Optimization of Process Parameters in ECM for AISI P20 Tool Steel

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Abstract— Electrochemical machining (ECM) has established itself as a major machining process which can be used as an alternative to conventional methods for machining hard materials and complex contours without the hindrance of residual stresses and tool wear. ECM has extensive applications in Aerospace, Petroleum, Automotive, Medical, Textile AND Electronic Industries. Material Removal Rate (MRR) is one of the important process parameters in ECM, because it is one of the determining factors in the process decisions. The project is an attempt to check the design parameters such as material removal rate (MRR), overcut diameter and overcut depth of AISI P20 work piece by using a rotating copper U-tube tool. Four parameters were chosen as process variables: Voltage, Feed Rate, Electrolyte concentration and Tool diameter. The experimental results show that the material removal rate (MRR), increase with increasing feed, voltage and electrolyte concentration but decreases with increasing the tool diameter, and for both overcut depth and overcut diameter they increases with increasing feed ,voltage and electrode diameter but decreases with increasing electrolyte concentration. To identify the optimal parameter setting in the experiment Grey relation grade (GRD) was also applied.

Keywords: Electrochemical Machining (ECM), Material Removal Rate (MRR), Taguchi Method, Overcut (OC), Grey Relation Analysis (GRA)

I. INTRODUCTION

Electrochemical machining (ECM) was developed in order as to machine extremely hard materials or materials that were difficult to machine using conventional methods. The process of ECM is an anodic dissolution process which is based on the phenomenon of electrolysis. The laws of Electro Chemical Machining (ECM) were established by Michael Faraday [1]. The Material Removal Rate (MRR) does not depend on the hardness of the metal. ECM has several advantages over a other machining methods but also has disadvantages.

The advantages are that there is no tool wear; machining is done at low voltage compared to other processes with high metal removal rate; no burr formation; hard conductive materials can be machined into complicated profiles; work-piece structure suffer no thermal damages; suitable for mass production work and low labor requirements.

The disadvantages is that there is a huge amount of energy that is consumed which is approximately 100 times that required for the turning or drilling of steel; High power consumption and initial investment cost; safety issues on removing and disposing of the explosive hydrogen gas generated during machining; not suited for nonconductive materials and difficulty in handling and containing the electrolyte [2].

II. RESEARCH WORK

In order to study the material removal rate (MRR), overcut diameter rand overcut depth in ECM, it is necessary to identify and understand the factors affecting the responses. A series of machining experiments have been conducted and the factors which affect the response have been studied by using AISI P20 tool steel as work-piece. The property of AISI P20 tool steel is that it is a pre hardened high tensile tool steel thus offers ready machinability in the hardened and tempered conditions therefore does not require any further heat treatment. This eliminates the risk, cost and time for heat treatment thus avoiding the associated possibility of distortion or even cracking. [3]

Experimental work is discussed which is based on Taguchi orthogonal array L16. MRR, overcut diameter and depth of the work piece were measured and Grey relational analysis is adopted to find the best parameters setting.

The work piece used to conduct the experiment is AISI P20 tool steel. Five such pieces of AISI P20 steel were taken to conduct 16 experimental runs. [4]

III. EXPERIMENTAL RESULT

Run order	Voltage (V)	Feed (F) mm/min	Electrolyte concentration (C) g/l	Tool Diameter (D) mm	MRR (mm3/min)	OC diameter (mm)	OC Depth (mm)
1	10	0.3	30	4	0.05600	4.825	6.500
2	10	0.3	30	6	0.04431	4.929	6.730
3	10	0.3	50	4	0.05830	4.812	6.287
4	10	0.3	50	6	0.05550	4.856	6.609
5	10	0.6	30	4	0.09850	5.128	6.980
6	10	0.6	30	6	0.09870	5.260	7.180
7	10	0.6	50	4	0.10800	5.089	6.830
8	10	0.6	50	6	0.09890	5.212	7.080
9	15	0.3	30	4	0.09120	4.893	6.620
10	15	0.3	30	6	0.07970	4.972	6.880
11	15	0.3	50	4	0.09110	4.853	6.474
12	15	0.3	50	6	0.08880	4.966	6.830
13	15	0.6	30	4	0.13510	5.207	7.274
14	15	0.6	30	6	0.12800	5.301	7.410

15	15	0.6	50	4	0.13640	5.208	7.140
16	15	0.6	50	6	0.12750	5.256	7.376

In the present investigation the analysis of variance (ANOVA) has been performed. The effect of the selected ECM process parameters on the selected responses have been investigated through the plots of the main effects based on ANOVA. The optimum condition for each of the quality characteristics has been estimated through analysis of variance.

During the work, Minitab 14 software for Taguchi design was used. 2 level design (four factors) with total of 16 numbers of experiments to be conducted and hence the OA L16 was chosen.

A. Sample Calculations (For run order 1):

MRR is calculated as given by the following formula:

$$MRR = \frac{\text{initial weight} - \text{final weight}}{\text{density} \times \text{total time}}$$

$$MRR = \frac{3.904 - 3.584}{0.00785 \times 755} = 0.056\ mm^3/min$$

Overcut diameter is calculated as given by the following formula:

$$OC = \frac{\frac{\text{observed diameter} - \text{actual diameter}}{2}}{} = \frac{\text{observed diameter} - 35}{2}$$

$$OC = \frac{44.65 - 35}{2} = 4.825mm$$

Overcut depth is calculated as given by the following formula:

Overcut depth = observed depth – actual depth = observed depth – 25

OC = 31.5-25 = 6.5mm

B. Grey Relation Analysis

In the grey relation analysis, experiment data, i.e., measured responses, are first normalized in the range of 0 to 1. This process is called grey relation generation. Based on this data, grey relation coefficients are calculated to represent the correlation between the ideal (best) and the actual normalized experimental data. Overall, grey relation grade is then determined by averaging the grey relation coefficient corresponding to selected responses. The overall quality characteristics of the multi-response process depend on the calculated grey relation grade

C. Grey Relation Generation

There are three different types of data normalization according to the requirement of Lower the Better (LB), Higher the Better (HB), or Nominal the Best (NB) criteria. The desired quality characteristics for MRR are HB criterion; therefore, the normalization of original sequence of these three responses is done using equation (1).

$$yi^*(k) = \frac{yi(k) - \min yi(k)}{\max yi(k) - \min yi(k)} \quad (1)$$

Where yi*(k) is the normalised data, i.e. after grey relational generation, yi(k) is the kth response of the ith experiment, min yi(k) is the smallest value of yi(k) for kth response, and max yi(k) is the largest value of yi(k) for the kth response.

Overcut diameter and overcut depth follows the LB criterion. Accordingly, the normalization of these responses is done using equation (2).

$$yi^*(k) = \frac{\max yi(k) - yi(k)}{\max yi(k) - \min yi(k)} \quad (2)$$

D. Grey Relation Coefficient

The grey relation coefficient is given as

$$\varepsilon_i(k) = \frac{\Delta\min - \omega\Delta\max}{\Delta_{oi}(k) - \omega\Delta\max} \quad (3)$$

Where $\varepsilon_i(k)$ is the grey relation coefficient of the i^{th} experiment for the k^{th} response, $\Delta_{oi}(k) = \|y^*_0(k) - y^*_i(k)\|$, i.e., absolute of the difference between $y^*_0(k)$ and $y^*_i(k)$, $y^*_0(k)$ is the ideal or reference sequence, $\Delta\max = \max_i \max_k \|y^*_0(k) - y^*_i(k)\|$ is the largest value of Δ_{oi}, and $\Delta\min = \min_i \max_k \|y^*_0(k) - y^*_i(k)\|$ is the smallest value of Δ_{oi}, and $\omega(0 \le \omega \le 1)$ is the distinguish coefficient.

E. Grey Relation Grade

The grey relation grade (Γ_i) is calculated by averaging the grey relational coefficients corresponding to each experiment.

$$(\Gamma_i) = \frac{1}{n}\sum_{1}^{Q} i(k) \quad (4)$$

Where, Q is the total number of response and n is the number of output responses. The grey relation grade Γ_i represents the level of correlation between the reference sequence and the comparability sequence. If higher grey relation grade occurred, then the corresponding parameter combination is closer to the optimal setting.

F. Sample calculation for Grey relation:

$$\text{Normalised value of MRR } Y_1(MRR) = \frac{(0.056 - 0.04431)}{(0.1364 - 0.04431} = 0.1269$$

$$\text{Normalised value of } (OC - dep) = \frac{(7.41 - 6.5)}{(7.41 - 6.287)} = 0.8103$$

$$\text{Grey relation coefficient of MRR } \varepsilon_1(MRR) = \frac{(1 - 0.5 \times 1)}{(0.8731 + 0.5)} = 0.3642$$

$$\text{Grey relation coefficient of } OC - dep\ \varepsilon_1(OC - dep) = \frac{(1.495 - 0.5 \times 1)}{(0.1897 + 0.5)} = 0.725$$

$$\text{Grey relation grade of run order 1 is } \Gamma_i = \frac{(0.3642 + 0.7250)}{2} = 0.5446$$

Evaluated grey relational grade for responses

Run order	Normalized values		Grey relational analysis		Grey relational coefficient		Grade
	MRR	OC-dep	MRR	OC-dep	MRR	OC-dep	
1	0.1269	0.8103	0.8731	0.1897	0.3642	0.7250	0.5446

2	0.0000	0.6055	1.0000	0.3945	0.3333	0.5590	0.4462
3	0.1519	1.0000	0.8481	0.0000	0.3709	1.0000	0.6854
4	0.1215	0.7133	0.8785	0.2867	0.3627	0.6355	0.4991
5	0.5884	0.3606	0.4116	0.6394	0.5485	0.4388	0.4937
6	0.5906	0.2048	0.4094	0.7952	0.5498	0.3860	0.4679
7	0.6916	0.5165	0.3084	0.4835	0.6185	0.5084	0.5634
8	0.5928	0.2939	0.4072	0.7061	0.5511	0.4145	0.4828
9	0.5092	0.7035	0.4908	0.2965	0.5046	0.6277	0.5662
10	0.3843	0.4720	0.6157	0.5280	0.4481	0.4864	0.4673
11	0.5081	0.8335	0.4919	0.1665	0.5041	0.7502	0.6271
12	0.4831	0.5165	0.5169	0.4835	0.4917	0.5084	0.5000
13	0.9859	0.1211	0.0141	0.8789	0.9725	0.3626	0.6676
14	0.9088	0.0000	0.0912	1.000	0.8457	0.3333	0.5895
15	1.000	0.2404	0.0000	0.7596	1.0000	0.3970	0.6985
16	0.9034	0.0303	0.0966	0.9697	0.8380	0.3402	0.5891

IV. Conclusion

Experiments are conducted according to Taguchi method by using the machining set up and the designed Rotary U-shaped tubular electrodes. The control parameters like voltage, feed, electrolyte concentration and diameter of electrode were varied to conduct 16 different experiments. A Mould cavity was produced by this process. The ECM process parameter setting voltage at 15v, feed 0.6 mm/min, electrolyte concentration 50 g/l and tool diameter 4 mm has highest grey relational grade. Therefore, this input parameter setting is the optimal machining parameters for maximum MRR and minimum for both overcuts simultaneously with in the experimental domain.

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