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Mathematical Modelling and Optimization of Electro Co-Deposition Process Parameters Using Response Surface Methodology and Genetic Algorithm

1.NaveenKumar[a],2.Vengatesh[a], 3.Nexon Brissac[a], 4.MadhanRaj[b]
[a] Student, Department of Mechanical Engineering, Christ College Of Engineering and Technology, Moolakulam, Pondicherry- 605 010.
[b]Assistant Professor, Department of Mechanical Engineering, Christ College Of Engineering and Technology, Moolakulam, Pondicherry- 605 010.

Abstract: **The Process electro co-deposition is a ceramic matrix composites processing method having ability to coat non-metallic ceramic particles in the substrate along with metals. The mathematical modelling of responses of a process helps us to predict the process and further used as the objective functions for optimization.**

In this paper, Response Surface Methodology is used for making empirical relation for each response by taking Current Density, W/L of SiC Added and Voltage as a governing parameters. The responses were analysed and discussed by ANOVA and Surface Plots. The wear rate for micro DC and micro PC is optimized as 4.78580E-9 and 2.13633E-9 using Genetic Algorithm. The optimized wear rates are found to be approximate to actual value. The Actual value and the Predicted Value are compared.

1.INTRODUCTION

Electro co-deposition is a chemical process in which atoms of metallic materials will be deposited on the surface of another material along with the non-metallic (ceramic) atoms in the electrolytic bath. In this process one of the materials is taken as anode and other as cathode. And this works by the principle of faradays's law of electrolysis. This method is more advantageous than conventional electro-plating process, because by electro co-deposition method we can make non-metallic atoms to be deposited on the substrate.

RSM is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. RSM also quantifies relationships among one or more measured responses and the vital input factors. The Design Expert version7 software was used to develop the experimental plan for RSM. The same software was also used to analyse data collected.

Genetic algorithm(GA) is a non-conventional optimization method which is based on the darwin's theory of "survival of the fittest". The biological terms like genes, chromosomes were used to represent the values of the parameters. Using GA we can solve constrained and unconstrained optimization problems to find the maximum or minimum of an objective function. The solution converges or diverges by repeatedly modifies a population of individual solution. The GA is applicable to solve variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, non-differentiable, stochastic or highly nonlinear

2.MATHEMATICAL MODELLING

There are many methods to plan and design an experiment. Response Surface Methods are design and models for working with continuous treatments when finding optima or describing the response is the goal.

RSM is an important subject in the statistical design which is a collection of mathematical and statistical techniques used to model and analyze a problem in which response is influenced by several input variables and the objective is to optimize this response.

The second order polynomial regression equation is to fit the non linear curve. The equation contains interaction of the variables and the square of them.

The second order equation is represented as follows:

$$Y = b_0 + \sum b_i x_i + \sum b_{ii} x_i^2 + \sum b_{ij} x_i x_j \qquad (a)$$

In this paper, mathematical model were developed and optimized the parameters to find the operating condition to get minimum wear rate. This analysis has three dependent such as %Wt of SiC incorporation in the coating, Specific Wear Rate and Wear Co-efficient are related to the three independent variables Current Density, W/L of SiC and Voltage.

$$Responses = b_0 + b_1(A) + b_2(B) + b_3(C) + b_{11}(A^2) + b_{22}(B^2) + b_{33}(C^2) + b_{12}(AB) + b_{13}(AC) + b_{23}(BC) \qquad (b)$$

The second order polynomial Equations were developed using DESIGN EXPERT - 7 software for the prediction of %Wt of SiC incorporation in the coating, Specific Wear Rate and Wear Co-efficient in terms of three independent variables.

A – Current Density

B – W/L of SiC supplied

C – Voltage

The Regressions equations are created for the two different experiments values, since the input and output parameters are same for these experiments the same Central composite design can be used.

Composite Method Design Matrix is used for all the Experiments. The Experiments are,

1. Micro SiC DC Supply
2. Micro SiC PC Supply

The parameters are almost same only differences are the Type of Current Supplied (DC or PC) and the Size of the SiC Particle Supplied in the Bath.

Table 1 Important Co-deposition process parameters

Factors	Unit	Variables	-2	-1	0	1	2
Current Density (DC/PC)	A/dm 2	A	0.5	1	1.5	2	2.5
W/L of SiC (Micro)	%W/L	B	0	5	10	15	20
Voltage	Volts	C	0.5	1	1.5	2	2.5

2.1.Micro-SiC for DC supply

The current supply to the electrolyte bath is Direct current and the experimental values are taken from the Literature [1]. The responses are obtained for varying current and amount of SiC in Electrolyte bath. The voltage also changed during experiment.

2.2.Micro-SiC for PC supply

In this experiment method every parameters are same as in the micro-SiC for DC supply except the type of current . The Pules Current is supplied during the deposition process. Other parameters like W/L added and Voltage are maintained unchanged.

Table 2 Experimental design matrix and respones

Micro DC						Micro PC					
Current Densit y	W/ L of SiC	Voltag e	%Wt of SiC incorpo ration in the coating	Specific Wear Rate	Wear Co-efficient	Current Densit y	W/ L of SiC	Voltag e	%Wt of SiC incorpor ation in the coating	Specific Wear Rate	Wear Co-efficient
1	1	-1	27.31	5.06E-09	2.86E-07	1	1	-1	30.23	3.01E-09	2.45E-07
-1	1	1	22.41	5.72E-09	3.43E-07	-1	1	1	24.78	4.34E-09	3.23E-07
-1	1	-1	24.56	5.15E-09	3.12E-07	-1	1	-1	27.01	4.12E-09	3.01E-07
0	0	0	22.38	8.58E-09	5.43E-07	0	0	0	25.12	6.55E-09	5.12 E-07
2	0	0	16.35	1.74E-08	1.45E-06	2	0	0	18.95	1.43E-08	1.99E-06
1	-1	-1	18.27	1.20E-08	8.51E-07	1	-1	-1	19.79	1.10E-08	8.23E-07
0	0	0	22.38	8.58E-09	5.43E-07	0	0	0	25.12	6.55E-09	5.12E-07

0	0	0	22.38	8.58E-09	5.43E-07	0	0	0	25.12	6.55E-09	5.12E-07
0	0	0	22.39	8.69E-09	5.92E-07	0	0	0	25.11	6.25E-09	4.98E-07
-1	-1	-1	19.21	1.14E-08	7.72E-07	-1	-1	-1	22.44	1.00E-08	7.00E-07
0	-2	0	0	2.23E-08	2.03E-06	0	-2	0	0	1.28E-08	1.12E-06
1	-1	1	19.5	1.23E-08	8.86E-07	1	-1	1	22.21	1.12E-08	8.56E-07
0	0	0	22.39	8.69E-09	5.92E-07	0	0	0	25.12	6.55E-09	5.12E-07
0	2	0	30.24	8.58E-09	2.03E-06	0	2	0	32.34	6.32E-09	4.01E-07
-2	0	0	16.3	1.54E-08	9.25E-07	-2	0	0	18.61	1.21E-08	9.01E-07
0	0	-2	21.28	1.01E-08	6.00E-07	0	0	-2	23.23	1.00E-08	5.97E-07
-1	-1	1	20.72	1.08E-08	7.10E-07	-1	-1	1	22.87	1.01E-08	7.43E-07
0	0	2	25.54	6.86E-09	2.57E-07	0	0	2	27.32	5.83E-09	2.34E-07
0	0	0	22.37	8.47E-09	5.01E-07	0	0	0	25.13	6.65E-09	5.45E-07
1	1	1	29.97	4.56E-09	2.73E-07	1	1	1	30.98	3.52E-09	2.45E-07

3. DEVELOPING EMPIRICAL RELATION

The %W/T of SiC incorporated in the substrate, Wear rate and Wear co-efficient are the responses. For this responses the second order polynomial regression equation were created in terms of Current Density(A), W/L of SiC Added in electrolyte(B) and Voltage(C) to predict. The empirical relation for coded values are shown below for micro-SiC DC and PC supply.

3.1. For Micro-SiC DC supply

%W/L of SiC incorp=+23.00+0.52*A+5.44*B+0.74*C+1.56*A*B+0.57*A*C-0.28*B*C-1.20*A^2-1.50*B^2+0.57*C^2 (c)

WearRate=+7.884E-009+2.974E-010*A-3.353E-009*B-4.174E-010*C-4.118E-010*A*B-2.122E-011*A*C+3.963E-011*B*C+1.615E-009*A^2+1.367E-009*B^2-3.719E-010*C^2(d)

Wear Coefficient=+4.547E-007+7.561E-008*A-1.254E-007*B-4.345E-008*C-4.398E-008*A*B+6.783E-009*A*C+5.628E-009*B*C+1.159E-007*A^2+3.275E-007*B^2-7.382E-008*C^2 (e)

3.2. For Micro-SiC PC supply

%W/LofSiCincorp=+25.79+0.42*A+5.65*B+0.60*C+1.59*A* B+0.62*A*C-0.54*B*C-1.25*A^2-1.90*B^2+0.38* C^2 (f)

WearRate =+6.131E-009+2.870E-010*A-2.519E-009*B-4.546E-010*C-5.035E-010*A*B+5.207E-011*A*C+5.142E-011*B*C+1.479E-009*A^2+5.705E-010*B^2+1.552E-010*C^2 (g)

WearCoefficient =+4.688E-007+1.436E-007*A-2.159E-007*B-3.926E-008*C-4.617E-008*A*B-4.034E-009*A*C-6.759E-009*B*C+2.103E-007*A^2+3.868E-008*B^2-4.818E-008*C^2 (h)

The above equations are obtained at 95% confidence level and Central composite design is used to obtain the coefficients

4. OPTIMIZATION BY GENETIC ALGORITHM

The Genetic Algorithm is a non-conventional search and optimization method based on natural selection mechanics. The genetic algorithm is ease in operation, global perspective and it can solve problems which are difficult to solve in conventional methods.

The Genetic Algorithm parameters are: Population Size = 100, Selection operator = Roulette Method, Crossover operator = Single point operator, Crossover Probability =0.9, length of chromosome = 90 and fitness parameter = Wear rate.

The objective function is the form of:

Wear Rate = f (Current Density, W/L of SiC added, Voltage)

The constraints are:

Current Density	0.5 – 2.5
W/L of SiC Added	0 – 20
Voltage	0.5 – 2.5

The optimization is carried out in the MATLAB software using GA tool. The objective function for wear rate is taken from the empirical relation developed through RSM in this previous work. The optimization is done for the wear rate of both DC supply and PC supply.

The Fitness value and generation plot is plotted while optimizing and the solution converges at around

50th Generation. Before this many local minima are reached and the average distance of the population decrease with the increase in the generation.

5. RESULTS AND DISCUSSION

5.1. Micro-SiC for DC supply

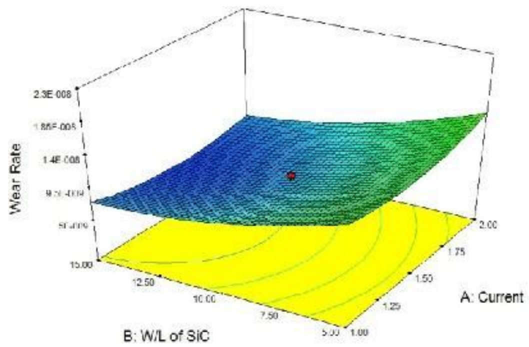

Fig. 1.Surface Plot for Wear Rate

The Surface Plot for the wear rate of micro –SiC under DC supply is shown in Fig. 1. This plot indicates that the wear rate is minimum for the maximum deposition of the SiC (15% addition) on the substrate and the respective current range is also found as around 1.50. The voltage factor is set to 1.50. It is inferred that wear rate is maximum for the minimum amount of SiCadded in the bath even though the current supply is maximum(2.0).

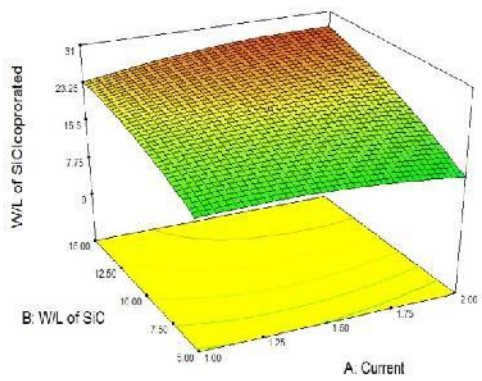

Fig. 2.Surface Plot for W/L of SiC Incorporated

The surface plot for the SiC incorporation for the micro-SiC DC supply in Fig.2.shows that the deposition of the SiC on the substrate is maximum at the 15% of SiC added and 2A/dm^2 of Current. The amount of SiC deposited is 30.24. And the minimum deposition is attained at minimum addition of SiC(5%) on the bath and the minimum current supply(1A/dm^2). The plot also shows that the deposition of the SiC on the substrate increases linearly proportional to the increase in the SiC addition in the bath and the current supply.

5.2. Micro-SiC for PC supply

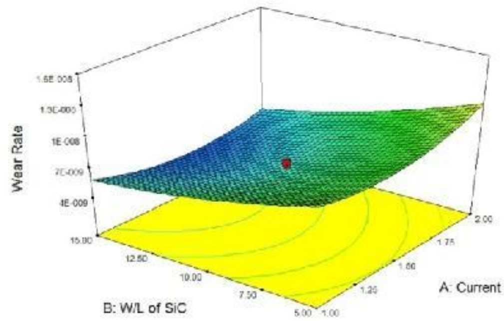

Fig. 5. Surface Plot for Wear Rate

This surface plot in Fig.5.is for the wear rate of the substrate obtained by micro-SiC for PC supply in the bath. The wear rate is minimum at 15% of SiC addition in the bath and the respective current supply is around 1.52A/dm^2. At 5% of SiC the wear rate is maximum at both 1A/dm^2 and 2A/dm^2. At the center of the surface plotthe wear rate is 1.21102E-008 where the SiC added is 10% and the current supply is 1.5A/dm^2.

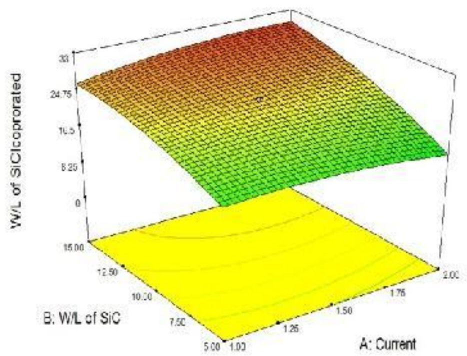

Fig. 6. Surface Plot for W/L of SiC Incorporated

The surface plot for the SiC incorporated in micro-SiC for PC supply in Fig.6. shows that the SiC deposition is maximum at 15% of SiC added in the bath and 2A/dm^2 of current supply. The SiC deposition in the substrate increases linearly as the increase in the current and SiC addition in the bath. It is also found the deposition of SiC on the substrate is minimum at 1A/dm^2 even though the SiC addition in bath is maximum(15%). So that the SiC addition and current should be mutually increased to get maximum deposition and hence to minimize the wear rate.

5.3. Genetic Algorithm optimization

The optimized input parameters range are used to calculate the respective Incorporation of SiC on the substrate by substituting the optimized Current density,, %W/L of SiC added and Voltage values in the

%W/L of SiC incorporated empirical relation developed through RSM. Both the Wear Rate and the respective incorporation of SiC obtained by mathematical method are approximate with the experimental value.

6. CONCLUSION

1) Empirical relation are developed to predict the %W/L of SiC deposited in the substrate, Wear rate and Wear coefficient for both DC and PC supply.
2) Surface Plots were developed to study the responses with respect to the governing parameter.
3) It is found that PC supply produces optimum SiC deposition and also has minimum wear than DC supply.
4) The wear rate is optimized by GA and found that PC has minimum wear rate.
5) The predicted values of the governing parameters are in good agreement with the experimental values.

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