PAPER • OPEN ACCESS

Enhancement the Thermal Effects Produce by EDM Using Hybrid Machining

View the article online for updates and enhancements.

Enhancement the Thermal Effects Produce by EDM Using Hybrid Machining

Saad K Shather[1], Shukry H. Aghdeab[1] and Waqass S. Khudhier[1]

[1]Department of Production Engineering and Metalluragy, University of Technology, Baghdad-Iraq.

Email: Waqass@yahoo.com

Abstract:- The present work is aimed to improve the thermal effects of electrical discharge machining (EDM) by 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. Concerning the process of EDM, the material will be removed via the vaporization and melting throughout all electric discharges. Thus, thermally damaged layers make the machined surface. 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 RSM, which is an abbreviation for Response surface methodology, these controllable effects include: pulse current, pulse on time, pulse off time, gap, voltage, and electrolyte concentration on white layer thickness (WLT) and Surface Roughness (SR). It has been noticed that model adequacy is acceptable because the coefficient of determination is closest to one for WLT and SR, in addition to that, the generated surface doesn't have thermally affected layers as the SR and recast layers which have been generated via EDM are removed entirely through ECM finishing.

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]. C. Kare et al. (2018) [3] examined the influence of various parameters of EDM on the following responses, radial over cut (OC) and electrode wear rate (EWR). The brass tool is utilized for machining of Al 7075-red mud metal matrix composite material. Authors have found out that the peak current has a considerable impact on responses in comparison

to other inputs such as gap voltage and pulse on time. K. Morankar and R. Shelke (2017) [4] 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 (2016) [5] 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. C. S. Jawalkar et al. (2014) [6] have studied the impact related to some of the process parameters on recast layer surface roughness in the process of EDM. ANOVA results show that when the pulse pause time increases, them the SR will decrease slowly, while when the pulse pause time increases, then the SR will rapidly increase. S. Rajendran et al (2012) [7] machined T90Mn2W50Cr4 Tool Steel by electrical discharge machining EDM for the purpose of determining the process parameters' effect on the resolidified layer and crack formation, The design of experiments was carried out using a central composite rotatable design (CCDR). They concluded that the layer on machined surface occurs with high peak current, which causes the rapid vaporization of dielectric fluid. Under the high current, the dielectric fluid vaporizes rapidly. Hence, the dielectric fluid is not available for flushing out the molten metal. Therefore, the resolidified layer is deposited on the machined surface. J. Jeykrishnan et al. (2017) [8] 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 SR followed-by electrolyte concentration. M. Zohoor et al (2016) [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 (2016) [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 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 roughness, and white layer thickness. The Aims of this study is to enhance the thermal effects of EDM with 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 made to the square shape with dimension(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.

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

Element	C	Mn	P	S	Cr	V	Mo	Si	Fe
Measured %	1	0.6	0.03	0.03	5	0.35	1.1	0.3	balance

An Electrical Discharge machine (CHMER EDM) model(CM 323+50N) with servo-control has been used to performe the experiments as illustrated in Figure 1, 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 was with the 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 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 it 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).

Figure1. EDM machine (CHMER EDM)

Table 2. EDM controlable parametrs.

	Level (1)	Level (2)	Level (3)
Current (A)	30	36	42
Pulse-on time(μs)	50	100	150
Pulse-off time(μs)	25	50	75

Table 3. ECM finishing controlable parametrs.

	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

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 trails were carried out at depth of cut equal to (1) mm. The machining characteristics value for SR, and WLT are tabulated in the table 4.

Regression analysis has been performed to determine the relation between input variable parameters and the responses of the machining process. The mathematical models were developed based on the experimental data, the general second-order model has been utilized in this study were developed by RSM. The mathematical models for different required performance measures were developed as illustrated in the equations (1) and (2).

SR= 14.41 – 0.779 current + 0.03222 pulse on + 0.0147 pulse off +0.01364 current* current – 0.000104 pulse on* pulse on – 0.000008 pulse off* pulse off - 0.000175 current*pulse on – 0.00073 current*pulse off + 0.000008 pulse on*pulse off   ……………(1).

WLT= 27.7 - 1.496 current - 0.0383 pulse on + 0.663 pulse off + 0.0335 current* current - 0.000101 pulse on* pulse on – 0.003861 pulse off* pulse off + 0.000205 current*pulse on – 0.00317 current*pulse off - 0.000361 pulse on*pulse off   …………(2).

The goodness of fit for a second-order regression model was developed can be examined by cofficent of determination(R^2). Table (5) present the value of (R^2), (R^2_{adj}) and (R^2_{pred}) for all mathematical models that have been developed.

Table 4. EDM Machining Characteristics Value.

Run Order	Blocks	Pt type	Current (A)	Pulse-On (μs)	Pulse-Off(μs)	SR (μm)	WLT (μm)
3	-1	30	150	75	4.68	23.594	
3	-1	36	200	75	4.36	21.216	
3	-1	42	150	75	6.012	31.764	
3	0	36	150	75	4.74	25.977	
3	-1	36	150	100	4.43	21.143	
3	-1	36	100	75	4.83	31.221	
3	-1	36	150	50	5.27	26.975	
3	0	36	150	75	4.74	25.964	
1	1	42	200	50	5.79	26.923	
1	0	36	150	75	4.75	26.112	
1	1	42	100	100	5.62	30.564	
1	1	30	100	50	4.56	25	
1	0	36	150	75	4.72	25.54	
1	1	30	200	100	3.9	13.441	
2	1	42	200	100	5.03	21.328	
2	1	42	100	50	6.34	34.546	
2	0	36	150	75	4.74	25.54	
2	1	30	200	50	4.14	17.321	
2	0	36	150	75	4.76	25.14	
2	1	30	100	100	4.2	23.112	

Table 5. Coefficient Value

	R^2	R^2_{adj}	R^2_{pred}
SR	99.00%	97.67%	86.05%
WLT	99.26%	98.24%	88.31%

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 of level of (95) %. Significance of the parameter has been tested by Fishers statistical test (F-test), the higher value of the (F-test) present the more significant factor. If p-value ≤ 0.05, it is concluded that the factor has a statistically significant effect. Tables (6 and 7) presents the analysis of variance ANOVA for all responses namely (SR and WLT), these tables include P-value, Mean Square (MS), F-Test, Degree of Freedom (DF) and Sum of Squares (SS).

Table 6. ANOVA For SR Response.

Source	DF	SS	MS	F-Value	P-Value
Model	11	7.59194	0.69018	73.35	0.000
I_p	1	5.34653	5.34653	568.20	0.000
T_{on}	1	0.54289	0.54289	57.70	0.000
T_{off}	1	0.85264	0.85264	90.61	0.000
$I_p * I_p$	1	0.64758	0.64758	68.82	0.000
$T_{on} * T_{on}$	1	0.18121	0.18121	19.26	0.002
$T_{off} * T_{off}$	1	0.00006	0.00006	0.01	0.937
I_p*T_{on}	1	0.02205	0.02205	2.34	0.164
I_p*T_{off}	1	0.09680	0.09680	10.29	0.012
$T_{on} * T_{off}$	1	0.00080	0.00080	0.09	0.778
Residual Error	8	0.07528	0.00941		
Total	19	7.66722			

Table 7. ANOVA For WLT Response.

Source	DF	SS	MS	F-Value	P-Value
Model	11	454.975	41.361	97.65	0.000
I_p	1	181.962	181.962	429.61	0.000
T_{on}	1	195.488	195.488	461.54	0.000
T_{off}	1	44.847	44.847	105.88	0.000
$I_p * I_p$	1	3.910	3.910	9.23	0.016
$T_{on} * T_{on}$	1	0.173	0.173	0.41	0.541
$T_{off} * T_{off}$	1	15.629	15.629	36.90	0.000
I_p*T_{on}	1	0.030	0.030	0.07	0.796
I_p*T_{off}	1	1.814	1.814	4.28	0.072
$T_{on} * T_{off}$	1	1.625	1.625	3.84	0.086
Residual Error	8	3.388	0.424		
Total	19	458.363			

Figure 2 display the major impact plot regarding the controllable parameters on SR.From this Fig can be observed that the I_p, T_{on}, and T_{off} have a significant influence on SR, the pulse current can be considered as the most important parameters between all the process variables parameters, Which is supported by table 6. This Fig shows the SR directly proportional to the current, The current is the most influencing factor exhibit the slightly increased in the mean of SR of (0.138) when current rises from (30 Amp to 36 Amp),whereas shows sharply increased of (1.024) when current rises (36 Amp to 42 Amp). This is because of the increase in the pulse current causes increased intensely of discharge spark which it strikes the surface of the workpiece, and causing degraded erosion effect leads to increase in molten materials, part of this molten material is flushed away by dielectric whereas the overheated material evaporates leads to large crater formation,thereby rough surface was produced. As it illustrates in Figure 2, the SR decreased by (0.226), pulse-on time increase from $100\mu s$ to $150\,\mu s$, whereas decreases by (0.24), when pulse-on time increased from $150\mu s$ to $200\mu s$. This may be due to the reason that at the initial level of the pulse-on time leads to maximize the spark density in the plasma channel because of not allow to expand of this channel as described earlier, this will cause an increase in the amount of heat energy which is transferred to the surface of the workpiece, and so more material melts. In the case when the molten material isn't flushed away from the machined surface via the dielectric medium, it will solidify and produced a resolidified layer with deterioration of the surface roughness. As it evident from Figure 3, the main effects of pulse-off time have the same tendency. The SR slightly decreased by (0.387), pulse-off time increased from $50\mu s$ to $75\mu s$ and slightly decreased by (0.201) when pulse-off time increased from $75\mu s$ to $100\mu s$. This is because the increase in pulse-off time causes undesirable heat dissipation and temperature of the machined surface will be decreased cause less amount of molten material and small crater produced, thereby surface roughness decreased. The combined effects of (pulse-off time, current and pulse current) on SR as displayed in Figure 3.
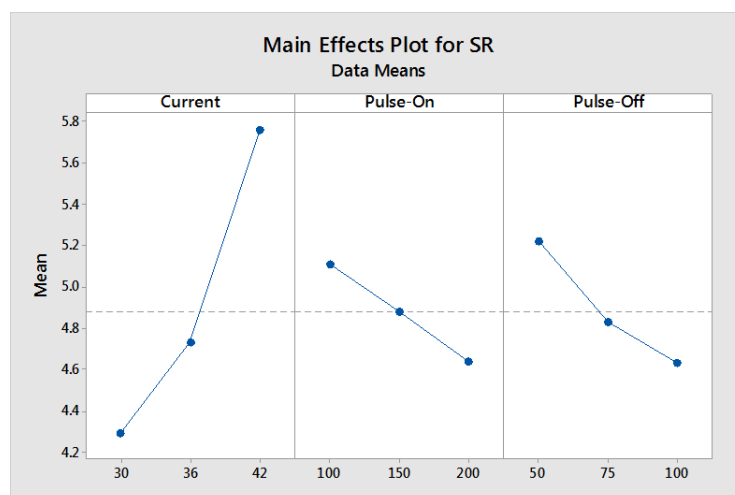

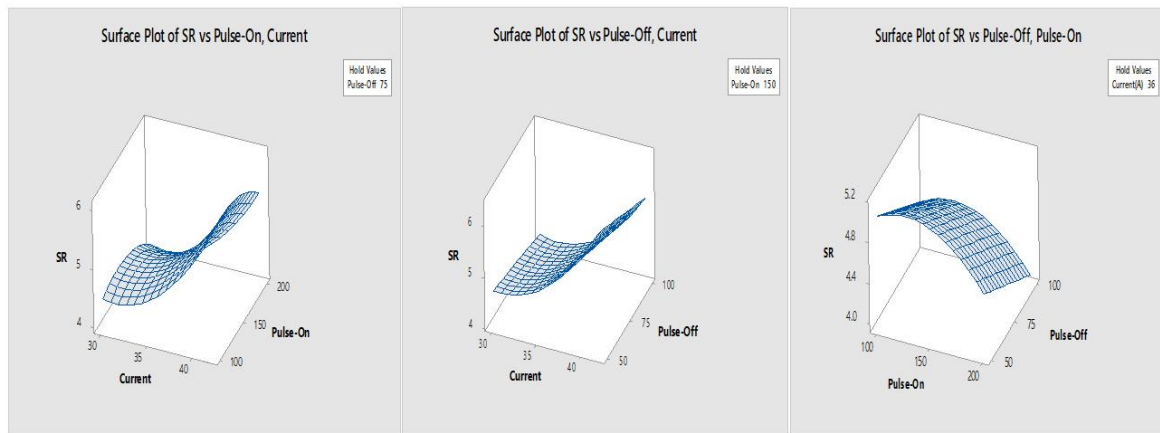**Figure 2.** Main effects plot for surface roughness.

Figure 3. Combination effects of (current, pulse crrent and pulse-off time) on surface roughness.
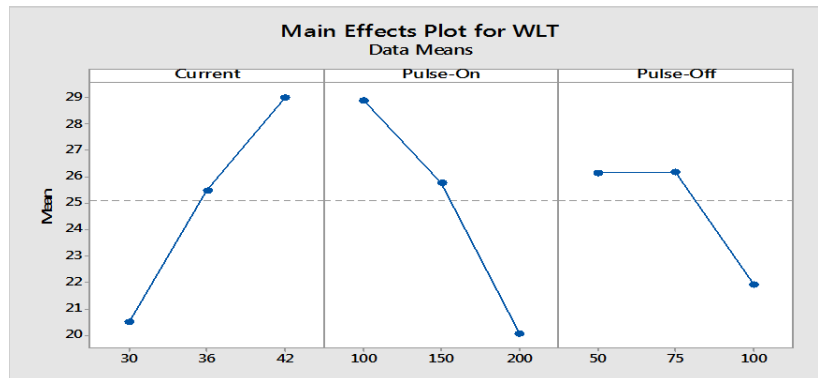

Figure 4. Main effects plot for white layer thickness

The main effects plot on MRR can be estimated by Figure 4, from this Figure can be observed that I_p, T_{on}, and T_{off} have a considerable impact on WLT, that is supported via a table 7.

In addition, the WLT directly proportional to the current, The current exhibit the sharp increased of (4.539) and (3.543) in the mean of WLT when current rises from (30 Amp to 36 Amp) and (36 Amp to 42 Amp) respectively. This is clarified through the point that as the current increase the more heat is transferred to the machined surface, due to which increases the amount of molten metal. The amount of molten metal that could be flushed away via dielectric is considered constant, this leads to the dielectric is increasingly unable to flush the molten material, and so it builds upon the machined surface as white or recast layer.

As it evident from Figure 4 the pulse-on time inversely proportional to the formation of WLT. Reduction in thickness of white layer respect to time may be attributed to the intensity of the plasma channel gets expanded when pulse-on time increase, because of the discharge energy and the spark intensity is decreased, causing less amount of heat generated on the machined surface, which resulted in reduced the thickness of the white layer.

In addition, the impact of pulse-off time on WLT as displayed in Figure 4, it can be observed that the pulse-off time cause less effect on the thickness of recast layer from the recent controllable parameter. It can be explained with the phenomenon that at a long time of pulse-off allow to clear the debris and flushed the molten material from the machining zone, due to which less thickness of recast layer is produced. The combined effects of (current, pulse current and pulse-off time) on WLT as shown in Figure 5.
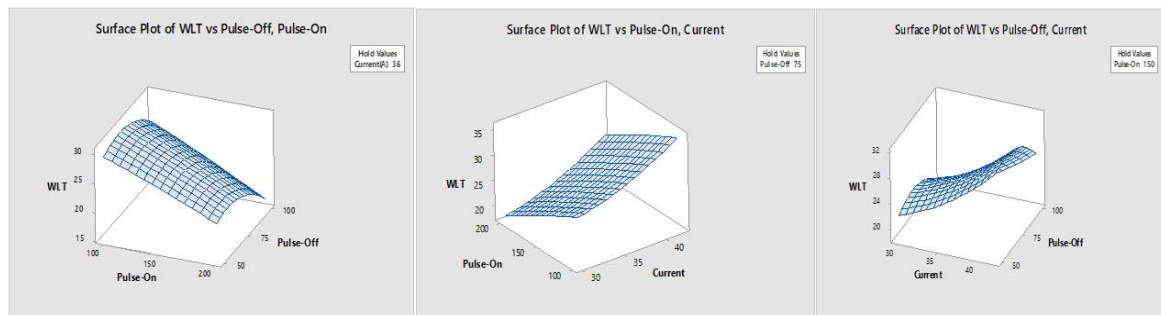
Figure 5. Combination effects of (current, pulse crrent and pulse-off time) on white layer thickness.

Multi-response optimization has been conducted through utilizing desirability function analysis (DFA) which is integrated with the response surface methodology, that is utilized for overcoming the issue of conflicting responses related to single response optimization of EDM process. Usually when selected optimum machining condition in EDM process the goal of optimization is achieved at the minimum values of other responses, whereas in this study the main objective is to improvement of thermal effects produced in EDM process by EDM/ECM combined process, due to which have been selected all responses at maximum value for optimization condition to enhancement of rough surface and thick recast layer by ECM finishing. The optimal set of the solution with higher desirability function under specified constraints are illustrated in Figure 6, from it can be observed that the highest desirability condition of (1) are achievable at discharge current I_P =42 A, pulse-on time T_{on} =100 μs, and pulse-off time T_{off}=50μs, this optimal solution.
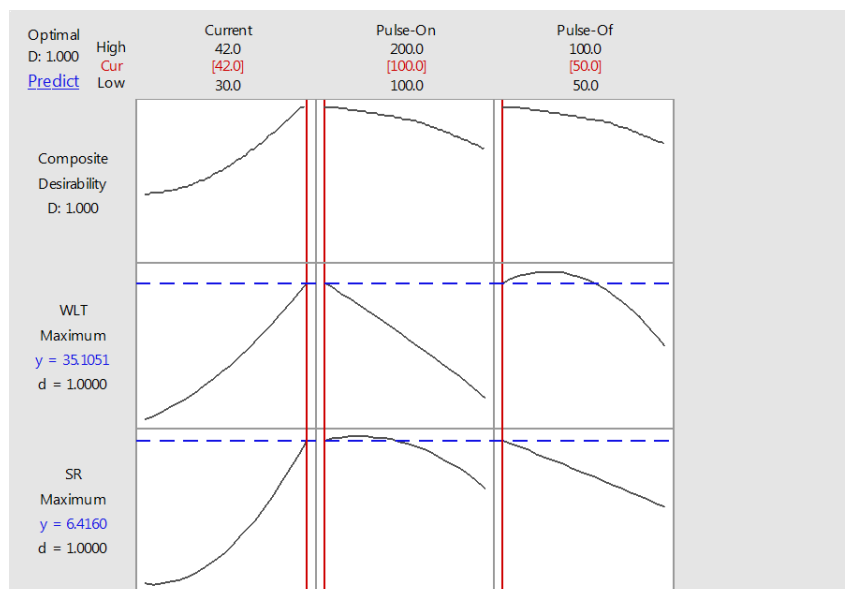

**Figure 6.** Multi response optimization by (DFA).

3.2 EDM/ECM Results

In order to enhancement the thermal effects 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, the machining characteristics value of EDM/ECM combined process are tabulated in the table 8.

As it illustrates in table 8, the minimum and maximum value of SR is (0.961) and (2.279) µm respectively,whereas the initial SR value of machined surface without finishing is (6.34) µm as shown in Figure 7, which also exhibit the comparison between EDM and EDM/ECM process. White layers are completely removed from the machined surface as shown in Figure 8.

Table 8. Characteristics of EDM/ECM combined process.

RunOrder	PtType	Blocks	Voltage (v)	Concentration (g/l)	Gap (mm)	Ra (µm)
1	0	3	10	20	0.8	2.071
2	-1	3	15	20	0.8	1.988
3	-1	3	10	20	1	1.846
4	0	3	10	20	0.8	2.081
5	-1	3	10	30	0.8	2.189
6	-1	3	10	10	0.8	1.6
7	-1	3	5	20	0.8	2.154
8	-1	3	10	20	0.6	2.199
9	1	2	5	30	0.6	1.99
10	0	2	10	20	0.8	2.081
11	1	2	15	10	0.6	2.03
12	1	2	15	30	1	2.132
13	1	2	5	10	1	1.317
14	0	2	10	20	0.8	2.081
15	1	1	5	30	1	2.279
16	1	1	15	10	1	0.961
17	0	1	10	20	0.8	2.089
18	1	1	5	10	0.6	1.95
19	1	1	15	30	0.6	2.041
20	0	1	10	20	0.8	2.066
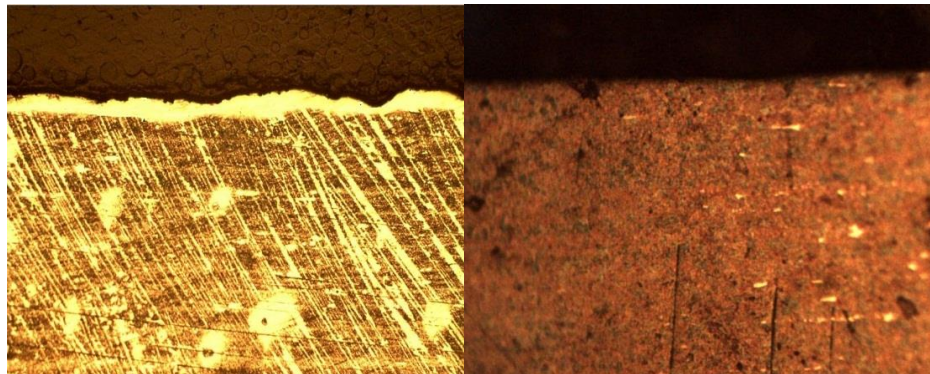
Figure 7. Machined surface by   (a) EDM   (b) EDM/ECM
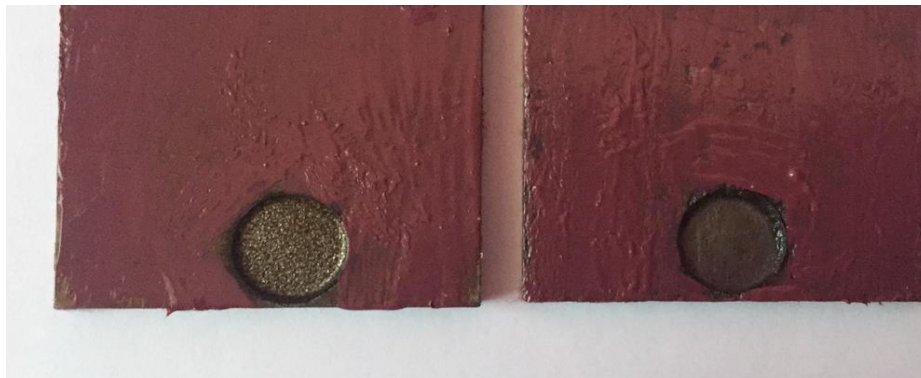
Figure 8.   (a) EDM machined surface.   (b) EDM/ECM machined surface

4.Conclusions

Based on the experimental results, the following conclusions are drawn

- The input parameters have significantly influenced the responses of the process.
- The developed model show high accuracy of prediction within the experimental data.
- Pulse current and pulse off time have a more significant contribution on the surface roughness than other parameters.
- Pulse current and pulse on time have a more significant contribution to the white layer thickness than other parameters.
- the white layer and surface roughness produced by single EDM process can be enhancement by hybrid EDM/ECM process. The highest percentage of enhancement for the SR was achieved to 84.8 % when surface roughness decreased from (6.34 to 0.961) µm, whereas the WLT has been completely removed from the machined surface.

References

[1] M. Dang, M. Rahman, and Y. S. Wong, 2012 " Simultaneous micro-EDM and micro-ECM in low-resistivity deionized water*," International Journal of Machine Tools & Manufacture*, **vol. 54–55**, pp. 55–65.

[2] Hassan Abdel Gawad El-Hofy, *Advanced Machining Processes; Non Traditional and Hybrid Machining Processes.* 2005.

[3] C.Kare, B.Surekha, Hemalatha Jena and Suvan Dev Choudhury, 2018 'Study of Influence of Process Parameters in Electric Discharge of Aluminum – Red Mud Metal Matrix Composite',*2nd International Conference on Materials Manufacturing and Design Engineering*, **vol. 20**, pp. 392–399.

[4] K. Morankar and R. Shelke, 2017 'Optimization of Electrical Discharge Machining Process Parameters using JIS S CM420 low alloy steel by Response Surface Methodology',*International Journal of Research in Engineering & Advanced Technology,* **vol. 5**, no. 1, pp. 58–63.

[5] V. Babu, J. S. Soni, and M. L. Rao, 2016 "Analysis and evaluation of heat affected zones (HAZ) of the work piece surface machined using different electrode by Die-sinking EDM of EN-31 die steel",*International Journal Of Engineering And Science (IJES),* pp. 37–42.

[6] C. S. Jawalkar, R. R. Mishra, and A. K. Sharma, 2014 "Study Of Recast Layers And Surface Roughness On A L-7075 Metal Matrix Composite During Edm Machining', *International Journal of Recent advances in Mechanical Engineering (IJMECH)*, **vol. 3**, no. 1, pp. 53–62.

[7] S. Rajendran, K. Marimuthu, and M. Sakthivel, "Study of Crack Formation and Resolidified Layer in EDM Process on T90Mn2W50Cr45 Tool Steel', *Materials and Manufacturing Processes*, **vol. 28,** no. 2012, pp. 664–669.

[8] J. Jeykrishnan, B. V. Ramnath, C. Elanchezhian, and S. Akilesh, 2017 " 'Parametric analysis on Electro-chemical machining of SKD-12 tool steel', *5th International Conference of Materials Processing and Characterization*, **vol. 4**, no. 2, pp. 3760–3766.

[9] M. Zohoor, S. Jalili, A. Alipour, and R. Mosallanejad, 2016 " 'Effect Of Electrolyte Type On Electrochemical Machining Of 304 Steel', *International Journal of Advances in Engineering Research (IJAER)*, **12**, pp. 20–39.

[10] S. H. Surekar and S. G. Bhatwadekar, 2016 "'Optimization of Parameters in Electrochemical Machining of Ni- Base Superalloy', *Nternational Journal Of Research In Aeronautical And Mechanical Engineering*, **vol. 4**, no. 1, pp. 72–80.