Modeling and simulation of Polymer Composite laminate bolted Joint

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Abstract—**Environmental awareness today motivates the researchers, worldwide on the studies of natural fiber reinforced polymer composite and cost effective option to synthetic fiber reinforced composites. This work is concerned with the modeling and simulation of bearing properties of hybrid fiber polymer composite mechanical joint using Artificial Neural Network (ANN). In general it was found that increase in bearing capacity was always with increasing the e/d and w/d ratio. However, the extent of increase/decrease depends on the type of stacking sequence. There was increase in strength with rise in natural fiber loading. In this study, an artificial neural network is developed to predict the response of bolt-loaded fiber reinforced polymer composite plates. To predict the behavior of the laminate failure, a multilayered feed-forward neural network trained with the back-propagation algorithm is constructed. The ANN was trained and verified using experimental data. Comparisons of ANN results with desired values showed that there is a good agreement between input and output variables of the experimental data. The results indicate that ANN was illustrated to be a valid useful and powerful tool for the prediction of bearing properties predictions of bolted joints in composite laminates.**

Keyword: Mechanical Joint, Polymer Composite and Artificial Neural Network

I. INTRODUCTION

The increased use of fiber reinforced plastic (FRP) composite materials in aircraft, space craft structures, sports product, robot arm etc., has generated the need for developing reliable models able to predict the static behavior of critical composite aircraft components, such as the bolted composite joints. Fiber-reinforced composite materials have become widely used in recent years for the strengthening of bridges and other civil engineering structures.

Natural fiber reinforced composite has been widely used in various structural applications (Irawan et al. 2011). Natural fibers exhibit many advantageous properties as reinforcement of composite, But pure natural fiber composite alone cannot satisfy the engineering requirement the reason behind this failure is due to their poor moisture absorption tendency and reduced mechanical property such as tensile strength, impact strength and compressive strength. So, this bought the need for hybrid composite. The hydrophilic nature of natural fibers affects negatively its adhesion to hydrophobic polymeric matrices (Sutharson et al. 2012a). To improve the compatibility between both components a surface modification required (Sutharson et al. 2012b). The properties of jute composites can be considerably improved by incorporation of glass fiber as extreme glass plies. Mirsha et al.(2003) studied the effect of glass fiber addition on tensile and flexural strength and Izod impact strength of PALF and sisal fiber reinforced polyester composite. John et al. (2004) have studied the unsaturated polyester based sisal glass composite with 5% and 8% volume fraction and found a considerable enhancement in impact compression flexural and tensile properties. However, the main disadvantages of natural fibers in composites are the poor compatibility between fiber and matrix and the relative high moisture absorption. A review of the investigations that have been made on the stress and strength analysis of mechanically fastened joints in fiber-reinforced plastics (FRP) by Camanho et al. (1997). The effects of varying the centrally located circular cut out sizes and fiber angle ply orientations under the ultimate load has been simulated by Manoharan and Jeevanantham (2011). Claire et al. (2003) studied the effect of bearing behavior of mechanically fastened joints in composite laminates. Bearing mode is a local failure. This kind of failure cannot be avoided by any modification of the geometry. This mode is progressive and associated with compressive failure (Icten et al.,2003; sutharson et al. 2012c)

Mechanically fastened joints are frequent and critical elements in composite structures (Sutharson et al. 2012c). The layer sequence has greater effect on flexural and inter laminar shear properties than tensile properties. Composite laminate strength depends on the various parameters like (1) Number of layers in the laminate, (sutharson et al. 2012e) (2) Lay-up sequence (symmetry, anti-symmetry, cross-ply etc.), (3) Fibre orientation angle, (4) Different aspect ratios, (5) Orthotrophy ratio (Sutharson et al, 2005). The effect of failure criteria and material property degradation rules on the tensile behaviour and strength of bolted joints in graphite/epoxy composite laminates was investigated using a parametric finite element analysis by Tserpes et al. (2002). Abd Naby et al.(1993) explained a simplified analysis to show that increasing the ratio of the nominal bearing strength to the nominal tensile strength increased the efficiency of the joint. Barut et al. (2009) developed a semi-analytical solution method for stress analysis of single-lap hybrid (bolted/bonded) joints of composite laminates under in-plane as well as lateral loading.

Inspired by the biological nervous system, an artificial neural network (ANN) approach is a fascinating mathematical tool, which can be used to simulate a wide variety of complex scientific and engineering problems. Also in polymer composites, a certain amount of experimental results is required to train a well-designed neural network (Sutharson et al, 2012d). Ashraf et al.(2005) constructed multilayered feed-forward neural network trained with the back-propagation algorithm using 7 design variables as network inputs and the uniform bond strength of adhesive anchors as the only output. After the network has learned to solve the material problems, new data from the similar domain can be predicted without performing too many, long experiments. Various principles of the neural network approach for predicting certain properties of polymer composite materials are discussed by Zhang et al.(2003). The objective of using ANN is to apply this tool for parameter studies in the optimum design of composite materials for specific applications.

II. MATERIALS AND METHODS

The material used in the tests was jute/glass- polymer matrix composite. In order to reduce fiber moisture absorption and to improve its adhesive property, the fiber is treated chemically. NaOH solution is prepared with 5% of NaOH. The fiber is dipped in the solution for 24 hours. After that it is dried to remove the presence of moisture. This chemical treatment helps to increase the surface roughness in better mechanical interlocking, to reduce its moisture absorption. Now the fiber is ready for composite making. Matrix is prepared with general purpose resin. Catalyst and accelerator are added with resin in order to improve its curing and adhesiveness with fiber. Composites with different volume of fiber contents are prepared. The laminates were made from 5 plies and fabricated by manual hand layup method. Three different Stacking sequence were chosen for the study: A1 = Glass-Jute-Jute-Jute-Glass ; A 2 = Glass-Jute-Glass-Jute-Glass ; A3 = Jute-Glass-Jute-Glass-Jute.

The composite plates to be tested were cut precisely to size using a diamond-coated, electroplated blade. The specimen geometry was designed to induce bearing failure, which occurs when the ratios of plate width-to-hole diameter (w/d) and edge distance-to-hole diameter (e/d) are large enough.

TABLE I
Parameters and their levels

Sl.No	**Parameters**	**label**	**Levels**		
			L1	**L2**	**L3**
1	Stacking sequence	A	1	2	3
2	e/d	B	3	4	5
3	w/d	C	4	6	8

Where Stacking sequence ,

A1 = Glass-Jute-Jute-Jute-Glass A2 = Glass-Jute-Glass-Jute-Glass
A3 = Jute-Glass-Jute-Glass-Jute

III. SIMULATION IN ARTIFICIAL NEURAL NETWORKS

Artificial neural networks (ANN) have emerged as one of the useful artificial intelligence concepts used in the various engineering applications. Due to their massively parallel structure and ability to learn by example, ANN can deal with non-linear modelling for which an accurate analytical solution is difficult to obtain. ANN generally consists of a number of layers: the layer where the input patterns are applied is called the input layer, the layer where the output is obtained is the output layer, and the layers between the input and output layers are the hidden layers. There may be one or more hidden layers, which are so named because their outputs are not directly observable. The addition of hidden layers enables the network to extract higher-order statistics which are particularly valuable when the size of the input layer is large. Neurons in each layer are fully or partially interconnected to preceding and subsequent layer neurons with each interconnection having an associated connection strength (or weight). The input signal propagates through the network in a forward direction, on a layer-by-layer basis. These networks are commonly referred to as multilayer perceptions (MLP). A schematic diagram of a input and output layer of a ANN network shown in fig.1. Performance function plot is shown in Fig.2. Which shows the variation of mean squared error (mse) with epochs.

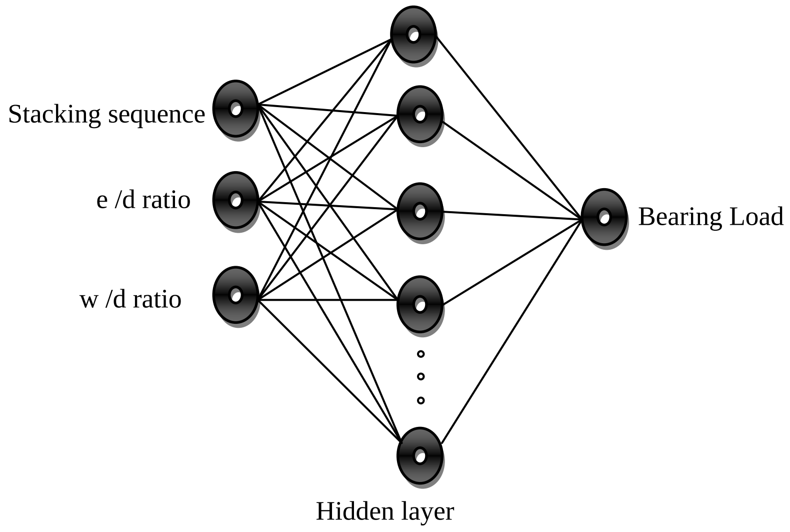

Fig.1. ANN network

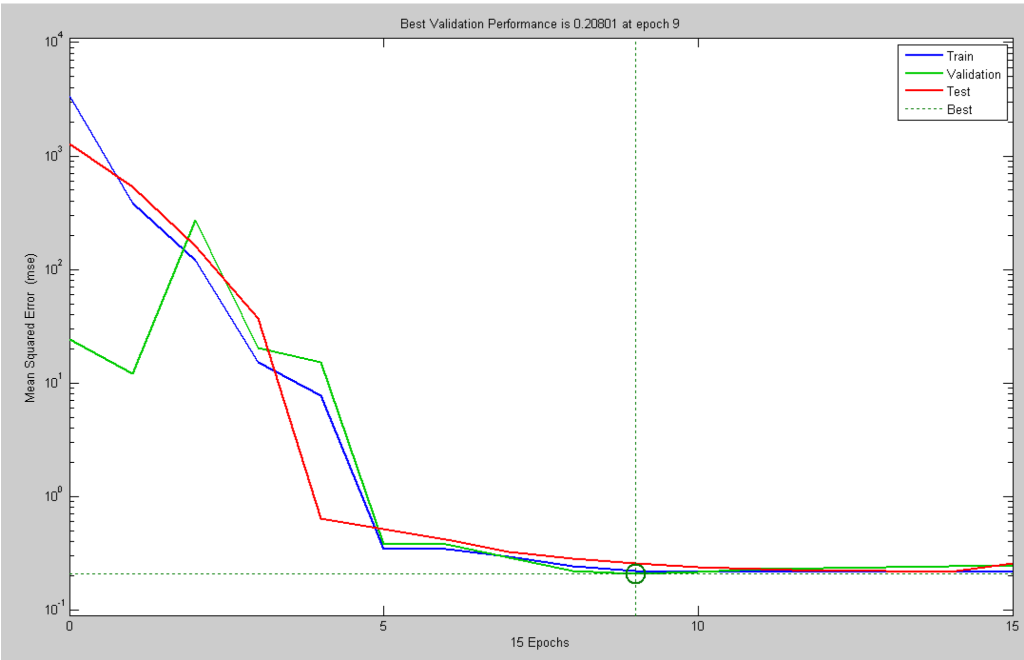

Fig.2. Performance plot

IV. Results and Discussion

The experiment results are summarized in table 2. The predictions of bearing loads were compared with experimental results in table 3. It shows that prediction error was minimum and acceptable limits. Laminate maximum bearing load capacities for the three different lay-ups are shown in figure 3. On comparing all three Stacking sequence, A1 (Glass-Jute-Jute-Jute-Glass) shows better bearing load capacity than others. Laminate having glass at outer layer performs well in bearing load test. First three experiments (1 to 3) are modeled as A1 stacking sequence that is 40% glass fiber and 60% jute fiber. Next three experiments (S.No 4 to 6) are modeled as A2 stacking sequence that is 60% glass fiber and 40% jute fiber. Last three experiments (S.No 7 to 9) are modeled as A3 stacking sequence that is 40% glass fiber and 60% jute fiber.

TABLE II
Input parameters and response

S.No	Sequence	e/d	w/d	Bearing load (kN)	
				Without oven curing	With oven curing
1	1	3	4	2.480	4.205
2	1	4	6	5.190	6.445
3	1	5	8	7.425	7.950
4	2	3	6	5.455	5.540
5	2	4	8	5.780	4.810
6	2	5	4	4.110	5.940
7	3	3	8	4.120	4.495
8	3	4	4	4.665	4.715
9	3	5	6	6.410	7.595

TABLE III
Bearing load (kN)

Without oven curing				With oven curing		
S.No	Experimental	ANN	% Error	Experimental	ANN	% Error
1	2.480	2.490	0.4032	4.205	4.250	1.070
2	5.190	5.250	1.1561	6.445	6.410	-0.543
3	7.425	7.410	-0.2020	7.950	8.050	1.258
4	5.455	5.560	1.9248	5.540	5.560	0.361
5	5.780	5.850	1.2111	4.810	4.900	1.871
6	4.110	4.200	2.1898	5.940	5.950	0.168
7	4.120	4.200	1.9417	4.495	4.600	2.336
8	4.665	4.800	2.8939	4.715	4.800	1.803
9	6.410	6.450	0.6240	7.595	7.700	1.382
Average absolute error =			1.349	Average absolute error =		1.078
Accuracy =			98.651	Accuracy =		98.922

A1 and A3 both stacking sequences are having 40% glass fiber and 60% jute fiber. But, A3 modeled with jute at outer layer where as A1 modeled with glass at outer layer. On comparing all the performance of the laminates with oven curing model perform well than laminates without oven curing. Since, the oven curing increases the fiber-matrix interface strength. On comparing oven curing characteristics, Average bearing load capacity for oven cured A1 model is 23% higher than non-cured. Cured A2 model yields 6% higher than without oven cured. A3 model with oven curing type produced 11% higher capacity than without oven cured model. Overall average bearing load capacity for oven cured model is 5.74 kN whereas for without oven cured model is 5.07 kN. Oven cured model produced 13% increase in overall all specimens average bearing load capacity.

The model predictions are summarized in Figure 4 and 5 for laminates with oven curing and without oven curing respectively. The experimental bearing load versus predicted ANN value for the three different lay-ups are presented in figure 4 and 5. ANN model predicted the experimental values very closely. Regression plots are shown in figure 6 and 7 for laminates with oven curing and without oven curing respectively. It shows the variation output with target for various “R^2” value. R^2 seems to be nearly one. It represents the ANN model performance is good and modeling is optimum design by proper selection of transfer function, no of neurons and the no of hidden layers.

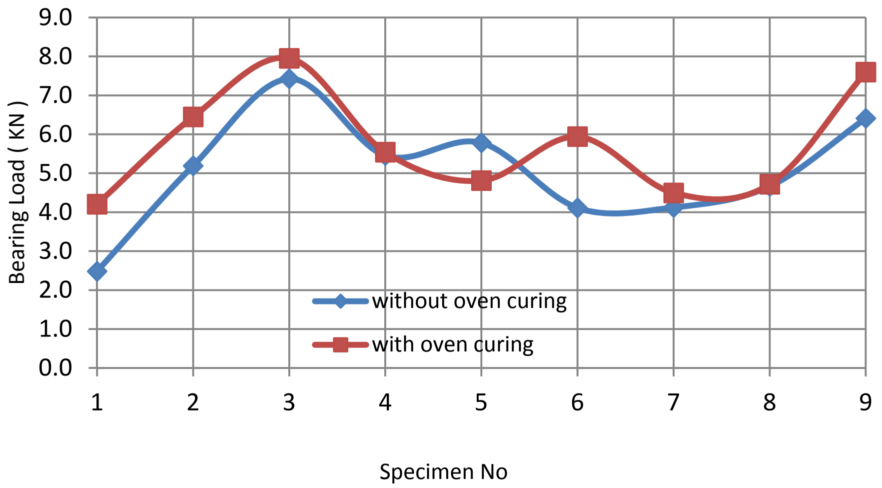

Fig. 3. Comparion of bearing load for different composite laminate

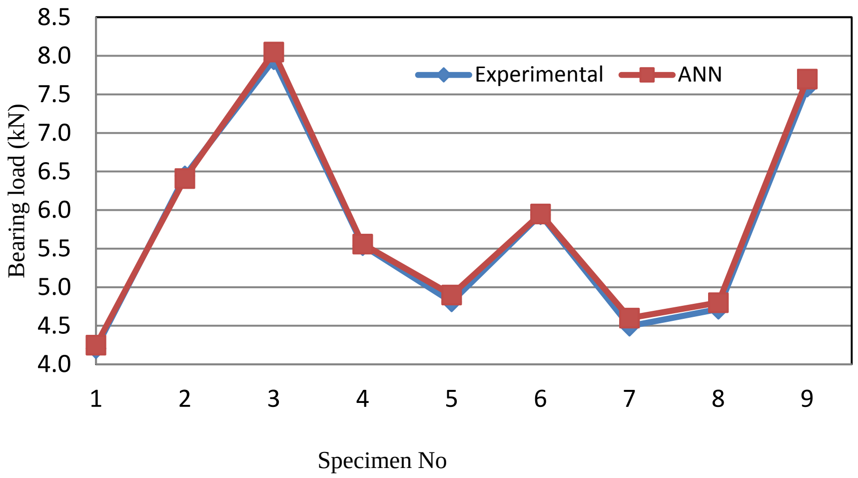

Fig.4. Actual vs predicted bearing load for laminate with oven curing

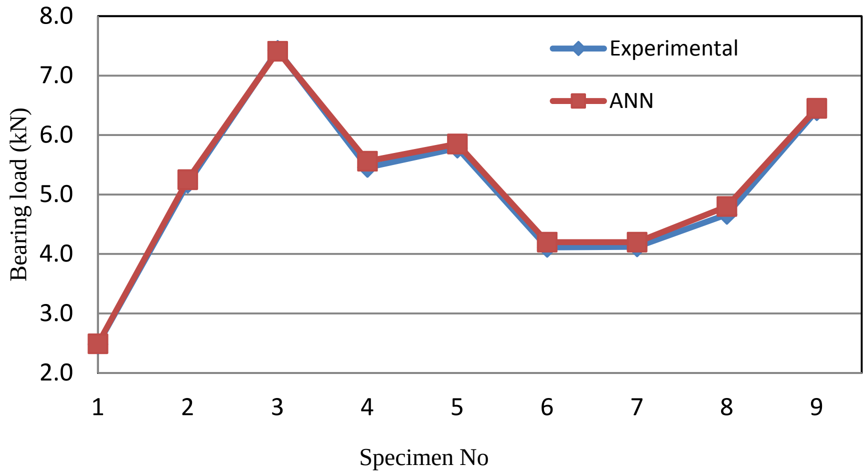

Fig.5. Actual vs predicted bearing load for laminate without oven curing

Average absolute error for laminates with oven curing is 1.345% and the accuracy of prediction is 98.65% .

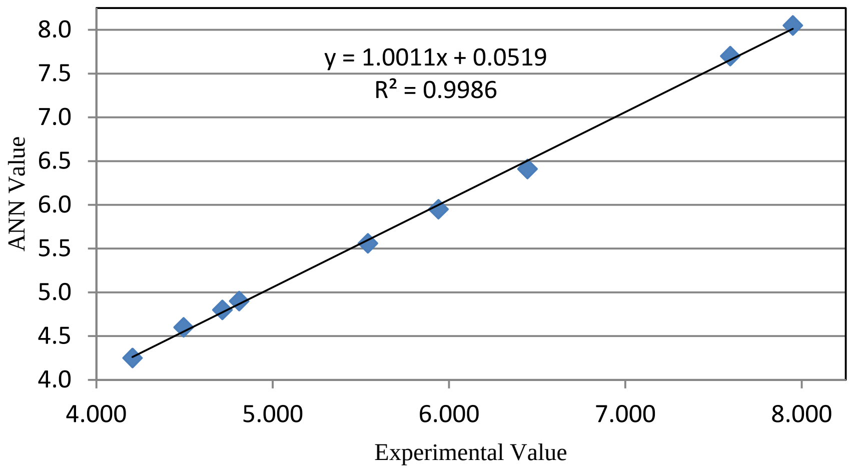

Figure 7. Experimental Vs ANN value for laminate with oven curing

For laminates without oven curing, Average absolute error is 1.078% and the accuracy of prediction is 98.92%.

V. CONCLUSION

In this study, an ANN model was developed based on the results of experimental bearing analysis of bolted composite laminates of different geometrical parameters and stacking sequences. ANN model was constructed by using 80% data for training set and 10% data for testing set and 10% data for validation set and MSE was found very less for each dataset. Therefore, comparison of ANN results with desired values show that there is a good agreement between input and output variables of the experimental data. The outcome of this study shows that, ANN model is a suitable tool to verify the results of experimental studies of bolted composite plates. ANN model was successfully tested with one hidden layer with 10 neurons. Composite laminates was optimized by ANN model without increasing hidden layers. No of neurons in the hidden layer was varied and obtain the optimum as a 10 neurons.

Composite laminates maximum bearing load capacity is studied. Optimum layer sequence is Glass-Jute-Jute-Jute-Glass (A1). Since, the laminate was cured in oven, it perform better (overall average capacity 13% increased) than uncured laminates. In general it was found that increase in bearing capacity was always with increasing the e/d and w/d ratio. However, the extent of increase/decrease depends on the type of stacking sequence. Placing the glass fiber at outer of natural jute fiber outperform its joint bearing load capacity. On increasing the natural fiber percentage from 40 to 60% of total fiber, joint performance also increases. From this result, it is inferred that it can be used to make chairs, automotive components and other light weight applications. Agricultural activities can also be encouraged if more composites are made from natural fiber. The study of other properties of this composite will be taken up and suitable applications would be suggested.

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