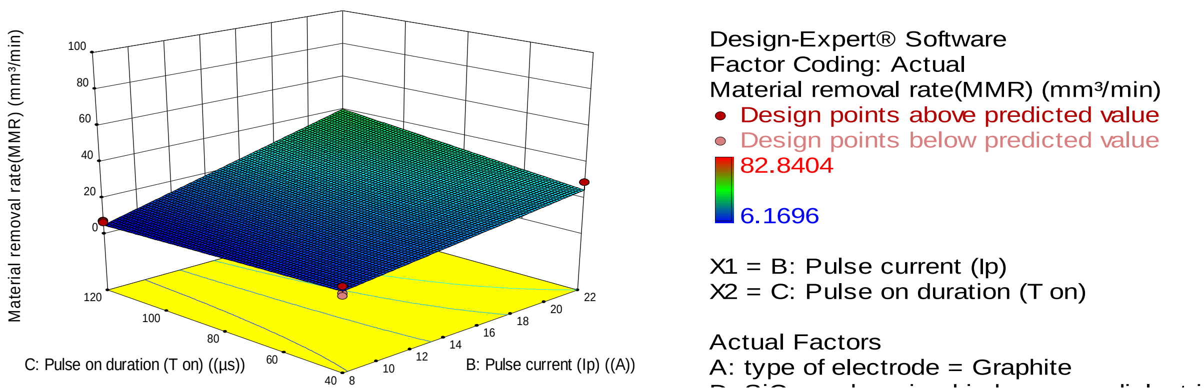

Fig. 4. The 3D graphs for MRR using kerosene dielectric alone and the graphite electrodes.

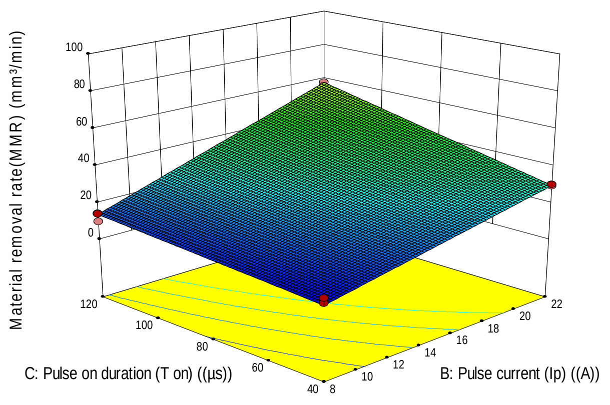

Fig. 5. The 3D graphs for MRR using kerosene dielectric with graphite powder mixing (PMEDM) and the copper electrodes.

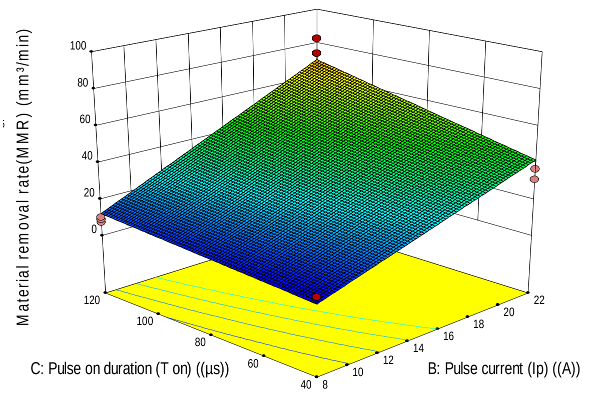

Fig. 6. The 3D graphs for MRR using kerosene dielectric with graphite powder mixing (PMEDM) and the graphite electrodes.

3.2 Modeling of Tool Wear Ratio Using Copper and Graphite Electrodes

The ANOVA technique for the tool wear ratio (TWR) response which are given in table (9) using the three factor backward levels for transform partial sum of squares model for lower the p-value.

Table 7,
The new constraints goals for optimization the MRR of the process.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:type of electrode	is in range	Copper	Graphite	1	1	3
B:Pulse current (Ip)	is in range	8	22	1	1	3
C:Pulse on duration (Ton)	is in range	40	120	1	1	3
D:Graphite powder mixed in kerosene dielectric	is in range	0	5	1	1	3
Material removal rate(MMR)	maximize	6.1696	82.8404	1	1	3

Table 8,
The desirability process for optimization of the predicted MRR.

No.	Type of electrode	Pulse current (Ip) (A)	Pulse on duration (T on) (µs)	SiC powder mixed in kerosene dielectric gm/l	Material removal rate (MMR) mm^3/min	Desirability	
1	Graphite	22.000	120.000	5	70.534	0.839	Selected
2	Graphite	22.000	119.162	5	70.239	0.836	
3	Graphite	21.860	120.000	5	69.954	0.832	

The Model F-value of 139.45 implies the model is significant. Values of "Prob> F" less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, AD, BD, ABC, ABD are significant model terms. The predicted final case, equation is:

Tool wear ratio (TWR)= $+ 9.29683 + 5.42634 * A - 0.13523 * B - 0.038354*C + 2.92512*D - 0.28365 * A * B - 9.40295 E-003 *A + 1.77480 * A* D - 0.12766 * B * D + 6.81399 E-004 * A * B * C - 0.062467 * A * B * D$ …(2)

The three dimensional (3D) graphs given in figures (7 - 10) show the influence the EDM and PMEDM parameters on the tool wear ratio. Figure (7) indicates that when using the pulse current (8 A) and pulse on duration (40 µs), the tool wear ratio decreased, reaching the values (3.05%) when using the copper electrodes and kerosene dielectric alone and (3.68%) when using the graphite electrodes and the kerosene dielectric alone with pulse current (22 A), as shown in figure (8). Figure (9) depicts the 3D graphs for TWR using the pulse current (8 A) and pulse on duration (120 µs), and the minimum tool wear ratio obtained when using the copper electrodes and the kerosene dielectric alone reaches the values (0.31%) and (1.05%) when using the graphite electrodes with pulse current (22 A), pulse on duration (120 µs) and the kerosene dielectric, as shown in figure (9) and (10), respectively. The main conclusion of the TWR calculation process is that the best minimum value obtained when using the pulse current (8 A), the pulse on duration (120 µs), the copper electrode and the kerosene dielectric alone reaches the values (0.31 %) and experimentally reaches the values (0.42 %). In all cases, the use of abrasive powder mixing like graphite increases the tool wear ratio but at the same time increasing the material removal rates up to (271%) as indicated in table (5), experiment (28) comparing with experiments (1, 18 and 42) which given the best MRR values with the same high levels of input parameters, but with copper electrodes and without using the graphite powder mixing.

The use of short pulse on time duration of (40 µs) and the low values of the used pulse current (8 A) will reduce the electrode wear ratio to its middle levels specially when using the kerosene dielectric alone. These wear levels are highly increasing when use the graphite electrodes and graphite powder mixing with the dielectric, because the efficiency of the material removal rates will be increasing due to high electrical and thermal conductivities as well as abrasive properties of graphite powder and the low density of graphite electrodes, where removal process will work efficiently even with low levels of thermal energy generated.

The use of high current for a short time slightly increasing the tool wear ratio and the use of powder mixing improving the performance specially with using of graphite electrodes which will give a better wear ratios than with copper for both cases of using or not the graphite powder mixing because it transmits the generated heat away by increase the gap distance between the tool and the workpiece, because the addition of graphite powder to dielectric fluid would cause an increase in the electrical conductivity of the fluid thereby increasing the gap and then the abrasive and erosive processes will be working at a longer distance from the electrode surfaces.

These tool wear ratios highly decrease with increasing the duration of pulse current time at the same values of used pulse current as shown in figures (9) and (10). These ratios are decreases to its minimum levels for all cases as indicated in figure(9), especially when using the kerosene dielectric alone specially when using the copper electrodes due to its high density as well as because the thermal conductivity of copper is less than graphite material which reduces the transition of thermal energy generated by the dielectric and this will reduce the ratio of carbon atoms interact with the electrode surface which is the main reason to its wear. These minimum TWR levels will allow to working with longer machining times for a greater amount of metal removal with the minimum electrode wear. It also allows access to the best accuracy for parts, especially when machining parts of large depths by using the same elect rode without the need to be replaced, because the tool can maintain its original form for the longest period with these few percentage of wear ratios.

3.2.1 Numerical Optimization of Tool Wear Ratio Results

For optimization the predicted model with the best EDM and PMEDM parameters, the desirability for minimize the values of response with the same ranges of the selected EDM parameters and electrodes types, as mentioned in table (10). The best solution founded from the desirability process shows that the optimum predicted values of the TWR when using the copper electrodes with pulse current (8.186 A), pulse of duration is (118.875 µs) and using the kerosene dielectric alone gives the best minimum predicted TWR of (0.364%) with a maximum desirability ratio (1.000). The desirability process reveals that the best predicting response values are approximately the same to the obtained values by experiments, and this confirms the results obtained experimentally. Table (10) indicated also that the use of graphite electrodes with pulse current (22 A), pulse of duration (120 µs) and using the kerosene dielectric alone gives also a good minimum predicted value of TWR of (1.059%) with a maximum desirability ratio (0.949).

Table 9,
The (ANOVA) analysis for material removal rate (TWR) after the EDM.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Block	8.52	2	4.26			
Model	399.00	10	39.90	139.45	< 0.0001	significant
A-type of electrode	43.82	1	43.82	153.14	< 0.0001	
B-Pulse current (Ip)	37.82	1	37.82	132.20	< 0.0001	
C-Pulse on duration (Ton)	98.54	1	98.54	344.40	< 0.0001	
D- Graphite powder mixed in kerosene dielectric	67.99	1	67.99	237.63	< 0.0001	
AB	29.12	1	29.12	101.79	< 0.0001	
AC	1.12	1	1.12	3.91	0.0572	
AD	25.22	1	25.22	88.14	< 0.0001	
BD	33.43	1	33.43	116.85	< 0.0001	
ABC	1.50	1	1.50	5.24	0.0293	
ABD	8.13	1	8.13	28.43	< 0.0001	
Residual	8.58	30	0.29			
Cor Total	416.10	42				

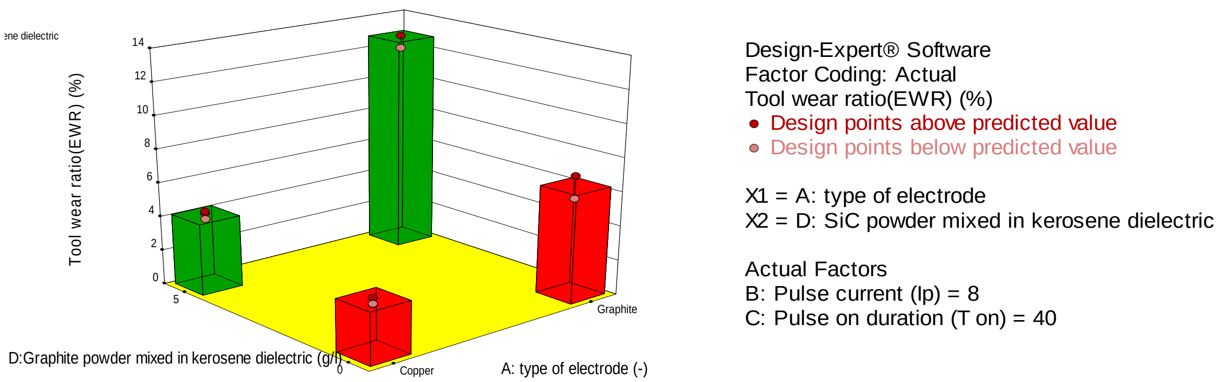

Fig. 7. The 3D graphs for TWR using the pulse current (8 A) and pulse on duration (40 µs).

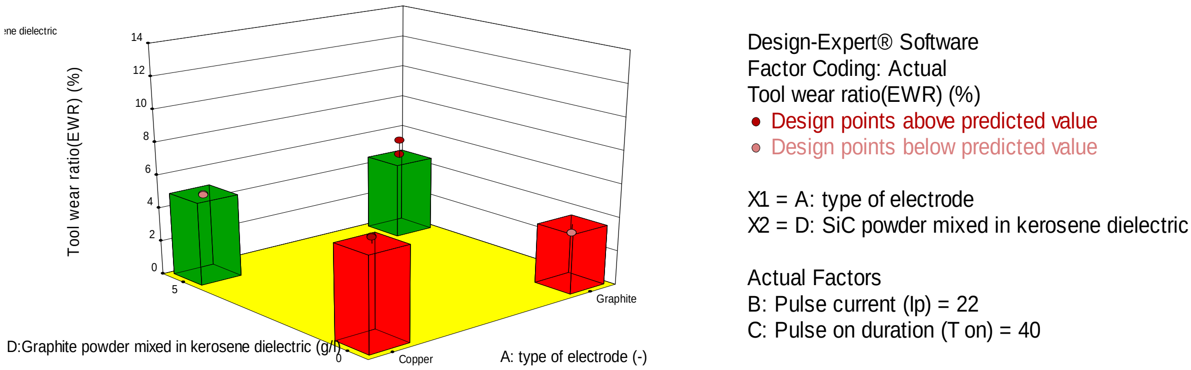

Fig. 8. The 3D graphs for TWR using the pulse current (22 A) and pulse on duration (40 µs).

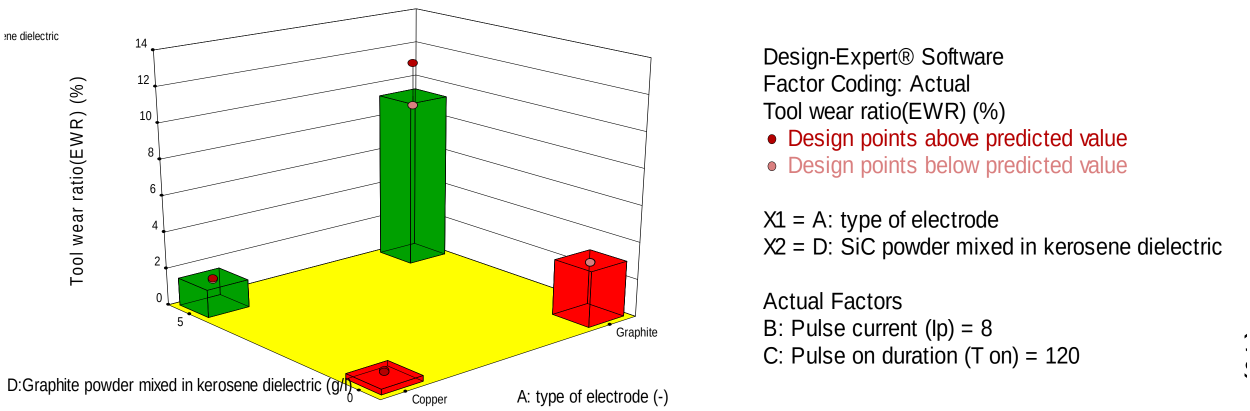

Fig. 9. The 3D graphs for TWR using the pulse current (8 A) and pulse on duration (120 µs).

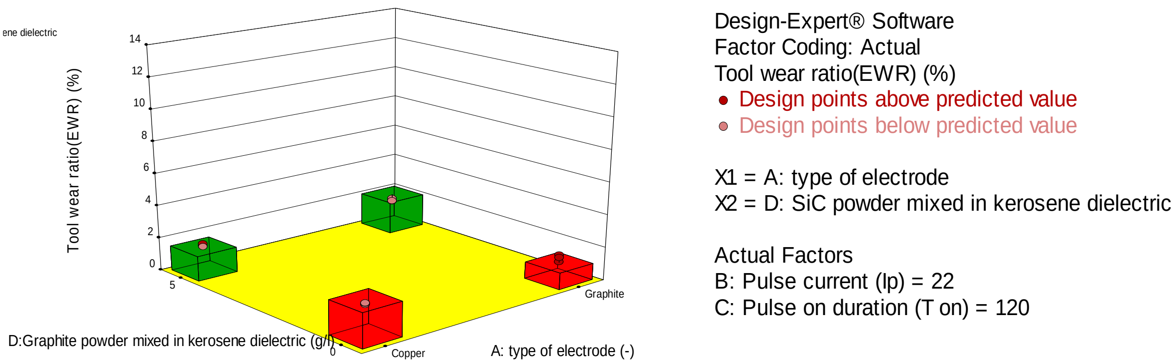

Fig. 10. The 3D graphs for TWR using the pulse current (22 A) and pulse on duration (120 µs).

Table 10,
The desirability Process for optimization of the predicted TWR.

No.	Type of electrode	Pulse current (Ip) (A)	Pulse on duration (Ton) (µs)	SiC powder mixed in kerosene dielectric (gm/l)	Tool wear ratio (EWR) (%)	Desirability	
1	Copper	8.186	118.875	0	0.364	1.000	Selected
37	Graphite	22.000	120.000	0	1.059	0.949	

3.3 Modeling of Surface Roughness Using Copper and Graphite Electrodes

The ANOVA technique for the surface roughness (SR) response which are given in table(11) using the three factor backward levels for transform inverse and Partial sum of squares model for lower the p-value. The Model F-value of 461.55 implies the model is significant. Values of "Prob> F" less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, AC, BC, BD, CD, ABC, ABD, ACD, BCD are significant model terms. The predicted final empirical equation is:

1/(Surface roughness (SR)) = + 0.40985 +0.11090 * A - 7.40310 E –003 * B – 1.40639 E-003 * C + 0.043313 * D - 3.47700E-003 * A* B- 1.10998E–003 * A * C + 3.35689E-005 * B *C-2.87530E-003*B*D-5.70120E*D+ 3.63772 E-005*A*B*C-4.80040E-004*A*B*D+9.13928 E-005*A*C*D+3.09331E-005*B*C*D …(3)

The three dimensional (3D) graphs given in figures (11 - 14) show the influence of the EDM and PMEDM parameters on the surface roughness. As shown in these figures, the minimum surface roughness (SR) values obtained when using the pulse current (8 A) and pulse on duration (40 µs) in all cases of the designed experimental groups.

Figure (11) indicates that when using the copper electrodes and the kerosene dielectric alone, the minimum surface roughness reduced to (4.0470 µm), experimentally (3.91 µm). When using the graphite electrodes figure (13), the minimum surface roughness reduced to values (2.8723 µm), experimentally (2.81 µm). This means that the surface roughness improved by (139 %) because the graphite powder mixing owns a high electrical conductivity which will working on increasing the dielectric electrical conductivity and consequently the gap distance increases, then the pressurized dielectric from both sides will remove the new fine removal layers from the surface of the workpiece and take them to the outside of the gap area combining operation of evaporation and melting leaving a fine surface quality.

Figure (12) and (14) show the 3D graphs for SR using the copper and graphite electrodes and graphite powder mixed with kerosene dielectric, where the minimum surface roughness reaches the values (3.8128 µm) and (2.7579 µm) respectively, experimentally with values (3.77 µm) and (2.77 µm), respectively. This means that the overall predicted minimum SR for all experiments runs obtained when working with graphite electrodes, the pulse current (8 A), the pulse on duration (40.µs) and kerosene dielectric mixed with graphite powder with (2.76µm) value, experimentally (2.77 µm), i.e., the process improved by (139 %), while experimentally improved by (141 %).

In general, it is better to use the graphite electrodes because it's thermal and electrical conductivity are less than copper materials in many levels, thus it will produce a little value of discharge energy works to minimize the defects resulting from increased discharge energy such as electromechanical pits and decay formation which keeps the producing surfaces with higher quality and fine roughness.

The use of graphite electrodes gives better surface roughness when using low pulse current levels for a small period of time, because the abrasion process cannot accomplish its work completely due to the little amount of thermal energy necessary for melting the surface layer of workpiece, and thus the abrasive phenomenon will be works with less abilities required to remove the surface layers as well as the lack of interactions required for the generation of new carbides due to low level of energy generated. The formation of a molten layer that freezes on the surface which is of better roughness than the erosive surfaces.

Table 11,
The (ANOVA) analysis for (SR) after the EDM.

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Block	7.328E-004	2	3.664E-004			
Model	0.14	13	0.011	461.55	< 0.0001	significant
A-type of electrode	0.018	1	0.018	756.53	< 0.0001	
B-Pulse current (Ip)	0.020	1	0.020	830.94	< 0.0001	
C-Pulse on duration (Ton)	0.025	1	0.025	1039.58	< 0.0001	
D-Graphite powder mixed in kerosene dielectric	2.766E-003	1	2.766E-003	114.75	< 0.0001	
AB	4.366E-003	1	4.366E-003	181.13	< 0.0001	
AC	0.016	1	0.016	645.36	< 0.0001	
BC	3.657E-003	1	3.657E-003	151.72	< 0.0001	
BD	2.926E-003	1	2.926E-003	121.39	< 0.0001	
CD	4.091E-003	1	4.091E-003	169.70	< 0.0001	
ABC	4.263E-003	1	4.263E-003	176.87	< 0.0001	
ABD	7.877E-004	1	7.877E-004	32.68	< 0.0001	
ACD	9.709E-004	1	9.709E-004	40.28	< 0.0001	
BCD	3.044E-003	1	3.044E-003	126.30	< 0.0001	
Residual	6.508E-004	27	2.410E-005			
Cor Total	0.15	42				

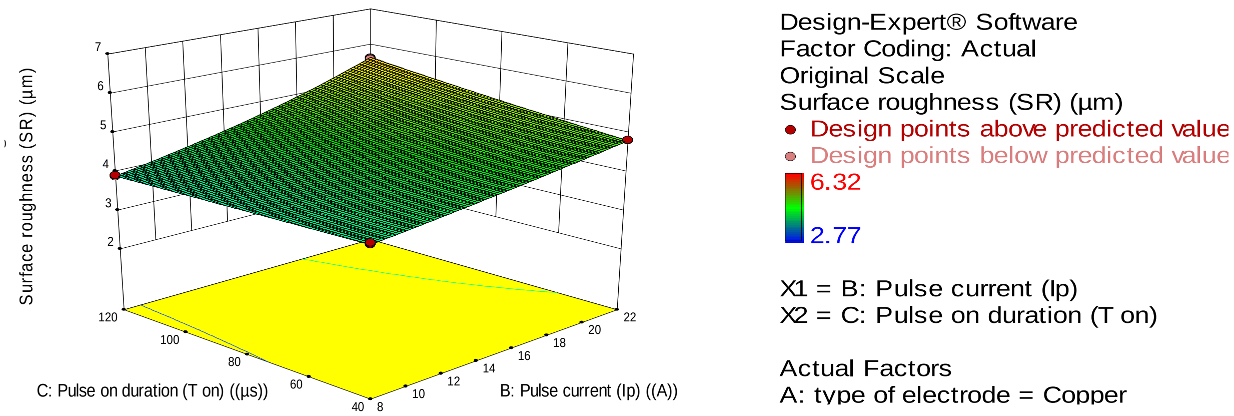

Fig. 11. The 3D graphs for SR using the copper electrodes and kerosene dielectric alone.

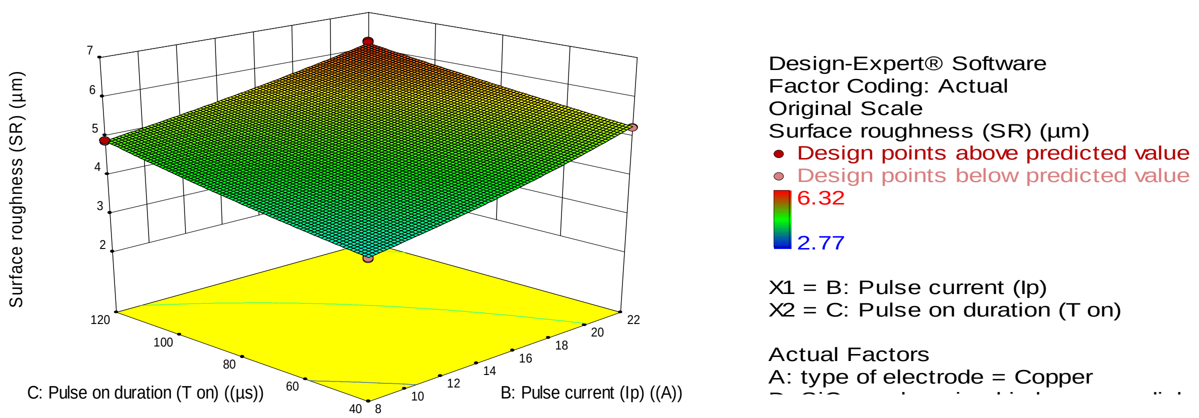

Fig. 12. The 3D graphs for SR using the copper electrodes and (5g/l) graphite powder mixing in kerosene dielectric

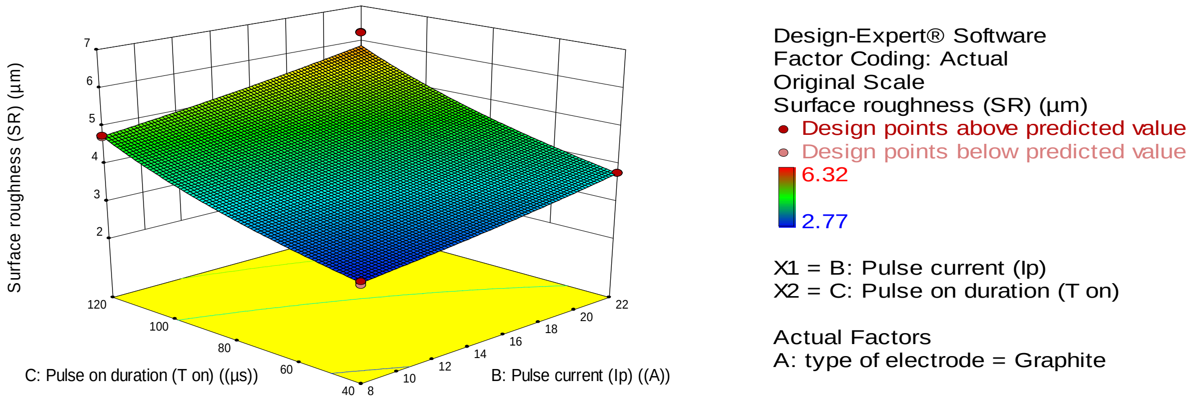

Fig. 13. The 3D graphs for SR using the graphite electrodes and kerosene dielectric alone.

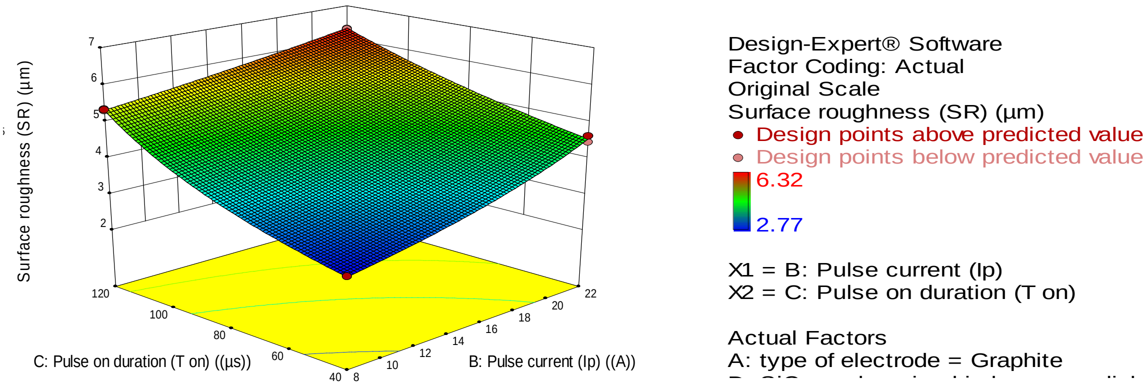

Fig. 14. The 3D graphs for SR using the the graphite and (5g/l) graphite powder mixing in kerosene dielectric.

3.3.1. Numerical Optimization of Surface Roughness Results

For optimization the predicted model with the best EDM and PMEDM parameters, the desirability for minimize the values of response with the same ranges of the selected EDM parameters and electrodes types as mentioned in table (12). The best
SR when using the graphite electrodes with pulse solution founded from the desirability process shows that the optimization predicted values of the current (8.009 A), pulse of duration about (40.408 µs) and using the kerosene dielectric with graphite powder mixed gives the best minimum predicted SR of (2.765 µm) with a maximum desirability ratio (1.000). The desirability process exhibits that the best predicting response values are approximately the same with the obtained values by experiments (2.77 µm), with a difference less than (0.015 µm), and this confirms the results obtained experimentally.

Table 12,
The desirability process for optimization of the predicted SR.

Number	Type of electrode	Pulse current (Ip)	Pulse on duration (T on)	SiC powder mixed in kerosene dielectric	Surface roughness (SR)	Desirability	
1	Graphite	8.009	40.408	5	2.765	1.000	Selected
2	Graphite	8.045	40.038	5	2.762	1.000	
3	Graphite	8.063	40.401	5	2.769	1.000	

4. Conclusions

The main conclusions obtained can be summarized in the following:

1- The best results for the productivity of the process (MRR) obtained when using the graphite electrodes, the pulse current (22 A), the pulse on duration (120 µs) and using the graphite powder mixing in kerosene dielectric reaches (82.84 mm³/min).This result gives an improvement in the material removal rate by (274%) with respect to the corresponding value obtained when using the copper electrodes with kerosene dielectric alone.

2- The best results for the tool wear ratio (TWR) of the process obtained when using the copper electrodes, the pulse current (8 A), the pulse on duration (120 µs) and using the kerosene dielectric alone reaches (0.31 %).

3- The use of graphite electrodes, the kerosene dielectric with graphite powder mixing, the pulse current (8 A) and the pulse on duration (40 µs) gives the best surface roughness (SR) of a value (2.77 µm). This result yields an improvement in SR by (141%) compared with using the corresponding value obtained when using copper electrodes, the kerosene dielectric alone and the same other parameters and machining conditions.

The desirability process showed that the best predicting response values are approximately the same as to those obtained values by experiments, as mentioned in the three above items, and this confirms the results of the present work.

Nomenclature

ANOVA	Analysis of variance
CCD	Central Composite Design
CNC	Computer numerical control
EDM	Electric discharge machining
FFD	Full factorial design
Ip	Pulse current (A)
MRR	Material removal rate (mm³/min)
PMEDM	Powder mixing electric discharge machining
RSM	Response surface methodology
SR	Surface roughness (µs)
TIG	Tungsten inert gas
Ton	Pulse on duration time (µs)
Toff	Pulse off duration time (µs)
TWR	Tool wear ratio (%)
Vp	Gap voltage (V)
WEDM	Wire electrical discharge machine
w/p	Workpiece

5. References

[1] J. W. Murray, J. C. Walker, A. T. Clare," Nanostructures in austenitic steel after EDM and pulsed electron beam irradiation", *Surface & Coatings Technology Journal*, 259, pp. 465–472, 2014.

[2] S. K. Majhi, M. K. Pradhan and H. Soni," Optimization of EDM parameters using integrated approach of RSM, GRA and ENTROPY method", International Journal of Applied Research in Mechanical Engineering, 3(1), pp. 82-87,2013.

[3] F. Klocke, D. Welling and J. Dieckmann, "Comparision of Grinding and WEDM concerning Fatigue Strength and Surface Integrity of Machined Ti6Al4V components", Procedia Eng., Elsevier, Vol. 19, pp. 184–189, 2011.

[4] S. K. Majhi, T. K. Mishra, M. K. Pradhan and Hargovind Soni," Effect of Machining Parameters of AISI D2 Tool Steel on Electro Discharge Machining", International Journal of Current Engineering and Technology, Vol.4, No.1, 2014.

[5] M. K. Pradhan and C. K. Biswas, (2009), Modeling and Analysis of process parameters on Surface Roughness in EDM of AISI D2 tool Steel by RSM Approach, International Journal of Engineering and Applied Sciences, 5 (5), pp 246-351.

[6] M. K. Pradhan and C. K. Biswas," Influence of process parameters on MRR in EDM of AISI D2 Steel, a RSM approach", Proc. of the International Conference on "Advances in Mechanical Engineering, pp 872-877, 2008.

[7] K. Wang, H. L. Gelgele, Y. Wang, Q. Yuan and M. Fang," A hybrid intelligent method for modeling the EDM process", International Journal of Machine Tools and Manufacture, 43, pp. 995–999, 2003.

[8] N. S. Khundrakpam, H. Singh, S. Kumar and G. S. Brar," Investigation and Modeling of Silicon Powder Mixed EDM using Response Surface Method", International Journal of Current Engineering and Technology, Vol.4, No. 2, 2014.

[9] Pradhan M. K. and Biswas C. K.," Multi-response optimization of EDM AISI D2 tool steel using response surface methodology", International Journal of Machining and Machinability of Materials (IJMMM), 9, pp. 66–85, 2011.

[10] Ranganathan S. and Senthilvelan T.," Multi-response optimization of machining

parameters in hot turning using grey analysis", The International Journal of Advanced Manufacturing Technology, 56, pp. 455–462,2011.

[11] M. K. Pradhan and C. K. Biswas," Investigating the effect of machining parameters on EDM components a RSM approach", International Journal of Mechanical Engineering, Vol. 7, pp. 47–64,2010.

[12] J. Lin and C. Lin,"The use of the orthogonal array with grey relational analysis to optimize the electrical discharge machining process with multiple performance characteristics", International Journal of Machine Tools and Manufacture, Vol. 42, pp. 237–244, 2002.

[13] Singh S., Maheshwari S., and Pandey P.," Some investigations into the electric – discharge machining of hardened tool steel using different electrode materials", Journal of Materials Processing Technology, 149, (1-3), pp. 272–277, 2004.

[14] Reddy S. and C. S. Rao," Design of Experiments based Grey Relational Analysis in Various Machining Processes, a Review ", Research Journal of Engineering Sciences, ISSN 2278 – 9472, Vol. 2, (1), pp. 21-26, 2013.

[15] Saurav D. and Siba Sankar M.," Modeling, simulation and parametric optimization of wire EDM process using response surface methodology coupled with grey-Taguchi technique", International Journal of Engineering, Science and Technology, Vol. 2, No. 5, pp. 162-183, 2010.

[16] B. Reddy, G .N. Kumar and K. Chandrashekar," Experimental Investigation on Process Performance of Powder Mixed Electric Discharge Machining of AISI D3 steel and EN-31 steel", International Journal of Current Engineering and Technology, Vol. 4, No. 3, 2014.

[17] ASTM A681, "Standard Specification for Tool Steels Alloy", American Society for Testing and Materials, Washington, D.C., 1976.

[18] ASTM A370,"Standard Test Method and Definitions for Mechanical Testing of Steel Products",American Society for Testing and Materials,Washington, D.C., 1977.

دراسة ونمذجة تأثير التشغيل بالشرارة الكهربائية لمسحوق الجرافيت الممزوج على الخصائص الرئيسة للعملية

*احمد نايف الخزرجي **سمير علي امين ***سعد محمود علي
*، ** قسم الهندسة الميكانيكية/ الجامعة التكنولوجية
*** قسم الهندسة الميكانيكية / جامعة كربلاء
*البريد الالكتروني: dr_ahmed53 @yahoo.com
**البريد الالكتروني: alrabiee2002@yahoo.com
***البريد الالكتروني: smaengg@yahoo.com

الخلاصة

يعني هذا البحث بدراسة تأثير مسحوق الجرافيت الميكروي الممزوج في مائع الكيروسين العازل كهربائيا خلال عملية التشغيل بالقطع بالتفريغ الكهربائي مع خلط المسحوق (PMEDM) لقطع صلب عالي الكربون والكروم عالية نوع D2 . وقد تم استعمال نوع القطب (النحاس والجرافيت) وتيار النبضة وزمن استمرار النبضة ومسحوق الخلط في مائع الكيروسين العازل كمعاملات الإدخال الرئيسة للعملية. وقد اخذ كل من معدل ازالة المعدن و نسبة تآكل العدة والخشونة السطحية لقطعة العمل كمعاملات الإخراج لقياس أداء العملية. وقد تم اعداد التجارب العملية باستخدام منهجية استجابة السطح بوصفه أداة للتصميم . وتم تطوير موديلات تجريبية لمعدل ازالة المعدن و نسبة تآكل العدة والخشونة السطحية ، وذلك باستخدام طريقة تحليل التباين . ان أفضل النتائج التي تم الحصول عليها لزيادة كفاءة معدل الإنتاجية للعملية عند استخدام أقطاب الجرافيت وتيار النبضة مقداره (٢٢ امبير) وزمن نبضة مدتها (١٢٠ ميكرو ثانية) وباستخدام مسحوق الجرافيت الممزوج في مائع الكيروسين العازل حيث بلغت (٨٢.٨٤ ملم³ / دقيقة). وهذه النتيجة تعطي تحسنا في معدل إزالة المادة تبلغ (٢٧٤٪) نسبة للقيمة التي تم الحصول عليها عندما تم استعمال أقطاب النحاس مع الكيروسين العازل لوحده. كما ان أفضل النتائج التي تم الحصول عليها لنسبة تآكل العدة للعملية عند استخدام أقطاب النحاس وتيار النبضة مقداره (٨ امبير) وزمن نبضة مدتها (١٢٠ ميكرو ثانية) وباستخدام الكيروسين العازل لوحده حيث بلغت (٠.٣١٪) . كما ان استخدام أقطاب الجرافيت والكيروسين العازل مع ٥ غم / لتر من مسحوق الخلط الجرافيتي وتيار نبضة مقداره (٨ امبير) وزمن نبضة مدتها (٤٠ ميكرو ثانية) يعطي أفضل خشونة سطحية قيمتها (٢.٧٧ ميكرومتر) ، وهذا النتيجة تعطي تحسنا في نعومة السطح بنسبة (١٤١٪) نسبة للقيمة التي تم الحصول عليها عندما تم استعمال أقطاب النحاس ومائع الكيروسين العازل لوحده مع نفس المدخلات والظروف الأخرى للتشغيل .