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Enhancement of Surface Crack Density Produced by EDM Using Hybrid Machining

Abstract- The present work is aimed to improve the surface cracks density of electrical discharge machining (EDM) by Electrical Discharge Machining (EDM)/Electrochemical Machining (ECM) EDM/ECM hybrid process. A hybrid method of EDM-ECM combined processing involve EDM shaping as well as electrochemical machining (ECM) finishing, also, they are conducted in sequence one same machine tool, same electrode, yet on the different dielectric. In this study, the used workpiece material is the A2-Tool Steel material, while the electrode material is copper. The influence of controllable parameters could be identified via response surface methodology (RSM), these controllable effects include: pulse current, pulse on time, pulse off time, gap, voltage, and electrolyte concentration on surface cracks density (SCD). It has been noticed that model has been developed by RSM adequacy is acceptable because the coefficient of determination is closest to one for SCD, whereas the optimal solution achieved by Desirability Function Analysis (DFA) are (current $I_p = 42$ A, pulse-on time $T = 100$ μ s, and pulse-off time $T_{off} = 50$ μ s) in addition to that, the generated surface doesn't have any crack which has been generated via EDM are removed entirely through ECM finishing..

Keywords- Hybrid Machining (EDM/ECM), Surface Cracks Density, Response Surface Methodology

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1. Introduction

Concerning the process of EDM which is an abbreviation for electrical discharge machining, the material will be removed via the vaporization and melting throughout all electric discharges. Thus, a machined surface composed of thermally damaged layers which involve heat affected zone and white layer. In these distinctive layers, the residual stresses and micro cracks will be observed.

Concerning ECM, depending on the metal's ionic dissolution, the material will be removed, the surface which has been machined through ECM is considered extremely smooth, in addition to that, the generated surface is considered stress free and does not have micro cracks and burr, also it doesn't have thermally affected layers. A suitable hybrid process of ECM and EDM might offer the benefits of them [1]. The main aim of combining and developing the hybrid machining process is reducing or avoiding unfavorable impacts, also to take advantage of the combined processes the constituent processes offer in the case when they are utilized separately. The performance features related to the hybrid process are significantly dissimilar to those of single-phase processes regarding surface quality, productivity, and accuracy [2]. K. Morankar and R. Shelke[3], Introduced a model through utilizing RSM, which is an abbreviation for Response Surface

Methodology, with regard to gap voltage, pulse on time and peak current for evaluating the surface roughness and metal removal rate. The results show that the pulse on time and the peak current have considerable effects on surface roughness and MRR values. V. Babu et al [4], investigated the influence of different EDM variables. The obtained outcomes of experiments indicate that high MRR is offered via the copper electrodes in comparison to machining which is done via brass electrodes. M. K. Pradhan [5], developed a predictive model by response surface methodology to study the effect of process parameters. For evaluation of surface crack density, four input parameters are considered pulse current (I_p), duty cycle, pulse-on-time (T_{on}) and gap voltage (V) were considered, the authors believe that the pulse-on-time was the most influential parameter for surface integrity followed by duty factor, pulse current, and discharge voltage. M. Boujelbene et al [6], performed a series of experiments on the tool steel, the results show that the crack formation is caused by the stress induced by the electrical discharge machining (EDM) process when the degree of induced stress exceeds the maximum tensile strength of the material cracking will occur. G. K. M. Rao et al. [7], have performed a group of

experimental studies to investigate the influence of process parameters, namely (peak current, pulse duration and duty factor) on the average crack length. Results show that, when Pulse-on-time is increased, the average cracks length are decreased. B. Bhattacharyya et al.[8], used analysis of variance (ANOVA) and a mathematical model developed by response surface methodology to find out the influence of controllable parameters. For evaluation of surface crack density (SCD), two controllable parameters are considered pulse current and pulse-on time. Die steel (M2) was used as a workpiece material, whereas copper was used as tool electrode. It was found that pulse current and pulse-on time significantly influence various criteria of surface integrity such as surface roughness (SR) and surface crack density (SCD).

Jeykrishnan et al [9], an attempt has been made to carry out the optimization of parameters based on the Taguchi method. The results show that voltage and current holds an extra impact on the process followed by electrolyte concentration. M. Zohoor et al [9], reported the influence of machining parameters of electrochemical machining namely (electrolyte type and current). It was found that in Sodium Chloride and Potassium Chloride electrolytes the surface roughness increases with the decrease in current but in Sodium Nitrate it increases with an increase in current. S. H. Surekar and S. G. Bhatwadeka [10], studied the impact of the ECM's machining parameters on the output parameter (SR). a used aqueous solution of Sodium Nitrate (NaNO_3) as the electrolyte. The Results show that the surface roughness decrease when increase gap voltage from (12 to 16) V.

From the above literature survey, it is concluded that the little researches have focused on the deionized water as the dielectric medium in electrical discharge machining (EDM), also can be used the same liquid in EDM and ECM process to made hybrid EDM/ECM process on the same machine tool. Few studies have focused on the mathematical modeling of surface crack density. The Aims of this study is to enhance the crack formation produced via the EDM with the shortest machining time by hybrid machining EDM/ECM.

2. Experimental Procedure

In this study, AISI A2-Tool steel has been utilized as the workpiece. The workpiece's chemical composition is listed in the Table 1. The workpiece was square shape with dimensions (3.5x38x38) mm, whereas copper was used as the electrode material for both

EDM and ECM machining processes, it is a cylindrical shaft with (10) mm diameter and (60) mm length as illustrated in Figure 1.

Table 1: chemical composition of the A2-Tool Steel.

Element	C	Mn	P	Cr	V	Mo	Si	Fe
Weight (%)	1	0.6	0.03	5	0.35	1	0.3	Balance

An Electrical Discharge machine (CHMER EDM) model(CM 323+50N) with servo-control has been used to perform the experiments, which is located at the workshop and training center in the University of technology-Iraq. In order to complete the ECM finishing experiments external power supply, with specific value of current and voltage was connected to the CHMER EDM machine. The power supply has been used due to the ECM finishing process required a lower value of controllable parameters which are not provided by the EDM power supply unit.

In the present study, one of the most important challenges is the choice of fluid that can be used as a dielectric and electrolyte medium. De-ionized water was selected as dielectric fluid to complete the experiments of EDM because of its non-conductivity, low cost, low viscosity, safe to use and non-toxic. The same dielectric medium can be converted to the electrolytic medium by the added solution of (NaCl) to it with different concentration for performed ECM finishing experiments.

Response surface methodology (RSM) has been utilized to design experiments, matrices have been developed based on Face-Centered Central Composite Design (FCCCD). The machining parameters as shown in the Tables 2 and 3, six factors and three levels of twenty experiments for each matrix. Generally, the experimental procedure can be summarized in two steps:-

Step (1):-EDM experiments (only) have been conducted for the purpose of studying the influence of independent parameters, and to find out the mathematical models which describe the relationships between independent and dependent parameters.

Step (2):- EDM/ECM hybrid process(EDM shaping+ ECM finishing) experiments have been conducted to remove the thermal effects produced by EDM shaping. These experiments have been

performed based on the optimum EDM parameters are obtained through Multi-objective-optimization of the responses obtained from step (1). The surface crack density can be expressed as the average length of cracks in μm , at a different area for the same machined surface divided by the total area in μm^2 . The top surface of the workpiece has been measured by an optical microscope at magnification 400X.

Table 2: EDM controllable parameters.

	Level (1)	Level (2)	Level (3)
Current (A)	30	36	42
Pulse-on Time (μs)	100	150	200
Pulse-off Time (μs)	50	75	100

Table 3: ECM finishing controllable parameters.

	Level (1)	Level (2)	Level (3)
Voltage (v)	5	10	15
Electrolyte Concentration (g/l)	10	20	30
Gap (mm)	0.6	0.8	1

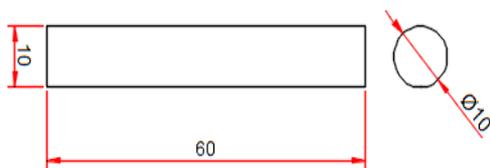


Figure1: Electrode Shape.

3. Results

3.1. EDM Results

A number of trials have been made to examine the effects of input variable parameters on the process's responses to determine the thermal effects and then to treat them by EDM/ECM hybrid process, these trials were carried out at depth of cut equal to (1)mm. The machining characteristics value for SCD are tabulated in the table 5.

Regression analysis has been performed to determine the relationship between input variable parameters and the response of the machining

process. The mathematical model was developed based on the experimental data, the general second-order model has been utilized in this study were developed by RSM. The mathematical model for different required performance measures was developed as illustrated in equation (1).

$$SCD = 0.0530 - 0.002549 \text{ current} + 0.000206 \text{ pulse on} - 0.00011 \text{ pulse off} + 0.000055 \text{ current}^2 - 0.0000004 \text{ pulse on}^2 - 0.0000003 \text{ pulse off}^2 - 0.000004 \text{ current} \times \text{pulse on} + 0.000001 \text{ current} \times \text{pulse off} + 0.000005 \text{ pulse on} \times \text{pulse off} \text{ (1)}$$

The goodness of fit for a second-order regression model was developed can be examined by a coefficient of determination (R^2). Table 4 present the value of (R^2), adjusted coefficient of dtermination (R_{adj}^2) and the prediction coefficient of dtermination (R_{pred}^2) for a mathematical model that has been developed. The difference between experimental and predicted data illustrated in Figure 2.

Analysis of variance (ANOVA) technique has been utilized for the determined dominating parameters and to checking the effectiveness of the second-order model for each response of the machining process. ANOVA was used for testing the null hypothesis of the observed values at a confidence level of (95) %. The significance of the parameter has been tested by Fisher's statistical test (F-test), the higher value of the (F-test) present the more significant factor. If $p\text{-value} \leq 0.05$, it is concluded that the factor has a statistically significant effect. Table 6 presents the analysis of variance ANOVA for SCD.

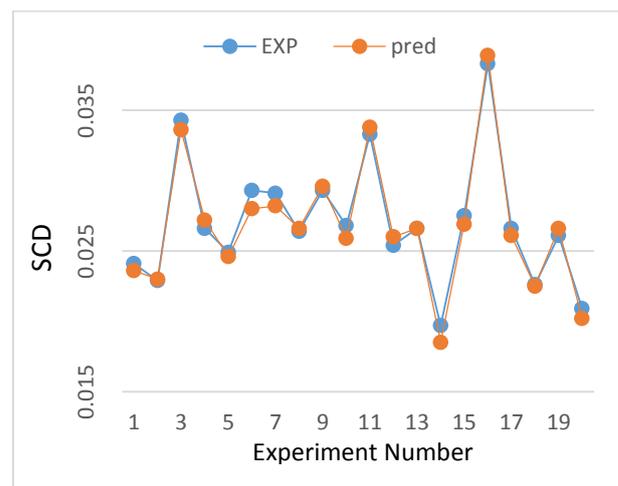


Figure 2: Comparison between experimental and predicted data.

Table 4: Coefficient Value.

	R^2	R^2_{adj}	R^2_{pred}
SCD	99.3%	98.34%	90.23%

Table 5 : EDM Machining Characteristics Value

RunOrder	Blocks	Pt type	Current (A)	Pulse-On(μs)	Pulse-Off(μs)	SCD($\mu m / \mu m^2$)
1	3	-1	30	150	75	0.0241
2	3	-1	36	200	75	0.0229
3	3	-1	42	150	75	0.0343
4	3	0	36	150	75	0.0266
5	3	-1	36	150	100	0.0249
6	3	-1	36	100	75	0.0293
7	3	-1	36	150	50	0.0291
8	3	-1	36	150	75	0.0264
9	1	1	42	200	50	0.0293
10	1	0	36	150	75	0.0268
11	1	1	42	100	100	0.0333
12	1	1	30	100	50	0.0254
13	1	0	36	150	75	0.0266
14	1	1	30	200	100	0.0197
15	2	1	42	200	100	0.0275
16	2	1	42	100	50	0.0383
17	2	0	36	150	75	0.0266
18	2	1	30	200	50	0.0226
19	2	0	36	150	75	0.0261
20	2	1	30	100	100	0.0209

Table 6: ANOVA For SCD Response.

Source	DF	SS	MS	F-Value	P-Value
Model	11	0.000376	0.000376	103.49	0.000
I_p	1	0.000250	0.000250	754.94	0.000
T_{on}	1	0.000064	0.000064	191.77	0.000
T_{off}	1	0.000034	0.000034	102.24	0.000
$I_p * I_p$	1	0.000010	0.000010	32.74	0.000
$T_{on} * T_{on}$	1	0.000003	0.000003	9.63	0.015
$T_{off} * T_{off}$	1	0.000001	0.000001	0.29	0.603
$I_p * T_{on}$	1	0.000014	0.000014	44.03	0.000
$I_p * T_{off}$	1	0.000000	0.000000	0.14	0.722

$T_{on} * T_{off}$	1	0.000002	0.000002	8.70	0.018
Residual Error	8	0.000002	0.000002		
Total	19	0.00038			

Figure 3 shows the main effects plot of controllable parameters on SCD. From this Figure it can be observed that the pulse current (I_p), pulse-on time (T_{on}) and pulse-off time (T_{off}) have the significant influence on SCD, and the discharge current is the most dominating parameter among all the process variables parameters, which is supported by Table 6. Figure 3 shows that the SCD is directly proportional to the current, the current exhibit the slightly increased in the mean of SCD of (0.0039) when current rises from (30-36 A), whereas shows sharply increased of (0.0060) when current rises (36 - 42 A). This may be due to the reason that the cracks initiation at the top surface of recast layer and then extended to HAZ, the density and propagation of this crack because of thermal stresses are developed on the machined surface, hence when the pulse current increased the large amount of heat is transferred to the machining zone, which results in the thermal stress are introduced and exceeds the maximum strength of material and so surface crack density increased.

As it is evident, the mean of SCD inversely proportional to the pulse-on time, introduced decreased in the mean of SCD of (0.0022) when pulse-on time rises from (100 μs to 150 μs), whereas it shows slightly decreased of (0.0027) when pulse-on time rises (150 μs to 200 μs). This is may be attributed to the expanded of plasma channel and high contamination at long times fill the cracks by metal particles and debris. The combined effects of (current, pulse current and pulse-off time) on SCD as shown in Figure 4.

Desirability function analysis (DFA) has been conducted through it integrated with the response surface methodology, that is utilized for overcoming the issue of conflicting responses related to single response optimization of the EDM process. Usually when selected optimum machining condition in EDM process the goal of optimization is achieved at the minimum value of SCD, whereas in this study the main objective is the improvement of surface cracks density (SCD) produced in EDM process by EDM/ECM combined process, due to which have been selected response at maximum value for optimization condition to enhancement of crack formation by ECM finishing. The optimal set of the solution

with higher desirability function under specified constraints are illustrated in Figure 5, from it can be observed that the highest desirability condition of (1) are achievable at a discharge current $I_p = 42$ A, pulse-on time $T_{on} = 100 \mu s$, and pulse-off time $T_{off} = 50 \mu s$, this optimal solution.

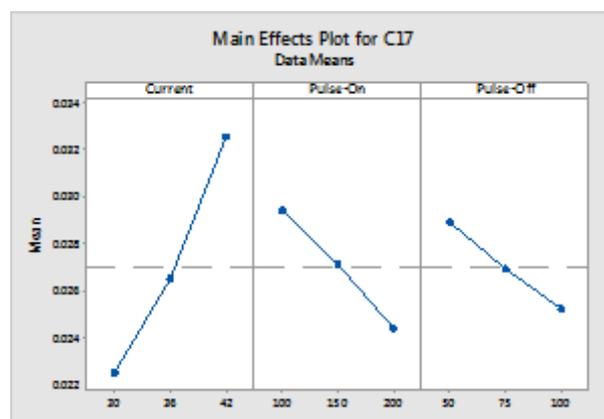


Figure 3: Main effects plot for surface cracks density.

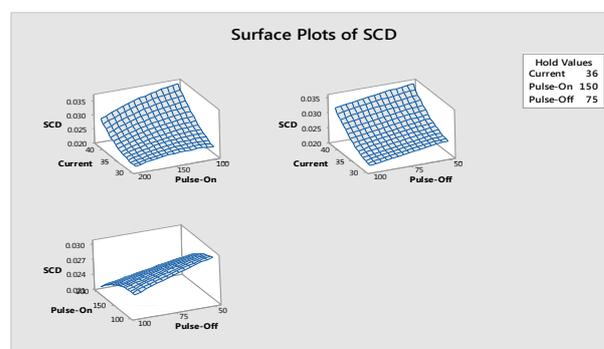


Figure 4: Combination effects of (current, pulse current and pulse-off time) on surface cracks density.

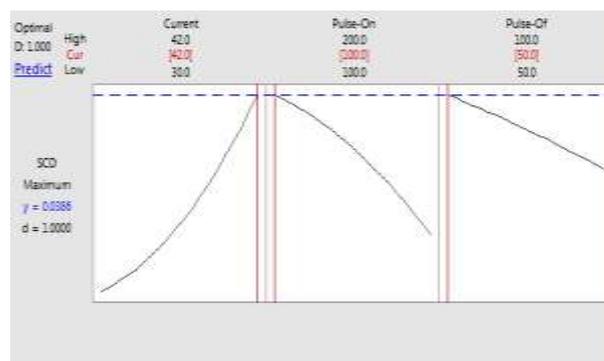


Figure 5: Multi-response optimization by (DFA).

II.EDM/ECM Results

In order to enhance the cracks formation of the machined surface by EDM process, EDM/ECM combined process has been carried out at the same machine tool. This process performed with two steps, the first step is EDM shaping at depth of cut equal to (0.85)mm, whereas the second step is ECM finishing at the recent depth of cut (0.15)mm.

EDM experiments have been performed at optimum conditions are obtained by (DFA), as discussed above, while the ECM trails were carried out for three parameters, three levels. Surface crack density is completely removed from the machined surface by the hybrid process at all condition of ECM finishing as shown in Figures 6, and 7.

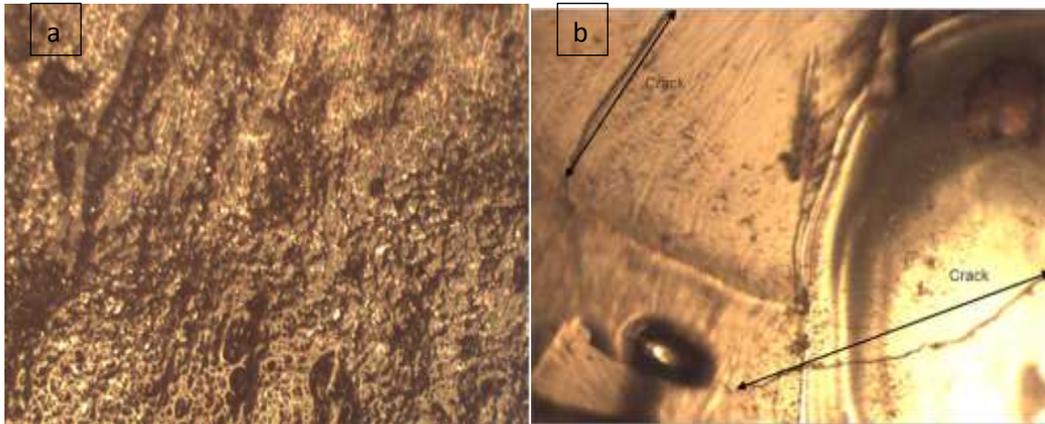


Figure 6: Machined surface at Magnification 40x (a) EDM (b) EDM/ECM.

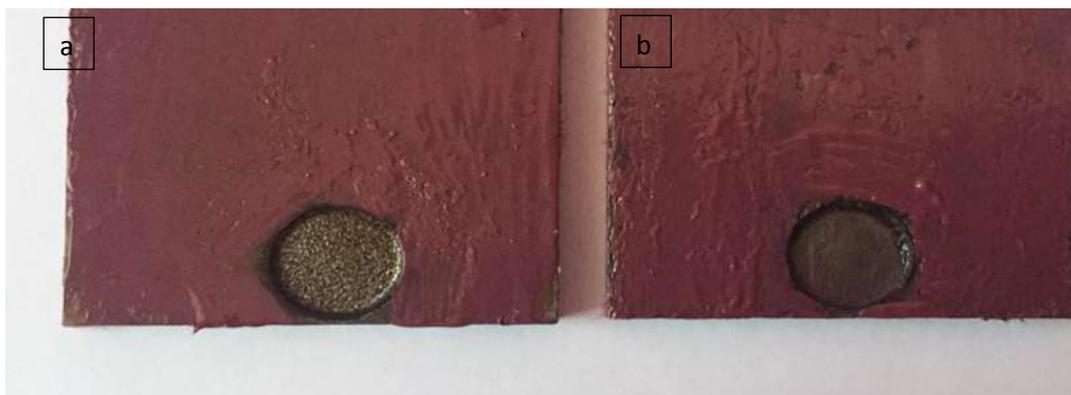


Figure 7: (a) EDM machined surface. (b) EDM/ECM machined surface.

4.Conclusion

Based on the experimental results, the following conclusions are drawn

- The surface cracks density (SCD) produced by a single EDM process can be enhancement by hybrid EDM/ECM process. The SCD has been completely removed from the machined surface.
- The developed model shows high accuracy of prediction within the experimental data, with the maximum difference between experimental and predicted data is (4.436%).
- The input parameters have significantly influenced the response of the process.
- ANOVA shows that the percentage contribution of input parameters, i.e, I_p , T_{on} and T_{off} are 65.789%, 16.842%, and 8.947 respectively.

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