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Optimization Of Copper Nano-Fluid Used ECM By Firefly Algorithm

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Abstract:

Electrochemical machining (ECM) is one of the most suitable machining processes for thematerialsthosearehaving high hardness and can't be machined by conventional machining process. However, the formation of spikes in the machined components affects its surface finish and Material removal rate (MRR). Hence, this investigation attempts to improve the surface finish and MRR by the way of controlling the formation of spikes in the machined components with help of Nano fluid i.e. CopperNanoparticles suspended in NaCl electrolyte. High hardness with poor machinability and highly preferred material for dies in Automobile Industries is High carbon high chromium die steel (HCHCr die steel) which has been chosen for this experimentation. The selected influencing parameters namely applied voltage, tool feed rate and electrolyte discharge rate and investigate the effects on MRR and surface roughness. Firefly algorithm has been applied to optimize the chosen parameters. Based on the predicted optimum values of machining parameters from Firefly algorithm, the results of confirmation experiments reveals that the percentage of deviation is found to be less than 4%.

Key words: Electrochemical Machining (ECM), Nano-fluid, MRR, Surface Roughness, Firefly Algorithm.

1. INTRODUCTION

Electrochemical machining (ECM) is one of the non-contact machining processes which are used to machine the poor machine able materials such as Stainless steel, Titanium and high hardness materials like High carbon high chromium die tool steel (HCHCr die steel), super alloys etc. ECM process an anodic dissolution of the material being machined occurs very rapidly [1], [2], [3]. ECM machining process responseparameters,namely MRR and surface roughness, values will be changedaccording to its selected influencing parameters, namely applied voltage, tool feed rate and electrolyte discharge rate [4], [5],[6]. However, the MRR and surface roughness are majorly affected in ECM by formation of spikes. This happens because of uneven current density in the machined area due to presence of passive layer formation and gas bubbles at inter electrode gap (IEG). This investigation attempts to remove the passive layer formation at IEG by the way of attacking Nano particles which has been suspended in NaCl electrolyte. The major criteria considered while selecting Nano Particle is, electrical and thermal conductivity. Hence, Copper nano powder is chosen for this experimentation. Firefly algorithm was applied in the past researches in ECM application [7], [8].

2. Experimental setup

The experiments are conducted using ECM setup as shown in Figure 1. The selected work piece material HCHCr die steel with hardness of 67 HRcis one of the poor machinability materials [9], [10] and most preferred material for making Automobile dies. The complete chemical composition of HCHCr die steel is presented in Table 1. Generally 15% of aqueous NaCl electrolyte solution is used for ECM[11], [12], [13] and the end results with poor accuracy and spikes in the machined surface. Hence, Copper Nano powder of 40 grams mixed with 15%ofaqueousNaCl electrolyte solution i.e., Nano fluid is used as an electrolyte for all experiments.

Figure 1 ECM setup

Table 1 Chemical composition of High carbon high chromium dies steel

Element	C	Cr	Mn	P	S	Fe	Si
Wt %	1.936	11.84	0.27	0.044	0.089	85.34	0.48

The electrolyte solutions were completely analyzed using ‘deluxe water and soil analysis kit’, Model-191E. A digital flow meter with two digit accuracy was employed to adjust the flow rate of electrolyte to the IEG. Copper is chosen for fabrication of tool material due to high electrical conductivity[14]In the present work, the IEG of 0.1mm was set at an initial stage of experimentation [15], [16]. Material Removal (MR) is the difference in the weight of the workpiece before and after machining. The accuracy of measurement is ensured using Sartorius electronic weighing machine with three digit accuracy. Mitutoyo surface tester with a range of 0-150µm is used to measure surface roughness (Ra) and the average of values observed in three different surfaces on the workpiece is computed in each experiment. The process parameters used in the complete experiment is presented in Table 2.

Table 2 Process parameters

Applied voltage (V)	12, 15 and 18
Inter electrode gap (mm)	0.1
Tool feed rate (mm/min)	0.1, 0.32 and 0.54
Electrolyte discharge rate (lit/min)	8, 10 and 12
Selected electrolyte	15% of aqueous NaCl solution 40 grams of copper Nano particles suspended in 15% of aqueous NaCl solution
Tool-electrode condition	Stationary
Electrolyte temperature range (^{o}C)	30^{o} - 40^{o}
Workpiece material with its hardness	HCHCr die steel - 67 HRc
Machining time (min)	3

3. Mathematical Modeling of machining parameters

Design expert 7.0 software is used to determine the relationship among the selected influencing parameters of ECM[17]. Threelevels have been selected for applied voltage, electrolyte discharge rate and tool feed rate. It is possible to assess the main and interaction effects of different machining parameters in L_{27} array with most reasonable accuracy. A first-order experiment was performed to determine the magnitudes of the relative changes to the process parameters that would result optimum MRR and surface roughness. It is obtained from the first-order experiments, copper Nano particles suspended in 15%ofaqueousNaCl solution is significantly improves the MRR and surface roughness compared to 15% of plain aqueousNaClsolution. Hence, it is decided that RSM can be employed to develop the optimized mathematical models for MRR and surface roughness, whereasFireflyalgorithm is used to converge the number of experiments conducted on ECM process. Subsequently, a second-order central composite design is selected to identify the optimum conditions which turn into the higher MRR and finest surface roughness. The general form of second order polynomial mathematical model applied to investigate the parametric effects of ECM is

$$Yu = b_0 + \sum_{i=1}^{n} b_i x_{iu} + \sum_{i=1}^{n} b_{ii} x^2{}_{iu2} + \sum_{i<j}^{n} b_{ij} x_{iu} x_{ju} \qquad \text{---------------------------------}$$

Where Yu is the response, terms b_0, b_i, etc., are the second order regression coefficients. For various sets of parametric combinations results are obtained by conducting a series of experiments.The respective mathematical model representing MRR and surface roughness in view of Cu Nano particles suspended inaqueousNaCl solution is computed as;

$$\begin{aligned} Yu(MRR) =& +832.44771 - 139.19774 X_1 + 36.47148 X_2 + 47.69863 X_3 - 13.68989 X_1 X_2 \\ & - 0.31428 X_1 X_3 + 50.04143 X_2 X_3 + 5.23654 X_1{}^2 - 55.31699 X_2{}^2 - 2.16948 X_3{}^2 \quad \text{-- (2)} \end{aligned}$$

$$\begin{aligned} Yu_1(\mathrm{SR}) =& -4.50296 + 0.21855 \mathrm{X}_1 + 7.87600 \mathrm{X}_2 + 0.81590 \mathrm{X}_3 + 0.00094 \mathrm{X}_1 \mathrm{X}_2 - 0.00454 \mathrm{X}_1 \mathrm{X}_3 \\ & - 0.18982 \mathrm{X}_2 \mathrm{X}_3 - 0.00595 \mathrm{X}_1{}^2 - 6.00175 \mathrm{X}_2{}^2 - 0.03565 \mathrm{X}_3{}^2 \qquad \text{----------- (3)} \end{aligned}$$

Where, X_1- applied voltage, X_2- tool feed rate, X_3- electrolyte discharge rate.

The coefficient of determination R^2 obtained from ANNOVA for MRR and surface roughness in Cu Nano particles suspended in aqueous NaCl solution were 97.10% and 95.20% respectively which confirms the fitness of the mathematical model.

3.1 Optimization using Firefly algorithm

Inspiration:

Fireflies belong with flashing characteristics of family of Lampyridae fireflies, which are, firefly is attracted to other fireflies regardless of their sex. Attractiveness is proportional to their brightness, thus for any two flashing fireflies, the less bright one will move towards the brighter one. The attractiveness is proportional to the brightness and they both decrease as their distance increases. If no one is brighter than a particular firefly, it will move randomly. The brightness of a firefly is affected or determined by the landscape of the objective function to be optimized [18], [19].

Algorithm:

Firefly Algorithm is a metaheuristic optimization algorithm based on the social

characteristics and flashing patterns of fireflies. Metaheuristic algorithms solve many optimization problems in engineering and technologies. These algorithms often produce different solutions even with the same initial starting point. However, the final results, though slightly different, will usually converge to the same optimal solutions within a given accuracy. It can take many forms such as simple randomization by randomly sampling the search space or by random walks within iterate values. Most metaheuristic algorithms can be considered for optimization solutions good examples are genetic algorithms (GA), Ant Colony Optimization (ACO) and particle swarm optimization (PSO). One of the modern metaheuristic algorithms is Firefly Algorithm developed by Yang, Lukasik and Zak 2009[20].
Table 3 summarizes the Firefly parameter settings used in researches for solving various optimization problems. Unfortunately, most of the work has not reported on the investigation of the appropriate setting of firefly algorithm parameters via proper statistical design and analysis.

Table 3 Parameters and definitions

Parameter	**Notation in Algorithm**
Brightness	Objective function
Beta (β)	Attractiveness
Alpha (α)	Randomization parameter
Gamma (γ)	Absorption coefficient
Number of generations	Iterations
Number of fireflies	Population
Dimension	Problem dimension
R	Radius, time interval etc. (depends on application

3.2 Pseudo-code of the Firefly Algorithm:
In the firefly algorithm, the optimization process depends on the brightness of the fireflies and the movement of fireflies towards their brighter counterparts. Every firefly is attracted to the other depending on brightness because the fireflies are all unisexual according to the first assumption about artificial fireflies. The Firefly algorithm starts by initializing a population of fireflies and each firefly is different from the other in the swarm. The differentiation is based on the brightness of the firefly. The brightness of the firefly is what determines the internal movement of the fireflies. During the iterative process, the brightness of one firefly is compared with the others in the swarm and the difference in the brightness triggers the movement[21], [22].

The following section describes the pseudo code of Firefly algorithm.
Objective function f(x), $x=(x_1,x_2,\ldots,x_d)^T$
Initialize a population of fireflies $X_i(i = 1,2, . . . , n)$
Define light absorption coefficient γ
While (t<MaxGeneration)

fori=1:n (all n fireflies)
forj=1:i
Light intensity I_i at X_i is determined by f (x_i)
If (I_i>J_i)

Move firefly i towards j in all d dimensions
$$x_i = x_i + \beta_0 \times \exp(-\gamma r_{ij}^2) \times (x_j - x_i) + \alpha(rand - \frac{1}{2})$$
Else
Move firefly i randomly
End if
Attractiveness varies with distance r via exp[-γr^2]
$$\beta(r) = \beta_0 \times \exp(-\gamma r^m)$$
Evaluate new solutions and update light intensity
End for j
End for i
Rank the fireflies and find the current best
End while
Post process results and visualization.

3.3 Problem formulation in Firefly by using JAVA

The problem of machining consists of determining the value of process parameters are voltage, tool feed rate and electrolyte discharge rate, in order to optimize the objective function (responses). For effective results in the optimization of machining parameters, it is better to provide the actual values of the process parameters and for this purpose experimental machining study was carried out. The following options are selected for formulating the problem.

Number of Variables	=	3
Population	=	27
No of Iteration	=	11
Beta (β)	=	1.3
Alpha (α)	=	0.8
Gamma (γ)	=	2.0
Number of generation	=	255
Number of fireflies	=	3
Dimension	=	9

The algorithm stops when the value of the fitness function for the best point in the current population is less than or equal to the fitness limit.
Lower bound [12 0.1 8]
Upper bound[18 0.54 12]
Figure 2 shows a running programme of JAVA with respected given boundary condition.

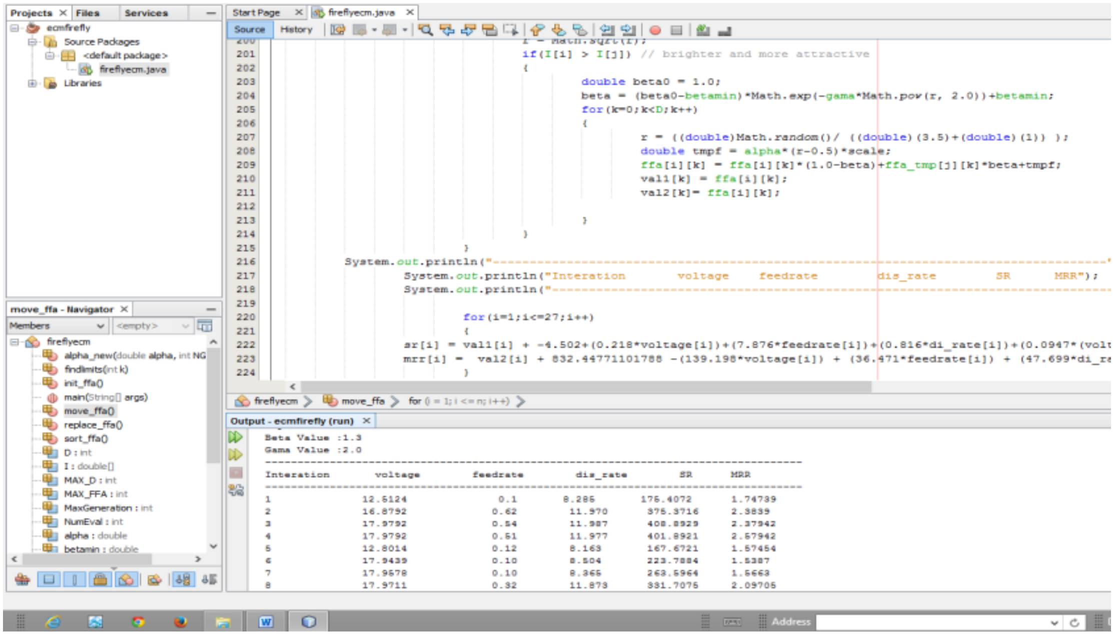

Figure 2 Optimal solutions from firefly in JAVA

3.4 Plot function for best fitness of Cu Nano particles suspended in aqueous NaCl electrolyte.

The obtained functional values and decision variables along with Optimized response for Cu Nano particles suspended in aqueous NaCl results are presented in Table 4 and is Figure 3, Firefly algorithm converge the total number of experiments to optimum possible number of experiments.MRR increases at higher values of electrolyte discharge rate and tool feed rate.

Table 4 Optimized response values for Cu Nano particles suspended in aqueous NaCl electrolyte

S. No	Applied voltage (V)	Tool feed rate (mm/min)	Discharge rate (lit/min)	MRR (mm^3/min)	Surface roughness (micron)
1	13	0.1	8.28	175.407	1.74
2	17	0.52	11.97	375.371	2.38
3	18	0.54	11.98	408.892	2.37
4	18	0.51	11.97	401.892	2.57
5	13	0.12	8.16	167.672	1.57
6	18	0.10	8.50	223.788	1.53
7	18	0.10	8.36	263.596	1.56
8	18	0.32	11.87	331.707	2.09
9	18	0.11	11.82	284.947	1.54
10	18	0.53	11.96	385.013	2.19
11	17	0.35	11.87	303.187	1.97

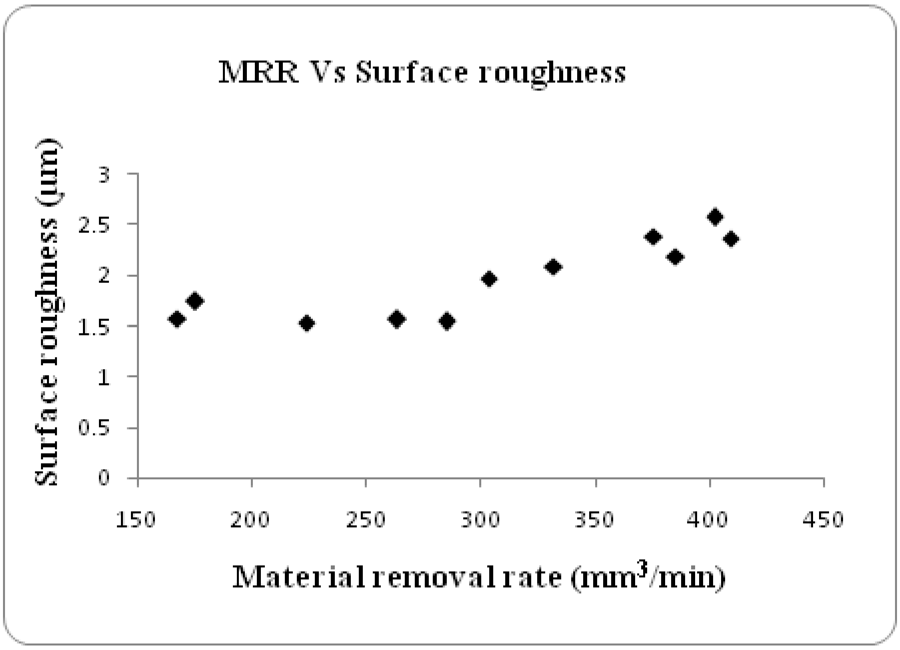

Figure 3MRR Vs Surface roughness from optimized value from firefly algorithm

The surface finish decreases when the discharge rate and tool feed rate are decreased. Optimized results reveal that a maximum value of MRR 408.892mm^3/min is predicted at 18V, 0.54 mm/min tool feed and 11.98lit/min electrolyte discharge rate conditions. The minimum surface finish of 1.54µm is predicted at 18 V, 0.11 mm/min tool feed rate and 11.82 lit/min electrolyte discharge rate conditions. MRR increases with applied voltage and tool feed rate. Surface roughness decreases with increase in the applied voltage and all tool feed rates.It is obvious that the optimum search can be obtained based on the developed second-order response, surface equations for correlating the various process variable effects with the MRR and surface roughness. The optimal combination of various process variables thus obtained for achieving controlled Electrochemical-machining of the work pieces are found to be within the bounds of the mathematical model.

3.5 Confirmation Test

The confirmatory experiments were conducted for ensuring the consistency of the developed mathematical model and finding the deviation from the obtained values. The deviation between the optimum values from Firefly and the confirmation results are presented in the Table 5.

Table 5 Deviation between optimum values from firefly and confirmation test value for maximum MRR and minimum surface roughness condition

S.No	**Electrolyte**	**Obtained from firefly**		**Confirmation test**		**% of deviation**	
		MRR (mm^3/min)	**Corresponding Surface roughness (µm)**	**MRR (mm^3/min)**	**Corresponding Surface roughness (µm)**	**MRR %**	**Surface roughness %**
Maximum MRR							
1.	Cu Nano particles suspended in aqueous NaCl	408.892	2.37	400.541	2.43	2.04	2.53
Minimum surface roughness							
2.	Cu Nano particles suspended in aqueous NaCl	284.9476	1.54	275.152	1.58	3.44	2.59

The deviation from the predicted performance is less than 4% which proves the composite desirability of the developed mathematical models for MRR and surface roughness. Similarly at minimum surface roughness conditions, error obtained between experimental and firefly values were 3.44% in MRR and 2.59% in surface roughness.

4. Conclusion

The present investigation attempts to improve the better MRR and surface roughness of High carbon high chromium die steel using Copper Nano particles suspended in aqueous NaCl electrolyte in ECM. For optimizing the influencing parameters, Firefly algorithm is applied and the following conclusions are drawn.

1. Nano fluid significantly improves the MRR and surface roughness by the way of controlling the formation of spikes in the machined work pieces.
2. The Nano particles breaks the formation of passive layer at theIEG results the uniformity in current density across the IEG, hence the better MRR and surface roughness are obtained.
3. Mathematical models for MRR and surface roughnesshave been developed

using Design Expert 7.0 software. MRR and surface roughness increases with applied voltage and tool feed rate.

4. Firefly Algorithm is applied to optimize the values of chosen influencing parameters in ECM of HCHCr die steel.
5. A maximum value of MRR 408.892mm^3/min is predicted under applied voltage of 18V, tool feed rate of 0.54 mm/min and electrolyte discharge rate of 11.98lit/min conditions. The minimum surface finish of 1.54µm is predicted at applied voltage of 17.84V, tool feed rate of 0.11 mm/min and electrolyte discharge rate of 11.82 lit/min conditions by Firefly algorithm.
6. Confirmatory tests showed that the actual performance at the optimum conditions were 400.541mm^3/min and 2.43µm at maximum material removal condition, 275.152 mm^3/min and 1.58µm at minimum surface roughness condition. Deviation from the predicted performance is less than 4% which has proven the composite desirability of the developed models for MRR and surface roughness while using Copper Nano particles suspended in aqueous NaCl electrolyte.

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