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MOISTURE ABSORPTION CHARACTERISTICS AND ADAPTIVE NEURO FUZZY MODELLING OF *AMPELOCISSUS CAVICAULIS* FIBER REINFORCED EPOXY COMPOSITE

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ABSTRACT

Natural fibre reinforced composite is fast becoming an important class of engineering materials due to its low cost, light weight and good mechanical properties; therefore increased natural fibre composite development is desirable. In this study, the effect of water soaking time and Ampelocissus cavicaulis natural fiber (ACNF) size factors on the water absorption characteristics of ACNF reinforced epoxy composite was investigated. The optimum membership function in Adaptive Neuro Fuzzy Inference System (ANFIS) structure that modelled and predicted the observed water absorption characteristics of the developed composite was investigated by giving consideration to minimum training error. ANFIS was also utilized to evaluate the sensitivity of ACNF reinforced epoxy composite's water absorption characteristics to water soaking time and ACNF size factors. Results showed that developed composites' water absorption increased as water soaking time and ACNF size increased. While optimising the ANFIS structure, the training error associated with ANFIS gauss, tri, gbell, gauss2, pi and gsig memmbership functions were 0.5171, 0.08997, 0.6706, 0.08803, 1.3770 and 0.6167, respectively. The optimum ANFIS model structured (trimf) had a coefficient of determination (R^2) value of 0.99947. The water absorption characteristics of ACNF reinforced epoxy composite was most dependent or sensitive to water soaking time with a root mean squared error (RMSE) of 1.577 followed by ACNF size with RMSE of 1.753. It is concluded that ACNF reinforced epoxy composite are best applied in non-moist or dry environments.

Keyword: Composite; membership function; ANFIS; Absorption; Modeling; Prediction

Introduction

The green and economic characteristics of natural fibre had popularised its applications and still doing so till the present day. In materials engineering particularly, the application of natural fibre in composite development is critical because of its easy accessibility, renewability and sustainability. Different natural fibres had been investigated for their suitability to reinforce various classes of matrices to produce cost effective and property enhanced modern composite materials. The application of natural fibre reinforced composite in human day to day activities including goods packaging, construction, automobiles and airplanes and others. The deficiency of natural fibre lies in its hydrophilic tendencies cause by the amorphous component such as lignin, hemicelluloses and pigment. When fibre absorbs moisture, the structure of the fibre becomes unstable, mould growth occurs, unwanted changes in dimension happens and general properties decreased (Huner, 2015). Although studies had been aimed to eliminate the natural fibre's hydrophilic tendencies (Nozari et al., 2012), results showed that this can only reduce but never eliminated through physical, chemical or enzymatic procedures; and this tends to limit the application of natural fibre reinforced composites to indoor applications (Wang et al., 2006). Therefore, understanding the hydrophilic behaviour of developed natural fibre reinforced composite through establishment of mechanism of moisture absorption and prediction of moisture absorption will not only assist in natural fibre reinforced composite pre-designing process, it will also assist in the specification of its condition of used and ultimate control of the hydrophilic behaviour through choice of suitable materials and processing factors.

The importance of prediction of process or property cannot be overemphasized. Since many of the real life processes or properties investigation can be expensive in time and cost; modelling and prediction from small experimental data set becomes a suitable option to forecast a process or properties (Jia et al., 2011). However, accurate forecast is a necessity to prevent process or property failure. For instance, inaccurate prediction of natural fibre reinforced composite used in building construction may lead to irreparable losses if structural collapse occurred. Therefore, accurate process or property prediction of natural fibre reinforced composite is a relevant study. The foremost traditional modelling and prediction method is statistical and physics method. However, the accuracy of these methods depends wholly on the accuracies of the experimental data and the assumptions used (Valavala et al., 2005). On the other hand, soft computing models are free of assumption deficiencies. They are data driven, non mathematical and tolerant to noisy data (Onwude et al., 2016). A number of researchers have established that soft computing methods are multivariate, robust, and precise and can handle even complex problems successfully (Abbaspour-Gilandeh, 2020).

In the related studies, Adeyi et al., (2018) investigated the water absorption property of *Momodical* fiber reinforced polyester composite using artificial neural network (ANN); it was concluded that increase in fibre quantity increased the composite's moisture absorption and ANN accurately modelled and predicted the process with a coefficient of determination close unity. More literature search showed that few studies have been made on the application of soft computing to model and predict the moisture absorption characteristics of natural fibre reinforced composite and most especially *Ampelocissus cavicaulis* Natural Fiber (ACNF) Reinforced Epoxy Composite. More importantly, establishment of the degree of sensitivity of natural fibre reinforced moisture absorption to the composite processing factors is scarce in the literature. Furthermore, increased studies on natural fibre reinforced composite are necessary so that the behaviour of other localized and novel materials can be unravelled and to facilitate in-depth technical knowledge to cater for new need and new solutions. Therefore, the aim of this study is to bridge these lacunae through the following objectives: to (1) develop and investigate the effect of water soaking time and ACNF size on the water absorption properties of ACNF reinforced epoxy composite, (2) investigate the suitability of adaptive neuro fuzzy inference system (ANFIS) to model and predict the water absorption properties of ACNF reinforced epoxy composite and (3) investigate the degree of sensitivity of ACNF reinforced epoxy composite water absorption behaviour to water soaking time and ACNF size.

Materials and Methods

Materials

Well grown harvested, washed and moisture stabilized (sun dried to constant weight) ACNF was utilized as the experimental natural fiber. Industrial grade epoxy and hardener were purchased from Ojota Chemical Market in Lagos State Nigeria. Chemicals were used as purchased. Digital weighing balance (0.000 g) and Stangas dryer oven were used for measurements and drying purposes, respectively. Burr grinder was used for fiber reduction into the desired experimental sizes.

Experimental process

Dried ACNF were burr grinded and manually sieved into three sizes (2, 6 and 10 mm). ACNF reinforced epoxy composites were developed in accordance with the method of Pani and Mishra (2019). The method involved measuring a 15.00 g epoxy matrix and gently mixed with 1.50 g of hardener. Thereafter, 6 g of different experimental sized ACNF (40.00 %wt. of 15.00 g epoxy matrix) was added and further mixed. The mixture was then poured into a prepared lined paper tape steel mould. After 30 min of curing, the mould was subjected to compression under a weight of 20 kg with the aim of developing a compact and bubble free specimen. The process is as represented in Fig. 1.

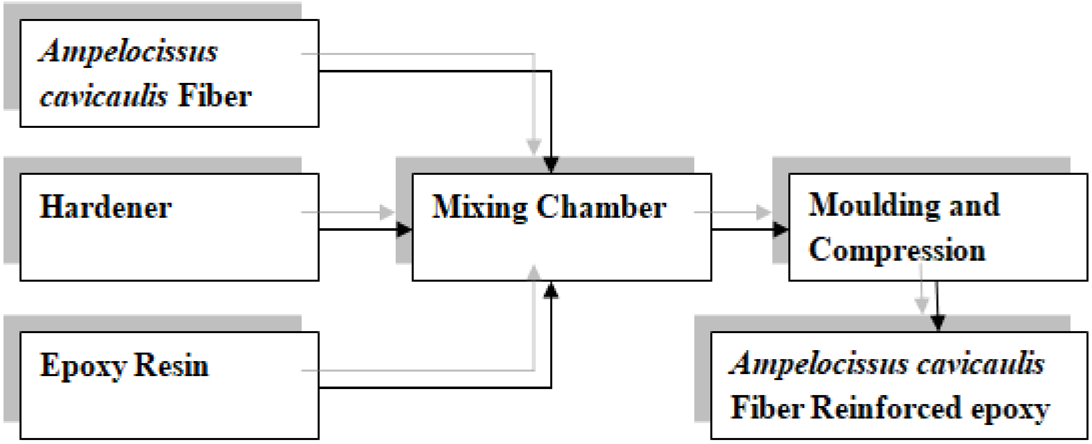


Fig. 1 Representation of composite development process

Water absorption characterisation

In accordance with the method of Osman, (2014), the water absorption property was investigated by complete immersion of a previously weighed ACNF reinforced epoxy composite in 1 lit of distilled water for 240 h. The soaked composite was removed from water after every 24 h, blotted dry with tissue paper to remove excess surface sticking water and re-weighed. The mass of composite before and after water immersion were used to establish the moisture absorption of the composite through Eqn. 1.

$$\text{Absorption} = \frac{A-B}{B} X\ 100 \qquad (1)$$

where: A = Final Weight
B = Initial Weight

ANFIS theory and experimentation

ANFIS is a Sugeno type of fuzzy inference structure. It accepts single input multiple output data dimension. The input and output data are modeled and predicted through an If-Then rule structure that consists of neurons. The rules formulations of a typical ANFIS structure are represented below;

Rule 1: If z is A_1 and k is B_1, then $f_1 = p_1z + q_1k + d_1$ (2)

Rule 2: If z is A_2 and k is B_2, then $f_2 = p_2z + q_2k + d_2$ (3)

Rule 3: If z is A_3 and k is B_3, then $f_3 = p_3z + q_3k + d_3$ (4)

Rule 4: If z is A_4 and k is B_4, then $f_4 = p_4z + q_4k + d_4$ (5)

Layer 1 corresponds to the crisp inputs for the system of interest, this layer is referred to as the input layer and it is represented in Eq. 6.

$$O_i^1 = (\text{inputs}) \qquad (6)$$

In this exemplified structure, the input later consists of two inputs x_1 and x_2. The supplied crisp input data are then put into a fuzzy space using a choice membership function. The membership function generally has a value between 0 and 1. This process is called fuzzification and therefore the second layer that does this process is called fuzzification layer (Kaveh et al., 2018). The nodes in this layer are adaptive and the layer is represented by Eq. 7 and 8 where μA_i and μB_i are the representation of the antecedent membership functions (gbell, pi, tri, gauss, gauss2, etc).

$$O_i^2 = \quad \mu A_i \,(\text{input 1}) \text{ for i} = 1, 2 \qquad (7)$$

$$O_i^2 = \quad \mu B_i \,(\text{input 2}) \text{ for i} = 3, 4 \qquad (8)$$

Layer 3 is called the firing strength layer. This layer gives the product of the degrees to which the inputs fit the membership functions.

$$O_i^3 = wi = \mu A_i \,(\text{input 1}) \times \mu B_i \,(\text{input 2}), \ldots\ldots = 1,2,3,4 \qquad (9)$$

Layer 4 is the normalization layer. Fixed nodes are available here and depicted in Eq. 10.

$$O_i^4 = w' = wi/w1 + w2,\ i = 1, 2 \qquad (10)$$

Layer 5 is the defuzzification layer and it is represented in Eq. 11. The layer consists of the consequent parameters of the fuzzy rules. The neurons here are connected to the normalization neuron.

$$O_i^5 = w_i' f_i = w'(p_i x + q_i y + r_i),\ i = 1, 2 \qquad (11)$$

Layer 6 produces the total output for each input in the fuzzy space, which equals the sum of inputs in layer 5. It is represented in Eq. 12

$$O^6 = \text{overall output} = \textstyle\sum_i w'_i f = \sum_i w_i f_i / \sum_{,} = 1, 2 \qquad (12)$$

The ANFIS modeling and prediction study was done in Matlab R2010b software. The observed experimental data ware partitioned into training (50%) data for ANFIS model structure development and testing (50%) data for the developed ANFIS model prediction. To get an optimum ANFIS structure, the membership function type that gives the minimum training error was investigated between gauss, tri, gbell, gauss2, pi and gsig memmbership functions. The performance of ANFIS prediction was established through coefficient of determination (R^2) and root mean squared error (RMSE) as represented in Eq. (13 and 14).

$$R^2 = \frac{[\sum_{i=1}^{N}(\text{Exp,i}-\text{Qm})(\text{Pred,i}-\text{Pm})]^2}{\sum_{i=1}^{N}(\text{Exp,i}-\text{Qm})^2 + (\text{Pred,i}-\text{Pm})^2} \qquad (13)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\text{Exp,i} - \text{Pred,i})^2}{N}} \qquad (14)$$

Results and Discussion

Effect of water soaking time and ACNF size on water absorption characteristics of ACNF reinforced epoxy composite

The water absorption property of ACNF reinforced epoxy composite is depicted in Fig. 2. It could be observed from the figure that the water absorption showed a strong dependence on both water soaking time and ACNF size. The higher the water soaking time and ACNF size, the higher the water absorbed in the experimental composites. The result can be attributed to the fact that natural fibre have polar hydroxide group (Das and Biswas, 2016) and therefore has high tendencies for water absorption and they do this till saturation. Some of the methods been applied to reduce the natural fibre hygroscopic / hydrophilic tendencies include fibre treatment (physical, chemical or enzymatic) and hybridization (Hamdan et al., 2019). Kushwaha and Kumar (2010) and Osman (2014) also reported a close result as observed in this study. Therefore, ACNF reinforced epoxy composite looks fit for indoor applications where its water interaction will be minimized or eliminated.

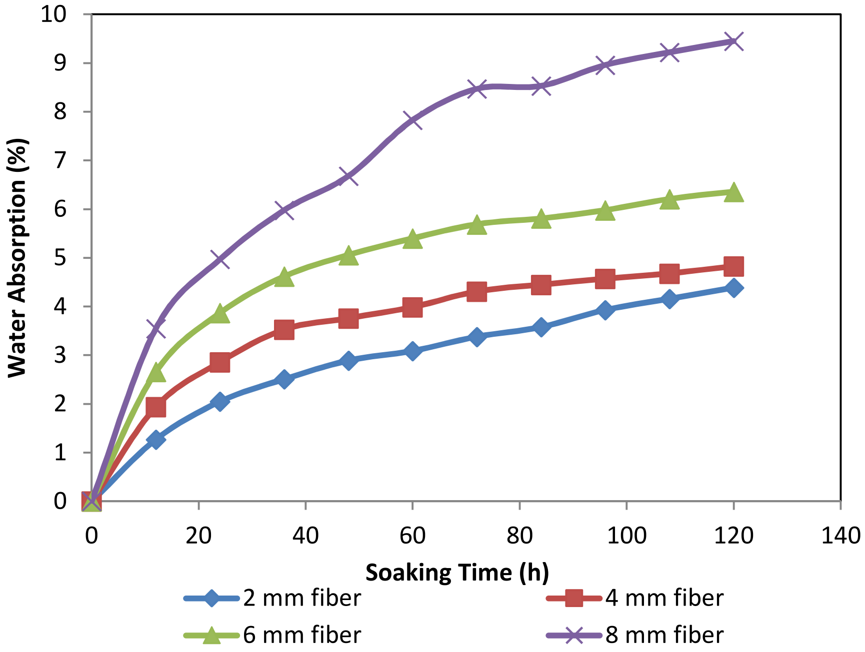
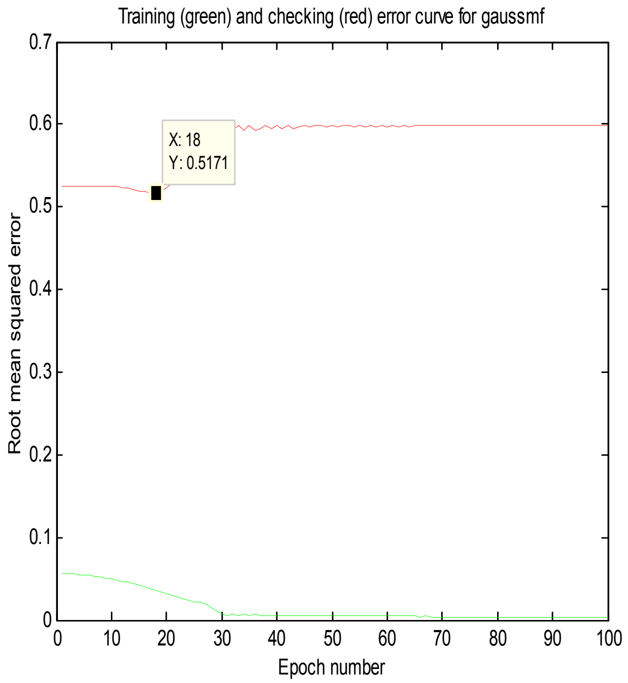


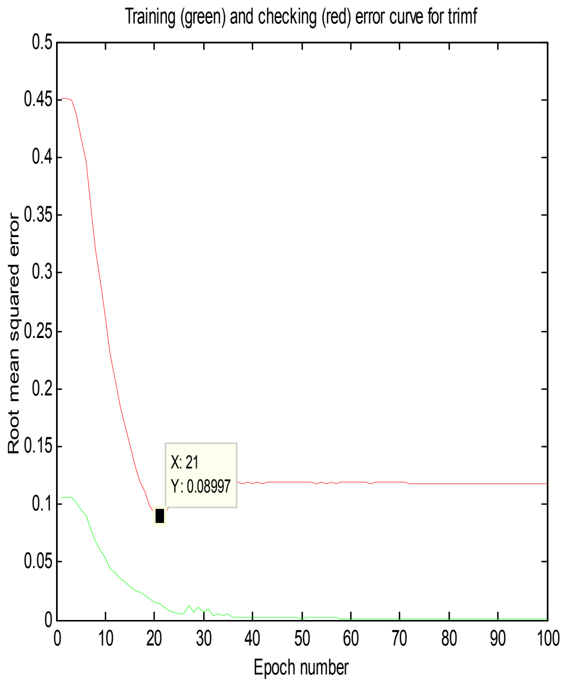
Fig. 2 Water absorption characteristics of ACNF reinforced epoxy composite

ANFIS prediction

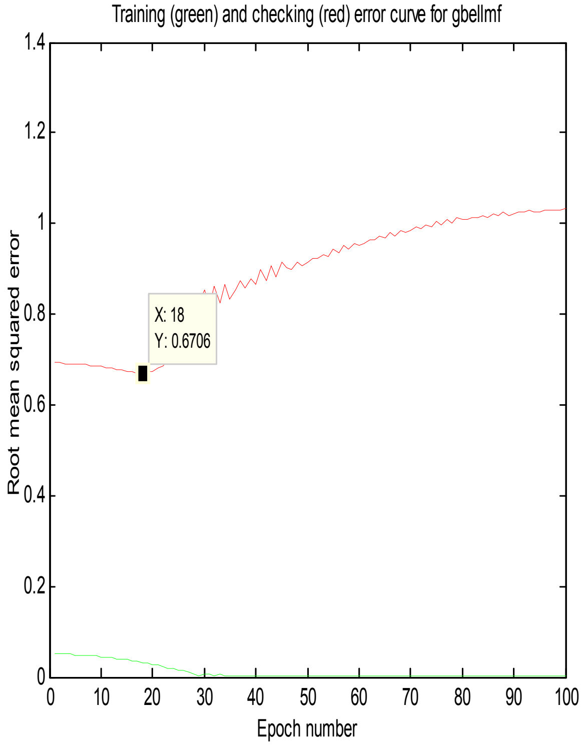
The type and number of membership function including the epoch number have a potent effect on the performance of ANFIS structure. In this study, the effect of the membeership function that minimises the error of ANFIS prediction was investigated and thus represented in Fig. 2 (a-f).


Training (green) and checking (red) error curve for gaussmf
Root mean squared error
Epoch number
X: 18
Y: 0.5171
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100

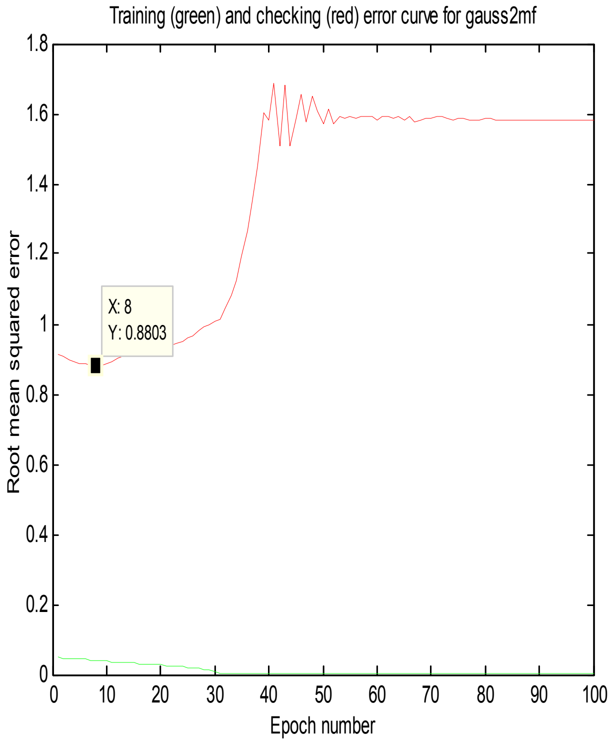
(a)


Training (green) and checking (red) error curve for trimf
Root mean squared error
Epoch number
X: 21
Y: 0.08997
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 10 20 30 40 50 60 70 80 90 100

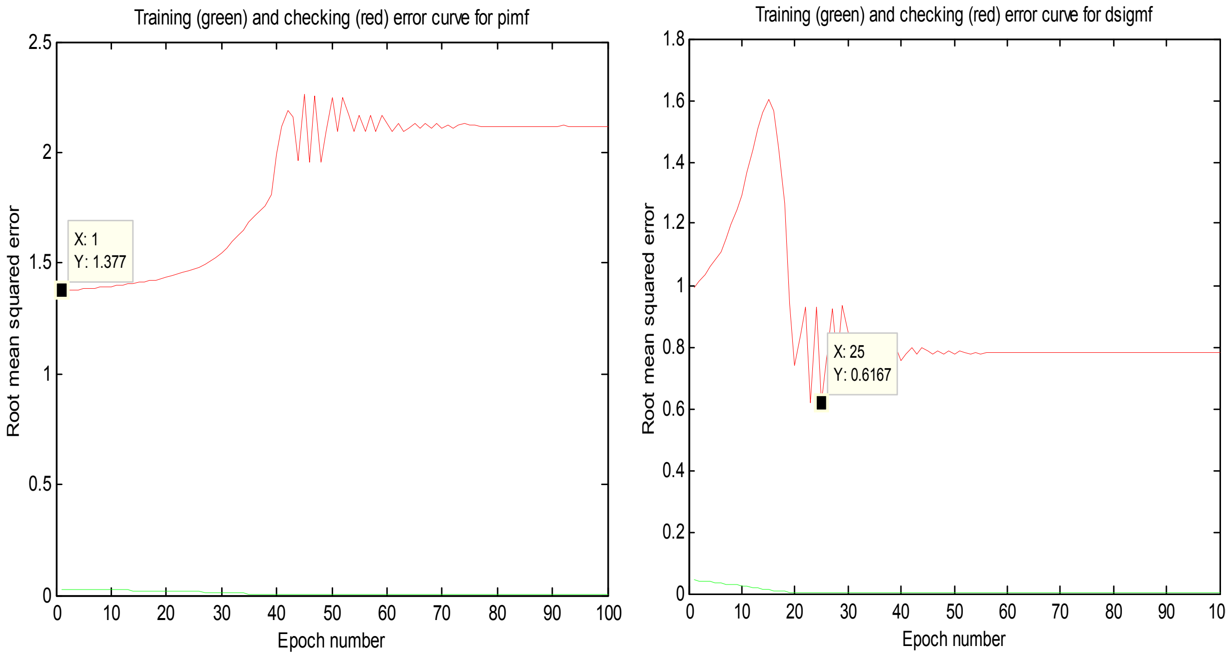
(b)


Training (green) and checking (red) error curve for gbellmf
Root mean squared error
Epoch number
X: 18
Y: 0.6706
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 10 20 30 40 50 60 70 80 90 100

(b)


Training (green) and checking (red) error curve for gauss2mf
Root mean squared error
Epoch number
X: 8
Y: 0.8803
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 10 20 30 40 50 60 70 80 90 100

(d)



(f) (g)

Fig. 2 Optimization of the ANFIS membership function types (a) gauss (b) tri (c) gbell (d) gauss2 (e) pi and (f) dsig membership function

The figure showed that gauss, tri, gbell, gauss2, pi and gsig memmbership function has training error of 0.5171, 0.08997, 0.6706, 0.08803, 1.3770 and 0.6167, respectively, showing that tri membership function has the least error. Therefore, the ANFIS structure for modeling and prediction of the ACNF reinforced epoxy composite was built using tri membership function.

The structure of the ANFIS model, developed using pi membership function to model and predict the water absorption property of ACNF reinforced epoxy composite is represented in Fig. 3.

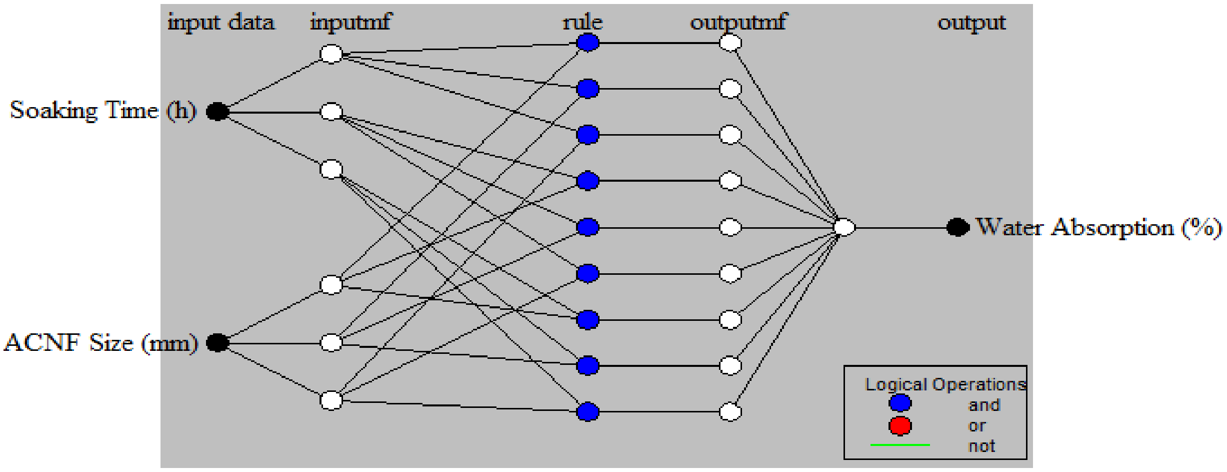
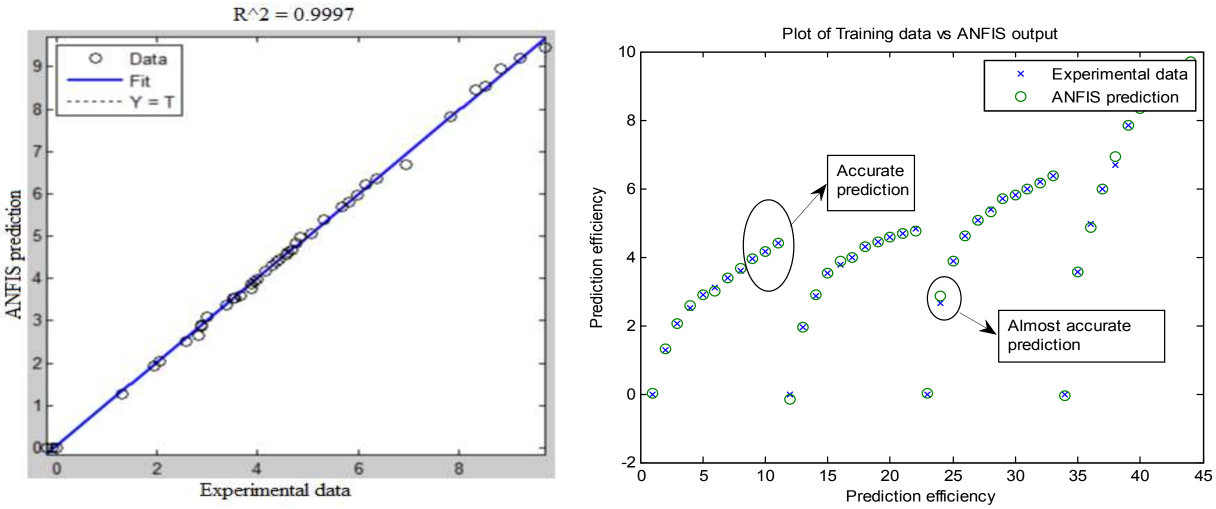


Fig 3 Optimized ANFIS structure

Artificial intelligent models are set of flexible structural interrelationships between nodes and layers that are linked together to perform the desired function (Kaveh et al., 2018). The figure showed that the input factors (water soaking time and ACNF size), membership function, rules and ouput (water absorption) are interconnected with neuron. The neuron relationship is known to be strong and robust against failure (Onwude et al., 2016). This structure possesses an excellent ability to learn the dynamics of data.

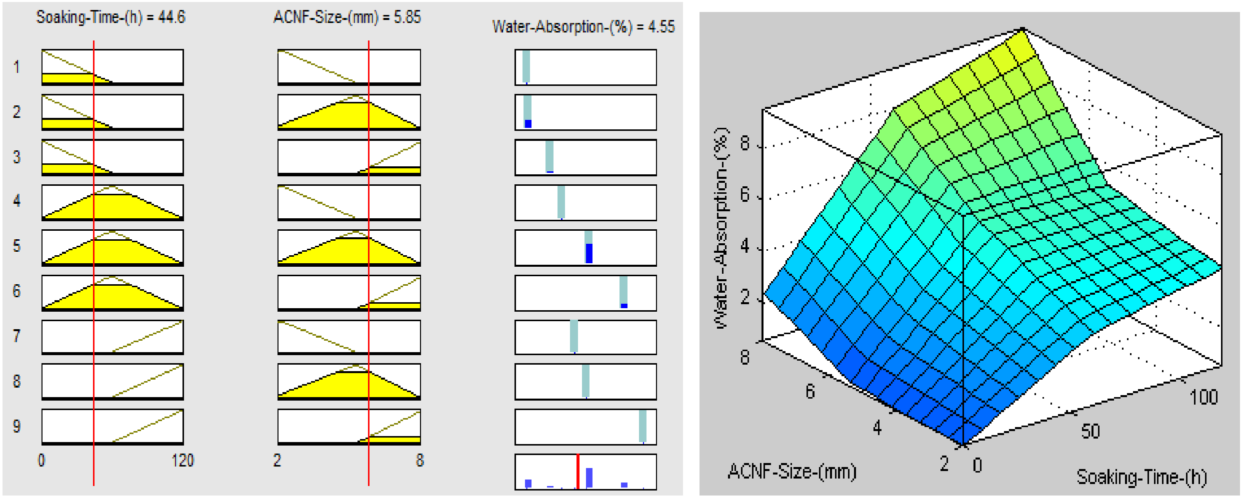
The efficiency of the ANFIS model is represented in Fig. 4 (a) and (b). Fig. 4 (a) showed parity plot where the experimental data and ANFIS predicted data are represented in the x and y axis. The figure showed that ANFIS prediction has a coefficient of determination (R^2) of 0.9997. This R^2 value is close to unity and desirable (Adeyi et al., 2020). Fig. 4 (b) showed a qualitative prediction efficiency of ANFIS. In the figure, most of the ANFIS predictions were close to the experimental data as depicted by accurate prediction and almost accurate prediction inscription on the figure.



(a) (b)

Fig. 4 Efficiency of the ANFIS prediction (a) parity plot (b) qualitative plot

The rule and interaction plot of the ANFIS prediction is represented in Fig. 5 (a) and (b).



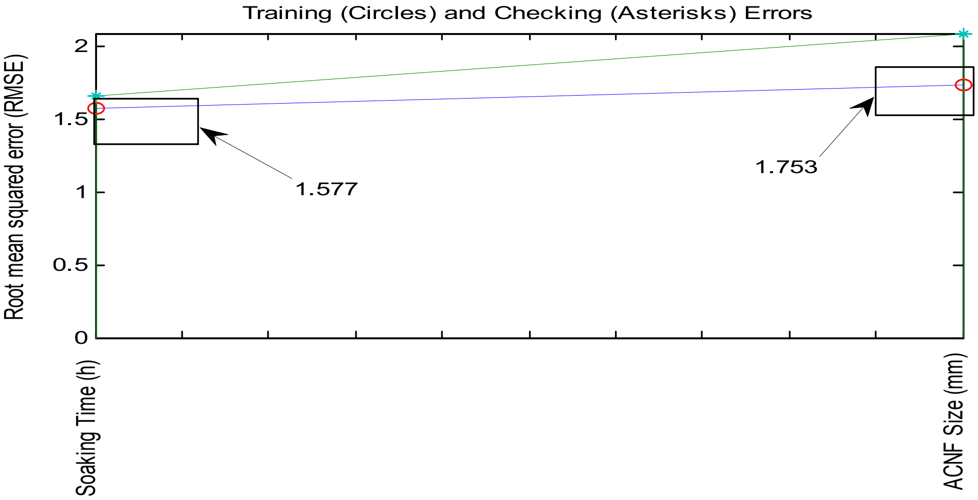
(a) (b)

Fig. 5 (a) ANFIS generated rules and (b) inputs-outputs interaction plot

The rules are essential in mapping input to output data which is the fuzzy logic aspect of ANFIS (Onwude, 2016). The numbers of expected rules is defined as K^d, where K is the number of input membership function and d is the number of independent data inputs factors. In this case, nine (9) rules are expected and are so represented in Fig. 5 (a). The moment the ANFIS structure is created, these sets of rules can be tuned to make a prediction even on points that were not experimentally examined but are within the experimental bound. The interaction plot is represented in Fig. 5 (b) and the observed trend is close to the previous observation in Fig. 2.

Sensitivity Analysis

The sensitivity of ACNF reinforced epoxy composite's water absorption property to water soaking time and ACNF size factors was investigated. Fig. 6 shows that water soaking time had the highest contribution to the composites water uptake occurrence, followed by ACNF size, as signified by the root mean squared error of both factors. This means that water soaking time factor is the most sensitive factor to the water absorption characteristics of ACNF reinforced epoxy composite and therefore should be taken most seriously during ACNF reinforced epoxy composite material specification determination and use.



Conclusion

Investigation of new composite development is important for increased production and use. In this study, the effect of water soaking time and ACNF size on the water absorption characteristics of ACNF reinforced epoxy composite was established. ANFIS was utilized to model, predict and conduct sensitivity analysis of the ACNF reinforced epoxy composite's water absorption properties. Results showed that water absorption of ACNF reinforced epoxy composite increased with increase in water soaking time and ACNF size. ANFIS model development was optimum when tri membership function was utilized. The R^2 of ANFIS prediction was 0.99947 and ACNF reinforced epoxy composite's water absorption characteristics was most sensitive to water soaking time followed by ACNF size based on root mean square value. It is concluded that because of the hydroscopic nature of natural fibre, the utilization of composites made with natural fibres should be restricted to indoor application. More studies are recommended in the area of natural fibre reinforced composite's hydrophilic properties mitigation.

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