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ORIGINAL ARTICLE

Failure load prediction of single lap adhesive joints using artificial neural networks

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Abstract The objective of this paper was to predict the failure load in single lap adhesive joints subjected to tensile loading by using artificial neural networks. Experimental data obtained from the literature cover the single lap adhesive joints with various geometric models under the tensile loading. The data are arranged in a format such that two input parameters cover the length and width of bond area in single lap adhesive joints and the corresponding output is the ultimate failure load. An artificial neural network model was developed to estimate relationship between failure loads by using geometric dimensions of bond area as input data. A three-layer feedforward artificial neural network that utilized Levenberg–Marquardt learning algorithm model was used in order to train network. It was observed that artificial neural network model can estimate failure load of single lap adhesive joints with acceptable error. Mean absolute percentage error and Nash–Sutcliffe coefficient of efficiency values of both training and testing data were 3.523 and 3.524 and 0.997 and 0.992, respectively. The results showed that the artificial neural network is an efficient alternative method to predict the failure load of single lap adhesive joints. Also estimated results are in very good agreement with the experimental data.

1. Introduction

As an alternative method to welding, riveting and other conventional fasteners, applications of adhesive joints have been increased in structures and industries such as aircraft and automobile [1]. In an assembly of composite structures, usage of mechanical fasteners causes high stress concentration that results in structurally inefficient joints. On the other hand, adhesive joints are capable of redistributing the loads so that stress concentrations can be lowered [2]. Adhesive joints provide good strength–weight and cost-effectiveness ratios. These requirements cannot be met by mechanical joints [3].

Recently, interest in using artificial neural networks (ANNs) for forecasting has led to huge increase in research areas [4]. Experimental studies are typically time consuming and costly processes and sometimes even complex to perform. To be able to overcome these problems, various modeling techniques are used. ANNs are one of the most popular techniques which get inspired from biological neural networks. The basic units of ANNs are the neurons which are connected to each

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other with weights. They can be trained to perform a particular function by adjusting the values of these weights [5]. As an effective prediction tool, ANN was frequently used by researchers.

Bardak et al. [6] used ANN to estimate bonding strength of wood joints pressed under different conditions. Their study showed that model predicted bonding strength with acceptable accuracy. Tiryaki and Hamzaçebi [7] predicted modulus of rupture (MOR) and modulus of elasticity (MOE) of heat treated woods by using ANN. They compared the actual values of MOR and MOE with the outputs of ANN model and concluded that ANN is successful in estimation of them. Ayatollahi and Akhavan-Safar [8] proposed a new failure criterion in order to predict the static strength of single lap adhesive joints under tensile loading. Their predictions based on the proposed criterion have good agreements with the experimental data. Tiryaki and Aydın [9] modeled an ANN structure to estimate compression strength parallel to grain of heat treated woods. With this model, there will be no need to comprehensive experiments. They suggested that, with the usage of ANN, satisfactory results can be obtained which reduces the testing time and cost.

Zgoul [10] used ANN modeling for the rate dependent response of adhesive materials with the purpose of expanding the established method for modeling the response of adhesively bonded structures, and in particular single lap joints. Tiryaki et al. [11] investigated the bonding strength of beech wood based on the amount of adhesive, pressing pressure, and pressing time. They used ANN modeling approach and concluded that this approach was useful tool in characterizing the effects of amount of adhesive, pressing pressure, and pressing time on the bonding strength of wood. Sekercioglu and Kovan [12] developed a prediction method to estimate a static shear force and fatigue life by using ANN. The results showed that developed model was convenient and powerful tool for static shear force and fatigue life prediction of adhesively bonded cylindrical joints. Apalak and Ekici [13] studied the three-dimensional stress state of an adhesively bonded double containment cantilever joint in tension. Furthermore, the effects of the joint dimensions and the compositional gradient exponent were determined by using an ANN model, and the design rules were presented for an optimal joint design. Balcıoğlu et al. [14] investigated the effects of bonding angle, patching type (single side and double side) and patching structure on the failure load in the adhesively bonded pultruded composites by using ANN. Domińczuka and Kuczmaszewski [15] investigated the suitability of artificial intelligence for processing of experimental information related to strength of adhesive joints. They compared the efficiency of ANN with the efficiency of typical methods of statistical analysis such as linear and polynomial regression. Tiryaki et al. [16] investigated multiple linear regression and ANN model to predict optimum bonding strength of heat treated woods. An ANN based explicit formulation for predicting the edge breakout shear capacity of single adhesive anchors post-installed into concrete member was proposed by Güneyisi et al. [17]. Gunes et al. [18] conducted the 3-D free vibration analysis of an adhesively bonded functionally graded tubular single lap joint by using the finite element (FE) analysis. The optimal design parameters of the adhesive joint were searched using both the ANNs and the genetic algorithms (GAs). Akpinar et al. [19] investigated the application of protrusion in single lap joints subjected to tension and bending loads using FE method experimental. They observed that the protrusion reduces the strength in the joint under tension, while the protrusion increases the strength in the joint under bending. Alia et al. [20] investigated the mechanical behavior of adhesive joints when subjected to long-term tests, adverse environmental conditions (i.e., immersion in seawater and different temperature) and stress in different mixed modes between peel and shear experimentally.

In this study, the failure load in single lap adhesive joints subjected to tensile loading was estimated by using ANN technique. The results showed that ANN model has reliable prediction capability and ANN results are in a very good agreement with the experimental data.

2. Materials and method

2.1. Experimental detail

The experimental data values in Table 1, width (W) and length of bond area (L) in single lap adhesive joints and failure load under tensile loading are the values used for the training of the ANN. These values were taken from an experimental work of Gültekin et al. [21]. In the experimental study, as adhesive was chosen a two-part epoxy DP460 produced by 3M (St. Paul, MN, USA). AA2024-T3 aluminum alloy was used as adherend. Thickness of adherend and bond is 5 and 0.1 mm, respectively. The geometry of the model is shown in Fig. 1.

The experiments of specimen were performed using Shimadzu AG-IS 100 (Shimadzu Corporation, Tokyo, Japan) (100 kN) machine at room temperature and relative humidity 30. During tensile tests, the crosshead speeds were maintained at 1 mm/min [21].

2.2. Artificial neural network

Inspiration of artificial neural network comes from biological neural networks. Basic unit of a biological network is called

Table 1 Average maximum failure loads and displacement values.

Data no	W	L	Failure load	Data no	W	L	Failure load
1	25	25	9094	21	25	15	5177
2	20	25	5381	22	20	15	4692
3	15	25	4311	23	15	15	3565
4	10	25	3980	24	10	15	2160
5	5	25	1827	25	5	15	1015
6	25	25	9094	26	15	25	4311
7	25	20	6390	27	15	20	4048
8	25	15	5177	28	15	15	3565
9	25	10	5039	29	15	10	2695
10	25	5	2507	30	15	5	1679
11	25	20	6390	31	25	10	5039
12	20	20	5006	32	20	10	3709
13	15	20	4048	33	15	10	2695
14	10	20	2903	34	10	10	1601
15	5	20	1371	35	5	10	596
16	20	25	5381	**36**	**10**	**25**	**3980**
17	20	20	5006	**37**	**10**	**20**	**2903**
18	20	15	4692	**38**	**10**	**15**	**2160**
19	20	10	3709	**39**	**10**	**10**	**1601**
20	20	5	2055	**40**	**10**	**5**	**1102**