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RESEARCH

ANN & ANFIS Models for Prediction of Abrasive Wear of 3105 Aluminium Alloy with Polyurethane Coating

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A B S T R A C T

The quest for safety and reliability has increased significantly after Industrial revolution, so is the case for coating industries. In this paper 3105 Aluminium alloy sheet is coated with organic polyurethane coating. After the implementation of coating, various processes are undergone to check its reliability under elevated conditions. ANN & ANFIS model were developed and trained with an objective to find abrasive wear during the process. ANN & ANFIS model were compared with the experimental results. It is observed that the abrasive wear of a coated specimen can be predicted accurately and precisely using ANN and ANFIS models.

1. INTRODUCTION

Coating technology was used since ancient ages, as the historical studies have shown that the first human used the extracts & plants juices extracted, the sap from the trees, animal fats, juicy berries and metal oxides to make the first paint or colors to be used for drawing and photographing in order to decorate the walls of the caves [1,2].

As a result of the high importance of the paint now, it was used for protection and acquisition painted aesthetic elements, so many of the industrial products are coated using organic and inorganic materials, to give these products long-term protection under a wide range of causing wear conditions and erosion during the functional age of these Products [3].

The most important mechanical tests for specific properties of paint durability are micro hardness and abrasion resistance that allows verification of the mechanical properties of the coated layer and this is not only on the outside but also on the coating thickness. The determination of the optimum value of the micro hardness contributes to reaching to the full performance of the corrosion resistance of coated sheets and to gain the necessary strength to resist the various mechanical and physical changes. This mechanical and physical change can drive to failure in the coating material which depends on many different wear mechanisms that can cause material removal which known as adhesion, abrasion, fatigue, erosion and corrosion wear. Therefore, Wear can describe as a complex phenomenon that depends on materials (hardness, surface morphology,) environment, and just as importantly, on normal load and motion conditions (sliding speed, time,) among others [4,5].

A surface may be scratched, grooved, or dented by a harder particle to produce one or more effects; Scratching implies some loss of materials, whereas grooving does not. Scratches and grooves may be no deeper than the thickness of the coatings. This may occur if the abrasive particles are softer than the substrate but harder than the coating, or it may occur if the abrasive particles are very small. Groove or scratch widths will probably be of the order of coating thickness [6,7].

Kassman et al. [24] developed a mathematical model for the wear of coating and its substrate; the mechanism of wear that is under investigation is abrasion. His main goal is to determine the wear behavior of the coating material and the substrate simultaneously; he states that the difficulties of determining coating properties stem from the fact that most testing performs a composite wear process of the substrate and coating together.

There are a number of factors which influence the abrasive wear and, hence, the manner of material removal. Several different mechanisms have been proposed to describe the manner in which the material is removed. Three commonly identified mechanisms of abrasive wear are: plowing, cutting, and fragmentation. Abrasive wear is caused by hard asperities on the counter face or hard particles that move over the surface. The process of abrasion, which is happening during the mutual movement of contact surfaces, as a result of penetration of asperities of harder material into the surface layers of softer material is accompanied by ploughing and/or cutting (plastic deformation) of both contact surfaces. Therefore, abrasive wear rate is proportional to the ultimate tensile stress of material and the corresponding strain [25,26].

Agunsoye et al. [27] used mass loss method to evaluate wear resistance of Aluminium Cans/Eggshell composites samples, this made by measuring of sample mass before and after performing wear test, and they found that the wear rate (mass loss) increased by increasing applied load during test performing.

American Society for Testing and Materials ASTM advises to use certain tests to ensure the quality of the characteristics for coated metal sheet. These tests are performed according to a specific standards like; bending test ASTM D4145, impact test ASTM D6905, scratch resistance test ASTM D7027, dry & wet adhesion test ASTM D2197, micro hardness test D1474, abrasion resistance test ASTM D4060, and chemical resistance test ASTM D1308 [8,9].

Many authors have used some parameters such as hardness, fatigue or tensile strength to represent resistance to wear. It has been observed that the hardness gives an indication of the material wear resistance. However, adding specific mixtures increase the resistance to wear but do not cause an increase in hardness [5].

Browning et al. [10] have proved in their research where they evaluate the scratch resistance of the polymeric coating, that the low thickness of the coating, will have double effect for each of the substrate and layer of paint on the micro hardness and the scratching hardness as a result of a complex relationship generated between the stresses of both materials.

Hardness measurements quantify the resistance of a material to plastic deformations. Indentation hardness tests include the majority of processes used to determine the hardness. Hardness, however, cannot be considered to be a fundamental material property. Instead, it represents an arbitrary quantity used to provide a relative idea of material surface properties [11,7].

Hardness is one of the most important properties of organic coatings, and is widely used to evaluate the mechanical properties of coatings. Although many test methods have been developed to evaluate coating's hardness, pendulum hardness and micro hardness tests are the most widely used ones in research laboratory because of their higher accuracy than common test methods used in industry such as pencil hardness and nail hardness [12,13].

Zivic et al. [28] used Vickers micro hardness methodology to measure elastic modulus and hardness of Bone Cement samples, conclude that the Indentation technique represents flexible mechanical testing due to its simplicity, minimal specimen preparation and short time needed for tests.

Alimam et al. [14] have proved in their research, which have followed three methodologies to evaluate the hardness of polyester coatings, Indentation hardness and damping hardness of polyester coatings decreases gradually with the increasing thickness of coating within a thickness range, and there was good correlation between coating thickness groups and pencil hardness ranks.

3015 aluminum alloy series is the most aluminum alloys used in manufacturing aluminum coil coating with organic coating, which are used in vehicle manufacturing, roofing, interior and exterior cladding for industrial, agricultural or administration buildings, mobile homes and pre coated metal for shutters and blinds. Where this alloy has excellent mechanical properties such as high formability and corrosion resistance with medium strength, and ultimate tensile strength range: 110 to 285 MPa [29,30].

This study has been undertaken to find out the correlation between the thickness, abrasive wear rate and the micro hardness of tested samples, which consisted of 3015 aluminum sheet as a substrate and polyurethane film coating. Further two soft computing techniques are used to predict mass loss (Viz. ANFIS & ANN) which is compared with the experimental value.

2. EXPERIMENTAL DETAILS

2.1 Materials

In this investigation, 3105 aluminium alloy sheets were used for substrate, and the chemical composition of the specimen were within the permissible limits as per ASTM B209 [15] standard specification. Further, the sheets were coated with a layer of polyurethane (coating film) with different thicknesses. The tested samples were obtained from a specialized factory for aluminum coil coating. A commercial polyurethane powder coating (NMP-free with Color RAL 5022- RAL 6007- RAL 8017- RAL 9001) with four types of pigment according to RAL color as following: Sicopal (cobalt blue), Sicopal (cobalt green) Sicopal (Brown Cr/Fe oxide), and White (titanium dioxide); was applied by electrostatic spray on the test samples, samples of aluminum sheet and film coating were cured in an oven for the time and the temperature recommended for the polyurethane powders used (200 °C for 10 minutes). Samples of aluminum sheet thickness of 0.25 mm and the dimensions (100 X100 mm) with polyurethane coating are shown in Fig. 1.

Fig. 1. Sample specimen with coating material.

2.2 Coating thickness measurement

Coating thickness measurement device (Electro Physic MiniTest 2100) has been used to determine the coating layer thickness, as provided in standard (ISO 2360) [16], where the use of the probe to determine the coating thickness No. N02. This test was applied on selected samples by four times in different parts of the sample then determines the mean values that were measured for the thickness, see Table 2.

2.3 Determination of Micro hardness

The micro hardness test was performed on coated samples by the micro hardness tester (Zeiss Axioskop 40 Micro Hardness Tester MHT 10) Fig. 2, where this device is available with a Knoop indenter, rhombic-based pyramidal shaped diamond indenter. This indenter has been using during the test and that degree lab temperature during test execution. ASTM D-1474 [8,17] deal with standard test methods for indentation hardness of organic coating when applied to a plane rigid surface.

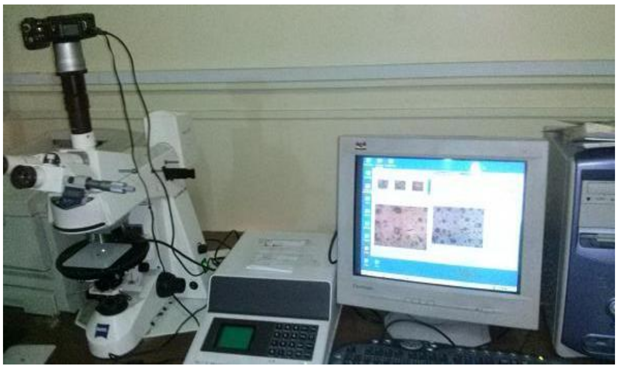

Fig. 2. Zeiss Axioskop 40 Micro Hardness Tester MHT 10.

Fig. 3a. Shows impression remaining in the studied sample with coating thickness 120.27 µm and Knoop micro hardness number is 13.85 KHN.

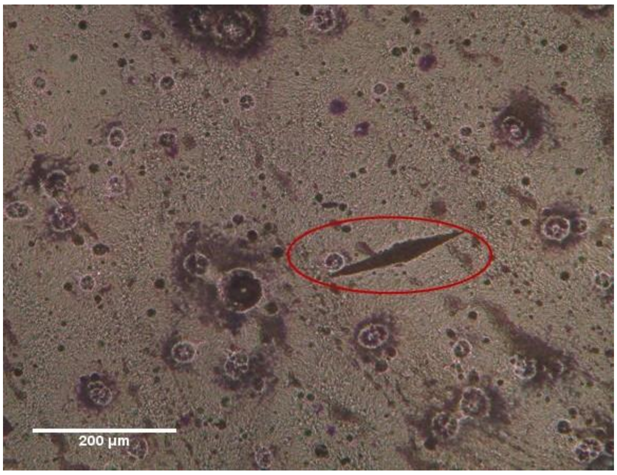

Fig. 3b. Shows impression remaining in the studied sample with coating thickness 160.4 µm and Knoop micro hardness number is 9.81 KHN.

The apparatus was pre-set to apply a Knoop indentation with a 25 g load for 18 seconds normally to the surface to be measured. The length of the long diagonal of the impression was determined by means of a semiautomatic measuring system (see Fig. 3a and 3b). The procedure was repeated in five widely spaced locations for each test sample and the results were expressed as the mean value. The results are summarized in the Table 2.

Table 2. Experimental result for mass loss with varying thickness and Knoop hardness number.

Sl No.	Thickness (µm)	Knoop Micro Hardness KHN	mass loss (mg)
1	100.03	15.38	17
2	100.08	15.67	17
3	100.08	17.01	16
4	100.29	16.66	16
5	100.31	16.93	16
6	100.4	15.2	15
7	100.42	15.04	16
8	100.52	15.23	16
9	100.6	17.24	15
10	100.74	15.34	17
11	120.03	13.35	24
12	120.04	13.32	21
13	120.27	13.85	24
14	120.6	15.76	24
15	140.03	13.41	31
16	140.14	12.41	31
17	140.23	11.67	29
18	140.36	13.71	31
19	140.65	11.23	30
20	140.86	9.56	31
21	140.9	9.8	30
22	160.02	10.9	38
23	160.04	9.04	37
24	160.05	10.3	35
25	160.23	11.63	34
26	160.3	9.41	36
27	160.3	9.12	38
28	160.4	9.81	34
29	160.4	8.02	33
30	160.79	10.58	35
31	160.86	9.74	38
32	160.9	8.2	32
33	160.98	7.21	33

2.4 Determination of abrasion resistance

After undergoing hardness test, TABER abrasion tests (ISO 7784-2 and ASTM D 4060) [8,18] was carried out by the Abrasion Tester (Rotary Platform Abraser, Taber Abraser Models 5135). The "abrasion resistance" is calculated as loss in mass at a specified number of cycles. Resilient calibrase wheels no. CS-10 was used, applying a 500 g load for a total of 1000 cycles. The test sample (100x100 mm) was weighed before the abrasion and after the completion of every 500 cycles, calculating the mass loss (mg). This test had been performed on tested samples, which consisted of 3015 aluminum sheet as a substrate and polyurethane film coating; because the wear mechanism is a composite process includes the substrate and coating film together. Figure 4 shows the remain effect of the abrasive wear on the polyurethane film coating, due to performing rotary abrasive wear test on coated samples. The results for a total of 1000 cycles are summarized in the Table 2.

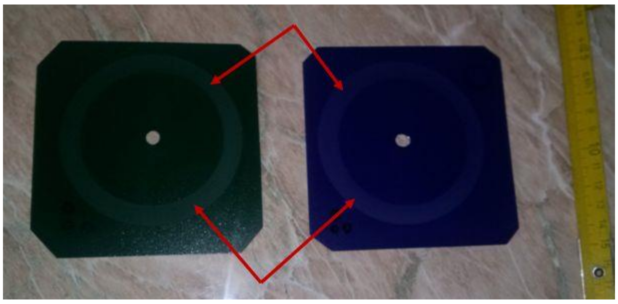

Fig. 4. Remain effect of the abrasive wear on the polyurethane film coating on coated samples.

3. RESULTS AND DISCUSSION

3.1 Experimental results

From the experimental set up 33 specimens with varying thickness of 100-161 µm were measured whose corresponding Knoop hardness number and mass loss (mg) were measured using Taber abrasion test as shown in Table 2.

3.2 Artificial neural network (ANN) method

ANN is one of the soft computing methods that have the ability to represent the complex relationship between input and output. The concept of ANN is inspired from the biological nervous system and was developed after the introduction of a set of simplified neurons in 1943 by Mc Culloc and Pitts. ANN is a system that receives input data, processes the data and provides it as an output. In neural network back propagation network is mostly used.

It generally has feed forward network architecture that allows the signal to travel in one direction i.e. from input to output which is placed together by a set of processing unit known as neurons. Application of back propagation method in the prediction of coating treatment process is widely observed as it can model complex relationship using training and testing data sample for self-learning and providing accurate output [19].

ANN model was trained using Levenberg-Marquardt method with two input as thickness and Knoop hardness number and mass loss as output as shown in Fig. 5.

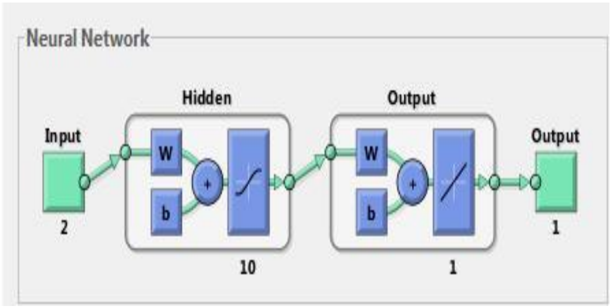

Fig. 5. Neural Network model for mass loss.

3.3 Adaptive neuro fuzzy interference system (ANFIS) method

It was Jang [20] who proposed ANFIS model in 1993. ANFIS is one of the important paradigms for processing information. It uses a system based on fuzzy for modeling and simulation of the complex relation between the input parameters and uses Neural Network for predicting the output [21]. In ANFIS system learning method is similar as compared to ANN [22]. ANFIS consists of five layers neural network [23], every layer has different function and it follows as:

Layer I: First layer of ANFIS is known as the fuzzy layer as it converts set of inputs in the fuzzy set by application of membership function. Fuzzy layer has set of adaptive nodes and its function is described as:

$$O_{1,i} = \mu_{Pi}(A) \quad (i = 1,2) \qquad (1)$$

$$O_{1,j} = \mu_{Qj}(B) \quad (j = 1,2) \qquad (2)$$

Here A and B are input variable nodes with i, j, P and Q are the label associated with input node. μ(A) and μ(B) are membership function. In this case, Gaussian shape was selected out of all membership function due to its versatility.

Layer II: In this layer node is fixed and the output signal is obtained by multiplying node function with an input signal.

$$O_{2,i} = M_i = \mu_{Pi}(A).\ \mu_{Qj}(B), \text{(for i and j= 1,2)} \qquad (3)$$

Here, $O_{2,i}$ is the output of layer II and M_i represents the strength of rule.

Layer III: It is also a fixed node network and the strength is represented as:

$$O_{3,i} = M_x = \frac{M_i}{M_1 + M_2}, \text{(for i= 1,2)} \qquad (4)$$

Here, $O_{3,i}$ is the output of layer III and M_X represents the normalized strength rule of layer III.

Layer IV: This layer is known as adjustable layer, here every node is adjustable and the strength function is represented as:

$$O_{4,i} = M_{xi}.f_i, \text{ (for i = 1,2)} \qquad (5)$$

Here f_i is a fuzzy rule for i=1,2 so fuzzy rule for a system is given as :

If A is P_1 and B is Q_1, Then $f_1 = c_1X + d_1Y + r_1$.

If A is P_2 and B is Q_2, Then $f_2 = c_2X + d_2Y + r_2$.

Here, c_i, d_i and r_i are the set parameters.

Layer V: The overall output of a system is given in this layer.

Overall output is calculated by: $O_{5,i} = \Sigma_i M_{ni}.f_i$

A set of experimental data were selected for training, testing and checking purpose for the test. Back propagation method is used for training.

Figures 6-9 show various attributes that were set up and obtained while undergoing ANFIS model for predicting mass loss.

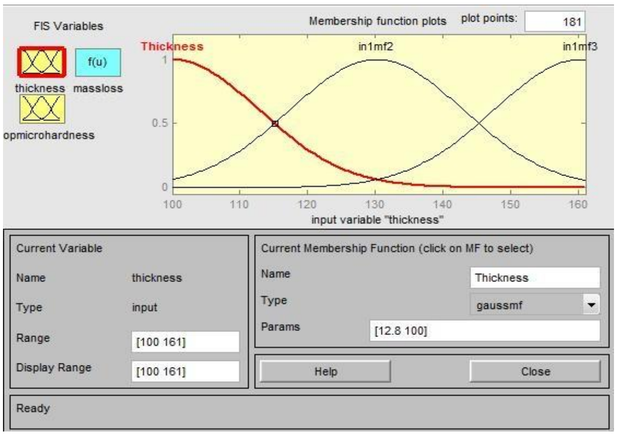

Fig. 6. Membership function of Thickness (μm).

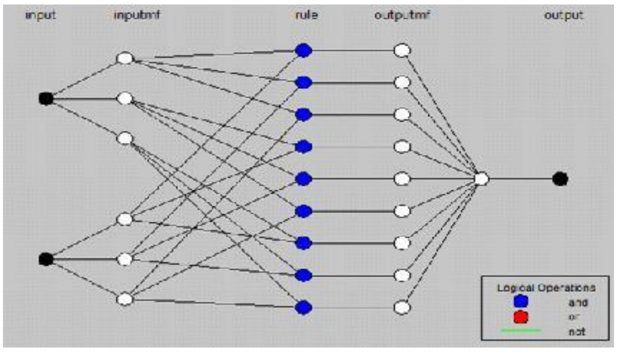

Fig. 7. ANFIS model for mass loss (mg).

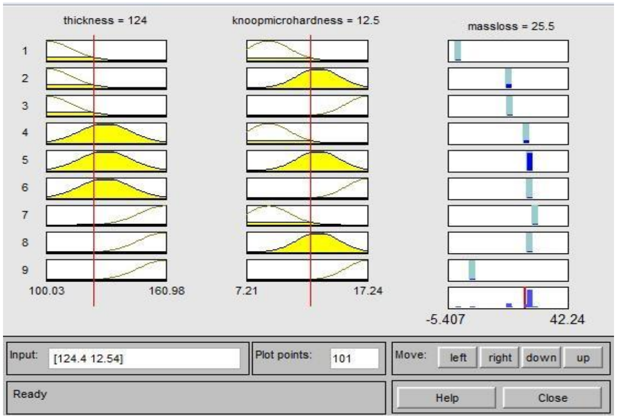

Fig. 8. Set of Rules for predicting mass loss (mg).

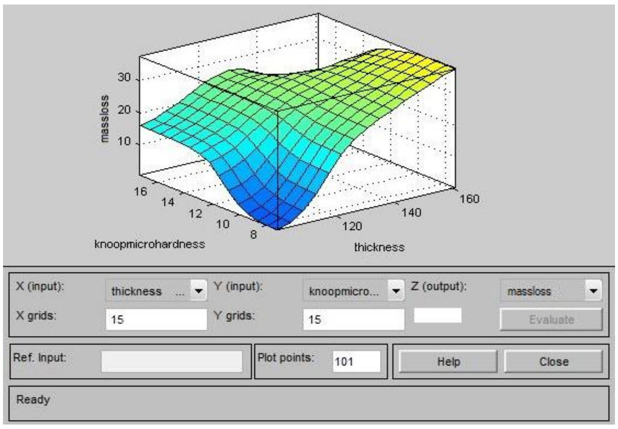

Fig. 9. Surface plot for predicting mass loss (mg).

The experimental data and predicted result using ANFIS & ANN were compared. The mass loss and number of experiment plot obtained from experimental and predicted values has been compared in Fig. 10.

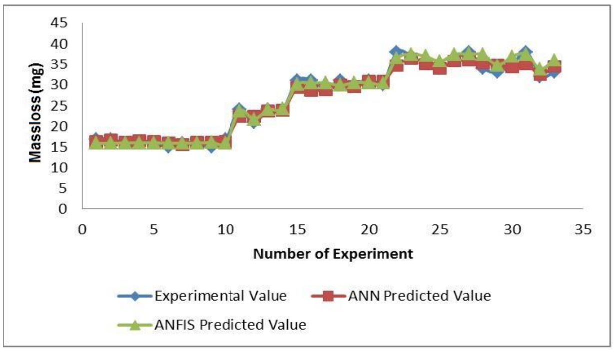

Fig. 10. Experimental and Predicted value for mass loss (mg).

Figure 10 show that the experimental data holds good agreement with the predicted results, it can be seen that the predicted results are in good agreement with the experimental data. It can be further said that the error % between the predicted & experimental data is less, which is the reason for coinciding curve between experimental and predicted values.

4. CONCLUSIONS

The following conclusion can be drawn based upon the results:

1. It is observed that the micro hardness and abrasive wear rate of the polyurethane coating with aluminum alloy substrate affected by the thickness of coating layer. It is seen that the value of micro hardness and abrasive wear rate are highly sensitive as compared to the value of the coating layer thickness of tested specimen.
2. Micro hardness values obtained by the Knoop indenter "rhombic-based pyramidal shaped diamond indenter", show that this methodology is one of the useful methodologies in determining the mechanical properties of the coating layer, and in which they can study the properties of the surface layer for the coating material.
3. The prime advantage of using a model based on soft computing techniques for predicting provides the necessary platform for cost reduction and accuracy to the output as compared to other models.

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