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Effect of SiC Powder Mixing (PMEDM) on surface residual stresses using copper and graphite electrodes

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ABSTRACT

Electric discharge machine (EDM) is a modern machining process with various advantages, as a result of which, its use is becoming more and more wide spread. This paper concerns with the influence of EDM input parameters (type of electrodes, peak current, pulse-on time and powder mixing concentration) on the induced surface residual stresses. The silicon carbide powder is mixed with the kerosene dielectric in powder mixing EDM (PMEDM) process. The experimental work was designed by using the response surface methodology (RSM). The analysis of variance (ANOVA) was used and regression models were built to predict the surface residual stresses as a response of the process for AISI D2 die steel. Empirical equations were obtained for predicting the performance of the process. Two type of electrodes were used, the copper and graphite electrodes. The results showed that the minimum tensile surface residual stresses obtained when using the copper electrodes with pulse current (22 A) and pulse on duration (120 µs). It is concluded that the use of graphite electrodes and kerosene dielectric alone induced minimum residual stresses with pulse current (22 A) and pulse on duration (40 µs) and with(120 µs) when using the kerosene dielectric with SiC powder mixing. The copper electrodes with kerosene dielectric alone induced residual stresses about (5%) lower than when using kerosene dielectric with 5g/l SiC powder and about (14%) lower than with graphite electrodes and (8%) when using the kerosene dielectric alone and with SiC powder, respectively.

Introduction

Electro Discharge Machining is among the earliest nontraditional machining process that is most extensively used in industry. For making molds, Punches and dies for blanking, shearing, and progressive die tooling, automatic stamping dies, the components/products used in biomedical, automobile, aircraft, and microelectronic industries. At present, EDM is a widespread technique used in industry for high-precision machining of all types of conductive materials, such as metals, metallic alloys, graphite or even some ceramic materials of any hardness [1].

However, the process suffers from few limitations, such as low machining efficiency and poor surface finish. To overcome these limitations, a number of efforts have been made to develop such EDM systems that have capability of high material removal rate (MRR), high accuracy and precision without making any major alterations in its basic principle [2–5]. The techniques used in the past include: (i) electrode rotating, (ii) electrode orbiting-planetary motion to tool or workpiece, (iii) applications of ultrasonic vibrations, and (iv) suspension of foreign powders in the dielectric fluid. The mixing of a suitable material in powder form into the dielectric fluid is one of the latest advancement for improving the capabilities of EDM process [6]. This process is called powder mixed EDM (PMEDM). In this process, the electrically conductive powder particles are mixed in the dielectric fluid, which reduce its insulating strength and increase the spark gap distance between the tool and work piece to spread the electric discharge uniformly in all directions. As a result; the process becomes more stable thereby improving material removal rate (MRR) and surface finish. N. S. Khundrakpam, have been used response surface method to explore the influence of process parameter on material removal rate on EN-8 steel [7]. B. Reddy et, al, [8] study the effect of fine metal powders such as aluminum (Al) and copper (Cu) mixed to the dielectric fluid, during Electric Discharge Machining of AISI D3 Steel and EN-31 steel. Material removal rate and surface roughness are taken as output parameters to measure the process performance. Taguchi design of experiments is used to conduct experiments. The obtained outcomes of experiments indicate that the addition of metal powders in dielectric fluid increases the material removal rate and improves the surface quality. T. C Bhagat et al [9] in his study found that increasing current intensity increases the surface roughness drastically. P. Janmanee et al [10] in his research found that increasing discharge current led to greater material removal rate and greater wear ratio but poor surface. R. Chaudhry [11] found that at the higher values of current arcing takes place and the debris particle size increases as a result MRR decreases after a limit of current, tool and machining surface gets drastically damages.

Many attempts have been made for modeling of EDM process, and investigations of the process performance are still challenging problems. Due to the complexity in nature, there is a lack of analytical models correlating the process variables, which restrict the expanded application of the technology [12]. Izquierdo, B. et al. [13] proposed a new contribution to the simulation and modeling of the EDM process. Jegaraj and Babu [14] attempted to make use of Taguchi's approach and ANOVA using minimum number of experiments for studying the influence of parameters on the cutting performance in abrasive

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water jet **(**AWJ**)**machining considering the orifice and focusing tube bore variations to develop empirical models. Pradhan and Biswas [15] developed a regression model and two artificial neural networks (ANNs) namely: Back propagation and radial basis function to predict the surface roughness in the electrical discharge machined surfaces.

Residual stresses in a work piece are a function of its material processing and machining history. They act in a body without applying forces or moments and changing the level of the yield strength. To clarify the residual stresses formation mechanism induced in EDM processes, many studies have been conducted on it. Jain et al. [16], and Yang and Mukoyama [17] conducted the temperature and residual stress analysis using the finite element method. It is by and large acknowledged that displaying of discharge in EDM is essentially a thermal erosion procedure, [18] where the heat transfer happens. In this manner various streamlined thermo-mathematical models focused around the comparisons of heat conduction equations through solids. Das et al. [19] simulated the temperature distribution, residual stress and the final crater shape using the commercial finite element solver DEFORM. Electrical discharge phenomena in EDM occur in a very short time period and in a very narrow space, thus making both observation and theoretical were analysis extremely difficult.

The present paper attempted to study the surface residual stress induced by EDM parametric effects and developed a model by using the response surface methodology (RSM) technique. Two groups of experiments are designed experiments to study the performance of the EDM process on AISI D2 die steel. The first group was performed in pure kerosene dielectric, while the second with addition of abrasives Silicone carbide powders mixed with dielectric fluid (PMEDM)in order to improve the machining efficiency and the instability of arcing effects.

Experimentation

Material used

AISI D2 cold-work die steel was selected to be used in this work due to its emergent range of applications in the field of manufacturing tools in mold industries. It is widely used for various dies and cutters for its high strength and wear resistance due to formation of chromium carbide in heat treatment. AISI D2 is a high-carbon, high-chromium tool steel alloyed with molybdenum and vanadium characterized by: high wear resistance, high compressive strength, good through-hardening properties, high stability in hardening, and good resistance to tempering-back. It is recommended for tools requiring very high wear resistance, combined with moderate toughness (shock-resistance). Strips of this type of steel were tested for chemical composition by using the AMETEXSPECTRO MAX material analyzer, and the results are listed in in table (1) together with the equivalent values given according to ASTM A 681-76 standard specification for alloy and die steels[20]. This table shows the conformity of the used steel with the standard one.

For mechanical properties tests, four specimens were prepared for tensile tests by using the universal testing machine type UNITED on the bases of ASTM-77 steel standards for flat work piece [21]. These four specimens were also tested for Rockwell hardness tests by using the hardness testing machine type INDENTEC. The average HRB hardness value with the tensile tests results are given in table (2). The workpieces were manufactured by using the wire electrical discharge machine (WEDM) type ACRA Brand/Taiwan and by a surface grinding machine, and then specimens were polished mechanically and manually by abrasive silicon carbide paper up to grade ASTM 3000.

XRD Measurements

Measuring the surface residual stresses before and after EDM machining were carried out by using the X-RAY DIFFRACTION (XRD) testing equipment type lABXRD-/Japan 5217A.

Used Electrodes

Two types of electrodes materials, Copper and Graphite were selected. The copper electrode material was examined for chemical composition using the X-MET 3000TXHORIZONT metal analyzer, and the compositions obtained are: 0.006% Zn, 0.001% Pb, 0.0005% Sn, 0.005% P, 0.0002% Mn, 0.007% Fe, 0.004% Ni, 0.011% Si, 0.007% Al, 0.002% S, 0.005% Sb, and the remaining is 99.96% Cu. 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 (3). The prepared electrodes were polished as mentioned above.

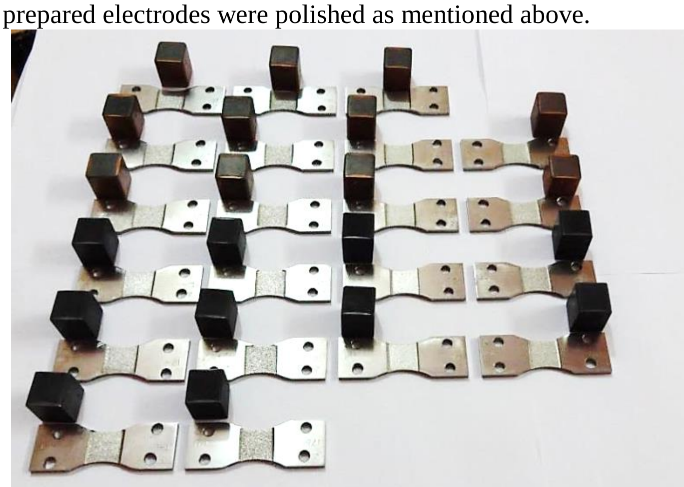

Figure 3. The copper and graphite electrodes and workpieces after PMEDM processes

EDM Parameters

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), i.e., the duty factor (33%), the SiC 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 conducted on ACRACNC-EB EDM machine with all the manufactured attachments shown in figure (4).

For the purpose of powder micro blasting (peening) by powder mixing with dielectric fluid (PMEDM), a stainless steel container (of about 30 liters volume and overall dimensions 400 x 300 x2 30 mm and with a cover of 400 x 230 mm, 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 work piece 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 (5). The chemical composition of the Silicone carbide powders substances was tested for its chemical compositions by using the X-Ray diffraction apparatus, and then the powder was inspected to measure its grains sizes using the laser diffraction particle size analyzer. The average grain size is (95,502 µm) for silicon carbide powder, as given in the test certificates.

Figure 4. The CNC EDM machine with all the manufactured accessories designed for the implementation the PMEDM experiments

Grouping the Experiments

In this paper, two groups of experiments are designed, each contains (22) experiments for comparing the surface residual stresses resulting from thermal stresses producing by EDM and PMEDM machining. Each group was divided in two subgroups for working with kerosene dielectric alone for the first subgroup and with kerosene dielectric mixed with silicone carbide (SiC) powder, with (5 liter/gm.) concentration. In the first group, the copper electrodes were used, while the 2nd group was used the graphite electrodes. A new set of w/p and electrode was used in each experiment.

Figure 5. The manufactured stainless steel container with accessories

Results And Discussion

Input Parameters levels and Experimental Design Matrix

The surface residual stresses experimentally measured after EDM and PMEDM machining with the input parameters are modeled by using the response surface methodology (RSM) and a two-level factorial design for both experimental groups. The input EDM parameters and their levels are given in table (3). The designed EDM experimental matrix in a random manner with the selected factors (actual and coded) and the experimental response (measured surface residual stresses) results for the both groups using the kerosene dielectric or the kerosene dielectric with SiC powder mixing with copper and graphite electrodes are given in tables (4) and (5), respectively.

Modeling Surface Residual Stresses Using Copper and Graphite Electrodes

The response results show that all the measured residual stresses after EDM and PMEDM machining are in tensile values for the both groups. In group (1) using copper electrodes, the maximum residual stresses obtained is (386.371), the minimum (316.8) and the mean (351.058) MPa. In group (2) experiments using the graphite electrodes the maximum residual stresses obtained is (469.062), minimum (344.873) and the mean (381.771) MPa. The two level factors (2^3) full factorial design (FFD) is used to set the necessary number of experiments to fit the model. The ANOVA technique is used to analyze the significance of EDM process parameters, where the F-test ratio is calculated for a 95% level of confidence. The inversion model obeys the least squares theory.

The ANOVA function then runs in order to assess the results which are given in table (6) using the inverse two factor levels forward transform model for lower the p-value. The Model F-value of 128.93 implies the model is significant. Values of "Prob> F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, BC are significant model terms.

The predicted final empirical equation in terms of actual factors is:

1/(Residual stresses) = + 2.98981E - 003-1.85970E-005 * A - 4.40508E-006 * B (Ton) +1.92327E-005

*C+4.24043E-007*A*B-3.05789E-007*B*C… **(1)**

The ANOVA analysis for the EDM machining surface residual stresses response for group (2) experiments using graphite electrodes with an inverse transform two factor level model is given in table (7). The Model F-value of 1833.87 implies the model is significant. Values of "Prob> F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, BC,ABC are significant model terms.

The final empirical equation in terms of actual factors for after EDM and PMEDM machining is:

1/(Residual stresses) = +2.13267E-003+2.91756E-005*A+4.34101E-006*B-1.69034E-004*C-2.17971E

-007*A* B+7.32570E-006*A* C+ 1.53874 E-006* B * C -5.43313E-008* A * B * C……………. **(2)**

The diagnostic process for evaluating the model fit and transformation choice as in figure (6) shows the normal probability plot to check for normality of residuals after EDM machining for copper and graphite electrodes. The plots show that the residual distributed normally on a straight line.

The two dimensional (2D) contour model graphs given in figures (7) and (8) are used to interpret and evaluate the model for group (1). These figures show the influence the EDM and PMEDM parameters on the work pieces surface residual stresses for copper electrodes, respectively.

Table (1): The chemical composition for the used material and the equivalent given by the standard for AISI D2 die steel

Material	C %	Si %	Mn %	P %	S %	Cr %	Mo %	Ni %	Co %	Cu %	V %	Fe %
Used	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	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 strength (N/mm²)	Yield strength (N/mm²)	Elongation (%)	Hardness (HRB)
704.25	415.25	18.12	90.25

Table (3): The input EDM parameters and their levels for both groups

Factor	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	SiC powder mixed in kerosene dielectric	g/l	0	5	-1	+1	2

Table (4): The designed experimental matrix for Group (1) using copper electrodes

Std.	BLOCK	Run No.	Input factors (Actual) X1 A: Pulse current Ip, (A)	X2 B: Pulse on duration Ton, (μs)	X3 C: SiC powder mixed in kerosene dielectric, (g/l)	Input factors (Coded) X1	X2	X3	Response Residual stresses (MPa)
6	1	1	8	120	0	-1	+1	-1	364.505
4	1	2	22	40	0	+1	-1	-1	356.990
15	1	3	22	40	5	+1	-1	+1	359.877
9	1	4	22	120	0	+1	+1	-1	316.800
12	1	5	8	40	5	-1	-1	+1	350.685
20	1	6	22	120	5	+1	+1	+1	320.788
17	1	7	8	120	5	-1	+1	+1	383.160
1	1	8	8	40	0	-1	-1	-1	358.885
2	2	9	8	40	0	-1	-1	-1	360.197
10	2	10	22	120	0	+1	+1	-1	318.167
18	2	11	8	120	5	-1	+1	+1	380.283
7	2	12	8	120	0	-1	+1	-1	365.906
21	2	13	22	120	5	+1	+1	+1	322.358
13	2	14	8	40	5	-1	-1	+1	354.008
5	2	15	22	40	0	+1	-1	-1	356.050
16	2	16	22	40	5	+1	-1	+1	358.726
3	3	17	8	40	0	-1	-1	-1	359.429
22	3	18	22	120	5	+1	+1	+1	322.358
8	3	19	8	120	0	-1	+1	-1	363.499
19	3	20	8	120	5	-1	+1	+1	386.371
11	3	21	22	120	0	+1	+1	-1	317.849
14	3	22	8	40	5	-1	-1	+1	346.386

Table (5): The designed experimental matrix for Group (2) using graphite electrodes

Std.	BLOCK	Run No.	Input factors (Actual)			Input factors (Coded)			Response
			X1	X2	X3	X1	X2	X3	Residual stresses (MPa)
			A: Pulse current Ip, (A)	B: Pulse on duration Ton, (µs)	C: SiC powder mixed in kerosene dielectric, (g/l)				
12	1	1	8	40	5	-1	-1	+1	467.98
6	1	2	8	120	0	-1	+1	-1	372.719
9	1	3	22	120	0	+1	+1	-1	367.231
17	1	4	8	120	5	-1	+1	+1	358.916
1	1	5	8	40	0	-1	-1	-1	405.987
20	1	6	22	120	5	+1	+1	+1	346.369
15	1	7	22	40	5	+1	-1	+1	358.426
4	1	8	22	40	0	+1	-1	-1	363.136
18	2	9	8	120	5	-1	+1	+1	356.675
5	2	10	22	40	0	+1	-1	-1	362.194
21	2	11	22	120	5	+1	+1	+1	344.873
2	2	12	8	40	0	-1	-1	-1	405.336
13	2	13	8	40	5	-1	-1	+1	469.062
16	2	14	22	40	5	+1	-1	+1	359.265
7	2	15	8	120	0	-1	+1	-1	373.753
10	2	16	22	120	0	+1	+1	-1	368.014
14	3	17	8	40	5	-1	-1	+1	465.73
3	3	18	8	40	0	-1	-1	-1	403.279
22	3	19	22	120	5	+1	+1	+1	348.006
11	3	20	22	120	0	+1	+1	-1	367.692
8	3	21	8	120	0	-1	+1	-1	373.876
19	3	22	8	120	5	-1	+1	+1	360.447

Table (6): The (ANOVA) table for the EDM group (1) experiments using copper electrodes

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Block	2.404E-009	2	1.202E-009			
Model	6.857E-007	5	1.371E-007	128.93	< 0.0001	significant
A-Pulse current (Ip)	6.257E-008	1	6.257E-008	58.83	< 0.0001	
B- Pulse on duration (Ton)	1.078E-007	1	1.078E-007	101.39	< 0.0001	
C-SiC powder mixed in kerosene dielectric	9.404E-009	1	9.404E-009	8.84	0.0101	
AB	2.900E-007	1	2.900E-007	272.65	< 0.0001	
BC	2.040E-008	1	2.040E-008	19.18	0.0006	
Residual	1.489E-008	14	1.064E-009			
Cor Total	7.030E-007	21				

Table (7): The (ANOVA) table for the EDM group (1) experiments using graphite electrodes

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Block	7.865E-009	2	3.932E-009			
Model	1.175E-006	7	1.679E-007	1833.87	< 0.0001	significant
A-Pulse current (Ip)	7.929E-008	1	7.929E-008	865.98	< 0.0001	
B-Pulse on duration (T on)	6.257E-008	1	6.257E-008	683.39	< 0.0001	
C-SiC powder mixed in kerosene dielectric	1.456E-007	1	1.456E-007	1590.60	< 0.0001	
AB	3.901E-008	1	3.901E-008	426.05	< 0.0001	
AC	6.440E-008	1	6.440E-008	703.35	< 0.0001	
BC	9.874E-008	1	9.874E-008	1078.40	< 0.0001	
ABC	3.086E-008	1	3.086E-008	337.01	< 0.0001	
Residual	1.099E-009	12	9.156E-011			
Cor Total	1.184E-006	21				

Table (8): The new constraints goals for numerical optimization for copper electrodes

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Pulse current (Ip)	is in range	8	22	1	1	3
B: Pulse on duration (Ton)	is in range	40	120	1	1	3
C: SiC powder mixed in kerosene dielectric	is in range	0	5	1	1	3
Residual stresses	minimize	316.8	386.371	1	1	3

Table (9): The desirability process for optimization of the predicted surface residual stresses for copper electrodes

Number	Pulse current (Ip)	Pulse on duration (T on)	SiC powder mixed in kerosene dielectric	Residual stresses	Desirability	
1	22.000	120.000	0.000	315.337	1.000	Selected
1	22.000	120.000	5.000	346.415	0.988	Selected

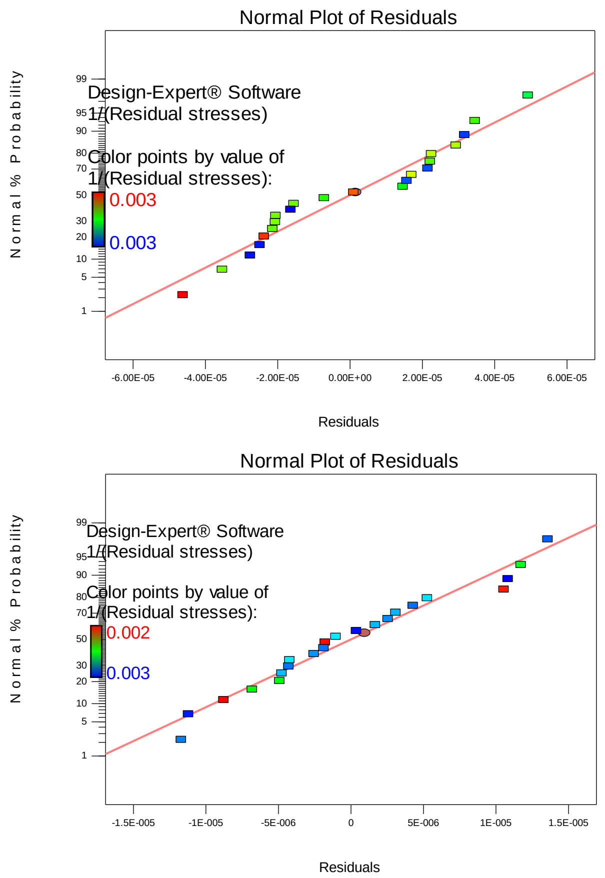

Figure 6. The normal probability plot the residuals, for copper electrodes (at the left) and graphite electrodes (at the right)

Both figures indicate that the tensile residual stresses decrease with increasing the pulse current up to (22A) and pulse on duration value (up to 120 µs). The minimum surface residual stresses reaches (315.337 MPa) when working with kerosene dielectric alone, experimentally (316.800 MPa), where the minimum residual stress obtained when using the copper electrodes and the kerosene dielectric with 5g/l SiC powder is (324.266 MPa), experimentally (320.358 MPa),as shows in figures (7) and (8), respectively. This means that the use of copper electrodes with kerosene dielectric alone induced residual stresses about (2.8%) lower than when using kerosene dielectric with 5g/l SiC powder, experimentally (1.1%). The reason for this behavior is attributed to that, the silicon carbide is the semiconductor material and therefore did not work to increase electrical conductivity of the dielectric fluid and worked to reduce the amount of heat energy required to complete the fusion of the surface layers near the gap. Also the silicon carbide as an abrasive material not has been able to play its role completely for the same reason and there by higher surface residual stresses were generated, so it's best to increase the proportion of carbon in silicon carbide to reduce these stresses. Figures (9) and (10) show the (2D) surface graphs for the influence of the selected EDM parameters on surface residual stresses for graphite electrodes without and with SiC powder mixing in kerosene dielectric, respectively. These figures show that the lower values of tensile residual stresses obtained when using the kerosene dielectric alone (figure 9) with maximum value of pulse current (22 A) and minimum value of pulse on duration time (40 µs) and reaches (362.802 MPa), experimentally (362.194 MPa),The lower values of tensile residual stresses obtained when using the kerosene dielectric with SiC powder mixing (figure 10) with maximum value of pulse current (22 A) and maximum value of pulse on duration time (120 µs) and reaches (346.415 MPa), experimentally (344.873 MPa). This means that the use of SiC mixed powder improves the tensile residual stresses obtained by about (5%) when comparing with the case of working with kerosene dielectric alone. Also, the use of copper electrodes and kerosene

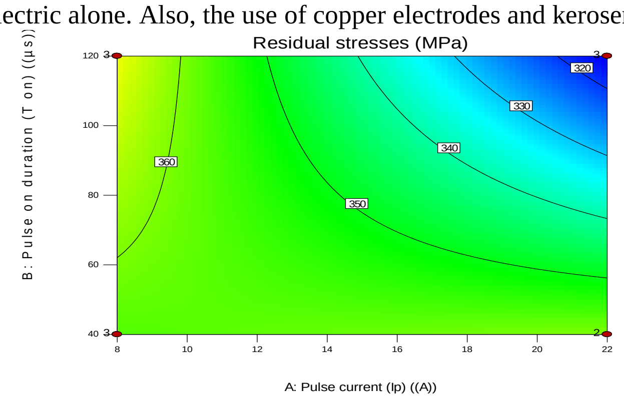

Figure 7. The contour model graphs for EDM processes using copper electrodes and the kerosene dielectric alone, group (1)

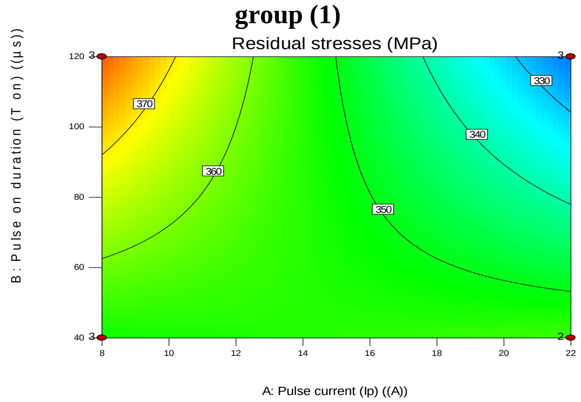

Figure 8. The contour model graphs for EDM and PMEDM using copper electrodes and the kerosene dielectric with 5g/l SiC powder, group (1)

dielectric alone gives residual stresses about (14%) lower than with graphite electrodes and about (8%) lower when use the copper electrodes and kerosene dielectric with SiC powder mixing.

The reason for this trend is ascribed to the high thermal conductivity of the graphite electrode as well as the silicon carbide and with the use of high current for a long period of time led to increase the amount of heat energy required to complete the fusion of the surface layers at the gap. At the same time, silicon carbide as an abrasive powder material play a major role in increasing the removal layers from the surface of the work piece and thus reduced the thickness of the white recast hard surface layer, which cause to increase the value of the surfaceresidual stresses.

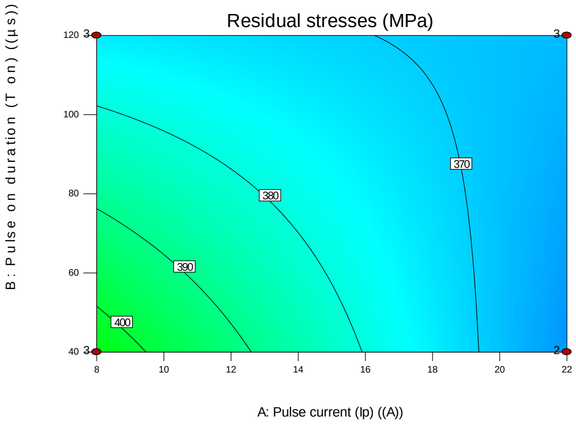

Figure 9. The contour model graphs for EDM processes using graphite electrodes and the kerosene dielectric alone, group (2)

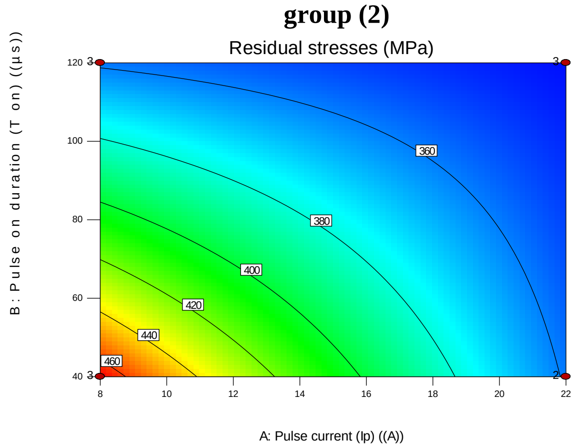

Figure 10. The contour model graphs for EDM and PMEDM using graphite electrodes and the kerosene dielectric with 5g/l SiC powder, group (2)

Numerical Optimization

For optimization and to develop the predicted inverse model with the best EDM and PMEDM parameters, a set of new goals for the response will be conducted to generate optimal combination conditions for these parameters. The new objective function named the desirability will allow evaluating the goals by properly combining. The main goals are to minimize the values of response surface residual stresses with the same ranges of the selected EDM parameters and electrodes types as mentioned in table (8) for EDM experiments using the copper electrodes. The best solutions found from the desirability process showed that the optimization predicted values of the surface residual stresses obtained when using the copper electrodes with pulse current about (22 A), pulse of duration about (120 µs) and without using the Sic mixed powder gives the best minimum tensile surface residual stress (315.337 MPa) with a maximum desirability ratio (1.000), as shown in table (9). , while the desirability process for graphite electrodes shows the optimum predicted values of the surface residual stresses obtained with similar parameters, those when use the copper electrodes, but with using the SiC powder mixing with kerosene dielectric gives the minimum surface residual stresses (346.415MPa) with a maximum desirability ratio (0.988) . The desirability process shows that the best predicting response values are approximately the same with the obtained values by experiments and this confirmation the results of the present work.

Conclusions

The main conclusions obtained can be summarized in the following:

By DOE and RSM technique with a two-level factorial design, empirical models were obtained for the surface residual stresses in terms of EDM input parameters

The results obtained when using the copper electrodes indicated that the tensile residual stresses decrease with increasing the pulse current up to (22 A) and pulse on duration value (up to 120 µs). The minimum tensile surface residual stresses reaches (316.8MPa) when working with kerosene dielectric alone, and (320.788 MPa) when using the kerosene dielectric with 5g/l SiC powder is. This means that the using of copper electrodes with kerosene dielectric alone induced residual stresses about (1.2%) lower than when using kerosene dielectric with 5g/l SiC powder.

When using the graphite electrodes and the kerosene dielectric alone, the results obtained indicated that the tensile residual stresses decrease with increasing value of pulse current (up to 22 A) and with decreasing value of pulse on duration time to (40 µs) and reaches (362.194 MPa), while when using the kerosene dielectric with SiC powder mixing with maximum value of pulse current (22 A) and maximum value of pulse on duration time too (120 µs) reaches (344.873 MPa). This means that the use of SiC mixed powder improve the tensile residual stresses obtained by about (5%) when comparing with the case of working with kerosene dielectric alone.

Also, the use of copper electrodes and kerosene dielectric alone gives residual stresses about (14%) lower than with graphite electrodes and (8%) lower when using the copper electrodes and kerosene dielectric with SiC powder mixing than with graphite electrodes.

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

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