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A comparative study of electrochemical machining process parameters by using GA and Taguchi method

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Abstract-In electrochemical machining quality of machined surface strongly depend on the selection of optimal parameter settings. This work deals with the application of Taguchi method and genetic algorithm using MATLAB to maximize the metal removal rate and minimize the surface roughness and overcut. In this paper a comparative study is presented for drilling of LM6 AL/B_4C composites by comparing the significant impact of numerous machining process parameters such as, electrolyte concentration (g/l),machining voltage (v),frequency (hz) on the response parameters (surface roughness, material removal rate and over cut). Taguchi L27 orthogonal array was chosen in Minitab 17 software, for the investigation of experimental results and also multiobjective optimization done by genetic algorithm is employed by using MATLAB. After obtaining optimized results from Taguchi method and genetic algorithm, a comparative results are presented.

1. Introduction

Electrochemical machining (ECM) is counted as one of the modernistic machining process in machining process. In ECM, a desired geometry of parent material achieved by anodic-dissolution and also applied to the numerous range of conductive material such as greater strength, heat-resistant and hardened steel. ECM has been used in ordinance, automobile and general engineering industry [1]. Quality of machined surface strongly depend on the selection of optimal parameter settings and type of machining process. Surface roughness and metal removal rate are important performance characteristics for any machining process [2]. Meanwhile the impact of ECM machining parameters on Material Removal Rate (MRR) and surface roughness(SR) are contradictory in nature, there is no unique combination of machining parameters that give better surface finish as well as high MRR simultaneously. Hence, selection of machining parameter is an important criteria to obtained desire level of accuracy with reasonable metal removal rate. Tiwari et al. [1] studied proper selection of optimal parameter settings, which is critically important for obtaining good quality of machined surface. ECM having several salient feature like higher material removal rate, good surface finish with machining a huge range of material. Biswesh et al. [2] carried out sets of experiments to investigate and suggest ECM optimization of process parameters. It is still a challenging problem because of its high complexity and non-linearity and that's why its application of optimization algorithms quite limited and hence, there is a need of powerful optimization techniques to get desired accuracy of optimum solution. Chinmaya et al. [3] suggested that essential properties of engineering material as well as in developing new materials and in monitoring the quality of materials for use in design and construction mechanical testing plays an important role. It is very important to know how material behave in varying loading condition. So researchers have developed number of experimental techniques for mechanical testing. Chambers [4] explained commonly used reinforcement B4C is lightest and hardest among all, making it a viable choice with respect to the reduced weight criterion. Also capacity of boron for high neutron capture has created much interest in using B4C reinforced aluminium composites in strategic applications. Aluminium/graphite composites have been used as self-lubricating materials due to the superior lubricating effect of graphite during sliding. Bhattacharyya et al. [5] conducted experiment and his result shows voltage 6 - 10 V offers an considerable amount of MRR at reasonable accuracy the most operative sector of pulse on time and electrolyte concentration can be taken as 15–20g/l and 10–15 ms , respectively. In the present work two different methods Taguchi method and genetic algorithm were employed for maximization of the metal removal rate and minimize the surface roughness and overcut. Rao et al .[14] considered also % of reinforcement as input parameter with the electrolyte con. ,voltage and FR. By using response surface method surface plot are generated to reveal effect of input parameters on MRR while ECM of Al-B4C MMC.

2. Methodology

In the present work twenty seven no of experiment (L27) were conducted based on the Orthogonal Array (OA) of Taguchi method. The multi-response optimization of the ECM parameters viz. MRR, SR & OC has been performed for machining of LM6 Al/B_4C composite. All the values of MRR, SR and OC are noted down for analysis in each run [8]. Our consideration for analysis MRR (Larger is better), SR (smaller is better) and Overcut (Smaller is better) [7].

2.1. Taguchi method

While conducting an experiment, we have to perform enormous number of experimental works. Upon increasing number of process parameters that problem is solved with the help of Taguchi method, in which by using design of experiment(DOE) a unusual design of OA we convert entire parameter space in very less number of experiment run subject to % accuracy. Among them all saving of work in accompanying experiments, saving experimental time, lowering the cost is the greatest advantage of this method [1]. The steps followed for Taguchi optimization in this work are presented as:

1. Smaller the better: $SN_S = -10 \log \left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right)$ (1)
2. Nominal the best: $SN_T = 10 \log (Y^2/S^2)$ (2)
3.Larger the better: $SN_L = -10\log \left(\frac{1}{n}\sum_{i=1}^{n} 1/Y_i^2\right)$ (3)

where *n* is the number of observations and y is the observed data [6].

2.2. Genetic algorithms(GA)

GA are a kind of optimization algorithm used to find out the optimal solution for a given computational problem that maximizes or minimizes a particular function. GA represent one branch of the field of study called evolutionary computation [4], in that they imitate the biological processes of reproduction and natural selection to solve for the ‘fittest’ solutions [13].

3. Experimentation & Analysis

Table 1. ECM process parameters [10].

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Table-1					
ECM Factor		Symbol	Level 1	Level 2	Level 3
A	Voltage (V)	V	6	8	10
B	Electrolyte Concentration(g/l)	E	20	25	30
C	Frequency (Hz)	F	30	40	50

Table 2. Experimental results for L27 orthogonal array & SN ratio for MRR,SR & OC of Drilling LM6 Al/B_4C [9].

Trial No.	Experimental Data According to Taguchi L27 Orthogonal Array Design						S/N Ratio for responses from Minitab		
	ECM parameters			Responses Parameter					
	Vol. (V)	Electrolyte Con. (g/l)	Freq^n (Hz)	MRR (mg/min)	SR(µm)	OC(µm)	MRR (mg/min)	SR(µm)	OC(µm)
1	6	20	30	0.268	4.948	212.46	-11.4373	-13.8886	-46.5455
2	6	20	40	0.335	5.002	167.32	-9.4991	-13.9829	-44.471
3	6	20	50	0.227	4.591	141.67	-12.8795	-13.2381	-43.0256
4	6	25	30	0.353	4.92	156.2	-9.0445	-13.8393	-43.8736
5	6	25	40	0.448	4.498	125.62	-6.9744	-13.0604	-41.9812
6	6	25	50	0.42	4.725	143.44	-7.535	-13.488	-43.1334
7	6	30	30	0.689	4.555	145.65	-3.2356	-13.1698	-43.2662
8	6	30	40	0.545	4.356	173	-5.2721	-12.7818	-44.7609
9	6	30	50	0.703	4.232	169.86	-3.0609	-12.5309	-44.6018
10	8	20	30	0.321	4.882	129.4	-9.8699	-13.772	-42.2387
11	8	20	40	0.329	4.823	171.1	-9.6561	-13.6663	-44.665
12	8	20	50	0.488	4.254	138.92	-6.2316	-12.5759	-42.8553
13	8	25	30	0.379	4.54	116	-8.4272	-13.1411	-41.2892
14	8	25	40	0.302	4.431	138.14	-10.3999	-12.93	-42.8064
15	8	25	50	0.583	3.998	155.86	-4.6866	-12.0369	-43.8547
16	8	30	30	0.615	4.274	89.4	-4.2225	-12.6167	-39.0268
17	8	30	40	0.619	4.346	152	-4.1662	-12.7618	-43.6369
18	8	30	50	0.812	3.598	76.6	-1.8089	-11.1212	-37.6846
19	10	20	30	0.282	5.472	162.72	-10.995	-14.7629	-44.2288
20	10	20	40	0.599	4.757	187	-4.4515	-13.5467	-45.4368
21	10	20	50	0.603	4.64	161.16	-4.3937	-13.3304	-44.1451
22	10	25	30	0.526	5.214	149	-5.5803	-14.3434	-43.4637
23	10	25	40	0.688	4.897	212.46	-11.4373	-13.7986	-46.5455
24	10	25	50	0.732	4.531	167.32	-9.4991	-13.1239	-44.471
25	10	30	30	0.688	5.002	141.67	-12.8795	-13.9829	-43.0256
26	10	30	40	0.887	4.389	156.2	-9.0445	-12.8473	-43.8736
27	10	30	50	0.944	3.989	125.62	-6.9744	-12.0173	-41.9812

S/N ratio of MRR (Larger the better), S/N ratio of SR (Smaller is better) and S/N ratio of OC(Smaller is better) is calculated. ECM characteristics MRR and OC as output responses for machining.

MRR= (weight before machining – weight after machining) / machining time (4)
ROC = (Hole diameter – Tool diameter) / 2 (5)
Surface is measured after machining by using a SURTRONIC 3+ surface texture having diamond stylus tip with accuracy of 0.005 µm and resolution of 1.0 µm horizontal, 10 µm vertical and having an extreme gauging range of 25 mm.

4. Results and Discussion

In MINITAB 17 software taguchi methodology is used for analysis and optimization [12].
4.1. Taguchi Analysis: Material Removal versus Voltage (V),Frequency (Hz), Electrolyte Concentration (g/l)

Table 3. Response Table for SN Ratios(LB)

Level	Vol. (V)	Electrolyte Con. (g/l)	Fre^{n} (Hz)
1	-7.660	-8.824	-7.340
2	-6.608	-6.512	-6.079
3	-4.019	-2.951	-4.867
Delta	3.641	5.873	2.473
Rank	2	1	3

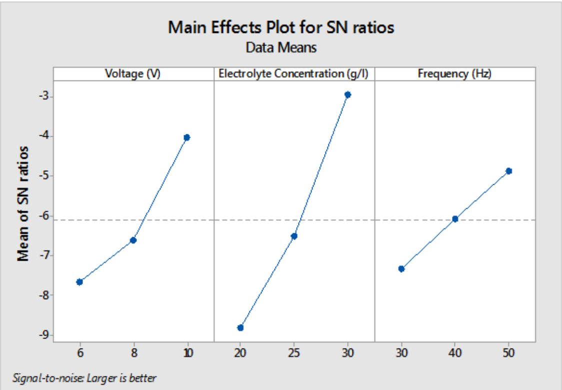

Fig 1. Main effect plot for SN ratios(MRR)

From the main effect plot for SN ratios parameter recommended for the higher MRR is Electrolyte concentration, 30g/l, Voltage, 10 V, Frequency, 50 Hz & From the Taguchi analysis it was found that the Electrolyte concentration (g/l) is the most significant factor which affects the material removal rate followed by Frequency (Hz) and Voltage (V) respectively.

4.2. Taguchi Analysis: Surface Roughness versus Voltage (V),Frequency (Hz), Electrolyte Concentration(g/l)

Table 4. Response Table for SN Ratios(SB)

Level	Vol. (V)	Electrolyte Con. (g/l)	Fre^{n} (Hz)
1	-13..33	-13.64	-13.72
2	-12.74	-13.31	-13.26
3	-13.53	-12.65	-12.61
Delta	0.79	0.99	1.12
Rank	3	2	1

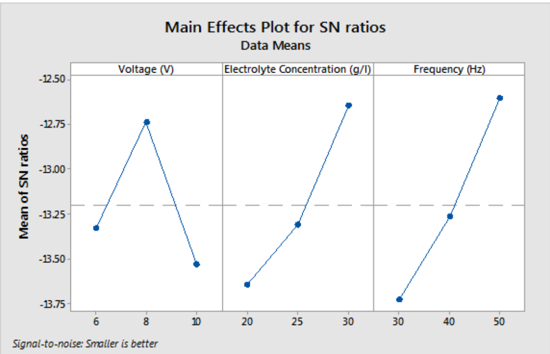

Fig 2. Main effects plot for SN ratios(SR)

From the main effect plot for SN ratios, parameter combination recommended for the lesser Surface Roughness is Electrolyte concentration, 30g/l, Voltage, 8 V, Frequency, 50 Hz & From the Taguchi analysis it was found that the Frequency(Hz) is the most important significant factor which affects the Surface roughness followed by Electrolyte concentration (g/l) and Voltage (V) respectively.

4.3. Taguchi Analysis: Overcut (μm) versus Voltage (V), Frequency (Hz), Electrolyte Concentration (g/l)

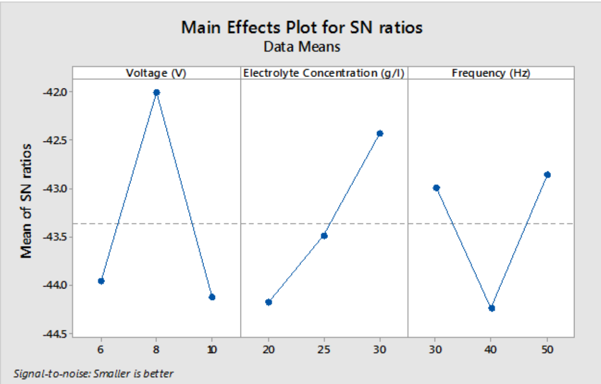

Fig 3. Main effects for SN ratios (OC)

Table 5. Response Table for SN Ratios(SB)

Level	Vol. (V)	Electrolyte Con. (g/l)	Fre^n (Hz)
1	-43.96	-44.18	-43.00
2	-42.01	-43.49	-44.24
3	-44.13	-42.43	-42.86
Delta	2.12	1.75	1.38
Rank	1	2	3

From the main effect plot for SN ratios parameter combination recommended for the lesser Overcut is Electrolyte concentration, 30g/l, Voltage, 8 V, Frequency, 50 Hz & From the Taguchi analysis it was found that the Voltage (V) is the most important significant factor which affects the overcut followed by Electrolyte concentration (g/l) and frequency (Hz) respectively.

4.4. Result obtained by using Genetic algorithm in MATLAB

Genetic algorithms is used for optimization of responses like MRR, SR and OC in ECM By using the multiple linear regression equations fitness functions are formulated. MRR is a maximizing function, SR and ROC are minimizing functions. The objective functions are maximized and minimized by using GA toolbox in MATLAB software. The fitness function in MATLAB environment is as follows. Multiple linear regression models are developed using the experimental data in the form of:

$$MRR/SR/ROC = K + K1(X1) + K2(X2) + K3(X3) \quad (6)$$

where k, $k1$, $k2$ and $k3$ are constants and Responses like MRR, SR and OC in ECM of Al/B4C composites are expressed as a linear function of the input variables [11].

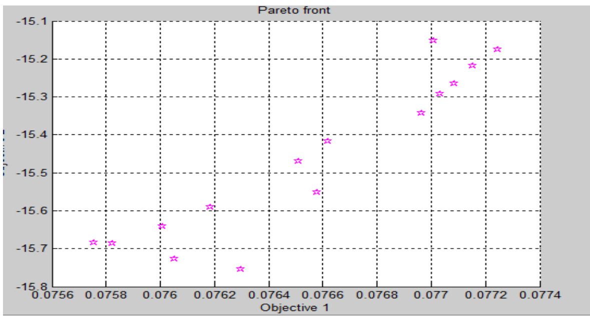

Fig 4. Pareto front

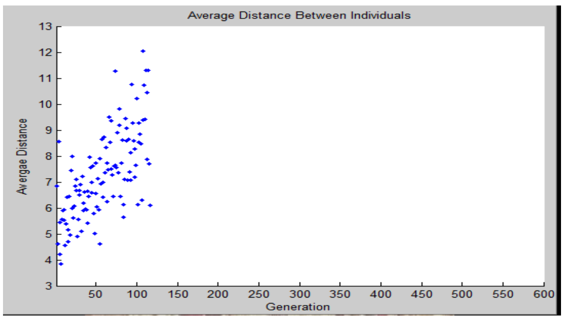

Fig 5. Average distance between individuals

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Figure 5 shows the performance of genetic algorithm, i.e., average distance verses generations for MRR, SR and OC and convergence rate at the earlier stage is much higher than that of the later stage. Mean fitness and best fitness values decrease very rapidly in the initial stage (1 to 100 generations). As the number of generations increases, rate of changes in these two fitness values decrease rapidly and programs are so designed that GA terminates when no significant improvement occurs in the solution. Usually maximum number of generations is set before the program starts.

Table 6. Optimum ECM parameters for MRR

Optimum Electrochemical micro machining parameters for MRR				
Level	Vol. (V)	Electrolyte Con. (g/l)	Fre^n (Hz)	MRR mg/min)
1	9.993	29.997	49.98	0.963

Table 7. Optimum ECM parameters for SR

Optimum Electrochemical micro machining parameters for Surface Roughness				
Level	Vol. (V)	Electrolyte Con. (g/l)	Fre^n (Hz)	SR (µm)
1	6.50	29.999	49.999	3.219

Table 8. Optimum ECM parameters for OC

Optimum Electrochemical micro machining parameters for Overcut				
Level	Vol. (V)	Electrolyte Con. (g/l)	Fre^n (Hz)	OC (µm)
1	6.50	29.999	49.999	74.39

After obtaining results, comparison of optimized response parameter value between taguchi method and genetic algorithm using MATLAB are presented in Table 9.

Table 9. Comparison of optimized response parameter value between taguchi method and genetic algorithm using MATLAB

Level/ Responses	ECM parameters by Taguchi Method	Optimal value of ECM parameters
		Prediction by MATLAB and Improvement on the basis of confirmation test
Material removal rate(mg/min)		
Level	10 v, 30 g/l,50 Hz	9.993 v, 29..997 g/l,49.98 Hz
MRR	0.944 mg/min	0.963 mg/min
Surface Roughness(µm)		
Level	8 v, 30 g/l,50 Hz	6.50 v, 29.999 g/l,49.98 Hz
SR	3.598µm	3.219µm
Overcut(µm)		
Level	8 v, 30 g/l,50 Hz	6.50 v, 29.999 g/l,49.98 Hz
Overcut	76.6 µm	74.39 µm

5. Conclusion

The objective of the present work is optimization and comparative study of ECM machining parameters. ECM data recommended for the higher MRR is Electrolyte concentration, 30g/l, Voltage, 10 V, Frequency, 50 Hz, for the lower Surface Roughness is Electrolyte concentration, 30 g/l, Voltage, 8 V, Frequency, 50 Hz and lesser overcut are Electrolyte concentration, 30 g/l, Voltage, 8 V, Frequency, 50 Hz. From the results Electrolyte concentration and Voltage are the most significant machining parameters for affecting the MRR and Overcut & Surface Roughness [13].

ECM data recommended from the result obtained by using Genetic algorithm in MATLAB for the higher MRR is Electrolyte con., 29.997g/l, Voltage, 9.993 V, Frequency, 49.98 Hz, for the lower Surface Roughness is Electrolyte con., 29.999 g/l, Voltage, 6.50 V, Frequency, 49.99 Hz and lesser overcut are Electrolyte con., 29.999 g/l, Voltage, 6.50 V, Frequency, 49.999 Hz .

Confirmatory test shows MRR is enhanced as compare to the initial parametric setting. Therefore from table 8 the parametric combination recommended for the higher MRR is the voltage of 9.993 V, electrolyte con. of 29.997 g/l and frequency of 49.98 Hz, for the lesser SR is the voltage of 6.50 V, electrolyte con. of 29.999 g/l and frequency of 49.98 Hz and for the lesser OC is the voltage of 6.50 V, electrolyte con. of 29.999 g/l and frequency of 49.98 Hz .

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