PARAMETRIC ANALYSIS ON ELECTRO CHEMICAL MACHINING WITH NaCl SOLUTION

Sasikumar, P and Elango, V

Department of Mechanical Engineering
Paavai Engineering College, Paachal, Namakkal, Tamilnadu
E-mail: Sasi.sasimech@gmail.com

Abstract: *Electrochemical Machining (ECM) is a non-traditional process used mainly to cut hard or difficult to cut metals, where the application of a more traditional process is not convenient. This work shows study of the effect of Sodium chloride solution (NaCl) on Material Removal Rate (MRR), Surface roughness and Overcut of high hardened die steel by ECM. In addition to analyzing the effects of influencing factors on High hardened die steel for finding the optimum parameters, four different process parameters were undertaken for this study; applied voltage, tool feed rate, electrolyte discharge rate and three types of electrolyte solution. The effects of NaCl aqua solution on the work piece are studied and the relationship among the variables have been determined for achieving maximum MRR and minimum surface roughness and overcut. NaCl aqua electrolyte solution presented the better results of the MRR, surface roughness, and overcut in electrochemical machining of high hardened die steel.*

Keywords: *Electrochemical Machining; Mathematical Modal; Fuzzy Logic; Response Surface Methodology*

1. INTRODUCTION

Electrochemical Machining (ECM) is an anodic electrochemical dissolution process. ECM uses electrical energy to remove material. An electrolytic cell is created in an electrolyte medium, with the tool as the cathode and the work piece as the anode. During the machining process, a D.C. voltage (usually about 10 to 25 volts) is applied across the inter electrode gap between a pre-shaped cathode tool and an anode work piece.

The electrolyte (e.g. NaCl aqueous solution) flows at high speed through the gap (about 0.1 to 0.5 mm). With current density of 20 to 200 g/cm^3, the anode work piece is dissolved According to Faraday's law, The final shape of the work piece is approximately negative mirror image of the tool electrode, as the latter does not alter during the ECM process.

Material is removed from the work piece and the flowing electrolyte solution washes the ions away. These ions form metal hydroxides which are removed from the electrolyte solution by centrifugal separation.

ECM has many advantages such as its applicability regardless of material hardness, the components are not subject to either thermal or mechanical stress, no tool wear during Electrochemical machining, non-rigid and open work pieces can be machined easily as there is no contact between the tool and work piece, complex geometrical shapes can be machined repeatedly and accurately, surface finishes of 25μ in. can be achieved during Electrochemical machining.

ECM is mainly used in manufacturing of blades and vanes in aircraft industry, and also in finishing of dies and moulds in automotive and other industries.

2. EXPERIMENTAL PROCEDURE

The experiments were conducted on METATECH Electrochemical machining equipment. The EN8 steel was chosen because its low machinability in conventional processes with high tool wear.

The tool was made up of copper with a square cross section. Electrolyte was axially feed to the cutting zone through a central hole of the tool.

It was used two electrolytic solutions: sodium

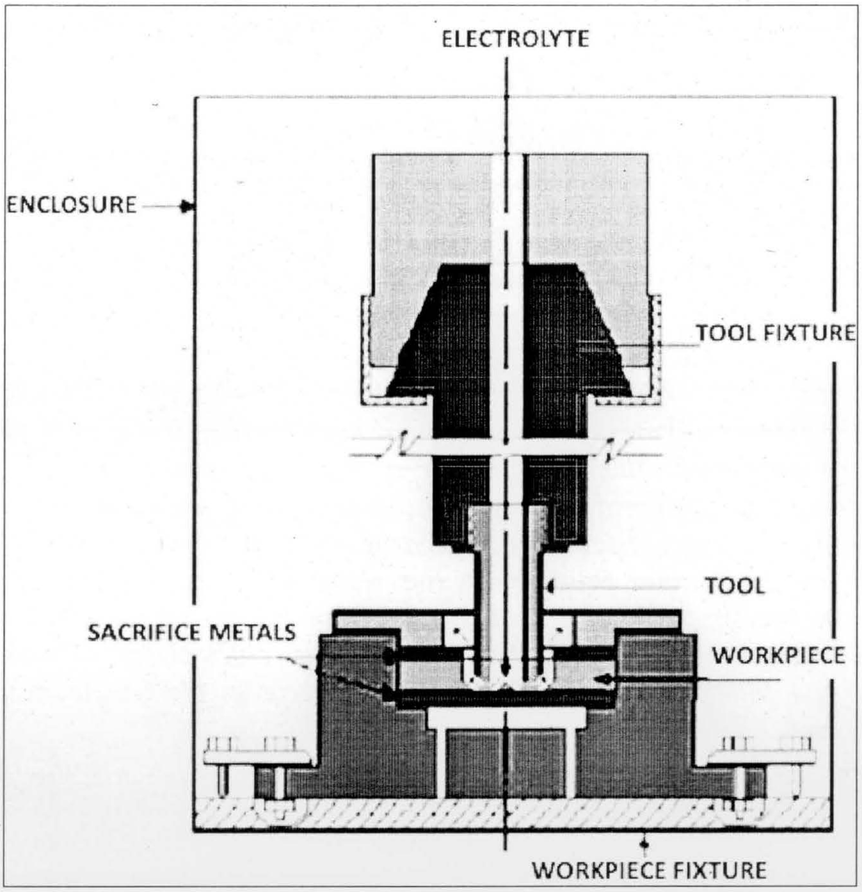

Fig 1. Schematic Diagram of the Experimental Setup

Table 1: Chemical Composition of Workpiece Material

C	0.5%
Si	0.40%
Mn	0.60%
Mo	0.20%
Ni	0.50%
Cr	1%

chloride (NaCl at concentration of 150 g/l) The machining has been carried out for fixed time interval.

The observations will made by varying predominant process parameters such as applied voltage, electrolyte concentration, electrolyte flow rate and tool feed rate.

The machined samples will be examined using SEM for micro structural observations. MRR will be measured from the weight loss.

3. RESULTS AND DISCUSSIONS

3.1 Design of Experiments

Design of experiments is a structured, organized method for determining the relationship between factors that affect the process and the output of that process, with minimum number of experiments. In the study, a central composite design (CCD) technique was chosen.

The CCDs are most popular due to the following attributes: (1) CCDs can runs sequentially; (2) CCDs are efficient, providing information on experiment variable effect on overall experimental error in a minimum number of runs; (3) CCDs are very flexible.

3.2 Response Surface Methodology

The RSM is an empirical modelling approach for determining the relationship between various process parameters and responses with the various desired criteria searching the significance of these process parameters on the coupled responses. It is a sequential experimentation strategy for building and optimizing the empirical model.

Therefore, RSM is a collection of mathematical and statistical procedures that are useful for the modelling and analysis of problems in which response of demand is affected by several variables and the objective is to optimize this response.

The general second order polynomial response surface mathematical model can be considered to evaluate the parametric influences on the various machining criteria as follows:

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

Where Yu represents the corresponding response, the code values of i_{th} machining parameters for u_{th} experiment are represented by x_{iu}. The values of n indicate the number of machining parameters. The terms bi, b_{ii} and b_{ij} are the second order regression co-efficient.

The second term under the summation sign of this polynomial equation attributes to linear effects, whereas the third term of the above equation corresponds to the higher order effects and lastly the forth term of the equation includes the interactive effects of the parameters. Using this quadratic model of y in this study is not only to investigate over the entire factor space, but also to locate region of desired target where the response approaches its optimum or near optimal value. The necessary data for building the response models are generally collected by the design of experiments.

Table 2: Experimental Parameters and their Levels

PARAMETERS	LEVELS				
	-1.682	-1	0	1	1.682
Applied voltage A, (Volts)	14	15	16	17	18
Electrolyte flow rate B (lit/min)	6	7	8	9	10
Tool feed rate C, (mm/min)	0.6	0.7	0.8	0.9	1

Table 3: 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

The pertinent process parameters selected for the present investigation are electrolyte Concentration (X1), electrolyte flow rate (X2), applied voltage (X3), tool feed rate (X4) were considered as controlling variables. The levels of each factor were chosen as -2,-1, 0, 1, 2 in closed form to have a rotatable design. Table 2 shows the factors and their levels in coded and actual values. For the four variables, the design required 31 experiments with the 16 factorial points, 8 axial points to form a central composite design with $\alpha=2$, and 7centre points for replication to estimate the experimental error. The design was generated and analysed using the Minitab statistical package.

3.3 Mathematical Modelling of Metal Removal Rate

Based on the Eq (1) the effects of the above mentioned process variables on the magnitude of the metal removal rate have been evaluated by computing the values of the different constants of the said equation using MINITAB 14.0.

3.3.1 Response surface regression: MRR versus A, B, C

The analysis was done using uncoded units.

Table 4: Estimated Regression Coefficients for MRR

Term	Coef	E Coef	T	P
Constant	-1.69994	0.292228	5.817	0.000
A	0.12552	0.024382	5.148	0.000
B	0.12209	0.022934	5.324	0.000
C	0.56116	0.229337	2.447	0.034
A *A	0.00346	0.000645	-5.356	0.000
B*B	-0.00628	0.000645	-9.734	0.000
C*C	-0.00628	0.064524	-0.067	0.948
A *B	0.00035	0.001144	0.306	0.766

S = 0.00323542 PRESS = 0.000774104
R-Sq = 93.23% R-Sq(pred) = 49.94%
R-Sq(adj) = 87.14%

Table 5: Analysis of Variance For MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	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 Error	5	0.000011	0.000011	0.000002	-	-

3.3.2 Response surface regression: O.C versus A, B, C

Table 6: Estimated Regression Coefficients for O.C

Term	Coef SE	Coef	T	P
Constant	-15.4396	2.39178	-6.455	0.000
A	1.1140	0.19956	5.582	0.000
B	0.7955	0.18770	4.238	0.002
C	8.7462	1.87704	4.660	0.001
A*A	-0.0339	0.00528	-6.420	0.000
B*B	-0.0390	0.00528	-7.378	0.000
C*C	-3.4930	0.52811	-6.614	0.000
A*B	0.0031	0.00936	0.330	0.748
A*C	-0.0684	0.09362	-0.730	0.482
B*C	-0.2651	0.09362	-2.832	0.018

S = 0.0264808 PRESS = 0.0576146
R-Sq = 91.62% R-Sq(pred) = 31.13% R-Sq(adj) = 84.07%

Table 7: Analysis of Variance for O.C

Source	DF	Seq SS	Adj SS	Adj MS	P	F
Regression	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-off it	5	0.006965	0.006965	0.001393	147.15	-
Pure Error	5	0.000047	0.000047	0.000009		0.000

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

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

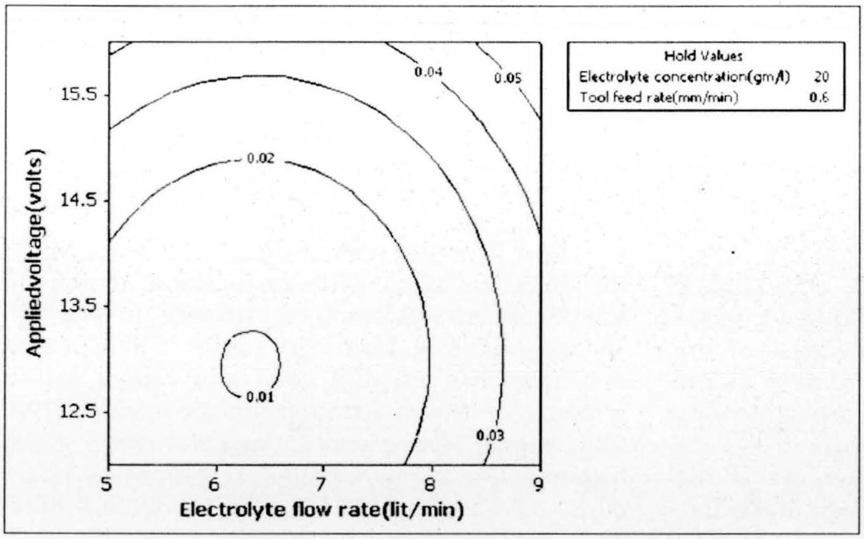

Fig 2. Effect of Flow Rate and Voltage on MRR

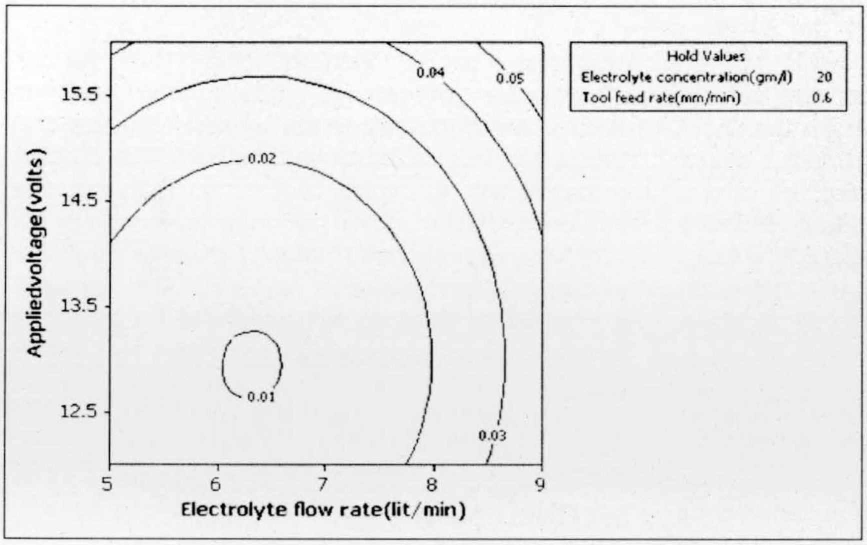

Fig 3. Effect of Voltage and Feed Rate on MRR

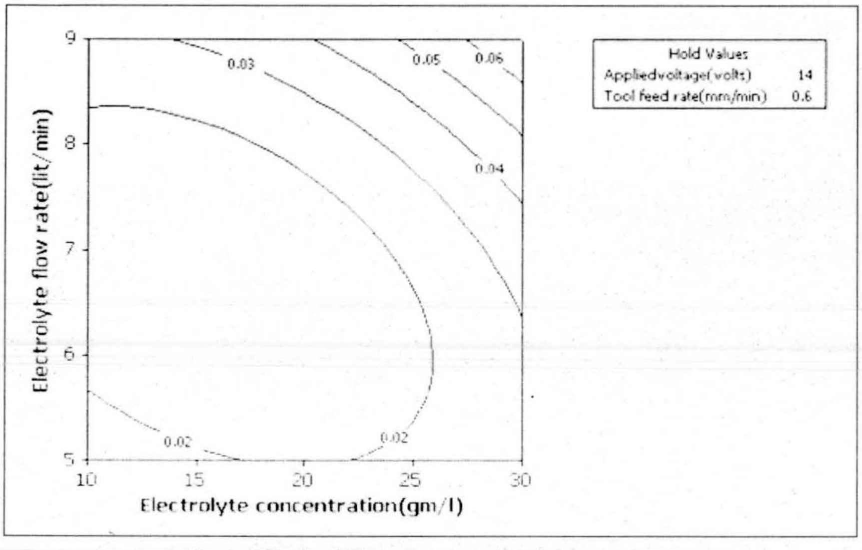

Fig 4. Effect of Flow Rate and Voltage on MRR

4. FUZZY MODELING OF ECM PROCESS

For the prediction of output parameters such as metal removal rate, tool wear rate, surface roughness and hardness, the ECM process is modelled using four input parameters such as current, open-circuit voltage, servo and duty cycle. The first step in establishing the algorithm for fuzzy model is to choose the shape of the fuzzy membership function or fuzzy sets of the process variables. Metal Removal Rate (MRR)

Fig. 2 shows the variation of the MRR with respect to the electrolyte flow rate and applied voltage. The figure indicates that an increase in the electrolyte flow rate and applied voltage MRR increases.

It is owing to the increase in applied voltage causes a greater machining current to be available in the machining gap, thereby causing the enhancement of the MRR.

Moreover, increase in electrolyte flow rates lead to faster removal of the reaction products from the machining gap and offset the possibility of passive layers on the surface of the work piece, results in overall increase in the MRR.

The influences of the applied voltage and tool feed rate on MRR are shown in fig.3. MRR increases with an increase in the tool feed rate. It is because increase in the tool feed rate, inter-electrode gap becomes smaller. This, in turn, causes a reduction of the electric resistance of the electrolyte and increases the current density and then MRR. Applied voltage in the low range yields low MRR, whereas high MRR results when the applied voltage. The reasons for the substantial increase in MRR can be attributed to the increase in current density in the gap as the higher machining current.

Influence of electrolyte flow rate and applied voltage on O.C is shown in fig. 4. O. C increases with increase in applied voltage because of the fact that at high voltage a large number of gas bubbles are generated at the tool sidewall.

O.C increases non-linearly with increase in the electrolyte flow rate, but after reaching a maximum, it has a tendency to fall. Increase electrolyte flow rate initially causes an increment in OC values because of the greater volume of electrolytic ions available in the machining zone.

This simultaneously causes a greater stray current effect at the side wall, due to the formation of stray current flux at the machining zone periphery. With increase in electrolyte flow rate the effects of stray current flow weaken gradually, because of the squeezing of the gas bubble diameters and the quicker removal of reaction products and gas bubbles from the machining zone. Hence lower O. C has been obtained.

Response surface plot of O. C with respect to applied voltage and tool feed rate is shown through fig. 5. Increase in applied voltage O. C increases it is owing to greater electrolysing current to be available in the machining gap, as well as causing a greater stray current intensity leads to weaken the stray current effect at the boundaries of the flow path. O.C increases with increase in tool feed rate, it is due to improper flushing of machined product from the machining zone and the chance of generation of micro sparks increases, which results in larger O. C. At lower tool feed rate, inter-electrode gap is more and proper flushing of machined product from the machining zone results in decreases in O.C. The quality of the machined hole is better than the previous hole.

4.1 Discussion

The experimental analysis highlights that the electrochemical machining criteria like MRR, O. C in ECM are parameters considered in the present study. Response surface methodology used in the present research work has proved its adequacy to be an effective tool for analysis of the ECM process. Mathematical models for correlating MRR and O. C with predominant process parameters have been obtained separately. The influence of different process parameters on machining performance criteria are exhibited though response surface plots.

It is clear from the response surface plot of MRR, the MRR increases with an increase in any of the machining parameters. Increase in applied voltage and tool feed rate causes high current density in the IEG and flow rates causes faster removal of the reaction products leads higher MRR. Higher level of machining parameters, gives higher O. C as shown on the O.C response surface plots. Increase in applied voltage and tool feed rate causes high current density in the IEG and flow rates causes improper removal of the reaction products leads higher O.C.

Therefore, it is evident that the various quantitative modellings, based on response surface methodology, experimental analyses and the test results as obtained through the present research will be quite useful for analysing the influence of the various process parameters for achieving suitable control over the electrochemical machining performance criteria. The present experimental findings will be useful for both the design and manufacturing engineers to assess the necessary information about influence of predominant machining parameters on electrochemical machining performance

5. CONCLUSION

The present investigation highlights that effect of metal removal rate during electrochemical machining is greatly influenced by the various predominant machining parameters. From the investigation, the following conclusions can be drawn:

Metal removal rate increases with increase in applied voltage, electrolyte flow rate tool feed rate and electrolyte concentration.

Mathematical model has been developed based on RSM approach for correlating the metal removal rate with predominant electrochemical process parameters.

From the developed mathematical model, the optimal machining parametric combination, i.e., electrolyte concentration, 21.54 g/lit, electrolyte flow rate, 7.08 lit/min, applied voltage, 15 volts, tool feed rate, 0.895 mm/min was found out to achieve the maximum metal removal rate as 0.06731g/min.

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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