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Performance Study on Electro Chemical Machining with Fuzzy Optimization

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Abstract—*Electrochemical Machining (ECM) primarily used to cut hard or difficult-to-cut metals. Influence of Sodium Nitrate solution (NaNO3) on Material Removal Rate (MRR), Surface roughness, and Overcut of high hardened die steel by ECM is investigated. In order to maximise MRR while minimising surface roughness and overcut, the effects of NaNO3 aqua solution on the work piece have been researched, and a relationship between the factors has been established. The NaNO3 aqua electrolyte solution provided improved results in terms of MRR, surface roughness, and overcut when electrochemically machining high hardened die steel.*

Keyword- *Electrochemical Machining; Mathematical Modal; Fuzzy Logic.*

INTRODUCTION

Electrochemical machining is a type of electrochemical dissolution that takes place anodically. Electrical energy is used in ECM to remove material from an electrolyte medium. A D.C. voltage (typically around 10 to 25 volts) is provided across the inter electrode gap.

The electrolyte (for example, aqueous $NaNO_3$ solution) flows quickly across the gap (about 0.1 to 0.6 mm). The anode work piece dissolves at current densities of 20 to 200 g/cm^3. Because the tool electrode does not change during the ECM process, the final form of the work piece is nearly negative mirror image of the tool electrode, according to Faraday's law.

Electrolyte and metal ions are used to create metal hydroxides, which are then centrifugally separated from the electrolyte solution. The material is removed from the work piece, and the ions are washed away by the flowing electrolyte solution.

ECM has many advantages, including its applicability regardless of material hardness and the fact that components are not subjected to thermal or mechanical stress.

ECM is primarily used in the aerospace sector to manufacture blades and vanes, as well as in the automotive and other industries to polish dies and moulds.

EXPERIMENTAL PROCEDURE

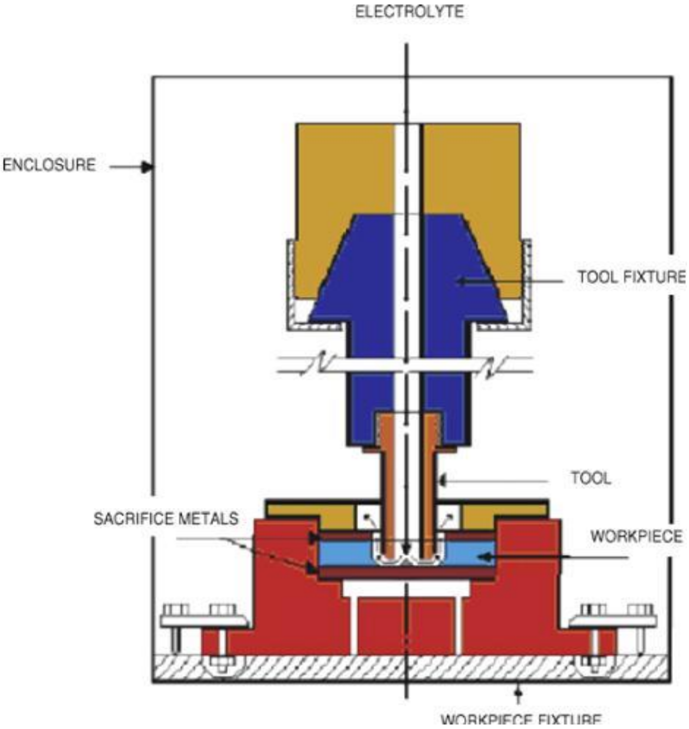

Fig.1.Schematic diagram of the experimental setup

METATECH Electrochemical machining equipment was used in the trials. Because of its limited machinability in traditional techniques and significant tool wear, EN8 steel was chosen.

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The process is powered by two different electrolytic solutions: sodium chloride (NaCl, concentration 100 g/l) and sodium nitrate ($NaNO_3$, concentration 250 g/1).

SEM will be used to study the microstructure of the machined samples. The weight reduction will be used to calculate MRR.

TABLE I

CHEMICAL COMPOSITION OF WORKPIECE MATERIAL

Carbon	0.5%
Silicon	0.40%
Manganese	0.60%

Molybdenum	0.20%
Nickel	0.50%
Chromium	1%

RESULTS AND DISCUSSIONS

A. Design of Experiments

The design of experiments is a method for discovering the link between elements that impact a process and the output of that process using the least number of trials possible. A central composite design (CCD) approach was used in the research.

The following characteristics make CCDs the most popular:

(1) CCDs may run in a sequential order; (2) CCDs are efficient, giving information on the influence of experiment variables on total experimental error in a small number of runs; (3) CCDs are very adaptable..

B. Response surface methodology

The RSM is an empirical modelling technique for determining the relationship between various process parameters and responses, as well as the impact of these process factors on coupled responses. It is a collection of mathematical and statistical processes for modelling and analysing problems where demand response is influenced by a variety of variables.

The parametric impacts on the different machining criteria may be evaluated using the following generic second order polynomial response surface mathematical model:

$$Y_u = b_o + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x^2{}_i + \sum_{j>1}^{k} b_{ij} x_i x_j \qquad (1)$$

The code values of i_{th} machining parameters for u_{th} experiment are represented by x_{iu}, where Y_u denotes the appropriate answer. The number of machining parameters is indicated by the value of n. The second order regression coefficients are denoted by the letters b_i, b_{ii}, and b_{ij}.

The linear effects are represented by the second term under the summation sign of this polynomial equation, while the higher order effects are represented by the third term, and the interacting effects of the parameters are represented by the fourth term. In this study, the quadratic model of y is used not only to analyse the complete factor space, but also to discover the region of the intended goal where the response approaches its optimum or near ideal value. In most cases, the essential data for creating the response models is gathered through the design of experiments.

Electrolyte concentration (X1), electrolyte flow rate (X2), applied voltage (X3), and tool feed rate (X4) were chosen as controlled variables for this study. To create a rotatable design, the levels of each factor were chosen as -2,-1, 0, 1, 2 in closed form. The components and their levels in coded and real values are shown in Table 2. The design called for 31 trials with 16 factorial points, 8 axial points to construct a central composite design with α=2, and 7 centre points for replication to determine the experimental error for the four variables. The Minitab statistical programme was used to create and analyse the design.

TABLE II

EXPERIMENTAL DOMAINS AND THEIR RANGES

DOMAIN	**RANGE**				
	-2	-1	0	1	2
Electro.conc. B1 (gm/lit)	11	14	22	27	32
Electro.f_r B2 (lit/min)	3	7	5	6	4
App. Volt. B3 (Volts)	10	12	11	12	18
Tool fd $_r$ B4 (mm/min)	0.3	0.5	0.8	0.7	2.2

TABLE III

EXPERIMENTAL DATA

B_1	**B_2**	**B_3**	**B_4**	**MRR (g/min)**
1	-1	-1	1	0.0312
-1	1	-1	1	0.0242
1	1	-1	1	0.0386
-1	-1	1	1	0.0398
1	-1	1	1	0.0326
-1	1	1	1	0.0464
1	1	1	1	0.0489
1	1	1	-1	0.0346
-2	0	0	0	0.0101
2	0	0	0	0.0386
0	-2	0	0	0.0192
0	2	0	0	0.0399
0	0	-2	0	0.0112
0	0	2	0	0.0397
-1	1	1	1	0.0464
1	1	1	1	0.0489
0	0	0	0	0.0137
0	0	0	0	0.0134
0	0	0	0	0.0134
0	0	0	0	0.0125
0	0	0	0	0.0134
0	0	0	0	0.0125
0	0	0	0	0.0128
0	0	0	0	0.0116
0	0	0	0	0.0134
0	0	0	0	0.0137
0	0	0	0	0.0134
0	0	0	0	0.0134
0	0	0	0	0.0125
0	0	0	0	0.0128
0	0	0	0	0.0116

C. Mathematical Modelling Of Metal Removal Rate

The impacts of the above-mentioned process factors on the magnitude of the metal removal rate have been examined using MINITAB 14.0 to compute the values of the different constants in Eq (1).

1 . Response Surface Regression: MRR versus X, Y, Z

The analysis was done using uncoded units.

TABLE IV

REGRESSION COEFFICIENTS ESTIMATED FOR MRR

Term	**Coefficient**	**E Coefficient**	**T**	**P**
Const.	-1.69994	0.292228	5.817	0.001
X	0.12552	0.024382	5.148	0.010

Y	0.12209	0.022934	5.324	0.030
Z	0.56116	0.229337	2.447	0.034
X *X	0.00346	0.000645	-5.356	0.000
Y*Y	-0.00628	0.000645	-9.734	0.070
Z*Z	-0.00628	0.064524	-0.067	0.948
X *Y	0.00035	0.001144	0.306	0.766

S = 0.00323542 PRESS = 0.000774104
R-Square = 93.23% R-Square(pred) = 49.94% R-Square (adj) = 89.10%

TABLE V

ANOVA FOR MRR

Source	**DF**	**Sequential SS**	**Adjust. SS**	**Adjust. MS**	**F**	**P**
Reg.	9	0.001442	0.001442	0.000160	15.30	0.000
Linear	3	0.000144	0.000417	0.000139	13.27	0.001
Square	3	0.001185	0.001185	0.000395	37.75	0.000
Interaction	3	0.000113	0.000113	0.000038	3.58	0.054
Residual Error	10	0.000105	0.000105	0.000010	-	-
Lack-of-Fit	5	0.000093	0.000093	0.000019	8.16	0.019
Pure	5	0.0000	0.000	0.000	-	-

Error		11	011	002		

2. Response Surface Regression: O.C versus X,Y,Z
Uncoded units where used to do the analysis.

TABLE VI

REGRESSION COEFFICIENTS ESTIMATED FOR O.C

Term	**Coeff SE**	**Coeff**	**T**	**P**
Const.	-10.4396	2.39178	-6.455	0.001
X	1.1140	0.19956	5.582	0.100
Y	1.7955	0.18770	4.238	1.002
Z	8.7462	1.87704	4.660	0.001
X *X	-0.0339	0.00528	-6.420	0.000
Y*Y	-0.0390	0.00528	-7.378	0.000
Z*Z	-3.4930	0.52811	-6.614	0.000
X *Y	0.0031	0.00936	0.330	0.748
X*Z	-0.0684	0.09362	-0.730	0.482
Y*Z	-0.2651	0.09362	-2.832	0.018

S = 0.0264808 PRESS = 0.0576146
R-Square = 91.62% R-Square(pred) = 31.13% R-Square(adj) = 85.01%

TABLE VII

ANALYSIS OF VARIANCE FOR O.C

Source	**DF**	**Sequential SS**	**Adjust. SS**	**Adjust. MS**	**P**	**F**
Reg.	9	0.076649	0.076649	0.00851	12.15	0.000
Linear	3	0.001941	0.030213	0.010071	14.36	0.001

Square	3	0.068634	0.068634	0.022878	32.36	0.000
Interaction	3	0.006074	0.006074	0.002025	2.89	0.089
Residual Error	10	0.007012	0.007012	0.000701	-	-
Lack-ofFit	5	0.006965	0.006965	0.001393	147.15	-
Pure Error	5	0.000047	0.000047	0.000009		0.000

$$MRR = -1.69994 + 0.12552A + 0.12209B + 0.56116C - 0.00346A^2 - 0.00628B^2 - 0.00628C^2 + 0.00035\,A*B - 0.01925\,A*C - 0.03200\,B*C$$

$$O.C = -15.4396 + 1.1140A + 0.7955B + 8.7462C - 0.0339\,A^2 - 0.0390\,B^2 - 3.4930\,C^2 + 0.0031\,A*B - 0.0684\,A*C - 0.2651\,B*C$$

TABLE VIII

EXPERIMENTAL DATA

Ex. no	Applied voltage	Electrolytic flow rate	Tool feed rate	MRR (g/min)	O.C (mm)
1	15	7	0.7	0.0212	0.011
2	17	7	0.7	0.0286	0.021
3	15	9	0.7	0.0292	0.092
4	17	9	0.7	0.0382	0.124
5	15	7	0.9	0.0261	0.032
6	17	7	0.9	0.0262	0.024
7	15	9	0.9	0.0215	0.017
8	17	9	0.9	0.0226	0.012
9	14	8	0.8	0.0212	0.045
10	18	8	0.8	0.0312	0.023
11	16	6	0.8	0.0109	0.016
12	16	10	0.8	0.0189	0.012
13	16	8	0.6	0.0385	0.013
14	16	8	1.0	0.0412	0.048
15	16	8	0.8	0.0391	0.169
16	16	8	0.8	0.0374	0.161
17	16	8	0.8	0.0385	0.164
18	16	8	0.8	0.0372	0.162
19	16	8	0.8	0.0413	0.163
20	16	8	0.8	0.0395	0.162

FUZZY MODELING OF ECM PROCESS

The ECM process is simulated using four input factors: current, open-circuit voltage, servo, and duty cycle, to predict output characteristics such as metal removal rate, tool wear rate, surface roughness, and hardness. The form of the fuzzy membership function or fuzzy sets of process variables is the first stage in developing an algorithm for a fuzzy model. Rate of Metal Removal (MRR)

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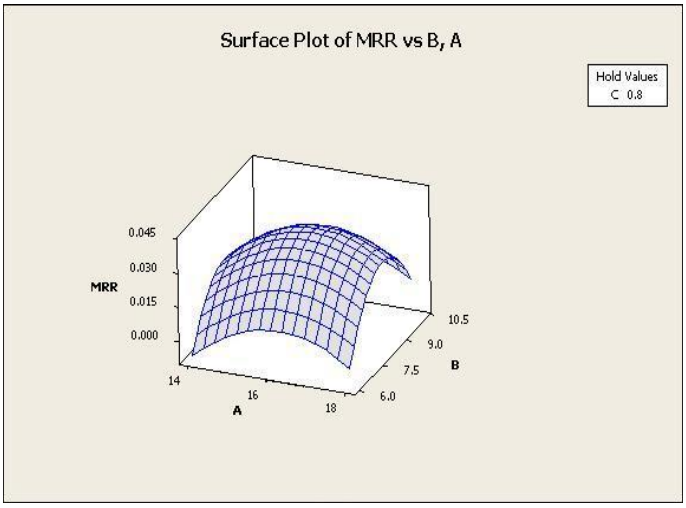
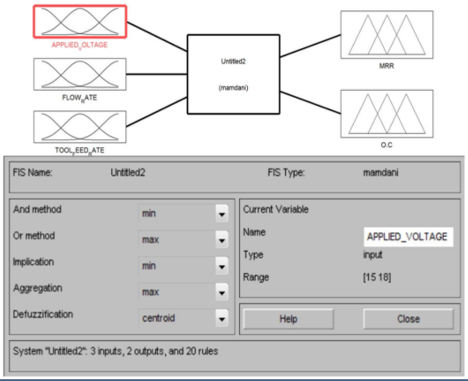

Surface Plot of MRR vs B, A

Fig 2.Surface Plot of MRR vs B,A

The MRR is directly proportional to flow rate of electrolyte as well as the voltage applied to it hence whenever there is rise in flowrate of electrolyte or the voltage applied to it the is seen that the MRR also rises.

The increase in applied voltage causes a higher amount of machining current to be accessible in the machining gap, resulting in an increase in MRR.

FUZZY OPTIMIZATION



FIS Name: Untitled2
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: APPLIED_VOLTAGE
Type: input
Range: [15 18]
System "Untitled2": 3 inputs, 2 outputs, and 20 rules

Furthermore, higher electrolyte flow rates result in faster elimination of reaction products from the machining gap, which offsets the likelihood of passive layers on the work piece's surface, resulting in a higher MRR overall.

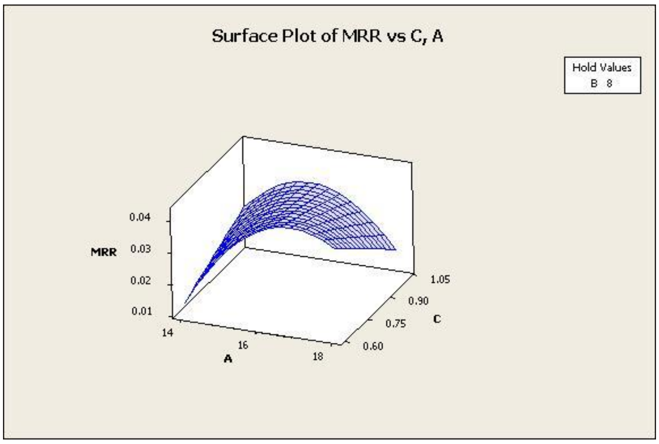

Surface Plot of MRR vs C, A

Fig 3.Surface Plot of MRR vs. C, A

Figure 3 portrays the observation made during the voltage applied on the tool it is inferred that as the voltage applied to the tool the feed rate of the tool increases thereby increasing the MRR which in turn decreases the tool electrode gap. As a result, the electrolyte's electric resistance is reduced, the current density rises, and the MRR rises. When the applied voltage is in the low range, the MRR is low, however when the applied voltage is in the high range, the MRR is high. The increased current density in the gap, as a result of the greater machining current, is one of the causes for the significant rise in MRR.

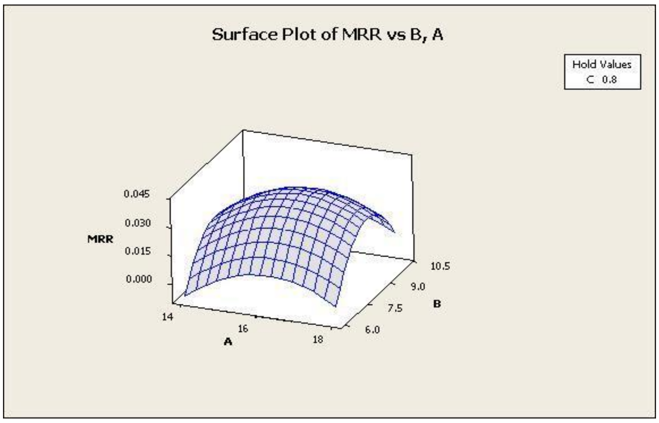

Surface Plot of MRR vs B, A

Fig4.Surface Plot of MRR vs B,A-I

The effect of electrolyte flow rate and applied voltage on O.C. is depicted in Figure 4. O.C increases as the applied voltage increases because a significant number of gas bubbles form at the tool sidewall at high voltage.

When the flow rate of the electrolyte is increased, O.C grows nonlinearly, but after reaching a maximum, it starts to fall. Because there are more electrolytic ions available in the machining zone, increasing the electrolyte flow rate initially results in an increase in OC values.

Because of the creation of stray current flux at the machining zone perimeter, the stray current impact at the side wall is increased. Because of the squeezing of the gas bubble diameters and the faster evacuation of reaction products and gas bubbles from the machining zone, the effects of stray current flow lessen gradually as the electrolyte flow rate increases. As a result, the O.C. has been reduced.

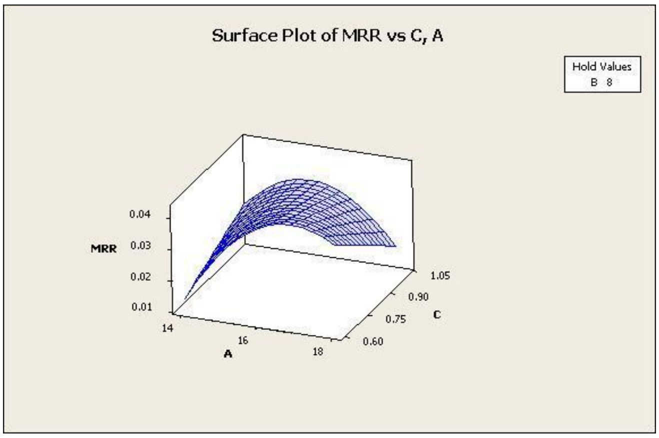


Fig5. Surface Plot of MRR vs. C, A-I

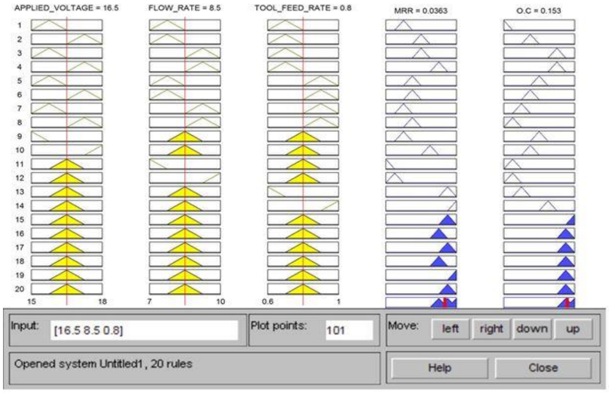
The response surface plot of O.C is shown in the Figure 5, it is inferred from the graph that when the O.C rises it in turn pave path to high electrolysing current in the machining gap which led to high stray current in the machining zone

That led to tool feed rate rises, owing to incorrect flushing of machined product from the machining zone, which increases the possibility of micro spark creation, resulting in higher O.C. The inter-electrode gap is larger at lower tool feed rates, and effective flushing of processed product from the machining zone results in decreased O.C. The machined hole is of higher quality than the previous one.

A. Discussion

The experimental analysis reveals that electrochemical machining criteria such as MRR and O.C in ECM are factors taken into account in this work. The response surface approach utilised in this study has shown to be a useful tool for analysing the ECM process. These factors are individually modelled mathematically for linking MRR and O.C with the most important process factors were developed. Response surface plots show the impact of different parameters of the process on machining performance criteria.

FUZZY OPTIMIZATION


APPLIED_VOLTAGE = 16.5
FLOW_RATE = 8.5
TOOL_FEED_RATE = 0.8
MRR = 0.0363
O.C = 0.153
Input: [16.5 8.5 0.8]
Plot points: 101
Opened system Untitled1, 20 rules

CONCLUSION

From the results obtained it is inferred that there is a significant relation between the MRR and the ECM process. The machining parameters settings has significant impact on the metal removal rate. It is proved that increase in voltage applied, flowrate of electrolyte & concentration, feed rate of the tool improves the rate of metal removal.

For linking the metal removal rate with the most important electrochemical process parameters, a mathematical model based on the RSM technique was constructed.

The ideal parameter for this machining process is as follows (i.e.,) 22.74g/lit concentration of electrolyte, with flowrate of 7.57 lit/min with applied voltage of 14.8V & feed rate of tool about 0.902 mm/min the metal removal rate proved to be 0.0513 g/min using the established mathematical model. The same result was obtained in fuzzy logic with slight variation, thus this fuzzy can also be applicable to find the material removal rate.

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