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EVALUATION OF TENSILE STRENGTH PARAMETERS OF BANANA POLYESTER COMPOSITES

B.E MEGHA *
Research Scholar, MITE, Moodbidri, India.

B.S KEERTHI GOWDA
Assistant Professor, Department of Civil Engineering VTU CPGS, Mysuru, India.

G.L. EASWARA PRASAD
Guide and Principal, MITE, Moodbidri, India.

Abstract

Usually Composites are manufactured using synthetic Fibers; in recent times natural fibers are deployed in the manufacture of composites since they are economical, locally accessible and bio-degradable. Water absorption by these fibers and weaker bondage between matrix phase and natural fibers results in the reduction of the strength of the composites. Therefore, alkali treatment for these fibers makes modifications on its surface which improve their mechanical properties. In the present study, fabrication of 3 mm and 5 mm thick banana polyester composites is done using compression moulding process to analyse their the tensile strength parameters. Tensile strength characteristics of 5%,10% and 15% NaOH treated banana fiber polyester composites are studied. In the present study of composites, the soaking period of NaOH treatment was adapted from 3 to 15 hours. A decrease in tensile strength was observed as the soaking period was increased. The composites fabricated with 25% Fiber volume fractions with 5% of NaOH treatment for 3 hours of soaking period exhibited peak Tensile Strength. These composites are very much suitable to use as alternative Building Materials, passengers seats in railway coaches and automobile doors. ANN approach provides an alternate solution for prediction of properties by utilizing minimum of experimental data. Hence in the present study, ANN weighted matrix adopted has given good results with low error as compared to experimental results.

Keywords: Natural Fiber, ANN, Material Charcterization, Alkali Treatment, Polymer, Mechanical Strength.

1. INTRODUCTION

In developing countries more emphasis is laid on developing environment friendly materials to address the issues of environmental pollution and reduction of usage of non renewable resources. When farming is completed, the majority of agricultural fibers and wastes are thrown into the ground. In addition to taking up more valuable land, the disposal of this waste depletes energy supplies and pollutes the environment. [1].

The composite material consists of two phases: i) reinforcing phase and ii) matrix phase. Matrix protects the fibers from adverse environmental effects and avoids the buckling of fibers under compressive forces and mechanical erosion [2]. Polymers; also called resins are used as matrix materials in Fiber Reinforced Polymer (FRP) composites. Thermoset polymers are defined as those in which chemical bonds or cross-links join extended molecular chains to form stiff, three-dimensional structures. Thermoset polymers cannot be re-melted by heating and it depicts good thermal stability. In the past years, during the manufacturing of composites, researchers have deployed natural fibers against synthetic fibers [4]. Natural fibers like Jute, areca, bamboo, coir, banana, hemp, sisal, sugarcane bagasse, and elephant grass are used as reinforcing materials for manufacturing composite materials. Fibers play a key role in the composite materials, as the fibers have the capacity of bearing load and providing the desired characteristics. As a result, the fibers in composites are treated with an alkali solution to improve their mechanical properties. Since the fibers are assumed to bear the majority of the loads, they must be strong enough to support the loads. The main factors influencing the properties of composites are the fiber's length, volume, and orientation as well as the interfacial bonding between the fiber and matrix. [5].

Natural fiber-reinforced composites can be used for the rehabilitation of bridges and buildings that are exposed to corrosive or marine weather. Furthermore, structures exposed to a variety of loading scenarios and environmental factors have been built using natural fiber composites [6]. High-performance synthetic fiber composite materials like glass fibers, carbon fibers, and aramids are derived from nonrenewable resources and have a lower biodegradability. Natural fiber reinforced composites are advantageous for the environment and the pocketbook. Natural fiber reinforced composites have a few drawbacks compared to synthetic fiber composites, including a higher water absorption rate of the fibers, low compatibility, and poor bondage between the fiber and matrix. Nevertheless, chemical treatments of natural fibers, such as those with alkali, chloride, or NaOH, can eliminate these shortcomings. Chemical treatment causes natural fibers to become hydrophobic and increase their interfacial bond with resin. As a result, composites reinforced with natural fibers have higher mechanical strength. Chemical treatments with alkali, acetylation, and isocyanides enhance the adhesive qualities of the fiber and matrix and decrease the fiber's absorption of water in the reinforced composites. Natural fibers that have been alkali-treated lose most of their cellulose, hemicelluloses, lignin, and pectins, giving the fibers a rougher surface.[7] The mechanical properties of the fiber are improved and a strong fiber-matrix interfacial bond is created by this rough surface. The process of coalescence between banana fiber and polyester composites yields banana fiber reinforced polyester composites. Tensile characteristics of treated and untreated polyester composites reinforced with banana fibers are examined in the current study. Reviews are given to earlier studies conducted in the area of polyester composites reinforced with natural fiber.

Thakur et al. (2021) [1] examined water absorption at various fiber concentrations. For 7.5% FVF, the ideal tensile strength values were obtained. The study's prepared composites exhibited higher water absorption values when compared to plain resin. In 2021, Ponnusamy et al. [2] studied the water absorption characteristics of sisal, banana, and their hybrid composites made with fiber lengths of 3 mm, 5 mm, and 7 mm. The composites were created via the injection molding process, and the water absorption properties were investigated for 120 days, with six-day intervals, over that time. Comparing banana fibers to sisal fibers (12.4%) and their hybrid (15.4%), banana fibers exhibited higher water absorption values (21.5%). Sakthivel et al. (2021) [3] conducted a comparative study of the tensile and toughness characteristics of banana-glass fiber composites with a thermoset plastic matrix. The hybrid composites had greater values of tensile strength than the individual fibers, according to Taguchi analysis of the composites. Using epoxy as the matrix, Kumar and Raja (2021) [7] investigated the various mechanical properties of untreated and treated banana, coconut, and prosopis-juliflora bark fiber composites. Studies on their morphology demonstrated that the fibers and matrix had been properly combined, and treated samples demonstrated greater strength than untreated ones. The surface modification of the fibers was the cause of the bonding between the fibers and matrix, according to the SEM results. Jordan and Chester (2017) conducted an analysis of the tensile and flexural mechanical characteristics of banana polymeric composite materials. [8] Peroxide and permanganate were used to treat the fibers. While permanganate treatment of fibers had no effect on the mechanical properties of composites, peroxide treatment of fibers increased the strength of composites. Subramanya et al. (2020) reviewed the tensile, flexural, and impact properties of banana-fibre polymeric composites [9]. The vaccum molding technique was used to prepare the composites. When compared to untreated composites, treated composites exhibited higher values for mechanical properties, with the maximum values obtained for FVF of 30%. Gowda et al. (2021) [10] investigated the mechanical qualities, fire resistance, and water absorption capabilities of BRF and PLF fiber reinforced polyester composites. 10% to 40% of FVF was taken into consideration. Values for Young's Modulus were calculated using the Halpin-Tsai model. FVF of 40% and 30%, respectively, for PLF and BRF fiber polyester composites were the maximum values of mechanical properties that were obtained. An analysis was conducted by Prasad et al. (2016) [11] on the impact strength properties of Sisal fiber reinforced composites, both treated and untreated. Composites made by hot compression molding were adopted with thicknesses of 2 mm, 3 mm, 4 mm, 5 mm, and 6 mm. FVF was evaluated from 10% to 30% with an increase of 5%. As composite specimens were made thicker, the impact strength increased. An FVF of 30% resulted in a maximum impact strength of 3.581N-m. Nevertheless, it was found that treating sisal-fibre polyester composites with merely 5% NaOH is insufficient to increase their impact strength. The variation of mechanical properties of banana-fibre composites with PLA and HDPE matrix was investigated by Orrego et al. (2021) [12]. The optimization results were attained for bio-composite materials consisting of 32.05% HDPE, 30% PLA, and 37.95% BF. The influence of symmetrically and asymmetrically woven jute fiber orientation on the mechanical properties of the composites was examined by Bindusara et al. (2018) [13]. Several specimen types were cast at various orientation angles, including 0°, 15°, 30°, 45°, 60°, 75°, and 90°. The study's findings indicated that woven jute-reinforced composites had superior mechanical qualities than composites with randomly distributed fibers, and that the strength of a composite increased with the proportion of layers and angles of fiber orientation. According to Ornaghi et al. (2021) [16], the dynamic mechanical behavior of Sisal and glass hybrid composites in the temperature range of 30 to 210°C was reviewed. The use of ANN and SRM approach was made to forecast the composites' dynamic mechanical properties. ANN is an effective tool for efficiently analyzing polyester composites, according to these results..

Accordingly, tensile properties of polyester composites reinforced with banana fibers are predicted in this study based on two distinct composite specimens with thicknesses of 3 mm and 5 mm. The proportions of composite materials in each specimen vary, with FVF being 5%, 10%, 15%, 20%, 25%, and 30%; NaOH being 5%, 10%, and 15%; and the soaking times being 3 hours, 6 hours, 9 hours, 12 hours, and 15 hours, respectively. Additionally, the accuracy of the required data prediction is tested by using a soft computing technique called artificial neural network (ANN) and the experimental values of these composite test specimens.

2. MATERIALS AND METHODS

2.1 Materials

In this study, LM-556 grade polyesteresin is the matrix adopted, banana fibers are used as the reinforcing material and are treated with an alkali NaOH solution. MEKP is the catalyst and cobalt naphthalene is the hardener (Fig 1). In tropical and subtropical regions, the banana plant is widely available. There are only about 20 species that are used for human consumption out of the 300 that make up the Musaceae family. The fruit, leaves, flower buds, and pseudo stem, among other parts of the plant, can all be used. Generally, only the fruit of the banana plant is used; the fiber portion of the plant is wasted or thrown out as trash [9]. Lightweight and environmentally friendly, this fiber is incredibly strong. Banana fiber densityis 1.4 gm/cc.

Fig 1: (a) Untreated banana fibers (b) Banana fibers treated with NaOH solution

[17]. The physical properties of the banana fiber are shown in table 1.

Table 1: Physical properties of banana fibers [5] [9].

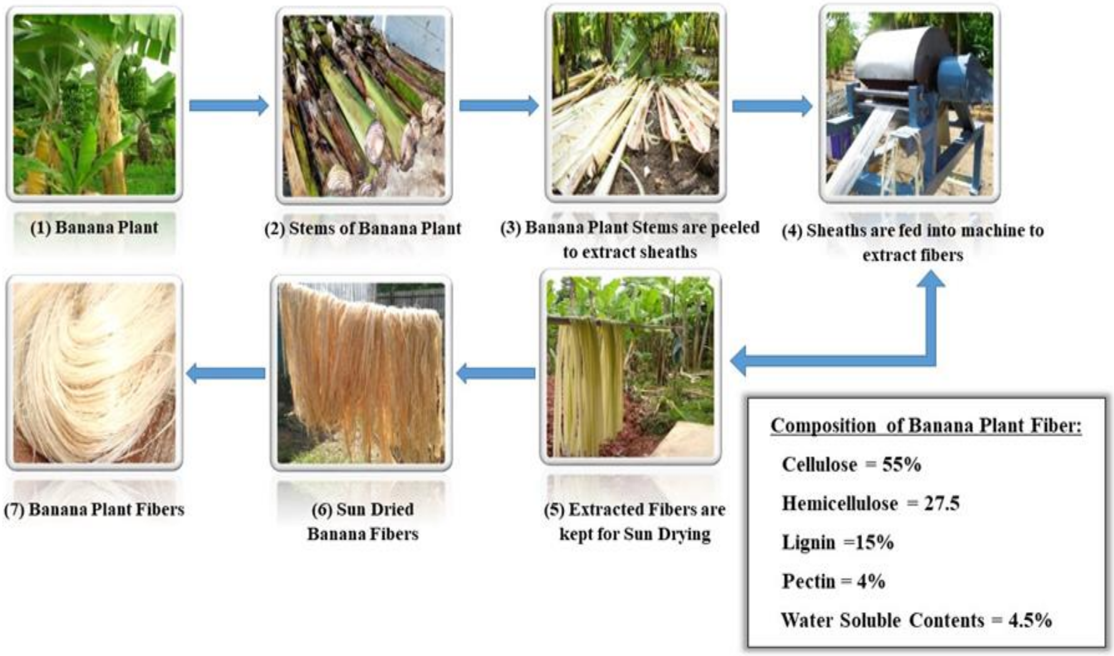
Physical properties	Range
Average diameter (µm)	110-130
Density (gm/cc)	1.4
Tensile strength (MPa)	529-914
Young's modulus (GPa)	27-32
Failure strain (%)	1-3
Specific tensile strength (MPa)	392-67
Specific young's modulus (GPa)	20-24

2.2 Methodology

2.2.1 Extraction of Banana fiber

After harvesting the fruits and leaves, banana fiber can be readily extracted from the pseudostem. From a banana plant's pseudostem, an enormous amount of fiber can be extracted. Made up of closely spaced, overlapping leaf sheaths, the robust, fleshy pseudostem resembles a trunk. Cut at the base of the pseudostems. The moment the pseudo-stem's leaves are trimmed, the extraction procedure begins. With a decorticator machine, the fiber is mechanically extracted. Banana fiber resembles ramie and bamboo fiber in appearance.In addition, the fiber from bananas can be readily obtained and extracted through various methods such as manual scraping, chemical retting, or mechanical raspador machines. Figure 2 depicts the process of removing banana fibers. Water retting and scraping is a commonly employed technique for fiber extraction. The pseudostems of banana plants are peeled into sheaths, which are then fed into a machine called a raspedor to extract the fibers. Following a thorough cleaning and water wash, the extracted fibers are stored to dry in the sun. The fibers that are extracted from the bunch (knot) isolating machine are cleaned, and they can either be dried in a hot air oven for 10 hours at 60 degrees or by washing them and drying them in the daytime. A lignocellulosic fiber, banana fibers are hydrophilic and do not withstand high moisture content as much. A chemical treatment of the fibers has been performed, and various surface modifications of the natural fibers are needed to get around these restrictions and solve the high water absorption issue. Sodium hydroxide/aqua solution was used to store the cleaned fiber after cleaning. Sodium hypochlorite/aqua solution was used to bleach it following alkaline treatment, and acetic acid was added as a final treatment [17]. Following chemical treatment, banana fiber was repeatedly washed with water to get rid of any debris that might have gotten on its surface. Following cleaning, the fiber was maintained for four hours at 600 degrees Celsius in a hot oven. The lignin content of the fiber was eliminated by bleaching and acetic treatment, which also strengthened the crystalline structure. The purpose of keeping collected fibers in the sun was to dry out any moisture before they were carefully combed. These combed fibers have been chopped to a length of 10 mm. In order to transmit load between broken fibers and maintain a tight hold on the fibers, the matrix is crucial to composite materials. Moreover, it serves as a shield to keep fibers safe from dangerous conditions. Due to its low cost and lightweight nature compared to other options, polyester resin was chosen as the matrix material for this study. A thermosetting polymer with a density of 1.10 gm/cc and a high viscosity, polyester resin of grade LM-

556, is used. Pragati Industries, a company based in Mysore, Karnataka, supplied the polyester resin.The catalyst utilized in this process was Methyl Ethyl Ketone Peroxide (MEKP), and the hardener, cobalt naphthenate, is a transparent fluid with a lower viscosity than polyester resin.



Composition of Banana Plant Fiber:

Cellulose = 55%

Hemicellulose = 27.5

Lignin =15%

Pectin = 4%

Water Soluble Contents = 4.5%

2.2.2 Fabrication of composites

In this work, laminates with thicknesses of 3 mm and 5 mm are made using 10 mm banana fibers, both treated and untreated. NaOH alkali solution was used to treat the banana fibers for varying lengths of time—3, 6, 9, 12, and 15 hours. A range of FVFs is available: 5%, 10%, 15%, 20%, 25%, and 30%. The process of hot compression molding was used to create composite samples. Using a thickness gauge, the mild steel molds measuring 300 mm by 300 mm by 3 mm and 300 mm by 300 mm by 5 mm were thoroughly cleaned. For the fabrication of the specimens, specimen molds with thicknesses of 3 and 5 mm are employed. Preheating to 82°C is done on the compression moulding machine. A mixture of 10 mm banana fibers and polyester matrix is pressed between the non-stick sheets on top and bottom. The matrix is prepared by using Cobalt Naphthenate and Methyl Ethyl Ketone Peroxide (MEKP) as catalysts and hardeners, respectively. Just before pouring the resin over the fiber, it was thoroughly mixed and combined with the hardener and catalyst in a 100:1:1 ratio. The banana fibers are uniformly distributed within the specimen mold. It is then put on the compression molding machine's lower plate. The upper plate is then lowered using a jack system to the top of the specimen mold and appropriately locked after the stirred mixture of polyester resin, catalyst, and hardener is evenly poured over the fibers in the specimen mold and covered with a plastic sheet. The polyester matrix mixture and fibers are laid out with two nonsticky sheets, one at the top and one at the bottom. About 20 minutes pass while the temperature stays at 82 °C. The desired composite specimens were then cut from the cast composite panels after the specimen mold was taken out of the plates, the composite specimen was unmolded, and it was allowed to cure for 24 hours at room temperature.

2.3 Tensile Strength Test

Tensile strength tests were conducted on composite specimens of FVF at 10%, 15%, 20%, 25%, and 30% in the current study, in accordance with ASTM D-3039 standards. After the composite specimen is ready, a professional cutting machine is used to cut it to the necessary dimensions in accordance with ASTM standards. For the test, specimens measuring 250 mm by 25 mm were utilized. The thickness of the test specimen ranged from 3 to 5 mm. In a computerized Universal Testing Machine (UTM) with a 50kN capacity, tensile strength tests were conducted. After inserting the test specimens into the machine's jaws, the tension load was applied axially through the ends at a crosshead speed of 2 mm/min until the specimen failed. The tensile strength averages are determined. Tensile characteristics of banana-fiber reinforced polyester composites are forecasted in the review for two distinct composite specimens with thicknesses of 3 mm and 5 mm. The proportions of composite materials in each specimen vary, with FVF being 5%, 10%, 15%, 20%, 25%, and 30%; NaOH being 5%, 10%, and 15%; and the soaking times being 3 hours, 6 hours, 9 hours, 12 hours, and 15 hours, respectively. The necessary data is also predicted by a soft computing ANN using the experimental values of these composite test specimens, and the accuracy is verified.

2.4 Artificial Neural Network (ANN)

An artificial neural network (ANN) is a machine learning process that belongs to the artificial intelligence family. A neural network is made up of neurons that are connected to one another. Neural networks function similarly to neurons in the brain, which is why they are similar to biological neural networks. Since the ANN model doesn't require a mathematical relationship between variables, it can be applied to a wide range of engineering problems. The fundamental method for creating a material behavior model based on neural networks is to train a neural network using the outcomes of a sequence of experiments. The term "topology," which represents the neurons in the input layer, hidden layer, and output layer of a general computational artificial neural network (ANN) model, is used (fig 3). Regardless, the input layer and output layer neurons are dependent on the problem domain's uncertainty. The present study predicts the tensile parameters of polyester composites reinforced with banana fibers, both treated and untreated, using the ANN model. The data is reviewed, network training, testing, and validation are carried out, and the output values that are produced are compared with experimental data [15].A database of input data was gathered through experimental research, and after the model had been trained and evaluated, it was applied to forecast or predict the experimental data. The training and testing of ANNs was used to determine the ideal weighed matrix, which then predicts the tensile strength.

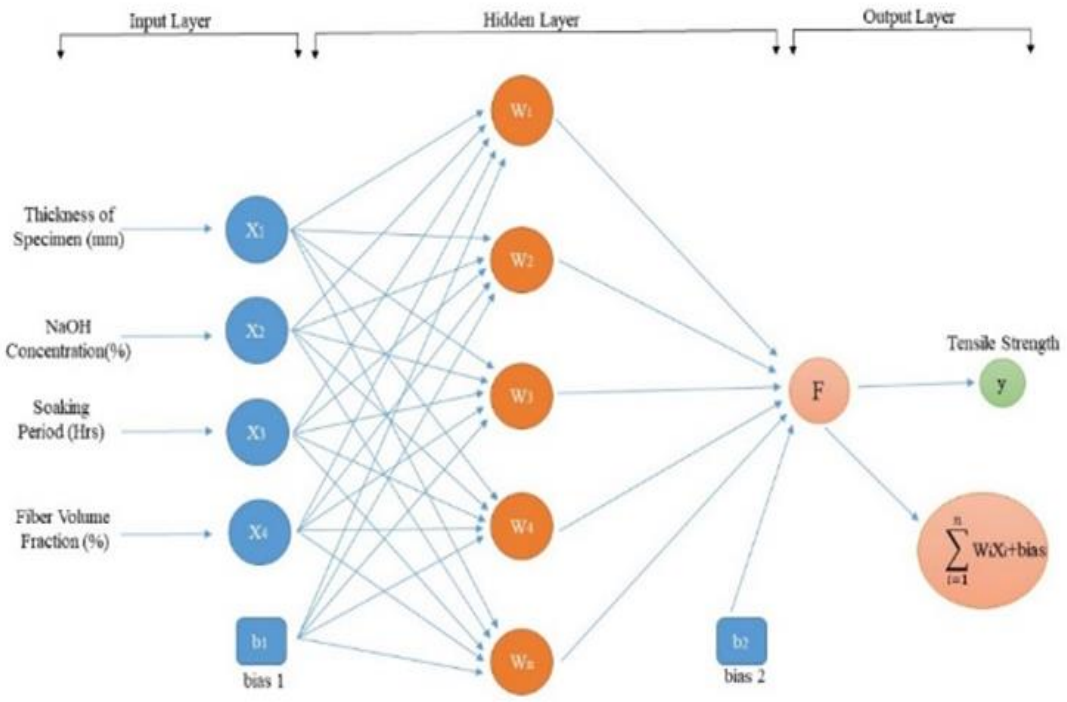


Fig 3: Illustration of an ANN containing the input, hidden, and output layers.

The ANN process starts with the input layer, goes through the middle hidden layer, and ends with the output layer, as illustrated in Figure 3. The ANN model that was proposed required four input factors: the thickness of the specimen, the NaOH concentration, the Fiber Volume Fraction, and the Soaking Period. Accordingly, in the current investigation, an artificial neural network has four input layers: the input layer, which has four parameters: the thickness of the specimens, which is 3 mm and 5 mm; the NaOH concentrations, which are 5%, 10%, and 15%; the Soaking periods, which are 3 hours, 6 hours, 9 hours, 12 hours, and 15 hours; and the FVF, which is 5%, 10%, 15%, 25%, and 30%, respectively. The second hidden layer is made up of a number of hidden neurons that depend upon the quantity of input parameters, the output parameters, and the accuracy of the results.

2.5 Model accuracy and Performance evaluation

Regression coefficient R2, Mean Squared Error (MSE), root mean square error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE) are used to assess the accuracy and performance of the ANN model. These can be found, respectively, in equations 1, 2, and 3. Reference [14] Aggregations of the magnitude of the errors in the ANN predictions are represented by the MSE and RMSE. Reference [14] The average squared difference (MSE) between the experimental and predicted values of the artificial neural network (ANN) is defined as follows. The MSE and RMSE are typically positive values.

The ANN model's predictive accuracy increases with decreasing values. The correlation that an artificial neural network (ANN) predicts is displayed by the variance of the experimental variables, or R2 [16]. It demonstrates the degree to which the ANN's predicted results accurately reflected the variability of the experimental results. It has a value between 0 and 1, and the closer it is to the upper threshold, if the value is 1, the more accurate ANN model is created. The following learning parameters were used during the supervised training of the models: one hidden layer, 2000 epoch limit, 13 hidden neurons, 0.5 learning rate, unipolar sigmoid activation function, linear transfer function, Levenberg–Marquardt algorithm. [15]

Mean Square Error (MSE), Correlation Coefficient (R), and Mean Absolute Percentage Error (MAPE) are commonly used metrics to evaluate the built ANN Model's performance. The term "mean absolute error" (MAE) refers to the average error between predicted and actual data. Predicting the developed model's accuracy is done with the correlation coefficient. In general, the value of "R" ranges from -1 to 1. In cases where the "R" value is close to unity, an accurate output prediction can be obtained. The mean percentage error (MAPE) between the expected and experimental outputs is measured. Equations 1 through 4 represent the statistical parameters used to evaluate the developed model.

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}\left(\mathrm{X}_{\mathrm{predicted}} - \mathrm{X}_{\mathrm{experimenta}}\right)^2 \tag{1}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(X_{\mathrm{predicted}} - \mathrm{X}_{\mathrm{experimental}}\right)^2}{n}} \tag{2}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(X_{\mathrm{experimental}} - \mathrm{X}_{\mathrm{predicted}}\right)^2}{\sum_{i=1}^{n}\left(X_{\mathrm{experimental}} - \mathrm{X}_{\mathrm{average}}\right)^2} \tag{3}$$

where n is the number of data that are used in the statistical analysis.

3. RESULT AND DISCUSSIONS

3.1 Tensile Strength Properties of untreated banana fiber reinforced polyester composites

This section discusses the tensile strength characteristics for 3mm and 5mm thick specimens of untreated banana-fiber reinforced polyester composites for 5%, 10%, 15%, 20%, 25%, and 30% FVF.

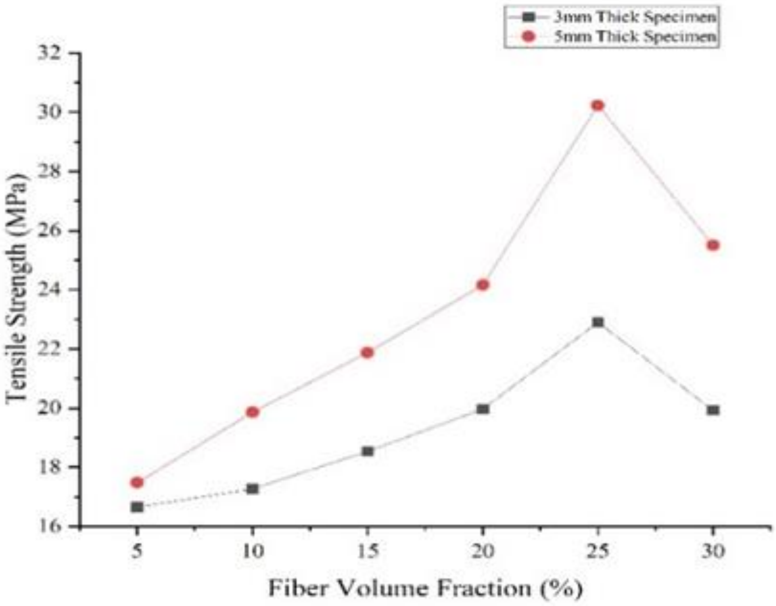


Fig 4: Tensile strength of 3mm and 5mm treated banana fiber polyester composite

A 50 kN Universal Testing Machine was used to test the composite specimens. When specimen thickness increases, the tensile strength increases as well. Figure 4 illustrates the maximum tensile strength values of 22.91 MPa and 30.23 MPa, respectively, that were achieved at 25% FVF for composite specimens that were 3 mm and 5 mm thick.

3.2 Tensile Strength Properties of treated Banana fiber reinforced polyester composites

Figures 5 and 6 depict the tensile strength characteristics of 3 mm and 5 mm thick Polyester composites reinforced with banana fiber and treated with 5%, 10%, and 15% NaOH at soaking times of 3, 6, 9, 12, and 15 hours, respectively. FVFs are varied for 5%, 10%, 15%, 20%, 25%, and 30% in this instance. The best tensile strengths of 29.19 MPa and 31.82 MPa, respectively, were recorded for these 3mm and 5mm thick 25% FVF coupons after a 3-hour soaking period. Tensile strength decreased with further increases in NaOH concentration in SP and FVF.

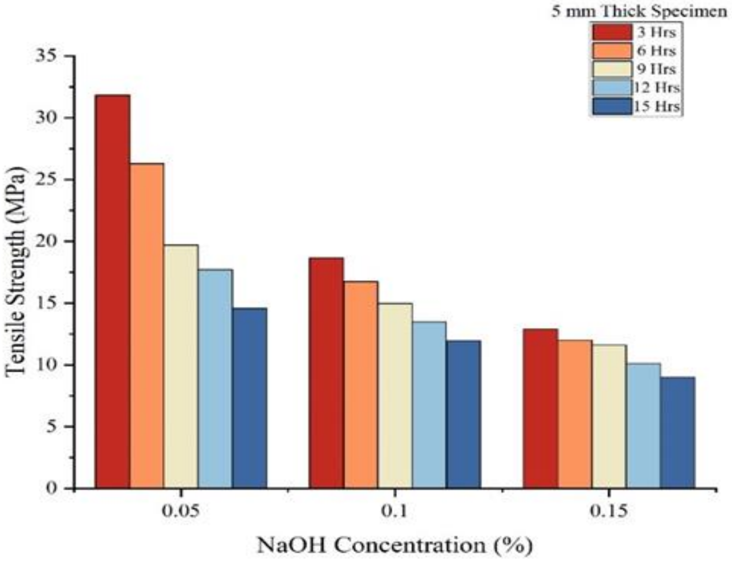


Fig 5: Tensile Strength of 3mm thick treated banana fiber reinforced polyester composite

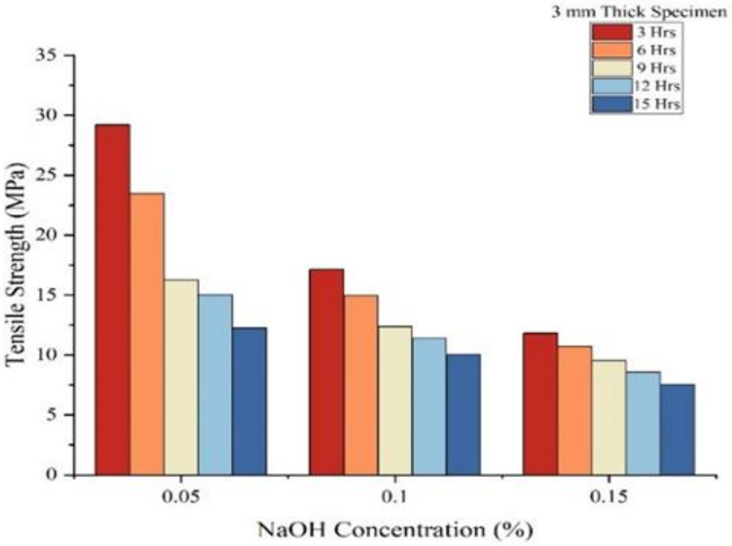


Fig 6: Tensile strength of 5mm thick treated banana fiber reinforced polyester composite

When treated for three hours in a 5% NaOH solution, a 3mm thick banana fiber reinforced polyester composite specimen yielded a maximum tensile strength value of 29.19 MPa, which is 27.41% higher than an untreated banana specimen. Comparing the 5mm thick composite specimen to the 3mm thick banana fiber reinforced polyester composite, similar types of variations are seen. After being soaked for three hours in a 5% NaOH alkali solution, a 5 mm thick banana fiber reinforced polyester composite specimen achieved a maximum tensile strength of 31.82 MPa, which is 5.26% greater than the untreated banana specimen.

3.3 ANN Modelling

Figure 7 shows the flow of the process for creating the ANN model.

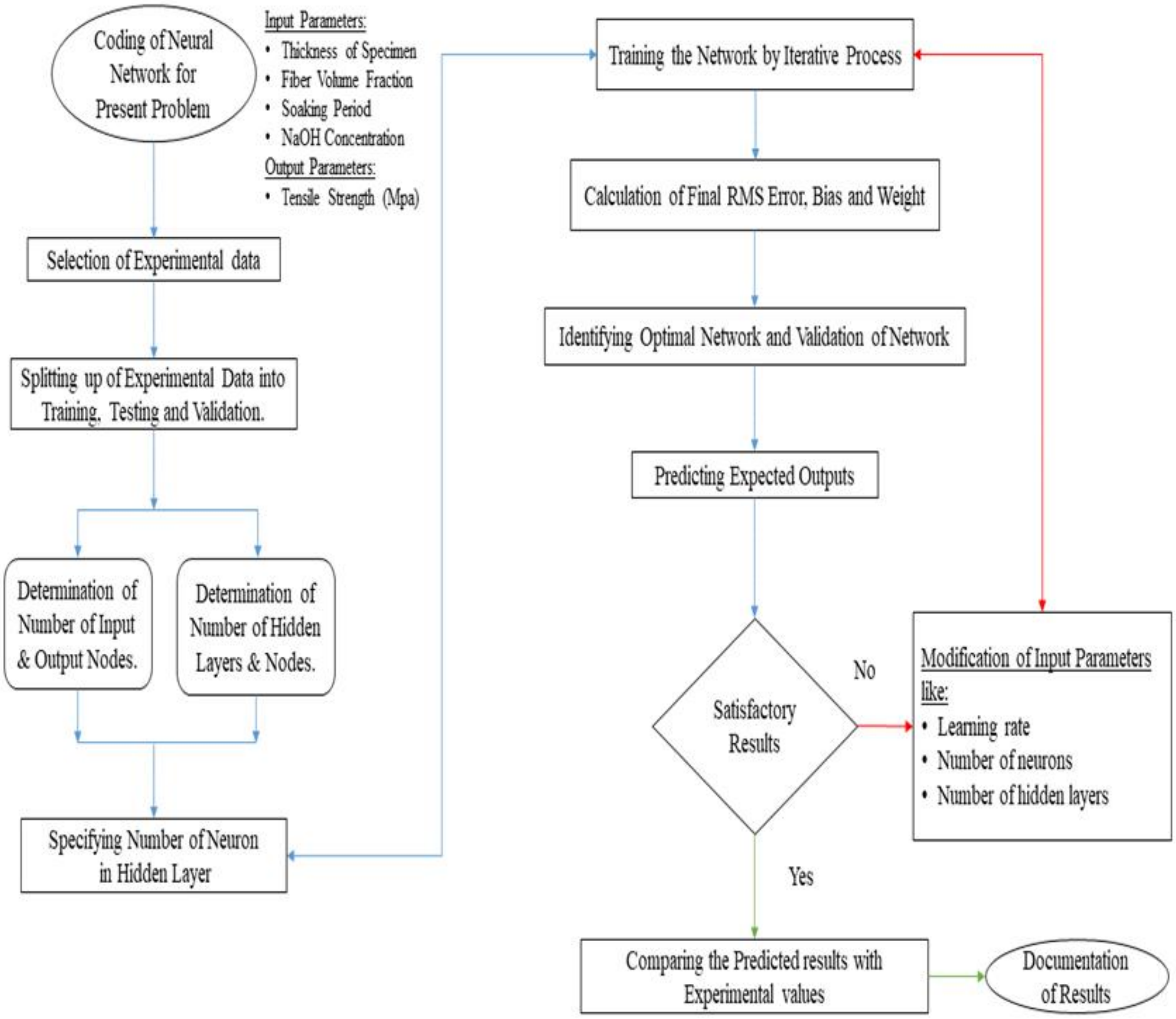


Fig 7: Schematic representation of ANN prediction process

3.3.1 Input values

This study establishes a soft computing procedure to predict the tensile properties of banana fiber reinforced polyester composites by training an artificial neural network (ANN). The experimentation conducted in this study provided the input data. The values were separated into distinct data sets for the model's training, testing, and validation after all experimental values were tabulated and chosen at random.

The input parameters include the specimen thickness (3 mm and 5 mm), the NaOH concentrations (5%, 10%, and 15%), the soaking time (3 hours, 6 hours, 9 hours, 12 hours, and 15 hours), and the FVF (5%, 10%, 15%, 20%, 25%, and 30%). The specimens with thicknesses of 3 mm and 5 mm, as depicted in Figure 8, have identical input parameters. In this article, the tensile strength characteristics of banana fiber reinforced polyester composites, both treated and untreated, are displayed on a ternary graph with NaOH concentrations, soaking times, and FVF represented at the vertices.

Out of the 180 experimental data, 164 are used to train the ANN model and 16 are used for testing and validation in the prediction process. In the hidden layer, thirteen neurons are used, and the output is the desired tensile strength. Until the best fit output data is obtained, with the least amount of error between the experimental and predicted data, the number of hidden neurons is varied in order to determine the optimal hidden neuron count. The NaOH concentrations, soaking times, FVF, and corresponding tensile strengths of each shape on the ternary graph are representative of the various conditions. Whereas the hollow shape represents other tensile strength values, the solid shape represents the maximum tensile strength values for 25% FVF. Take a look at a necessary point on the graph to gain an understanding. Consider, for instance, a point with a solid rectangular shape that stands for 25% FVF, 5% NaOH concentration, and 3 hours of soaking time. The graph's other points are all understood in a similar way.

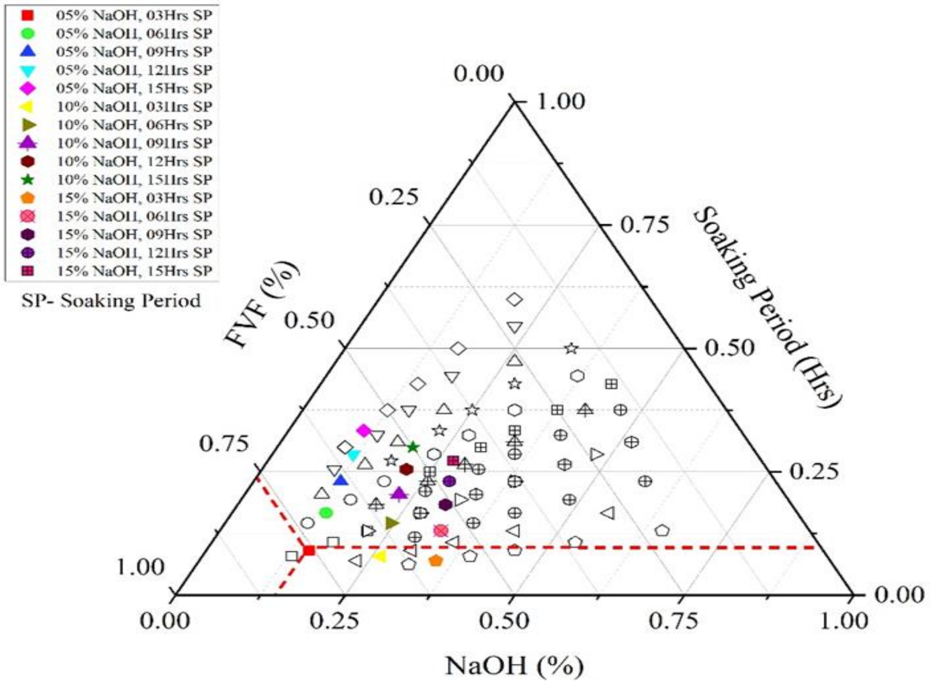


Fig 8: Ternary plots showing tensile strength values of banana fiber reinforced polyester composite

3.3.2 ANN Architecture

Topology, node characteristics, and training or learning rules define ANN models. ANN models can be broadly divided into two categories: supervised and unsupervised. When learning, both the input and the output patterns are known in supervised learning environments. In this study, the experimental values of the tensile strength properties of the polyester composite reinforced with banana fiber are taken into consideration, and a feed-forward supervised artificial neural network (ANN) model is utilized for value prediction.

The number of hidden layers, the error goal, the learning rate, and the number of iterations (epoch) are the training parameters. The ideal training parameters are adjusted by optimizing these parameters until the ANN training converges. The testing and validation procedures make use of these ideal parameters.

Based on the model's performance during the network's training, the architecture of the artificial neural network is determined. Throughout the training process, the number of neurons and hidden layers is fixed. The Levenberg-Marquardt (LM) algorithm is used in this case. When the required accuracy is attained, the training must end because it is an iterative process.

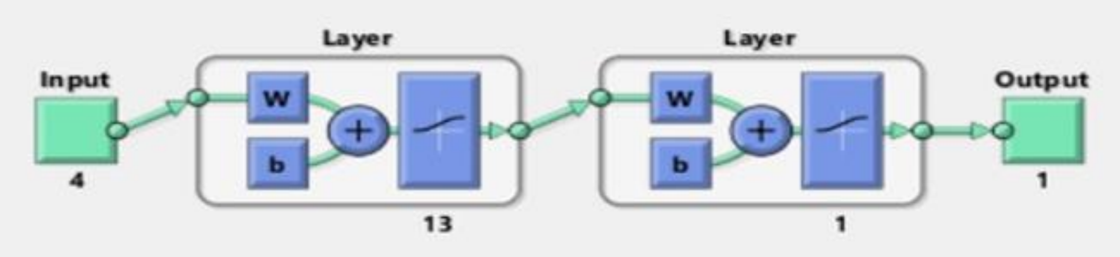
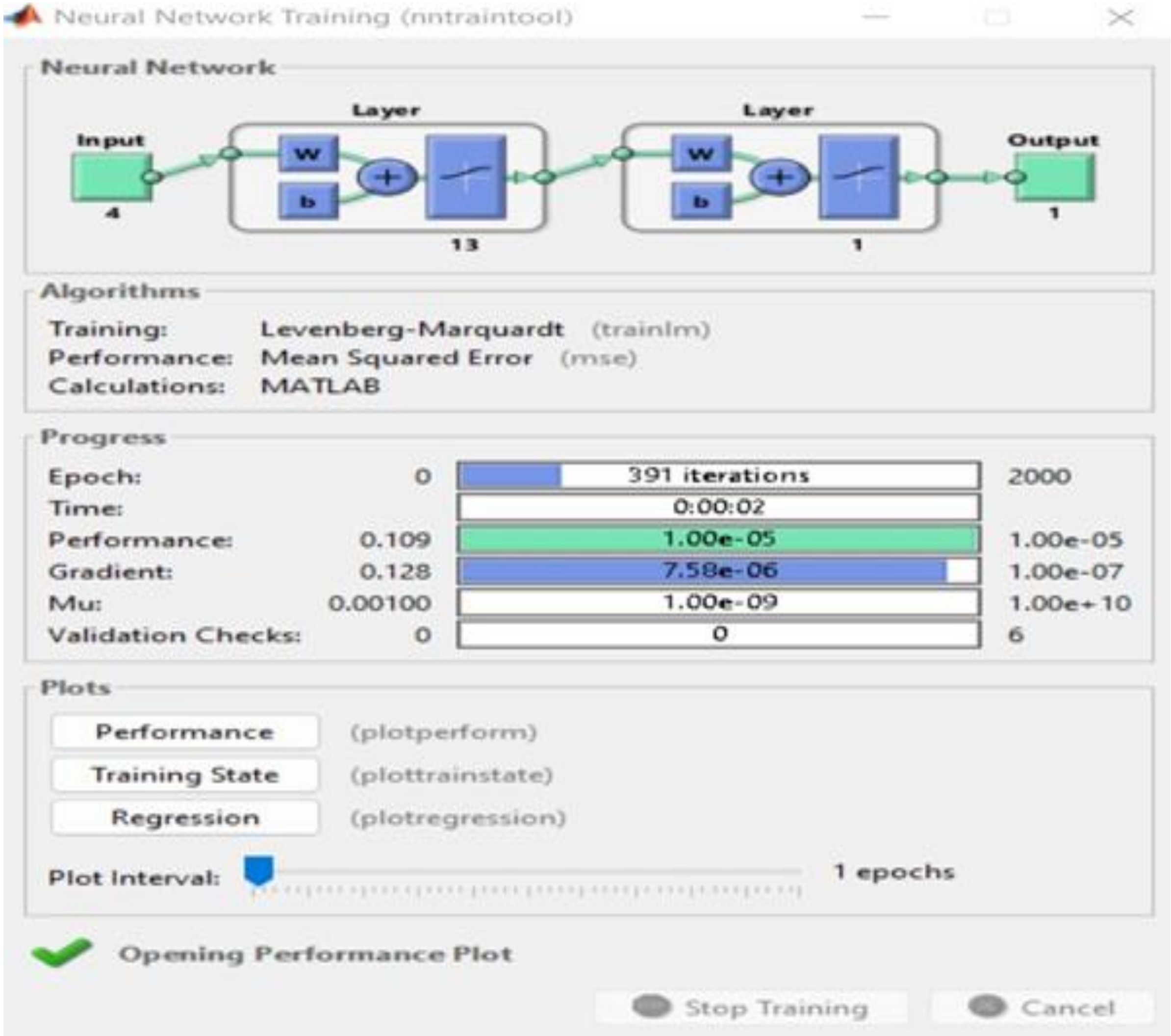


Fig 9: Network architecture developed by ANN model

There are four inputs in the ANN model, thirteen neurons in the hidden layer, and one neuron in the output layer. Consequently, as illustrated in figure 9, the network architecture of the developed model is represented as a 4-13-1model. When the least amount of error is made, training ends automatically. For the purpose of this study, the optimal performance in the 9.98x10-06 MSE range is obtained by stopping the training process at the 391st epoch. Figures 11 through 14 plot and display the confusion matrix, receiver operator characteristics plot, performance diagram, error histogram, and training performance diagram for each neural network.



Training: Levenberg-Marquardt (trainlm)
Performance: Mean Squared Error (mse)
Calculations: MATLAB

Epoch:	0	391 iterations	2000
Time:		0:00:02	
Performance:	0.109	1.00e-05	1.00e-05
Gradient:	0.128	7.58e-06	1.00e-07
Mu:	0.00100	1.00e-09	1.00e+10
Validation Checks:	0	0	6

✓ Opening Performance Plot

Fig 10: ANN topology for training tensile testing data

The performance plot, which illustrates the errors in the developed model, is a graph based on the correlation between target and predicted values. The MSE values are shown at each epoch in the performance plot until the target performance or best performance is achieved. The best performance of the developed model is indicated by a gradual decrease in the curve.

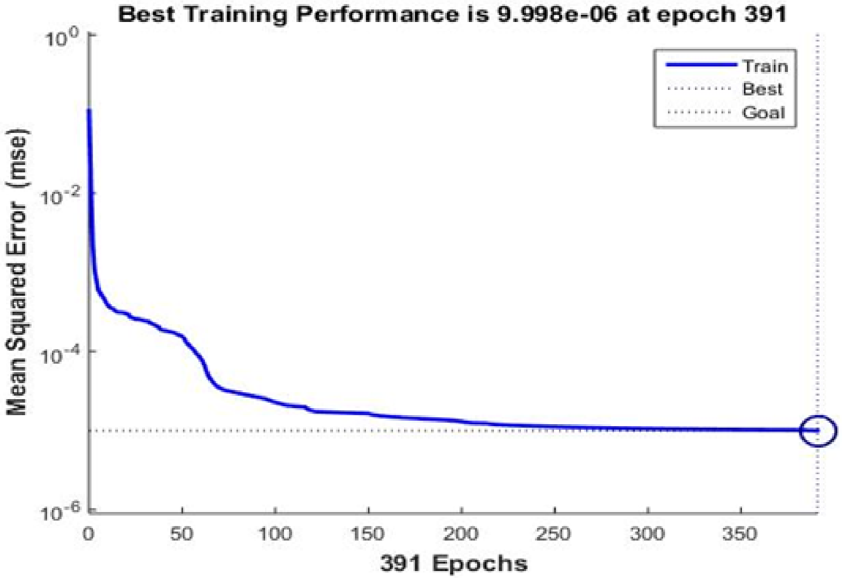


Fig 11: Performance plot for testing ANN network

The training data set's regression graph is shown in fig 12. The data generated by the developed model exhibits improved correlation. Through the ANN network's training process, the correlation coefficient of 0.99951 is obtained. Given that it is much closer to unity, the developed model predicts outputs that are extremely similar to the real values. After testing to interpret the new data sets, the developed model—which has greater accuracy—is finalized.

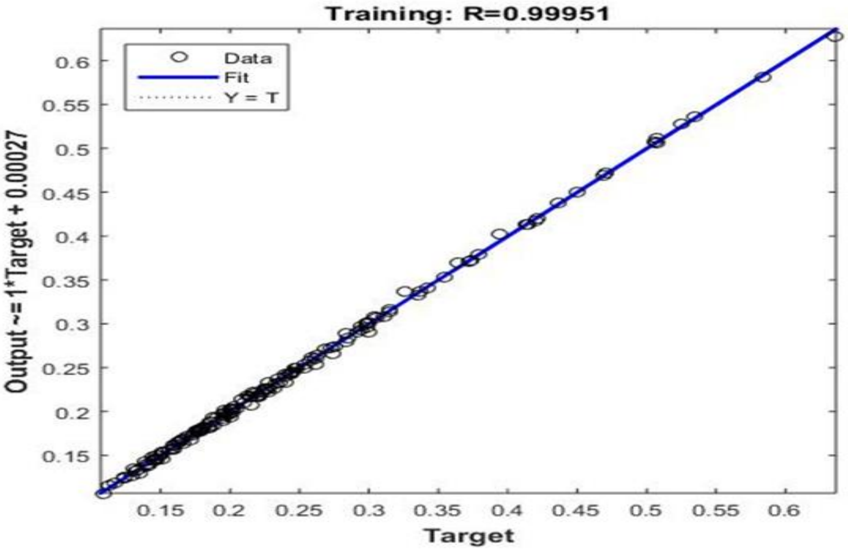


Fig 12: Regression plot for training data set

The created model underwent training until desired outcomes were attained. Based on the lowest mean square error (MSE) and highest R-squared value, the optimal model was chosen.

The trained artificial neural network model's predictive performance is significantly influenced by the number of hidden layers and hidden neurons.

When the model meets its objectives, produces positive outcomes, and displays fewer MSE values with a correlation coefficient that is closer to unity, it should be tested and validated using additional sets of values that were not used during the training phase. The model's suitability for the current data sets is determined by this process. Approximately sixteen data sets are tested in this research project. During the training process, these are kept apart. Thus, in order to compare the experimental procedure with the ANN model, this becomes the new data set that the developed model was supposed to predict. Figure 13 displays the testing process' regression plot. By comparing the developed model with the real data set, the outputs are predicted with accuracy. For the real experimental testing data sets and the predicted data sets, a correlation coefficient of 0.99908 is found.

3.3.3 Testing and validation

After the model satisfies the necessary training parameters and shows reduced mean square errors (MSSE) with a correlation coefficient that is closer to unity, it should be examined and verified on additional data sets that were not utilized in the training phase. The actual effective model that best fits the current data set domain is determined by this process. About sixteen data sets were tested in the current study. In order to compare the theoretical process with the soft computing techniques, it functions as a set of new data sets that will be obtained from the developed model. The testing process' regression plot is displayed in Fig. 13. By comparing the developed model with real data sets, the outputs are accurately predicted. For testing data sets, the correlation coefficient is found to be 0.99812.

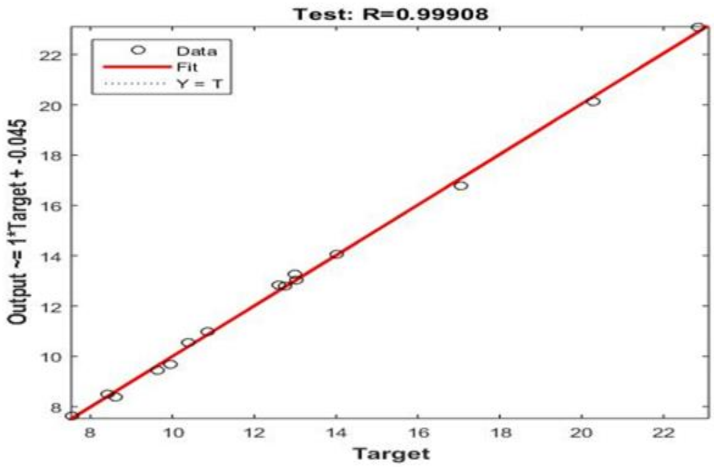


Fig 13: Regression plot for testing data

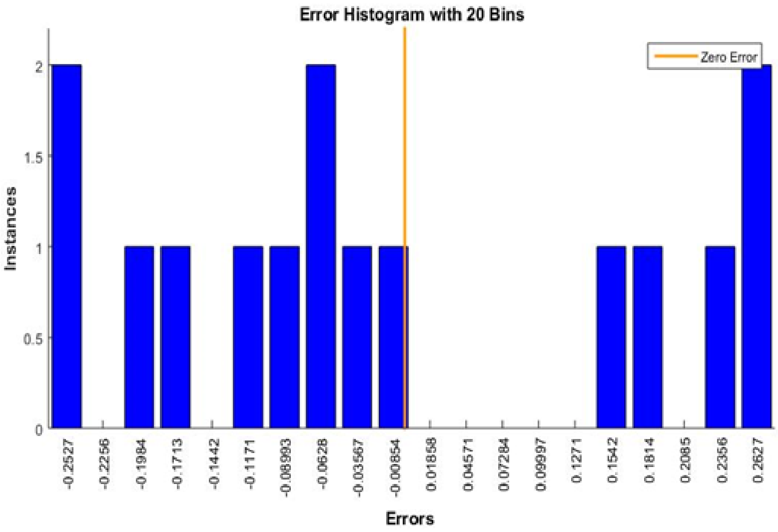


Fig 14: Error histogram

An error histogram is a graphical representation of the number of samples distributed into distinct bins. Figure 14 displays a histogram graph that plots the error that the ANN model produced for the actual experimental values and the predicted values. The centerline denotes the zero coordinate axis, and all of the errors included in this study are categorized into 20 bins. Because the maximum errors are much closer to zero, the model can predict the values more accurately. The training data set's mean square error (MSE) between experimental and predicted values is

9.98x10^{-06} while for the testing data sets, it is 3.336x10^{-06}. For the training and testing sets of data, the coefficient of correlation (R2) is 0.99951 and 0.99908, respectively. For training and testing, the corresponding mean absolute percentage errors are 1.35 and 1.15, and the corresponding mean absolute errors (MAE) are 0.160929 and 0.122618. Since the absolute errors in this case are less than 2%, it can be said that the developed model predicts the outputs with 98% accuracy.

3.4 Model output results

The maximal tensile strength values of the experimental and ANN predicted values for 3 mm thick treated banana fiber reinforced polyester composite specimens are displayed in the ternary diagram in Figure 15(a), and Figure 15(b) shows the maximum absolute error between the experimental and predicted values. With respect to the maximum experimental values and predicted values, which are indicated without and with parenthesis, respectively, the composite specimens with varying concentrations of NaOH and soaking periods at 25% FVF display said values. There is a maximum error of less than 4% in tensile strength prediction for a composite specimen that is 3 mm thick.

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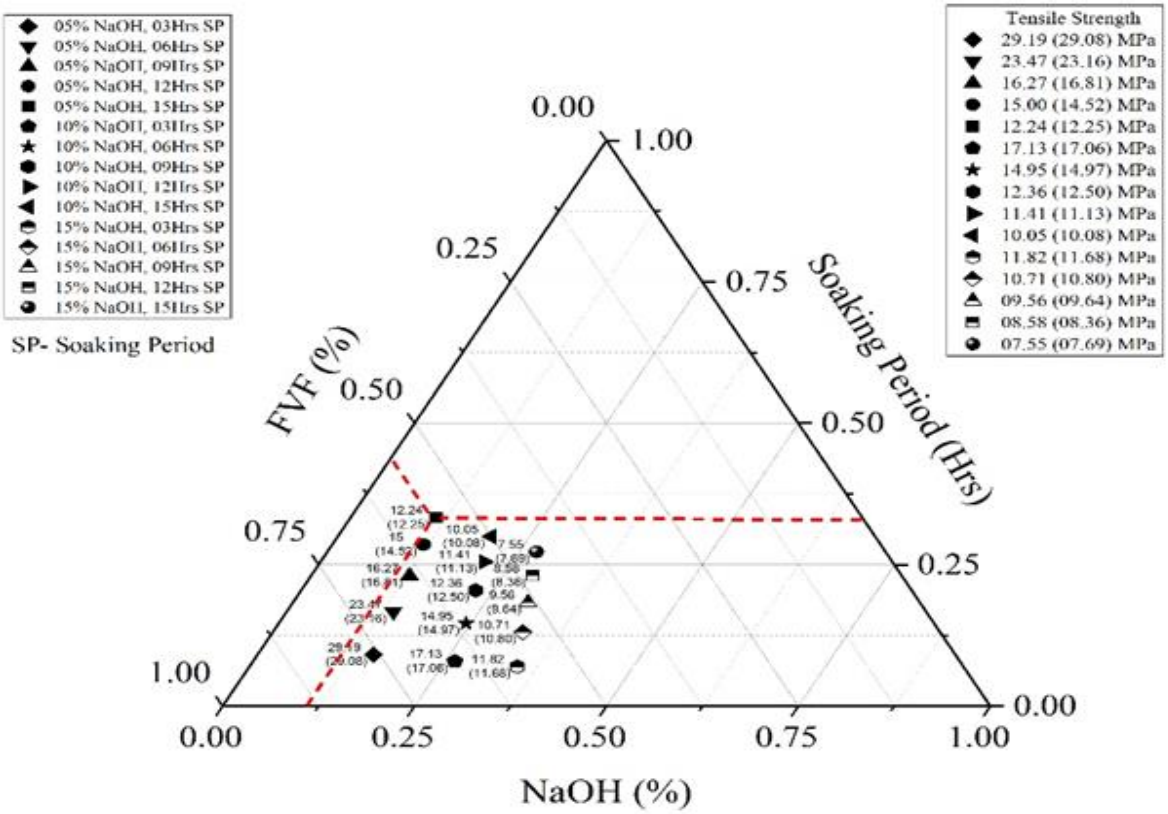
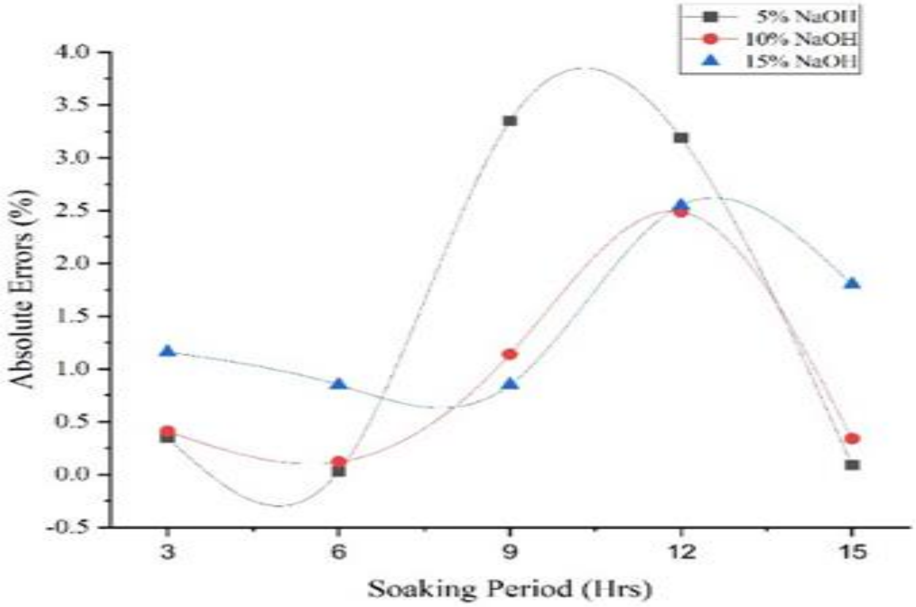
Similarly, the ternary diagram in Figure 16(a) represents the maximum tensile strength values of the experimental and ANN predicted values for 5mm thick treated banana fiber reinforced polyester composite specimens, while Figure 16(b) shows the maximum absolute error between the experimental and predicted values. The composite specimens demonstrate the maximum experimental values and predicted values, which are represented without and with parenthesis, respectively, at 25% FVF and with varying concentrations of NaOH. The maximum error involved in predicting the tensile strength for a composite specimen with a thickness of 5 mm is less than 2.5 %. The experimental and predicted values for the 3 mm and 5 mm thick NaOH treated banana fiber reinforced polyester composites are almost closer to one another. Consequently, it is acknowledged that the developed model is a reliable predictor of tensile strength characteristics.

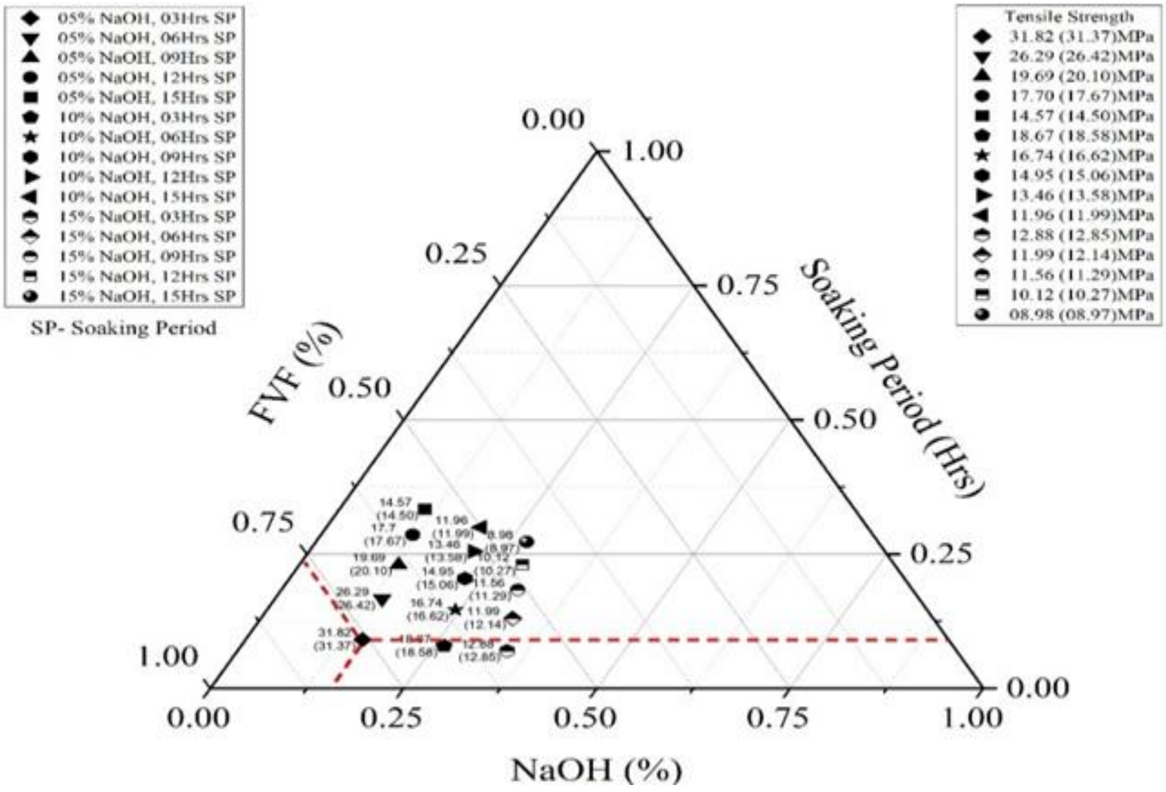


(a)

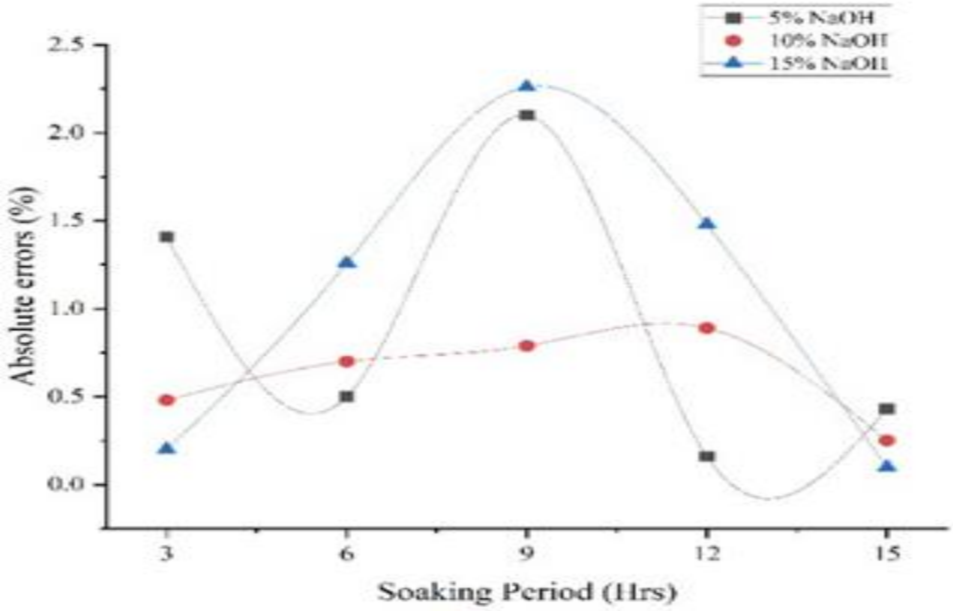


(b)

Fig 15 (a) -Experimental and predicted tensile strength representation for 3 mm thick composite (b) - Absolute errors for 3mm specimen



(a)



(b)

Fig 16: (a) – Experimental and predicted tensile strength representation for 5 mm thick composite (b) Absolute errors for 3mm specimen

4. CONCLUSIONS

The current study uses an ANN model to predict the tensile strength parameters of polyester composites reinforced with banana fibers and conducts laboratory experiments to determine those parameters. Tensile parameters are compared between treated and untreated banana fibers, and the findings are interpreted. Up to 25% FVF, the tensile strength of the untreated polyester composites reinforced with banana fibers increases with increasing fiber content. For 3 mm and 5 mm composite thickness untreated specimens, the optimum tensile strength is 22.91 MPa and 30.23 MPa, respectively, at 25% FVF. For composites that are 3 mm and 5 mm thick, respectively, additional alkali treatment of the fiber increases the tensile strength by 27.41% and 5.26%. An ANN model is created using data from experimental tensile tests. The predicted outputs are much closer to the experimental values because the model has the lowest MSE values for training and testing, 9.8898×10^{-06} and 3.336×10^{-06}. The training and testing correlation coefficients are 0.99951 and 0.99908, respectively. These values exhibit a linear relationship between the predicted and experimental values, as they are much closer to unity. It is determined that the developed model predicts the output with 98% accuracy because the MAE and MAPE values obtained for training and testing are less than 2%. By using an artificial neural network (ANN) to predict the tensile parameters of banana-fiber reinforced polyester composites, less human effort and energy are required.

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