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Intervening Variables in Electrochemical Micro Machining For Copper

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Abstract

Electrochemical micromachining (EMM) is one of the promising techniques for micro-hole finds application in aerospace, electronic circuit board and automobile industries. This paper aspires to investigate the effect of machining parameters on indigenously developed EMM. Preliminary experiments have been carried out to realize the best machining parameters levels on machining of copper material. The influencing factors such as electrolyte concentration, machining voltage, duty cycle and frequency levels on Material Removal Rate (MRR) and overcut were identified. The experiments are planned based on L18 orthogonal array. The optimal combination of process parameter was determined using TOPSIS method for the higher MRR and lower overcut. The optimal combinations were found to be 20 g/l electrolyte concentration, 7 V machining voltage, 65 % duty cycle, and 75 Hz frequency. Based on the Analysis of variance (ANOVA) the most influencing factor for higher MRR and lower overcut are electrolyte concentration and voltage.

Key words: Electrochemical, Micromachining, Overcut, orthogonal array, Micro hole.

1. INTRODUCTION

EMM appears to be a very potential technology for micro machining due to its advantages that include high machining rate, better precision and control, rapid machining time, reliable, flexible, environmentally acceptable and it also permits machining of chemically resistant materials like titanium, copper alloys, super alloys and stainless steel, which are widely used in biomedical, electronic and MEMS applications [1].Research on EMM is pursued worldwide by many researchers in last decade.[2] machined various cross sectional microgrooves on metallic surfaces by regulating depth of microgroove on each layer. The use of side wall insulated disk type micro tool along with tool vibration enhances the availability of fresh electrolyte at machining region during machining of deep microgrooves.[3] have investigated the machining performance with assistance of infrared (IR) heated electrolyte. The IR heated electrolyte has an significant effect on machining rate.The experiment combination such as electrolyte temperature at 37^{o},25 % duty cycle,35 g/l electrolyte concentration and 9 V machining voltage is produces 4.5 times more machining rate than the room temperature electrolyte.[4] have endeavored to diminish the taper angle, overcut, and corner deviation on stainless steel by EMM. the micro features were carried out by different tool electrodes used such as φ 115 μm straight, conical 10° taper, conical 13° taper to improve the machining parameters with various parametric combinations.0.2M H_2SO_4 electrolyte and conical micro tool of taper angle 13° is suitable for lesser taper angle and lesser overcut. [5] have developed a EMM system and used the vibrating tool electrode on a 0.2-mm thick steel plate. The uses of vibrating tool electrode significantly increase machining rate of the EMM process. [6] have developed a EMM system and machined micro holes on 304 stainless steel using high speed steel cylindrical tool, dilute H_2SO_4 electrolyte. They found a lower taper angle at 0.4 mol/L H_2SO_4, 700 kHz, 600 ns, and 21 V. [7] have fabricated a EMM setup and found a optimal arameter values for machining a copper plate by nickel coated steel wire. In EMM they have generates the various micro holes and micro channels in the copper sheets of varying thicknesses. [8] have studied the machining parameters on Al / (Al_2O_{3p}+SiC_p+C_p) hybrid MMC. The optimal parameter combination found was 1.5 A machining current, 13 V machining voltage, 10 ms pulse-on time, 10 ms pulse-off time, 15 g/L electrolyte concentration, and 0.2 L/min electrolyte flow rate. [9] have study the machining performance of ECM with assistance of magnetic field in the machining zone. The use of concentrated magnetic field reduces the stray current and improves the flow of electrolyte. [10] have studied the effect of machining parameters on machining rate and overcut using Taguchi's concept and ANOVA. They noticed that the electrolyte concentration and frequency is the most significant factor for material removal rate (MRR) and overcut. It is clear from the above literature survey that research on EMM is pursued by various researchers and still the database available on machining of ductile material such as copper is insufficient. Hence this research focus on studying the effect of process parameter an MRR and OC during the machining of copper work piece.

2. EXPERIMENTAL SET UP

The electrochemical micromachining setup has been made indigenously developed as shown in figure 1. The setup comprises of different system, such as, Mechanical Machining unit, Tool Electrode feeding system, Inter-Electrode Gap control system, electrolyte supply system, and pulsed power supply system. The Machining body contains, tool electrode feeding attachment, work holding fixture and machining chamber are fitted in the mechanical machine unit. Pump and filter are comprised of the electrolyte supply system. Pulsed power supply system has designed to vary the voltage and current of 30V and 2A. Sodium nitrate ($NaNO_3$) as electrolyte of varying concentrations, stainless steel electrode of φ 460 μm and Copper work piece of thickness of 220 μm were utilized to conduct the experiments. Machining current of 0.8 A is maintained constantly.

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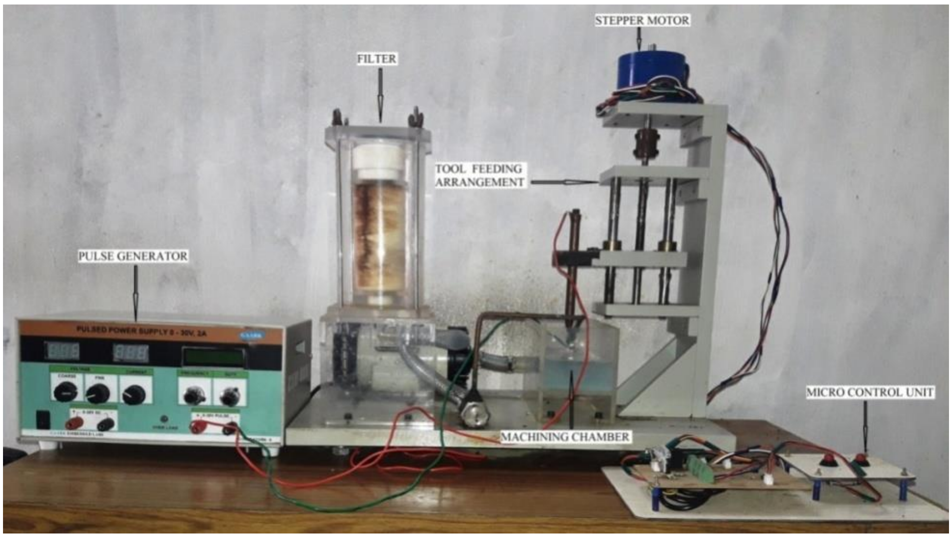

Figure 1. EMM Setup

The machining parameters are selected based on the literature review and shown in the table 1. L_{18} orthogonal array are presented in Table 2. Machining performances, MRR and overcut is to be evaluated.MRR was calculated as material removed per unit machining time. Overcut is calculated as the difference between the radius of machined hole and the radius of tool electrode through the optical microscope. Machining time has been noted carefully for the each experiment. Based on the machining time and micro hole diameter the MRR and overcut were calculated. The experimental parameter levels were examined by the Taguchi technique and Technique for order preference by similarity to ideal solution (TOPSIS).

Table 1 Machining parameters Levels

Symbol	Factors	Level 1	Level 2	Level 3
A	Electrolyte concentration (g/l)	20	25	30
B	Machining voltage(V)	7	8	9
C	Duty cycle (%)	55	45	65
D	Frequency (Hz)	65	75	50

In the Taguchi method, the S/N ratio is used to determine performance deviation from the desired values. To attain optimal machining performance, minimum overcut and maximum MRR are preferred. The signal-to-noise ratio for the smaller-the-better performance characteristic can be expressed as:

$$S/N = -10\log\left(\frac{1}{n}\sum_{i}^{n} Y_i^2\right) \quad \ldots\ldots\ldots.(1)$$

The signal-to-noise ratio for the larger-the-better performance characteristic can be expressed as:

$$S/N = -10\log\left(\frac{1}{n}\sum_{i}^{n} Y_i^{-2}\right) \quad \ldots\ldots.. (2)$$

Where Yi the i^{th} result of the experiment,
n= number of tests in a trial for overcut and MRR.

The experimental results for the MRR and overcut are shown in the table 2. The S/N ratios are calculated based on Equations 1 and 2. Technique for order preference by Similarity to ideal solution (TOPSIS) helps to find the, most suitable alternative from a predetermined experimental set. Based on the TOPSIS theory, the selected alternative should have the smallest interval from the positive ideal solution and the farthest interval from the negative ideal solution. The steps are expressed below [11]:

Step 1: The decision matrix of TOPSIS consists of 'n' attributes and 'm' alternatives as represented in equation 3.

Table 2.Experimental system L18 Mixed orthogonal Array

Ex. No	A	B	C	D	Material Removal Rate (µm/sec)	Over cut (µm)
1	20	7	55	50	0.108	92.41
2	20	8	45	65	0.319	99.61
3	20	9	65	75	0.552	135.62
4	20	7	65	75	0.159	88.81
5	20	8	55	50	0.356	118.82
6	20	9	45	65	0.370	114.41
7	25	7	55	65	0.185	91.42
8	25	8	45	75	0.367	124
9	25	9	65	50	0.661	140.02
10	25	7	45	75	0.376	158.42
11	25	8	65	50	0.383	124.82
12	25	9	55	65	0.567	122.42
13	30	7	45	50	0.394	101.22
14	30	8	65	65	0.565	117.62
15	30	9	55	75	0.711	142.82
16	30	7	65	65	0.449	147.62
17	30	8	55	75	0.333	126.42
18	30	9	45	50	0.537	131.22

$$D_m = \begin{vmatrix} P_{11} & P_{12} & \ldots & \ldots & P_{1n} \\ P_{21} & P_{22} & \ldots & \ldots & P_{2n} \\ P_{31} & P_{32} & \ldots & \ldots & P_{3n} \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ P_{m1} & P_{m2} & \ldots & \ldots & P_{mn} \end{vmatrix} \quad \ldots..(3)$$

Where Pij is the performance of *i* th alternative with respect to *j* th attribute.

Setp 2: normalized matrix is obtained by the following equation 4.

$$r_{ij} = \frac{P\,ij}{\sqrt{\sum_{i=1}^{m} P\,ij^2}} \quad \ldots\ldots(4)$$

Step 3: the weight of each attribute was assumed to be W_j (j=1,2,….,n).the weighted normalized decision matrix $V = [v_{ij}]$ can be obtained by equation 5.

$$V = W_j\, r_{ij} \quad \ldots\ldots\ (5)$$

where, $\sum_{j=1}^{n} \mathrm{W\,j} = 1$

Step 4: the positive ideal (best) and negative ideal (worst) solutions have been calculated by the equation 6 and 7.

$$V^{+} = \{(\textstyle\sum_{i}^{max} V\,ij \,|\, j \in J), \{(\textstyle\sum_{i}^{min} | j \in J \,|\, i = 1,2,.\,m)\} \ \ldots\ldots\ (6)$$

$$= \{\mathrm{V}_1^{+}, \mathrm{V}_2^{+}, \mathrm{V}_3^{+}, \ldots \ldots . . \mathrm{V}_{\mathrm{n}}^{+}\}$$

$$V^{-} = \{(\textstyle\sum_{i}^{min} V\,ij \,|\, j \in J), \{(\textstyle\sum_{i}^{max} | j \in J \,|\, i = 1,2,.\,m)\} \ \ldots\ldots.\ (7)$$

$$= \{\mathrm{V}_1^{-}, \mathrm{V}_2^{-}, \mathrm{V}_3^{-}, \ldots \ldots . . \mathrm{V}_{\mathrm{n}}^{-}\}$$

Step 5: The separation of each alternatives from ‘ideal’ solution is given by equation 8.

$$S_i^{+} = \sqrt{\sum_{j=1}^{n} (Vij - V_j^{+})^2}, \qquad i=1,2,\ldots.m \qquad \ldots\ldots(8)$$

The separation of each alternative form ‘negative-ideal’ solution is given by in equation 9.

$$S_i^{-} = \sqrt{\sum_{j=1}^{n} (Vij - V_j^{-})^2}, \qquad i=1,2,\ldots.m \qquad \ldots\ldots(9)$$

Step 6: In this step relative closeness of particular alternative to the ideal solution is evaluated which is expressed as following equation 10.

$$X_i = \frac{S_i^{-}}{S_i^{+} + S_i^{-}} \qquad i=1,2\ldots m \qquad \ldots\ldots\ (10)$$

Step 7: the X_i value was ranked in descending order to find the optimal parameters combination.

3. RESULTS AND DISCUSSION

3.1 TOPSIS

EMM is optimized for different attributes like MRR and overcut using TOPSIS. The Preference value (Xi) and its experimental combinations is obtained by the equations (3-10). Equal importance is specified to all the responses. The preference values (Xi) of each experimental runs are shown in the table 3. Maximum preference value and highest rank considered as the best combination. This gives the optimum parameter combination to the ideal solution. Experiment 7 and 1 holds the second and third ranking in the experimental combination which is considered as a next best optimal combination. Therefore 20 g/l electrolyte concentration, 7 V machining voltage,65 % duty cycle, and 75 Hz frequency is considered as optimal combination for higher MRR and lower overcut.

Table 3.Evaluation of Preference value with Rank order

Ex No.	Preference Value (X_i)	Order
1	0.94828	3
2	0.84485	4
3	0.32754	14
4	**0.99969**	1
5	0.56888	8
6	0.63224	6
7	0.96250	2
8	0.49447	10
9	0.26433	15
10	0.00202	18
11	0.48269	11
12	0.51716	9
13	0.82171	5
14	0.58612	7
15	0.22410	16
16	0.15516	17
17	0.45971	12
18	0.39075	13

The S/N ratio is evaluated from the preference values (Xi).Based on the mean effect table 4 the optimal parametric values are 20 g/l electrolyte concentration **(A_1)**, 7V machining voltage **(B_1)**, 65 % duty cycle **(C_3)**, and 75 Hz frequency **(D_2).** This optimal condition is perfectly correlates with the TOPSIS preference values.

Table 4 Main effects table for TOPSIS

Factors	S/N ratio			
	Level 1	Level 2	Level 3	Maximum
A	**-3.418**	-13.991	-8.406	-3.418
B	**-5.033**	-12.095	-8.686	-5.033
C	-12.553	-8.068	**-5.194**	5.194
D	-5.519	**-5.389**	-14.907	-5.389

TOPSIS parameter combination = $A_1\ B_1\ C_3\ D_2$

3.2 ANOVA for TOPSIS:

ANOVA (Analysis of variance) is useful tool to study the effect of machining parameter by statically. The experimentally observed values (S/N ratio values) were statically studied using ANOVA to investigate significant effect machining parameter. F value also used to determine significant process parameter on the EMM performance. Based on the ANOVA table 5 electrolyte concentration is the most significant factor that affects the MRR and overcut. The use of moderate concentration electrolyte influences the mass transportation and anodic reaction resulting in accurate micro holes. The voltage is the next contributing factor that affects the output performance.

Table 5 ANOVA for Preference number

Symbol	Sum of squares	DOF	Mean square (variance)	F value	% Contribution
A	0.29988	2	0.14994	1.85	20.92
B	0.20693	2	0.10346	1.28	14.43
C	0.06277	2	0.03139	0.39	4.37
D	0.13357	2	0.06679	0.82	9.31
Error	0.73004	9	0.08112		50.93
Total	1.43319	17			100

4. ANALYSIS BASED ON SEM MICROGRAPHS

Figure 2 & 3 exhibits the SEM micrograph of machined micro-holes for the optimal parameter conditions.

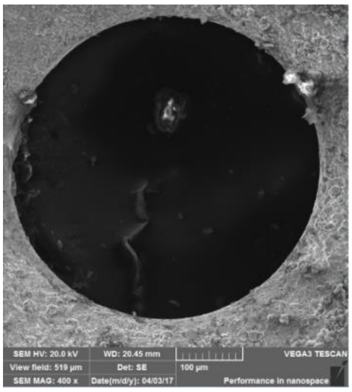

Figure 2. Micro hole
(20g/l electrolyte combination, 7V machining voltage, 65 % duty cycle, and 75 Hz frequency)

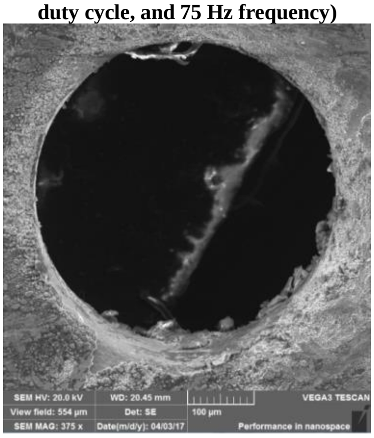

Figure 3. Micro hole
(25g/l electrolyte combination, 7V machining voltage, 55 % duty cycle, and 65 Hz frequency)

Based on the figure 2 the micro hole machined with 1st optimal combination show's good circularity without any stray cut. Figure 3 the micro hole machined with 2nd optimal combination exhibits good circularity with slight stray cut due to the electrolyte concentration.

5. CONCLUSION

The EMM setup successfully fabricated and its performance were studied by varying process parameter such as electrolyte concentration, voltage, duty cycle, and frequency. Based L_{18} OA the MRR and overcut values were determined. The optimal combination of process parameter was determined using TOPSIS method for the higher MRR and lower overcut. The optimal combinations were found to be 20 g/l electrolyte concentration, 7 V machining voltage, 65 % duty cycle, and 75 Hz frequency. Based on the ANOVA the most influencing factor for higher MRR and lower overcut are electrolyte concentration and voltage. The SEM micrograph of the micro hole shows good circularity for optimal process parameter.

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