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EXPERIMENTAL STUDIES AND ARTIFICIAL NEURAL NETWORKS (ANN) MODELING OF MOISTURE ABSORPTION CHARACTERISTICS OF POLYESTER/*MOMODICAL* FIBRE REINFORCED COMPOSITE

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ABSTRACT

Nowadays, there are interests around the world concerning the applicability of natural fibers in polymer composite development for technological advancement. Natural fiber inclusion in synthetic polymer is termed partially degradable polymer composite which is considered environmentally friendly and acceptable. However, a notable deficiency is their poor moisture resistance behaviour that degrades their mechanical properties over time. This work therefore investigated the effect of Momodical fiber fractions on the moisture absorption properties of Polyester/Momodical fiber reinforced composite. The Momodical fibers were alkali treated to improve the fiber properties. The Polyester/Momodical fiber composite were developed by incorporating the alkali treated Momodical fibers in the weight fraction of 10, 20, 30 and 40 % in polyester resin. Water immersion test was used to evaluate the water absorption characteristics from which the water diffusion mechanisms of the developed composites were established. For the sake of system behaviour prediction and control, Artificial Neural Networks (ANN) was used for modeling and prediction of the moisture gain of the Polyester/Momodical reinforced composites. Scanning Electron Microscope (SEM) was used to elucidate the morphology of raw and alkali treated Momodical fiber. The results showed that the water absorption process was diffusion controlled and diffusion mechanisms cut across less Fickian / Fickian behavior for investigated composites. The composite weight gained and percentage water absorption increased with increased immersion time and fiber loading. The moisture diffusivity ranged from 1.98 E – 12 to 5.38 E - 12. The ANN structure 2-5-

1-1 developed using 'tansig' 'tansig' 'purelin' transfer function showed a high capability and reliability in modeling and prediction of moisture gain observed in the developed composites. The results suggested an outdoor application in desert cooler pad and built material development where the moisture diffusion tendencies could be beneficial and loss of mechanical strength is trivial.

Keywords: Composite, Polyester, *Momodical* fiber, Artificial Neural Networks, Fickian diffusion.

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1. INTRODUCTION

The importance of plastic in human day to day activity is overwhelming. Plastics have been applied in many technological requirements. Sectors that include automobile, construction, food packaging, aerospace, aquaculture or plasticulture, medicine, and drug release have all benefited from the usefulness of plastic. However, plastics are deficient in some functional requirements and the need for creation of low cost, improved mechanical properties, better environmental resistant and eco-friendly (biodegradable) plastic is a global one (Begum and Islam, 2013).

Natural fiber reinforced polymer composite is not a new technology and has gained popularity because of its many important environmental properties and service strength. Although the effects of many natural fibers on properties of choice polymers matrix have been well documented over the years, research in this area will continue in other to cater for new need and new solution. More also, natural fiber reinforcement has still not matched the synthetic fiber reinforcement especially in applications that demand high mechanical strength; therefore, progress of research on natural fiber reinforcement is critical so as to realize the full benefit and or potential of this environmentally conservative material. The tailorability of composites for a specific purpose has been one of their greater advantages and also one of the more perplexing challenges to adopting them as alternative materials to metallic ones (Hussain, 2011). Although the use of natural fiber in composite development is glamorous, deficiencies of same are obvious. The deficiencies include irregular geometry, low processing temperature and great affinity for moisture or water. Furthermore, because natural fiber are highly hydrophilic, hence, their mechanical properties gets degraded over a period of time (Londhe and Mache, 2016) and this have limited there application to mostly indoor use. Although, literature details that chemical treatment of fiber prior to inclusion in polymer resin reduces the hydrophilic and increases the interfacial property of the fiber/polymer, the eradication of moisture absorption tendency from such composite seems impossible even in cases of hybrid developments.

Diffusion is the process by which matter is transported from one part of a system to another as a result of random molecular motions and moisture absorption takes place according to diffusion and Fick’s Law (Londhe *et al.,* 2016). Based on experiments of moisture uptake and assuming one – dimension diffusion for Frick’s law, several researchers have discussed characteristics of moisture absorption. Moisture diffusion in polymeric composites has been characterized to be Fickian and non – Fickian (Osman *et al.,* 2003). Polymer composites’ outdoor applications are usually demanded of mechanical, and weather (including temperature and moisture) resistance, therefore, the effect of moisture diffusion on the mechanical properties is important in the evaluation of the properties of natural fiber reinforced polymer composite especially in damp situations. Moisture diffusion study can be used as guidance in the optimal design of new natural fiber based composites for moisture absorption resistant in service performance (Londhe *et al.,* 2016). Daramola *et al.* (2017) studied the mechanical and diffusion properties exhibit by Polyester/Soil retted Banana Fibre (SRBF) composites. Composites consisting 10, 20, 30 and 40 wt. % continuous fiber volume fraction were developed. The result showed that there was improvement in the mechanical properties of the polymer composites developed. Water absorption test showed that neat polyester and the composites with 10 and 40 wt. % SRBF has Fickian diffusion mechanism whereas 20 and 30 wt. % SRBR deviated from Fickian behaviour.

One of the promising applications of composites is in the construction of desert coolers for storing agricultural produces because of their intrinsic properties. Much of the post-harvest losses of fruits and vegetables in developing countries like Nigeria are due to the lack of proper storage facilities. While refrigerated cool stores are the best method of preserving fruits and vegetables they are expensive to buy and run. Consequently, in developing countries there is an interest in simple low-cost alternatives, many of which depend on evaporative cooling which is simple and does not require any external power supply. Such passive cooling technology is also called a desert cooler. The evaporative cooling works by utilizing the natural process of water evaporation, along with an air moving system, to create an effective cooling environment. The fresh and warm outside air moves through the wet porous pad that cools the air through water evaporation as depicted in Figure 1 below (Ndukwu and Manuwa, 2014).

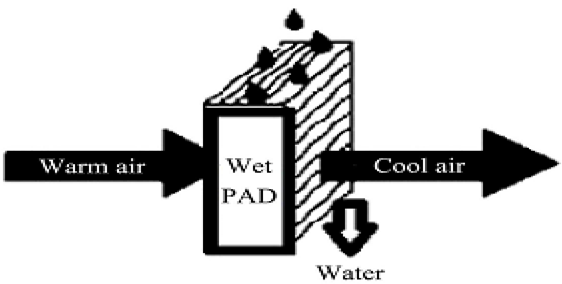


Figure 1: Analogy of wet pad in desert cooler

According to Ndukwu *et al.,* (2014), several organic and inorganic materials have been tested for the evaporative cooling purpose under different climates. These include the metal pads, cellulose pad, hessian pads, Aspen, PVC pad, porous ceramic pad, wood shaven, jute, rice straw; excelsior of pine, fir, cotton wool, charcoal and latex foam. Others are luffa, cedar, red wood, spruce, plain and etched glass fibers, copper, bronze, galvanized screening, vermiculite, perlite, palm leaf, palm fruit fiber, expanded paper, woven plastic etc. The use of natural fibre reinforced plastic composite may also be important because of its water sorption characteristic. Since wet pad material does not also support external load in desert cooler application, therefore, degradation of mechanical properties consequent of moisture absorption becomes trivial.

Momodical stem fiber is an abundant natural fiber in Nigeria. It shows good physico-mechanical strength and durability in use. The exhibited properties must have paved way for its ancient applications which included its use as sponges, ropes, carpets and animal beddings. However, these traditional usages have faded away due to the advent of synthetic alternatives. Despite the fact that *Momodical* fiber is physically strong and abundantly available and accessible in Nigeria, the information regarding its characterization and use as natural fiber reinforcement in composite development is scarce in the literature. Literature agrees that it is important to obtain previous information about the structure and properties of lignocellulosic fibers before use in composite formulations (Paletto *et al.,* 2014).

Modelling and prediction is an important feat in understanding, designing and control of processes and systems. Recently the application of intelligent modelling such as Artificial Neural Networks (ANN) to process data has been of interest because of their accuracy and non-mathematical nature. Aside that, especially for industrial adoption of established processing routing, investigation and application of suitable control systems is important. Control ensures reproducible standard and automation of the process. Artificial neural networks are computational tools, which are also seen as complex tools for complex systems and dynamic modeling. They are inspired by the biological neural system as a useful statistical tool for nonparametric regression. One advantage of ANN over conventional models (such as the empirical model) is the increased flexibility, reduced assumptions, online non-destructive measurement and tolerance of incomplete or noisy data (Onwude *et al.,* 2016). It can be seen as models of human brain and nervous systems. It has ability to model linear and non-linear system without making explicit assumptions. Designing an ANN model follows a number of systematic procedures. In general, there are five basic steps which are; collection of data, processing of data, building the network, training, and validation and performance evaluation of model.

The structure of a neural network is in form of interconnected layers. These are the single layer feed-forward network, the multi-layer feed-forward network and the recurrent network. The number of neurons in the input and output layers is the representative of the amount of independent variables (input) and dependent variables (output) respectively (Onwude *et al.,* 2016). A typical ANN is depicted in Figure 2 where the scalar inputs are transmitted through connections that multiply their strength by scalar weight to form product ‘xw’ which is again a scalar. All the weighted inputs ‘xw’ are added and also added to bias b. The result is the argument of the transfer function f which produces the output y. The bias is just like a weight except for the fact that it has a constant input 1.

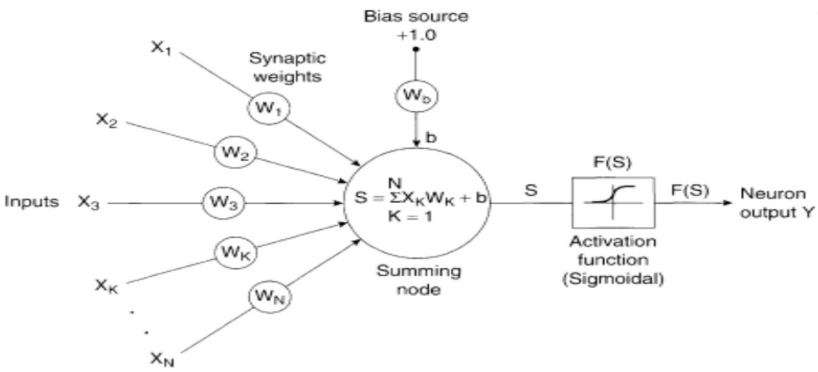


Figure 2: Structure of Artificial Neural Networks

Important to know is that the selection of an appropriate neural network topology is important in terms of model accuracy and simplicity (Ahmad *et al.,* 2012).

The present study therefore investigated the moisture diffusion characteristics of alkali treated *Momodical* fiber reinforced polyester composite with proposed application in desert cooler pad or built material. ANN was further used to model and predict the moisture gain in the composites developed for the benefit of process control. The number of neuron in the first and second hidden layer, number of epoch and computational speed that best model the moisture diffusion based on 'tansig' 'tansig' 'purelin' transfer functions were also investigated.

2. MATERIALS AND METHODS

2.1. Materials

Materials used in this study are unsaturated polyester resin, Sodium Hydroxide (NaOH), Acetic acid, Methyl Ethyl Ketone Peroxide (MEKP) – catalyst or initiator, Dimethyl Aniline (NNDMA) – accelerator, weighing scale (0.000g accuracy) and pH meter. All chemicals were obtained in a chemical store at Ilupeju Lagos, Nigeria. *Momodical* stems were harvested from a farmland in Ogbomosho, Oyo State Nigeria.

2.2. Methods

2.2.1. Preparation of Momodical Fibre

The *Momodical* stem was washed with distilled water to remove stains and foreign materials. The fiber strands were extracted by soaking the stem in distill water at fiber – water ratio of 1:10 for 24 h to enable the softening of fiber outer layer covering membrane. Thereafter, the outer layer covering membrane was peeled off to expose the core which containes the fibers strands. The extracted strands of fiber were further washed to remove stains and gums. The well washed fiber strands were then air dried for 72 h in accordance with the method of Srinivasa and Bharath (2013) and finally dried in an air circulatory oven at 70 ^{O}C (Ali *et al.,* 2012) till constant weight. The dried fibres were ground to 3 mm size and kept in sealed glass bottle to prevent moisture reabsorption. Proximate analysis of the extracted fibers was carried out in order to understand the intrinsic composition of *Momodical* fibers.

2.2.2. Momodical Fibre Alkali Treatment

Momodical fiber alkali treatment was achieved by soaking about 200 g of fiber in solution containing 6.321 % of NaOH for 9 h 32 min, being an earlier experimentally established optimum alkali treatment parameter for *Momodical* fiber. Fiber/liquor ratio of 1:20 (Afroz *et al.* 2013) was used. After alkali treatment, the treated fibres were washed with 5 % acetic acid solution. It was further washed severally with distilled water to remove any trace of NaOH. The treated fibre was air dried for 24 h before finally dried to constant weight in fan oven at 70 ^{O}C. The dried treated fibres were kept sealed in glass bottle to prevent moisture absorption till further use.

2.2.3. Momodical Fibre Morphology

Scanning Electron Microscope (SEM) was used to determine the fibre dimensions and surface morphology before and after treatment of the fibre. The SEM analyses were done at the University of Cape Town, South Africa and micrographs were obtained with machine parameter SEM HV: 5. kV, WD: 16.43 mm, View field: 2.08 mm, 500 µm, SEM MAG: 100 X.

3. PREPARATION OF COMPOSITE

Composite samples were prepared following the recommendation specified in ASTM D 5229. Four fiber volume fraction inclusion ratios of 10, 20, 30, 40 wt.% were used for composite preparation. The test samples were produced in accordance with the method of Adeosun *et al.* (2015). To produce the test composite samples, measured quantity of fiber of each volume fraction was manually added to measured quantity of unsaturated polyester resin and mixed gently to prevent bubbles. Thereafter, 1 % (by volume of polyester) Methyl Ethyl Ketone Peroxide (MEKP) catalyst was added to the mixture using micropipette and further mixed for 5 min. Furthermore, 0.5 % of Cobalt Naphthanate Accelerator (by volume of polyester) was added and mixed for another 5 min. The mixture was then poured into a prepared lined paper tape steel mould die. The mould was made in the form of male and female components for compression so that compact specimens which were devoid of trapped air were produced. The specimens were allowed to cure for 24 h (Henri *et al.*, 2014). The fabrication process was done at room temperature (27 – 30 ^{O}C). The cured composites specimens were removed from the mould and the specimens were post cured in fan oven at 70 ^{O}C for 5 h (Raju *et al.,* 2015). For neat polyester sample, only the polyester, catalyst and accelerator were mixed and poured into the mould. Three specimens for each fibre volume fraction inclusion ratio and neat polyester were prepared and analysed for statistical significance.

4. WATER ABSORPTION TEST

The water absorption tests were carried out following the recommendations specified in ASTM D5229M. The initial weight of each specimen was taken using electronic balance (0.000g) before water immersion. Samples were then immersed in distilled water (pH value of 7) at room temperature only. At every 6 h interval, samples were taken out, wiped with tissue paper to remove surface sticking water in preparation for weighing. Thereafter, the weights of the specimens were quickly taken. The weight gain of specimen was taken for 21 days after which not further increment in weight was observed. The water absorption behaviour by each specimen was recorded and moisture content M_t was calculated from the respective initial weight, W_o and instantaneous weight absorption data, W_t by using Eqn. (1).

$$M_t = \frac{W_t - W_o}{W_o} \, x \, 100\% \quad (1)$$

5. ESTIMATION OF ABSORPTION MECHANISM AND DIFFUSION COEFFICIENT

Estimation of water absorption mechanism in the prepared composites was done by using the method of Daramola *et al.* (2017). Graphical plots of percentage water absorption for all the composites samples produced were made. The water absorption curves obtained for all the composite samples were used for analysis of diffusion mechanism. The water absorption profile data were fitted to Eqn. (2) and equation parameters were determined.

$$\frac{M_t}{M_\infty} = kT^n \quad (2)$$

Where M_t is the water absorption at interval time, *T*, which is the time of immersion, M_∞ is water absorption at saturation point, k is a constant parameter related to the polymer network structure and n is the diffusion exponent value that determines the type of diffusion mechanism (Daramola *et al.,* 2017). A logarithmic simplification of Eqn. (2) shows that n represents the slope of the linearized equation while k is the intercept. The diffusion mechanism is usually categorized using the value of n (Daramola *et al.,* 2017).

Furthermore, the average coefficient of diffusion, *D*, for each specimen was determined from the maximum percent of moisture uptake, $M\infty$, the initial slope of the line of the moisture content vs. square root of time graphs and the specimen thickness, h, as represented in the figure 3 below. The average diffusion coefficient, *D*, measures the rate of moisture diffusion through all faces of the specimen and it is material specific or material dependent (Londhe *et al.,* 2016).

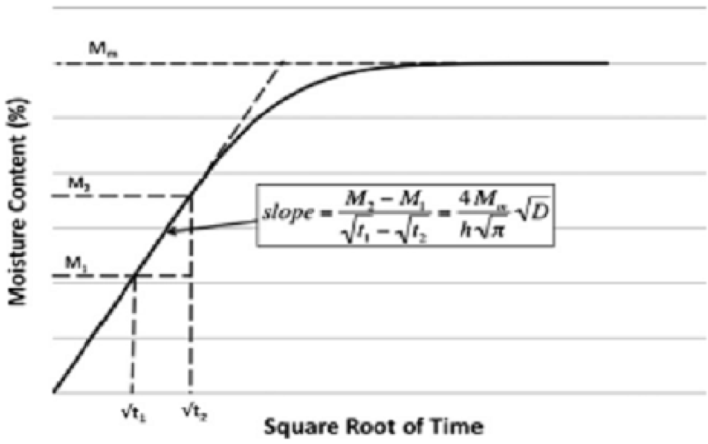


Figure 3: Determination of Diffusion Coefficient (Londhe *et al.,* 2016)

6. ARTIFICIAL NEURAL NETWORKS MODELING

Artificial Neural Networks with feed-forward structure, hyperbolic tangent sigmoid transfer function for neurons of hidden layer (s), linear transfer function for neuron of output layer and Levenberg–Marquardt training algorithm was selected to investigate the optimum topology (i.e. optimum number of network layer (s), number of neuron in hidden layer (s) and number of epoch) that best model the moisture gain of composites and neat cured polyester in this study. The choice of network was assisted by given consideration to the highest value of correlation coefficient R and lowest value of root mean square error (RMSE). Perfect agreement is achieved when RMSE and R are close to 0.0 and 1.0 respectively (Mehrabi and Pesteei, 2010). Equations 3 and 4 detail the evaluation of the correlation coefficient (R) and root mean square error (RMSE). Other simulation parameters such as net.trainParam.show, net.trainParam.lr, net.trainParam.epochs, net.trainParam.goal were also set to 50, 0.05, 1000 and1e-3 respectively. Throughout the modeling process, 60 % of data were applied for the training stage, 15 % for validation stage and 25 % for testing of selected networks. A mean of five different simulations was reported for each ANN topology investigated due to randomness in ANN network number generator used in creating the initial values for the network weights.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i}^{N}(Q_i - P_i)^2} \tag{3}$$

$$R = \frac{\left[\sum_{i=1}^{N}(Q_i - Q_m)(P_i - P_m)\right]^2}{\sum_{i=1}^{N}(Q_i - Q_m)^2 + (P_i - P_m)^2} \tag{4}$$

Where Q_i is observed and P_i is predicted value. Q_m and P_m represent the average value of observed and predicted values.

7. DISCUSSION OF RESULTS

7.1. Morphology of Treated and Untreated *Momodical* Fiber

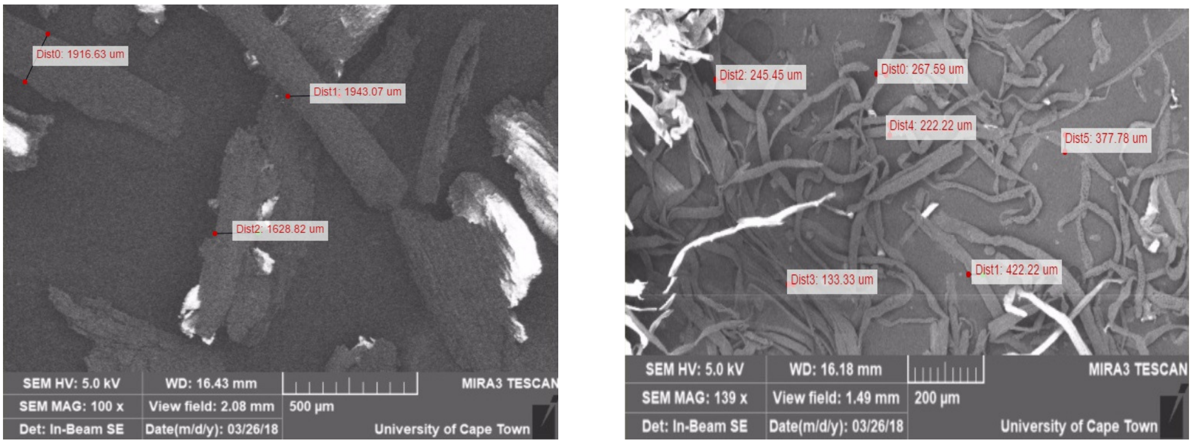
Cellulose is the only useful component of lignocellulose or natural fiber for composite reinforcement. Therefore, for a lignocellulose fiber to be considered as a suitable reinforcement, high yield of cellulose content is desirable. Other considerations may also include the mechanical property. A strong fiber will most likely give a strong reinforcement. The proximate composition of *Momodical* fiber is depicted in Table 1 below.

Table 1 Proximate Composition of *Momodical* Fiber

Proximate	Percentage Composition (%)
Cellulose	29.98
Hemicellulose	14.91
Lignin	8.97

The high cellulose content of *Momodical* natural fiber indicates its potential in giving suitable reinforcement for polymer composite materials development. This cellulose composition is higher than those reported by Oladele *et al.,* (2015) for banana fiber.

Furthermore, the SEM morphology of *Momodical* fiber before and after alkali chemical treatment is presented in Figure 4. Alkali treatment of natural fiber is usually performed to reduce the hydrophilic or moisture absorption properties of the natural fiber. The problem of moisture absorption is due to the inherent nature of lignocellulose resulting from the hydroxyl groups in its structure. Besides, alkali treatment also improves the fiber – matrix interaction in composite as well as thermal property (Poletto *et al.* 2014). Alkali treatment is considered an etching mechanism resulting in removal of organic impurities and exposing higher amount of cellulose (Oza *et al.* 2014). Although other chemical treatment methods also exist, however, alkali treatment seems to be the most adopted fiber treatment method due to its effectiveness, low cost and simplicity.



(a) (b)

Figure 4: SEM Micrograph of (a) Raw/Untreated and (b) Alkali Treated *Momodical* Fiber

Also, the visual observation from the micrograph of raw/untreated *Momodical* fiber in Figure 4a shows that the raw fiber is compact in its natural existence. This is typical of natural fiber because components like lignin and hemicellulose give a strong cementing structure that binds the cellulose together (Osman, 2004). However, because cellulose is bound in the natural fiber structure, alkali treatment is usually applied to remove significant amount of wax, pectin, hemicellulose and lignin, thereby exposing more cellulose that result in increased reaction sites for bonding with polymer (Oza *et al.* 2014). Generally, in alkaline treatment, the cellulose is depolymerized (Mohd *et al.* 2015). This fact is observed in the SEM micrograph of the treated fiber as represented in Figure 4 (b). It is observed that the fibers have lost most of the initial compact structure after alkali treatment and are now separated into layers as can also be confirmed in difference in diameter (represented as distance in the micrograph) of untreated and treated fibers. Treated *Momodical* fibers particles have less diameters compared to raw *Momodical* fiber as shown in the scanning electron micrograph.

7.2. Water Absorption Properties

The result of water absorption by the developed cured *Momodical* fiber reinforced polyester composite is represented in Figure 5. It can be observed from the plot that the water absorption behavior of the composite increased monotonically as a function of fiber volume fraction and immersion time until equilibrium was reached. Neat cured unsaturated polyester shows the least water absorption behavior. This is expected because water absorption in neat polymer can only be attributed to polymer chain swelling. Water absorption behavior of composite on the other hand has contribution from both polymer and natural fiber reinforcement. Daramola *et al.* (2017) also reported an increased water absorption behavior with increased fiber volume fraction in Polyester / Soil Retted Banana fiber (SRBF) composites. The absorption of water in composite despite fiber alkali treatment shows that alkali treatment is not totally sufficient in eliminating the hydrophilic tendencies of fiber. This could be attributed to the fact that alkali treated fiber absorbs moisture due to left-over impurities in the fiber even after treatment. These left over-residues include lignin and hemicellulose content of natural fiber. These impurities may however be reduced further through subsequent bleaching treatment. Carvalho *et al.* (2013) attributed the increase in the water sorption of polymer composites reinforced with vegetable fiber to the hydrophilic nature, capillarity effects and the permeability of this type of reinforcement and also to the sample surface area exposed to water.

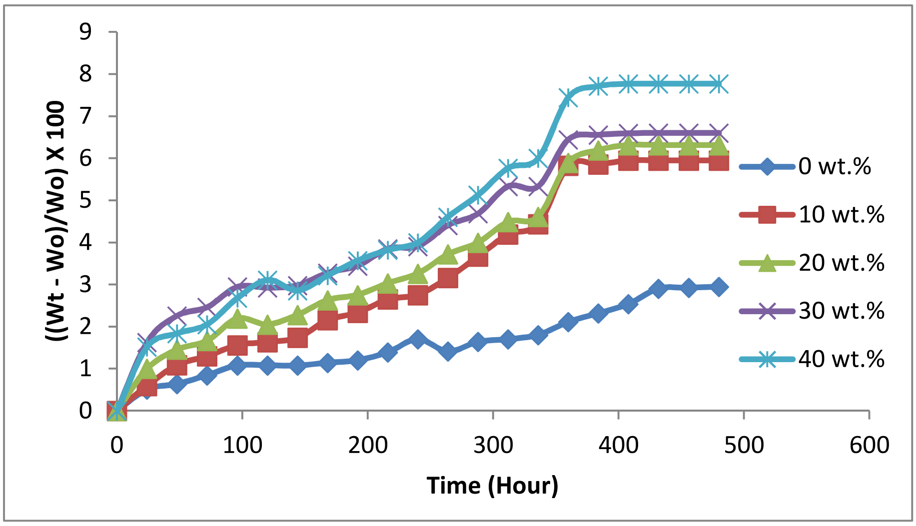


Figure 5: Water Absorption Behavior of Cured neat and *Momodical* Reinforced Polyester Polymer Composite

7.3. Mechanism of water absorption

The result of water absorption mechanism and corresponding diffusion coefficient of cured neat and *Momodical* reinforced polyester polymer composite is summarized in Table 2. These were determined from the shape of the water absorption curves in accordance with the method of Daramola *et al.,* (2017) and also Carvalho *et al.,* (2013).

Table 2: Water transport mechanism of samples of *Momodical* reinforced polyester composite

Sample	*n*	*K*	*D* (m^2s^{-1})	*Diffusion Mechanism*
0 wt.%	0.4701	1.3546	1.98 E – 12	Less Fickian or Fickian
10 wt.%	0.5908	1.776	3.44 E - 12	Anomalous

20 wt.%	0.4641	1.4293	4.52 E - 12	Less Fickian or Fickian
30 wt.%	0.3464	1.0677	5.17 E - 12	Less Fickian or Fickian
40 wt.%	0.4076	1.2912	5.38 E - 12	Less Fickian or Fickian

Also, curve fittings used to determine the water absorption mechanisms and coefficient of diffusion of prepared composites are represented in Figure 6 (a) and (b).

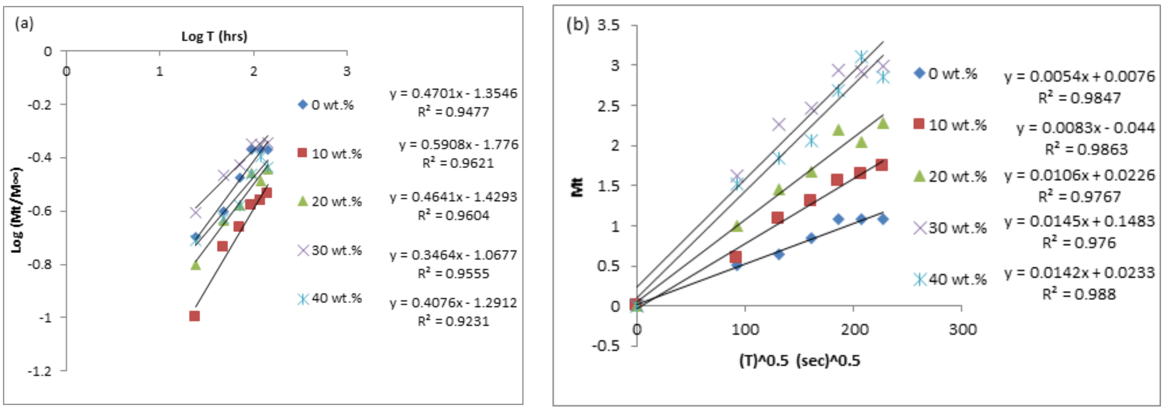


Figure 6: Graphical estimation of diffusivity (a) and mechanism of water absorption (b)

There are three major mechanisms of moisture absorption in natural fiber composites. First, diffusion of water molecules inside the micro gaps between polymer chains; second is the capillary transport of water molecules into the gaps and flaws at the interface between fibers and the polymer due to the incomplete wettability and; finally the third mechanism is the transport of water molecules by micro cracks in the matrix, formed during the compounding process (Osman *et al.,* 2004). It is an established fact that water diffusion behavior of polymer matrix composites obeys Fick's diffusion theory and this was reported to be dependent on the relative mobility of water molecules and polymer segments (Osman *et al.,* 2004; Daramola *et al.,* 2017; Dhakal *et al.,* 2006). Categorically, when the rate of diffusion of water molecules is much lesser than that of the polymer composite segment mobility, it is known as Case I or Fickian diffusion mechanism. For this particular mechanism diffusion exponent value (n) is 0.5 and its independent of time. If the rate of penetrant (water molecules) mobility is much greater than other relaxation processes (polymer segment mobility), Case II or relaxation diffusion mechanism prevails. This diffusion is characterized by the development of a boundary between the swollen outer part and the inner glassy core of the polymer. The boundary advances at a constant velocity and the core diminishes in size until an equilibrium penetrant concentration is reached in whole polymer (Osman *et al.,* 2003). The value of n is greater than 0.5. The range $0.5 < n < 1.0$ indicates case III or anomalous diffusion mechanism and it describes a case where the diffusion and relaxation rates are comparable (Ghasemi and Behzad, 2009). However, when the water penetration rate is much below the polymer chain relaxation rate, it is probable to record the (n) values below 0.5. This situation, which is also classified as Fickian diffusion is commonly referred to as less Fickian behaviour. Also, there are cases where $n > 1$, such case is usually referred to as Super Case II mechanism (Daramola *et al.,* 2017).

As can be deduced in Table 2, the water absorption behaviors are mostly Less Fickian or Fickian except in 10 wt% where the behavior is anomalous. In the Fickian behavior, moisture can penetrate randomly into the materials at atomic scale and using voids inside of the material (free volume) and concentration changes as time increases. There is a minimum required size of free volume for a water molecule to diffuse and to be placed in voids and movements of the molecules are not directed and they are completely free to move in every direction of the void (Brownian motion) (Küçük 2017). However, while diffusion progresses, the speed of diffusion decreases with time and at the end, diffusion stops when the moisture concentration gradient reaches equilibrium. At this point more moisture cannot be absorbed. In anomalous behavior, because both the relaxation and diffusion rate govern the moisture absorption, the water gain by the composite is in the "free" state. Placette and Xuejun, (2011) explains that as more moisture is collected in the compound in anomalous behavior, the diffusion rate is reduced. This is attributed to the fact that as moisture is gained, more molecules are bonded to the polymer chains. This reduces the amount of moisture which can be absorbed in classic diffusion by limiting the space in the nanopores; also, the relaxation rate becomes larger than the diffusion rate and governs the rest of the absorption process.

Also from Table 2, it could be observed that diffusion coefficient is dependent on the volume fibre inclusion ratio. The neat cured polyester showed the least water absorption due to lack of contribution from the fiber. The diffusion coefficient is used to compare the diffusion rate and estimate how much time total moisture saturation of a sample takes, depending on the dimensions (Abacha *et al.,* 2009). The amount of moisture absorption during a specific period of time depends on the diffusion coefficients of the individual component in the plastic/composite. Hemicelluloses are considered to be mainly responsible for the absorption of water, although non-crystalline cellulose and lignin also play an important role in this process (Bezerra *et al.,* 2017). Generally water absorption increases with increasing fiber addition (Rakshit *et al.,* 2015). Similar result was reported by Osman *et al.* (2004).

Apart from contribution of fiber fraction in composite systems, Valcineide *et al.* (2014) noted that the water absorption or uptake of the composites as revealed by the moisture diffusivity may be an indication of difficulties during processing. These difficulties may include incomplete curing of the thermoset matrix or the presence of voids or cracks or even poor matrix / fiber adhesion. The effect of water absorption in lignocellulose reinforced composite is in no way beneficial because when the water molecules are penetrating through a polymer, degradation by the moisture occurs in the material. Plasticization and swelling can also occur due to de-bonding of bonds between polymer chains by moisture. Since voids (spaces between molecules) are getting expanded by water molecule settlement, this leads to a reduction of the interfacial strength of polymer and fiber interaction; in this case, a failure in service is eminent.

The result here shows that despite fiber surface treatment, cured *Momodical* fiber reinforced composites still showed tendencies to absorb moisture when immersed in water. As remarked earlier, this is a common behavior in all fiber reinforced composite which have seriously limited the application of natural fibre reinforced composites to indoor applications. Although, Ghasemi and Behzad, (2009) observed that hybridization of fiber with clay in polymer composite can reduce the water absorption of natural fiber reinforced composites.

It is important is to acknowledge the fact that moisture absorption of composite leads to loss of mechanical properties and dimensional stability (Osman *et al.,* 2004). Therefore, in natural fiber reinforced composite outdoor load bearing purposes, consideration must be given to safety due to moisture absorption tendencies of the material. However, such material can be easily engaged in other outdoor applications where there is no requirement for mechanical strength; and moisture absorption tendency will rather be a merit than demerit like case of desert cooler pad. In desert cooler, the basic job of a pad is to hold water for evaporative cooling mechanism through moisture absorption, moisture drying and moisture reabsorption. Therefore, with the light weight characteristics, insulation and water absorption properties of fiber reinforced composite; an outdoor application in desert cooler pad or built material is recommended due to the recurring moisture absorption property even after fiber treatment.

7.4. Artificial Neural Networks Modeling and Prediction of Moisture ~~Gain~~ Absorption

Investigation concerning modeling and prediction of moisture absorption behavior of cured neat and alkali treated *Momodical* reinforced polyester composites was conducted using a selected 'tansig' 'tansig' 'purelin' transfer function after exhaustive investigation of other transfer function combinations. The effect of topology (number of neuron in the first and second hidden layer) on epoch number, computational speed (Oke *et al.,* 2017) and modeling efficiency was investigated in order to establish best neural networks architecture. Table 3 summarizes the results of the simulation of different ANN topologies.

Table 3: Different ANN Topologies using 'tansig' 'tansig' 'purelin' Transfer Function

S/N	Topology	Epoch Number	Time of Simulation (sec)	R
1	2-1-1-1	149	0.00.08	0.95238
2	2-2-1-1	18	0.00.01	0.97124
3	2-3-1-1	10	0.00.01	0.98361
4	2-4-1-1	1.2	0.00.05	0.9934
5	2-5-1-1	37	0.00.02	0.99484
6	2-1-2-1	11	0.00.01	0.95222
7	2-1-3-1	40	0.00.02	0.95257
8	2-1-4-1	15	0.00.01	0.95264
9	2-1-5-1	25	0.00.02	0.95262

The table shows that the best ANN modeling was observed at a topology of 2-5-1-1 (R = 0.99484) for the selected transfer functions. It can also be observed in Table 3 that the higher the number of first hidden neuron, the higher the efficiency of the networks. The epoch number (which signifies the number of iteration) in the best topology was 37 and the simulation time was two seconds. The closest in this category was topology 2-4-1-1 (R = 0.9934) with a slightly higher time of simulation. The least performance was however observed with topology 2-1-1-1 where the epoch number was the highest at 149 and the computational speed was 8 seconds. For low computational cost and improved accuracy of modeling, topography 2-5-1-1 showed the best performance in modeling and prediction of moisture gain of the cured neat and alkali treated *Momodical* reinforced composites. The performance of the established best topology with root mean square error (RMSE) value of 0.010482 is represented in Figure 7.

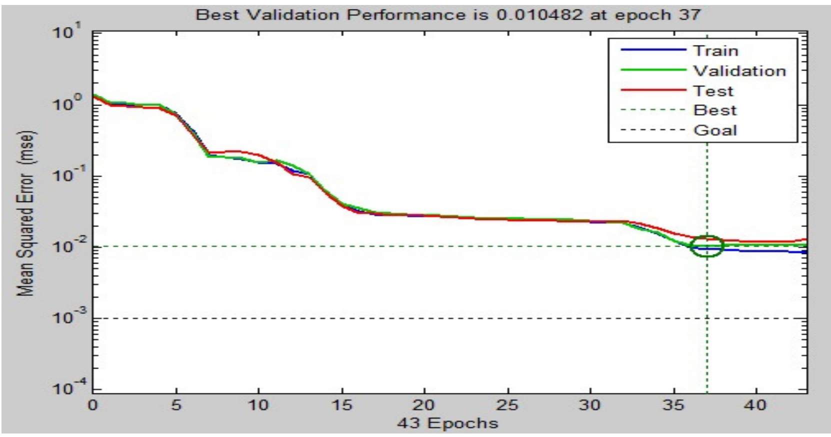


Figure 7 Performance of ANN with 2-5-1-1 topology

Also, the efficiency of best topography in predicting the water absorption process data is represented in Figure 8. The concentration of data points around the parity line proved the high correlation ~~coefficient~~ (R = 0.99484) between the experimental data and ANN predicted data; and the ~~ability~~ suitability of ~~ANN with the~~ ~~chosen~~ the selected transfer function and optimized topology to adequately predict and model the experimental moisture data.

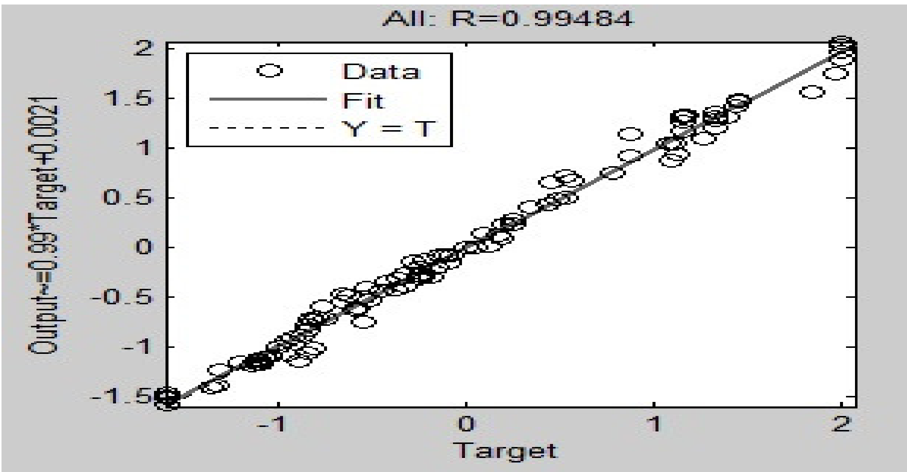


Figure 8 Model Efficiency for 2-5-1-1 Topology

8. CONCLUSION

Water absorption characteristics of polyester matrix composites reinforced with varying weight fractions of *Momodical* fiber have been investigated and water absorption data have been modeled using Artificial Neural Networks. From the results of the investigations the following conclusion can be drawn:

a) *Momodical* fibers can be extracted from *Momodical* plant stems and alkali treatment of the fibers enhanced fiber depolymerisation as a result of removal of hemicellulose, wax and lignin amorphous fiber constituents.

b) Neat polyester would perform better than Polyester/*Momodical* reinforced composites in applications that require long-term exposure to water or humid conditions as the *Momodical* fiber addition led to increase in water absorption in the composites.

c) The mechanism of water absorption process for all the investigated composites cut across less Fickian / Fickian and anomalous (Non-Fickian) behaviour with only composite containing 10 wt.% *Momodical* fiber exhibiting Non-Fickian behaviour.

d) *Momodical* reinforced composites may find applications in desert cooler pad and built material development.

e) Artificial Neural Networks with 2-5-1-1 topology gave the best structure for the modelling of water absorption process of investigated cured neat Polyester and Polyester/*Momodical* fiber composites.

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