ANN modeling for coefficient of friction of electro deposited Nickel-Graphite electro composites

Dr. T. Louie Frango
Associate Professor, Department of Mechanical Engineering,
Mahath Amma Institute of Engineering and Technology, Pudukkottai, Tamilnadu, India.

Dr. K. Ramanathan
Associate Professor, Department of Mechanical Engineering,
A.C.Government College of Engineering & Technology, Karaikudi, Tamilnadu, India.

Dr. S. Rajesh
Associate Professor, Department of Mechanical Engineering,
Addis Ababa Science and Technology University, Addis Ababa, Ethiopia.

Dr. P. Raveendran
Associate Professor, Department of Mechanical Engineering,
Mahath Amma Institute of Engineering and Technology, Pudukkottai, Tamilnadu, India.

***Abstract*—** Nickel-Graphite composite coatings are produced by electro deposition using conventional techniques at various cathode current densities, pH and temperature. Electro deposition was carried out from a conventional Watts bath. Natural graphite powder of 20-30 μm size was used in this study. 3^3 full factorial designs of experiments were designed by adopting the Design of Experiments approach with three level of experiment namely Low, Medium and High. The volume percentage of graphite deposition in composite coated specimens was measured gravimetrically. The coefficient of friction of coated specimen was measured using scratch tester. An Artificial Neural Network (ANN) model was developed using 27 practical data obtained to predict the co efficient of friction of Nickel-Graphite metal matrix. Within the range of input variables for the present case (pH) = 3 to 5; current density (i) = 3 to 5 A/dm^2; temperature (T)= 40 to 60^{0}C, the prediction capability of Artificial Neural Network (ANN) is very close to the experimental measurement of friction of Ni-Graphite metal matrix.

***Keywords*:** Coefficient of Friction, Scratch tester, ANN model, Ni-Graphite composite coatings, MATLAB

I. INTRODUCTION

Particle-reinforced metal matrix composites generally exhibit wide engineering applications due to their enhanced hardness, frictional resistance, wear and corrosion resistance compared to pure metal or alloy. Composite electroplating has been identified to be a technologically feasible and economically superior technique for the preparation of such kind of composites. Nickel-Graphite composite by electro forming technology were dispersed in the Nickel sulphamate bath [1]. Graphite is a natural material, is known to be the good lubricant material. Because of its excellent mechanical and electrical properties Nickel-Graphite is of great interest for a number of applications (e.g. bearings, engine parts, electronic gaskets, etc.).

II. EXPERIMENTAL PROCEDURE

A. The electrolyte

The conventional Watts bath of the following composition was used: Nickel sulphate - 225 g/l; Nickel chloride- 30 g/l; Boric acid- 40 g/l. The electrolyte was purified in the conventional manner for removal of organic and inorganic impurities [5]. The pH value of the electrolyte was adjusted electrometrically using dilute H_2S_{O4} or NH_3. 0.01 g/l of sodium laurel sulphate was added to the electrolyte as anti-pitting agent before plating. The temperature of the electrolyte was maintained using a thermostat.

B. Plating procedure

Deposition was carried out on a 500 ml capacity using conventional technique. Nickel anodes and mild steel cathodes were used. The cathodes of 7.5×2.5 cm area were mechanically polished, degreased, bent to 90°, suitably masked to expose an effective plating area of 12.5 cm^2, electro cleaned. A bagged nickel anode bent similarly was placed above the area to be coated. Graphite powder (20 µm) was added to the electrolyte in the form of slurry. The solution was stirred using a magnetic stirrer. Stirring was given initially for 30 s to bring all the Graphite powder into the suspension and then stopped. The deposition was continued for 40 minutes to allow the particles to settle on the substrate while the deposition proceeded. The same process was repeated to obtain various thicknesses.

Figure 1 Electro deposition experimental setup

C. Nickel-Graphite deposition

Nickel-graphite composite coatings which were prepared by the electro deposition technique from a nickel sulfate bath [2]. The study revealed the fact that coefficient of friction is dependent on volume percent of Graphite presence in the matrix [10]. Natural grade graphite powder of 20–30 µm sizes was used. Prior to the co-deposition, the graphite particles were ultrasonically dispersed in the bath for 10 min. Experiments were conducted at a fixed Graphite concentration of 20 g/l, varying the plating parameters like temperature, pH, and current density. Ranges of coating parameters in the coating process are as follows:

Current density, I = 3 – 5 A/dm^2 ; pH value = 3 – 5; Temperature = 40 to 60^0C. For the prediction of Coefficient of Friction of Graphite under a variation of coating conditions, a training database with regard to different coating parameters needs to be established.

D. Design of experiment

Design of Experiments (DOE) or Experimental Design (ED) is the design of any information-gathering exercises where variation is present, whether under the full control of the experiment or not. Statistical design of experiments is the technique of planning the experiments so that suitable in the sequence could be composed which may be evaluated by the statistical technique resultant invalid and objective conclusions. Experimentation was planned by the DOE approach covering the process factors pH, current density and temperature at three levels. The level designations are shown in Table 1.

Table 1 Process parameters and their levels for Nickel-Graphite coating

Process Parameters	Units	Levels		
		Level 1	Level 2	Level 3
pH		3	4	5
Current Density	A/dm^2	2	4	6
Temperature	^{0}C	40	50	60

E. Coefficient of Friction

Table 2 lists the coefficient of friction of Nickel-Graphite electro composite obtained at various coating parameters.

Table 2 Coefficient of friction of Nickel-Graphite electro composite at various coating parameters

Sl. No.	pH	Current Density (A/dm^2)	Temperature (°C)	COF
1	4	2	50	0.23
2	4	4	50	0.18
3	4	6	50	0.27
4	4	2	60	0.24
5	4	4	60	0.19
6	4	6	60	0.28
7	4	2	40	0.27
8	4	4	40	0.21
9	4	6	40	0.31
10	3	2	50	0.28
11	3	4	50	0.26
12	3	6	50	0.30
13	3	2	60	0.29
14	3	4	60	0.27
15	3	6	60	0.31
16	3	2	40	0.32
17	3	4	40	0.31
18	3	6	40	0.33
19	5	2	50	0.24
20	5	4	50	0.20
21	5	6	50	0.29
22	5	2	60	0.25
23	5	4	60	0.22
24	5	6	60	0.30
25	5	2	40	0.29
26	5	4	40	0.26
27	5	6	40	0.32

The Figure 2 denotes the Coefficient of friction experimental setup for our uses. Nickel- graphite composites have been tested through the Scratch tester with constant load condition at starting load should be 10 Newton’s, loading rate should be zero, stroke length is 10mm, scratch speed should be 0.20 mm/sec and scratch offset is 0.25 mm. Then we have transfer loading condition enter the file name. Finally we have seen the view file and how much of Coefficient of friction is obtained.

Figure 2 Coefficient of friction experimental setup

III. ARTIFICIAL NEURAL NETWORK (ANN)

A. General

The first wave of interest in neural networks was emerged after the introduction of simplified neurons by McCulloch and Pitts. The basic processing elements of neural networks are called artificial neurons, or simply neurons or nodes. In a simplified mathematical model of the neuron, the effects of the synapses are represented by connection weights that modulate the effect of the associated input signals, and the nonlinear characteristic exhibited by neurons is represented by a transfer function. Figure 3 is the schematic of a mammalian neuronal structure. ANN developed a model for the electro-deposition of copper–tin alloy. Copper–tin alloy was electro deposited from a cyanide bath [6].

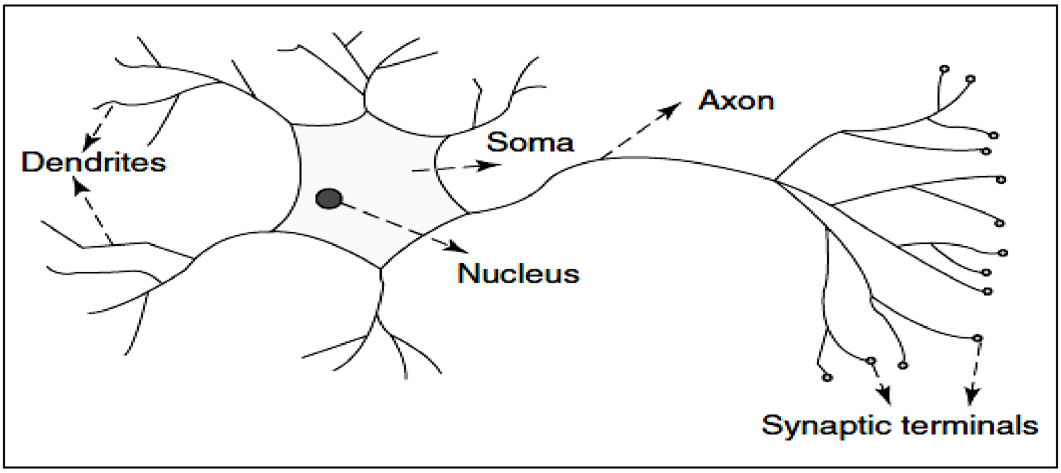

Figure 3 Mammalian neurons

A typical artificial neuron and the modeling of a multilayered neural network are illustrated in the Figure 3. Referring to Figure 4, the signal flow from inputs $x_1 . . . x_n$ is considered to be unidirectional, which are indicated by arrows, as is a neuron's output signal flow (O).

The neuron output signal 'O' is given by the following relationship:

$$O = f\ (net) = f\ \left(\sum_{j=1}^{n} w_j x_j\right)$$

Where, w_j is the weight vector and the function f (net) is referred to as an activation (transfer) function. The variable net is defined as a scalar product of the weight and input vectors,

$$net = w_T x = w_1 x_1 + \cdots + w_n x_n$$

B. Neural network architectures

The basic architecture consists of three types of neuron layer input, hidden, and output layers. In feed forward networks, the signal flow is from input to output units, strictly in a feed forward direction. The data processing can extend over multiple units, but no feedback connections are present. Recurrent networks contain feedback connections. Bishop is reviewed for an extensive overview of the different neural network architectures and learning algorithms.

A neural network has to be configured such that the application of a set of inputs produces the desired set of outputs. A forward pass is done, and the errors or discrepancies between the desired and actual response for each node in the output layer are found. These are then used to determine weight changes in the net according to the prevailing learning rule.

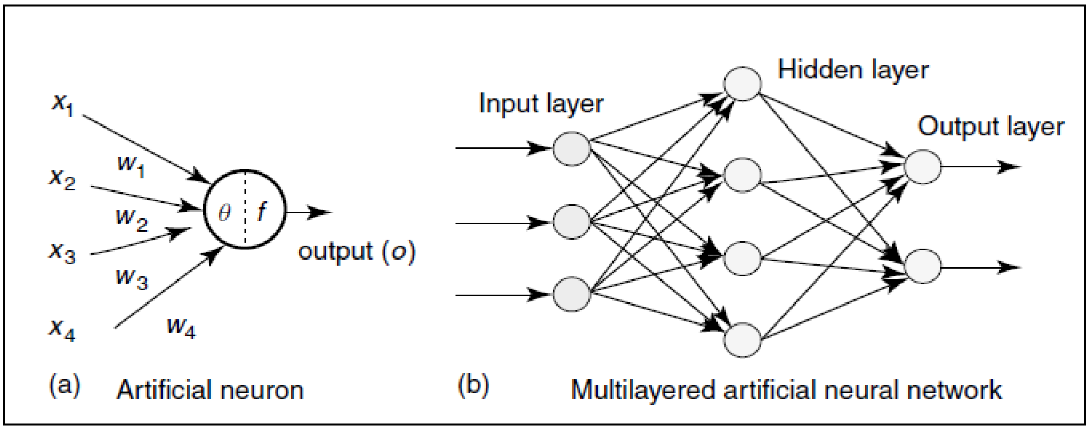

Figure 4 Architecture of an artificial neuron and a multi layered artificial neural network

The best known examples of this technique occur in the back propagation algorithm, the delta rule, and the perception rule. Unlike the supervised learning paradigm, there is no a priori set of categories into which the patterns are to be classified. These two characteristics, trial-and error search and delayed reward are the two most important distinguishing features of reinforcement learning.

C. Training the Neural Network Model

An ANN model was developed for the prediction of coefficient of friction of Nickel-Graphite composite coated specimen using practical data. The neural network was first trained and then tested using for the application. The training was done with ANN module available in MATLAB software using a computer. For developing the ANN model, the data were normalized and were given for training the network. To valid the trained network, six experimental data were given after normalization and values shown in Table 3.

Table 3 Normalized values fed into the ANN model for coefficient of friction prediction

Test No.	Experimental Data				Normalized Value			
	pH	CD (A/dm^2)	T (^0C)	COF	pH	CD (A/dm^2)	T (^0C)	COF
1	4.5	5.5	50	0.22	0.9	0.916	0.833	0.709
2	3.5	3.5	50	0.26	0.7	0.58	0.833	0.838
3	3.5	4.5	55	0.29	0.7	0.75	0.916	0.935
4	3.5	4.5	45	0.26	0.7	0.75	0.75	0.838
5	4.5	3.5	55	0.24	0.9	0.58	0.916	0.774
6	4.5	4.5	45	0.28	0.9	0.75	0.75	0.903

The features pH, current density and temperature were the inputs and the coefficient of friction was the output for training the neural networks. The number of patterns used for the training of artificial neural network using feed forward, back propagation algorithm was 27. Training of the ANN was performed without any allowable error. The data fed into the ANN model were normalized so that they were between 0 and 1.

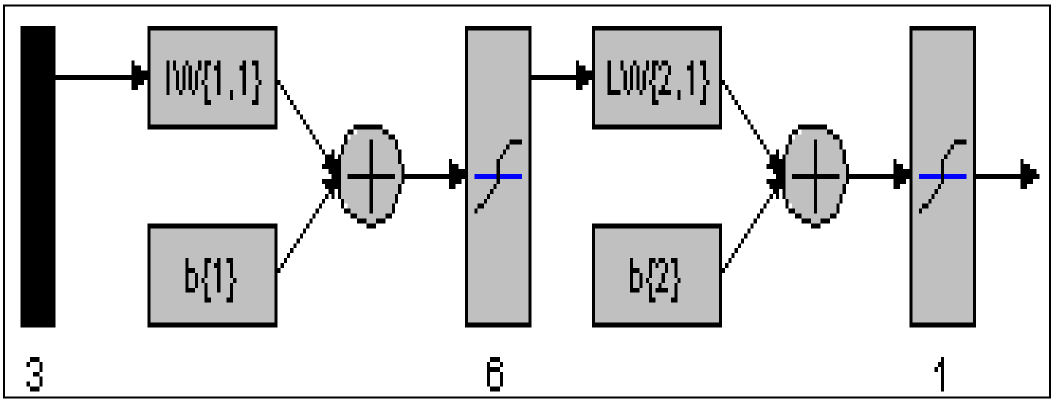

Figure 5 3-6-1 Feed forward, back propagation networks for COF

Network with different topologies has been tried for the prediction of COF of the deposition and the optimal result with 3-6-1 feed forward, back propagation network was trained and the network was shown as Figure 5.

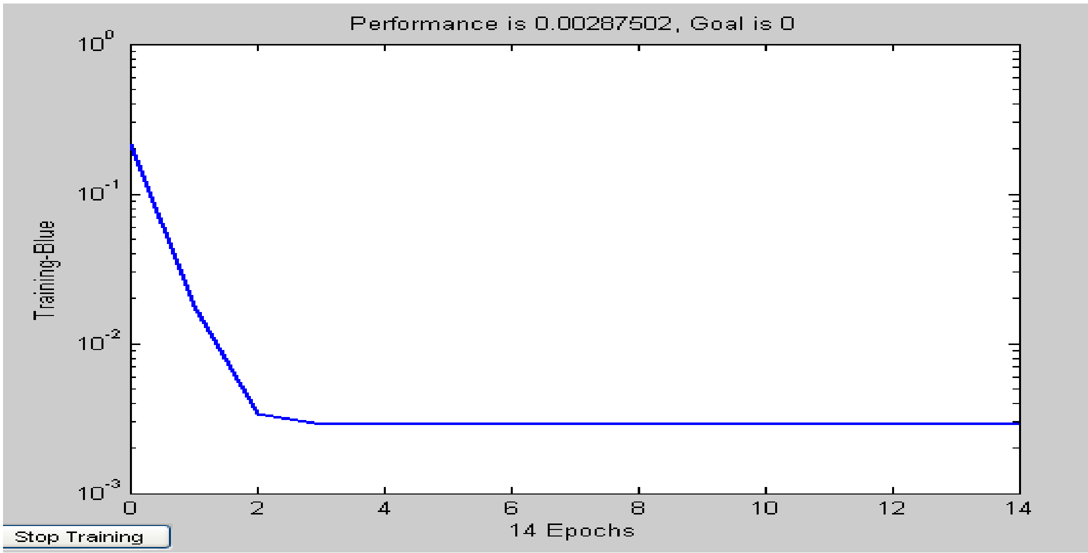

Figure 6 Performance curve of ANN model for COF

The learning process of the above model is shown as Figure 6 and it may be seen that there was a good converging of the trained model with the goal and it happened in 3rd iteration (epochs) itself with a performance value of 0.0028. After the ANN training the model, the model is to be validated. For validation also data are to be normalized and the normalized data used for validation is shown in the Table 3.

D. Validating the Artificial Neural Network

Once the network was trained such that the maximum error for any of the training data was less than allowable error, the weights and the threshold values were automatically saved by the program. As the input values from the validation experiments were given to the ANN program, the program predicted the required output. To validate the results of the artificial neural network analysis six experimental data were considered and its percentage error was listed as Table 4.

Table 4 Experimental data for verifying ANN model and its error in respect of coefficient of friction prediction

Test No.	Process Parameters			Coefficient of Friction (COF)		
	pH	CD (A/dm^2)	T (^{0}C)	Measured	Predicted by ANN Model	% Error
1	4.5	5.5	50	0.709	0.710	-0.055
2	3.5	3.5	50	0.838	0.850	-1.358
3	3.5	4.5	55	0.935	0.935	0.011
4	3.5	4.5	45	0.838	0.832	0.715
5	4.5	3.5	55	0.774	0.772	0.222
6	4.5	4.5	45	0.863	0.85	1.235
Average Absolute Error Percentage						0.128 %

IV. RESULTS AND DISCUSSION

A comparison of measured COF value using the prediction technique Artificial Neural Network (ANN) is presented in the Table 2. Once the pH, current density and temperature were fed into the trained networks, the coefficient of friction of the deposited Graphite coating was calculated using the ANN model. The average absolute error of the trained ANN model was 0.128% and its error graph was shown as Figure 7 and the closeness of the ANN model in predicting the coefficient of friction of Graphite deposition with actual value was shown as Figure 8.

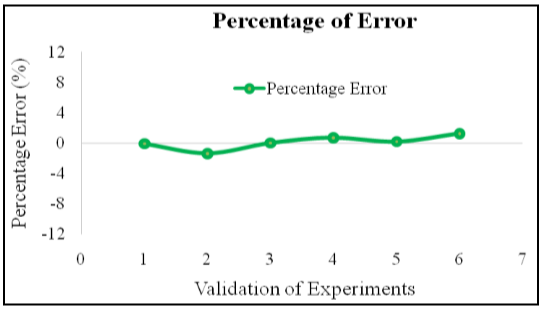

Figure 7 Percentage error of ANN model

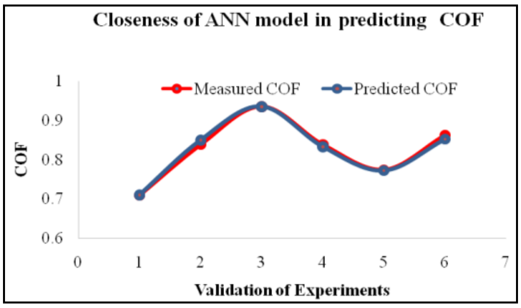

Figure 8 Closeness of ANN model in predicting COF values

It was shown clearly that the prediction technique ANN was better in predicting the coefficient of friction of the Nickel-Graphite composite coated specimens.

V. CONCLUSION

A 3-6-1 Feed forward back propagation Artificial Neural Network (ANN) model was developed for predicting Coefficient of Friction in Nickel-Graphite composite coated metal matrix using 27 test data .The developed neural net work was validated with eight data. Values obtained by the above ANN model were compared with the experimental values of the response variables to decide about the nearness of the predictions with the experimental values. Within the range of input variables for the present case (pH = 3 to 5; current density (I) = 3 to 5 A/dm^2; temperature (T) = 40 to 60^{0}C), the results showed that Artificial Neural Network comes in nearness of the predictions to the experimental values of Coefficient of Friction as the average errors in case of ANN is very less i.e. 0.128 % only.

References

1 Haijun Zhao, Lei Liu, Wenbin Hu, Bin Shen“Friction and wear behaviour of Ni–graphite composites prepared by electroforming”,(2007) Materials& design, Vol. 18, pp.1374-1378.

2 Lv Jinlong, Liang Tongxiang & Wang Chen 2016, ‘Investigation of hydrogen evolution activity for the nickel, nickel-molybdenum nickel-graphite composite and nickel-reduced grapheme oxide composite coatings’, Applied Surface Science, vol.366, pp.353-358.

3 L.Q. Zhoua,b, J.G. Tanga, Y.P. Lia, Y.C. Zhoub “Predicting forming limit of electrodeposited nickel coating based on practical stress–strain relationship”(2008), Journal of materials processing technology , Vol. 206, pp.431-437.

4 Haijun Zhao , Lei Liu, Jianhua Zhu, Yiping Tang, Wenbin Hu “Microstructure and corrosion behavior of electrodeposited nickel prepared from a sulphamate bath”(2007) Materials Letters ,Vol. 61, pp.1605-1608.

5 Y.S. Jeona, J.Y. Byunb, T.S. Oha “Electrodeposition and mechanical properties of Ni–carbon nanotube nanocomposite coatings”(2008) Journal of Physics and Chemistry of Solids ,Vol. 69, pp.1391-1394.

6 K. Subramanian , V.M. Periasamy , Malathy Pushpavanam , K. Ramasamy “Predictive modeling of deposition rate in electro-deposition of copper–tin using regression and artificial neural network” (2009) Journal of Electro analytical Chemistry, Vol. 636, pp.30-35.

7 M. Surender, B. Basu , R. Balasubramaniam “Wear characterization of electrodeposited Ni–WC composite coatings” (2004) Tribology International Vol. 37, pp.743-749.

8 D.P.Weston, P.H. Shipway, S.J. Harris, M.K. Cheng “Friction and sliding wear behaviour of electrodeposited cobalt and cobalt–tungsten alloy coatings for replacement of electrodeposited chromium” (2009) Wear ,Vol. 267, pp.934-943.

9 J. Lamovec , V. Jović , D. Randjelović , R. Aleksić , V. Radojević “Analysis of the composite and film hardness of electrodeposited nickel coatings on different substrates” (2008)Thin Solid Films, Vol. 516, pp.8646-8654.

10 M. Ghorbani, M. Mazaheri, A. Afshar “Wear and friction characteristics of electrodeposited graphite–bronze composite coatings” (2005) Surface & Coatings Technology, Vol. 190, pp.32-38.