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A Neural Network System for Predicting the Effect of Quartz and Heat Treatment on the Corrosion Properties of Ceramic Coating

[1]OMAR M ELMABROUK, [2]ALI KALKANLI
[1]Benghazi University, Department of Industrial and Manufacturing System Engineering, Benghazi-Libya
[2]Middle East Technical University, Department of Metallurgical and Materials Engineering, Ankara, Turkey
[1]Omar.elmabrouk@uob.edu.ly
[2]kalkanli@metu.edu.tr

***Abstract*—Glass-ceramic coatings have found a growing number of applications since the original patent by Pfandler Permutit Company. However, little fundamental information is available on the interactions between the glass-ceramic and metal. In this paper, prediction of the effects of various heat treatments at temperatures (500,550, and 600˚C) at different times (60 & 120)min and with quartz addition in the range (0-15)% on the acid corrosion rate of the resultant coating of low carbon alloyed steel with (0.2)%C was created by using artificial neural network (ANN). The results were compared with previously published results using multiple regression model It was found that the ANN model is much more accurate in prediction as compared to the multiple regression model.**

Keywords—Artificial Neural Network, glass-ceramic coatings, prediction.

1. INTRODUCTION

Glass-ceramic enamels have been developed for mild steel based on a Li20-A1203-SiO2 composition. Davis et al (1) and a Li20-B203-SiO2 composition, Partridge (2). These are used essentially to provide protection from oxidation and corrosion. A glass-ceramic coating based on a BaO-MgO-B203-SiO2 composition has been developed by Andrus (3) and the RCA company (4) to provide an electrically insulating layer for use as electrical substrates.

It has been shown that glass ceramics can be made to bond to various metals either in the ceramic state, by the use of intermediate bonds, 4" or starting from the glassy state, as in vitreous enamelling, followed by a suitable heat treatment to achieve conversion to a glass ceramic. (5,6) Such a schedule is represented in Figure 1.

Glass ceramic coatings can provide distinct advantages such as increased hardness, improved mechanical strength, and also better control of the thermal expansion coefficient of the coating so that it closely matches that of the substrate. This results in a lower residual stress at the interface, giving improved thermal shock resistance.

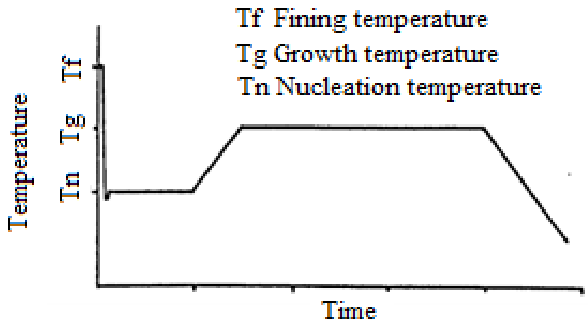

Figure 1. Typical thermal heat treatment schedule for enamellings with a glass ceramic.

Artificial neural network (ANN) is a highly simplified model of the structure of a biological network [5]. The fundamental processing element of ANN is an artificial neuron (or simply a neuron). A biological neuron receives inputs from other sources, combines them, generally performs a non-linear operation on the result, and then outputs the final result [6]. The ability of the ANNs, to recognize and reproduce the cause-effect relationships through training for the multiple input-output systems makes them efficient to represent even the most complex systems [7]. The main advantages of ANN as compared to multiple regression model include: 1) ANN does not require any prior specification of suitable fitting function, and 2) ANN also has a universal approximation capability to approximate almost all kinds of non-linear functions including quadratic functions, whereas multiple regression model is useful only for quadratic approximations [8]. There are some studies in the literature where model were developed based on multiple regression model and ANN using the same experimental design [8-12]. For example, Basri *et al*. (2007) reported the comparison of ANN and multiple regression model in the lipase-catalyzed synthesis of palm-based wax ester, and they suggested the superiority of ANN over multiple regression model .

Both the ANN and multiple regression model techniques were recently compared for their predictive and generalization capabilities, sensitivity analysis and optimization efficiency in fermentation media optimization [8]. It was found that the ANN predicted model has higher accuracy and better generalization capability than multiple regression model, even with the limited number of experiments. In this study, the multiple regression model and ANN methodologies were applied for predicting the amount of zinc by flame atomic absorption spectrometry (FAAS) in fish samples. The results which were obtained through multiple regression model were then compared with those through ANN. Figure 2 shows the concept of neural networks.

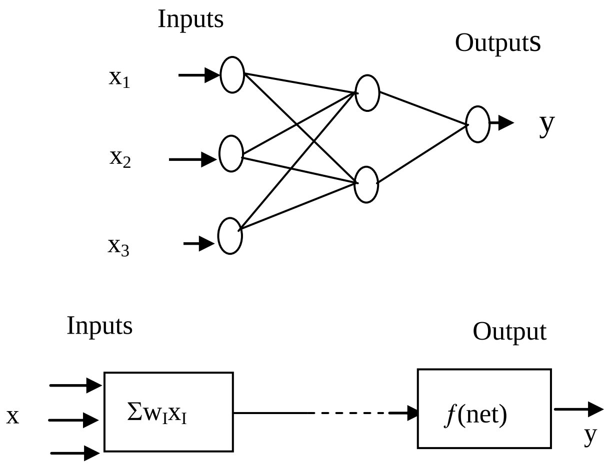

Figure 2 : Concept of neural networks

The neural network resembles biological nervous systems, is a parallel distributed information-processing system [13] that consists of processing elements called nodes interconnected by the signal channels called connections. The output of each node can be connected to the input of other nodes via these connections. Each connection has an associated weight that determines the strength of the signal passed along the connection. Such networks are programmed by applying training patterns that fix the output states of the nodes. A learning algorithm then adjusts the connection weights in response to the training patterns where

$$net = w1x1 + w2x2 + w3x3 \quad (1)$$

The weighted sum of the inputs are sent through various layers of nodes to the output node. The activation function of the net f(net) is the compared with the predetemined threshold value θ. The output node will give an output signal if activation function is greater than the threshold value.

$$f(\text{net}) = \quad (2)$$

$$y = \begin{cases} 1 \text{ if } a >= \theta \\ 0 \text{ if } a < \theta \end{cases} \quad (3)$$

In this paper, the investigation is based on a previous work [3] carried out by one of the authors in which a new glass-ceramic coating has been developed and applied, as a single coat without prior chemical treatment of the surface, by using the dipping technique on metal substrate. the coating were designed for application on varies grades of low alloy steel, the selected substrate was low carbon low alloyed steel with (0.2)%C. Various heat treatments at temperatures (500,550, and 600˚C) at different times (60 & 120)min and with quartz addition in the range (0-15)% were used to obtain a glass-ceramics that have the optimum coating properties.

3. Experimental work Sample preparation

The samples used as substrate for enamel coating were rectangular billets (20mm×30mm with a thickness of 1.5mm) of low alloyed low carbon steel, their chemical composition is carbon, 0.18 per cent; silicon, 0.05 per cent; chromium, 1.3 per cent; manganese, 0.12 per cent; nickel, 1.35 per cent. Tungsten, 1.0 per cent; silicon, aluminum, niobium and cobolt,0.05 per cent; copper, titanium, vanadium and lead is less than 0.05 per cent. The sample surface is exposed to a jet of an abrasive material shots to remove scale, rust and dirt. The surface becomes clean and slightly pitted which helps promote good bonding. Removal of material from the surface should not be excessive and is controlled by adjusting the air pressure and exposure time of blasting. Before blasting, oil and drawing compounds are removed by heating the surface at 455˚C to burn off the organic contaminants.

3.1 Frit manufacturing

Glass frit is the major constituent in bisque (unfired) enamel coating. Frit is the homogeneous melted mixture of inorganic materials that is used in enameling steel process. Frit is prepared by fusing a variety of minerals in a furnace and then rapidly quenched the molten material. In this study we developed coating material which are designing for application as a single-coat on various grads of steel alloys. The frit was prepared from reagent grade chemicals: SiO2, Al2O3, Na2B4O7.10H2O,CaCO3, Na2CO3, ZnO, P2O5, TiO2, Li2CO3,CoO, NiO and CaF2. The batch was evenly blended and melted in a graphite crucible in resistance furnace at 1250 ˚C, the batch hold at this temperature until all the raw materials have reacted and the batch has become a homogeneous, bubble-free liquid. Then a stream of the smelted and refined molten batch is drawn from the graphite crucible and quenched into water to produce a coarse granular frit.

The coarse frit was milled by using a ball mill with alumina ball as the grinding media and screened with a mesh size of 200 μmesh, stored in an oven at 100˚C to prevent problem with moisture. Chemical composition in weight percent of frit powders is silicon dioxide, 52-55; aluminum Oxide, 0.5-2; boric oxide, 12-16; sodium oxide, 6-9; diphosphorus trioxide, 3-5; Zinc oxide, 2-4; Titanium dioxide, 1-5; Cobalt oxide, 1-2; Nickel Oxide, 0.5-1; Calcium oxide, 2.5-4; Lithium Oxide, 2-5; and fluorine, 1-3. Preparation of enamel slip for application of the coating, the frit is further processed by mixing it with certain mill-additive to make a thick slurry called "slip" to enable its uniform and thin application on the clean metal parts by dipping technique.

The rheological properties of coating material slips are very important for ensuring proper application of the coating on the substrate. Kaolinite, borax, and water were added to form a batch of enamel slip. Refractory materials can be added to impart desired properties to the fired coating. In this work quartz was added in different amounts (5,10,15%) to study their effect on coating properties. The specific gravity of the enameling slip was measured using an electronic weighing balance and was controlled between (1.7-1.8) by adjusting the water content. Subsequently, the slip was aged for 24 hours before enameling to improve its fluidity. the weight percent composition of enamel slip is Frit,100; Clay,7;Borax,1; Quartz,0.5,10,15; water,50;. The coating material in the slip form is applied on the clean metal surface by dipping method. Dipping method is a simple and quick technique requiring no special plant, where the specimen is immersed in the enamel slip, withdrawn, allowed to drain.

After application of coating slip, the coated samples were dried in an oven at 120˚C for 15min to remove moisture. The dried coated samples are then fired in a box furnace at 860˚C for 10min, the coating material then fuses and reacts with the clean metal surface to form a strongly adherent coating. Subsequently, to obtaining the glass-ceramic coating, the enameled samples were held in a furnace at different temperatures (500, 550,600)˚C for 60 & 120 min, respectively. Inspection and testing coating characterization The thickness of the resultant coating was measured by an eddy current based thickness measuring instrument with ND-2 type probe, suitable for non-ferrous alloys. Phase analysis of the resultant coating before or after heat treatment was done by X-ray diffraction analysis (Philips PLO1840 X-ray diffractometer in 2θ ranging between 10˚ to 90˚ using Cu Kα radiation.

Acid resistance test

The acid resistance test complying with ISO: 2743. A glass-ceramic sample was exposed to solution of 11% sulfuric acid acting for 2.5 hrs at the boiling temperature[9]. The corrosion rate expressed in (mg/dcm2. day) is calculated as follows:

$$\text{Corrosion rate (mdd)} = \Delta \mathbf{w}/(\mathbf{A}.\mathbf{t}) \quad (4)$$

Where: Δw: weight loss in (mg), A: area of the specimen in (dcm^2), t: time in day.

4.1. ANN Modeling

4.1.1. Artificial Neural Network

The same experimental data, which had been published for the MULTIPLE REGRESSION MODEL design [3], were also employed in designing the artificial neural network. A multi-layer perception (MLP) based feed-forward ANN, which makes use of the back propagation learning algorithm, was applied for modeling.

The network consists of an input layer, one hidden layer and an output layer. The inputs for the network include heat treatments at temperatures at different times and with quartz addition; output is the acid corrosion rate. In order to determine the optimum number of hidden nodes, a series of topologies was used, in which the number of nodes was varied from 1 to 20. The structure of proposed ANN is shown in Figure1.

The hyperbolic tangent was used as the transfer function for the input and hidden layer nodes. The linear activation function is also used as the output layer activation function. The algorithm used to train ANN in this study is quick propagation (QP). This algorithm is belonging to the gradient descent backpropagation. The details of the algorithm have been reported elsewhere [14]. It was reported in literature that the quick propagation learning algorithm can be adopted for the training of all the ANN model. The performance of the ANNs was statistically measured by the mean absolute error (MAE), obtained as follows:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|f_i - y_i| = \frac{1}{n}\sum_{i=1}^{n}|e_i|. \quad (5)$$

3.3. Comparison of MULTIPLE REGRESSION MODEL and ANN Model

Table 1. Shows the Experimental data of four variables, the experimentally determined, multiple regression model model predicted, ANN model predicted amount of zinc in the samples and their mean absolute error .

The estimation capabilities of the techniques (multiple regression model and ANN) were examined in this study. For this purpose, the techniques were used to predict the responses at 28 experimental points. The predicted responses, obtained from multiple regression model and ANN, were then compared with the actual values.

The mean absolute error (MAE), was used to compare the multiple regression model and ANN. The scatter plot of multiple regression model and ANN predicted values versus actual values for the experiment is shown in Figure 3.

Table 1. Experimental data of four variables and the experimentally determined, multiple regression model predicted and ANN model predicted amount of zinc in the samples.

No	Quartz added (%)	Tem (C˚)	Time (min.)	Acid C.R (mmd)		
				Actual	Predicted MRM	Predicted ANN
1	0	0	0	48	47.72	47.86
2	0	500	60	40.25	27.71	40.27
3	0	500	120	24.2	22.33	32.27
4	0	550	60	13.45	22.92	13.51
5	0	550	120	11.8	17.37	21.50
6	0	600	60	10.7	11.72	10.61
7	0	600	120	9.6	5.799	15.80
8	5	0	0	21.45	22.91	21.47

9	5	500	60	11.3	14.7	11.40
10	5	500	120	11.3	11.33	11.36
11	5	550	60	10.75	13.14	10.58
12	5	550	120	10.45	11.58	10.53
13	5	600	60	9.95	8.2	10.35
14	5	600	120	9.35	9.969	9.94
15	10	0	0	10.45	10.08	10.45
16	10	500	60	10.25	8.71	10.01
17	10	500	120	10.05	6.704	8.63
18	10	550	60	9.75	8.831	9.57
19	10	550	120	9.45	8.91	8.26
20	10	600	60	8.85	6.575	9.12
21	10	600	120	8.1	9.803	7.99
22	15	0	0	9.7	9.206	9.76
23	15	500	60	8.95	9.741	8.61
24	15	500	120	8.55	8.454	8.51
25	15	550	60	8.2	9.98	8.37
26	15	550	120	7.55	9.352	7.48
27	15	600	60	7.1	6.846	8.26
28	15	600	120	6.4	5.301	7.02

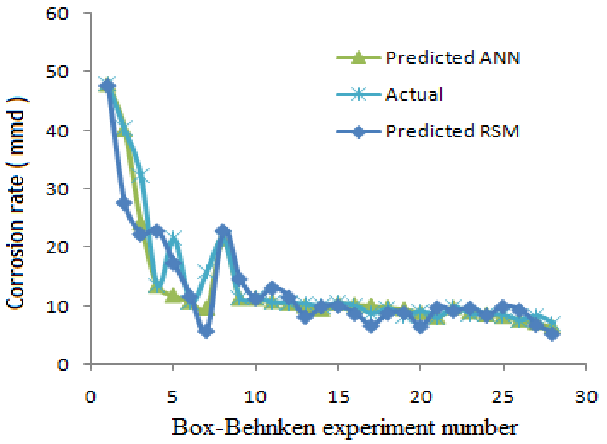

Figure 3. The plot of actual, predicted values of ANN and MULTIPLE REGRESSION MODEL predicted values versus Box-Behnken experiment number for corrosion rate

Table 3 shows the comparison of the multiple regression model and ANN predicted values for corrosion rate based on MAE.

Table 3. Comparison of MULTIPLE REGRESSION MODEL and ANN.

Box-Behnken design data		
MAE	MULTIPLE REGRESSION MODEL	ANN
	2.22	1.12

4. Conclusions

This paper has described the use of artificial neural network to predict the acid corrosion rate of the resultant coating of glass-ceramic carried out by one of the authors in which multiple regression model had been used to predict the acid resistance properties with higher accuracy for different quartz addition, and thermal treatment conditions. Two model were developed for predicting the acid corrosion rate. multiple regression model and artificial neural network (ANN). First, multiple regression model was used for predicting the amount of acid corrosion rate. Then, the independent variables, namely heat treatments temperatures, addition times and with quartz addition were fed as inputs to an artificial neural network while the output of the network was the acid corrosion rate. A multilayer feed-forward network was trained by the sets of input-output patterns using quick propagation algorithm. Finally, two methodologies were compared for their predictive capabilities. The present work indicates that the ANN is much more accurate in predicting the acid corrosion rate in comparison to the multiple regression model .

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