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Artificial neural network based delamination prediction in laminated composites

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Abstract

The present paper deals with an approach in predicting the presence of embedded delaminations (in terms of their size, shape and location) in fibre reinforced plastic composite laminates using natural frequencies as indicative parameters and artificial neural network as a learning tool. Here, a 3D finite element model has been used to model $[0]_{20}$ graphite/epoxy plate having an embedded delamination at the interface of two $[0]_{10}$ sub-laminates. Hundreds of finite element models have been run to generate natural frequencies up to 10 modes for various combinations of size, shape and location of embedded delamination in a graphite/epoxy plate and then these data have been used to train a back propagation neural network till the network learns to an acceptable level of accuracy. The trained network has been tested to predict the presence of a delamination along with its size, shape and location from the input natural frequencies. An optimum network architecture has been established which can effectively learn the pattern. It has been observed that, the network can learn effectively about the size, shape and location of the embedded delamination present in the laminate and can predict reasonably well when tested with unknown data set.

Keywords: Finite element method; FRP composites; Delamination; Artificial neural network

1. Introduction

Increasing use of laminated composites demands not only rational methods of analysis and design, but also tools to detect imperfections and flaws and measures to rectify them. In a fibre reinforced plastic (FRP) laminate, the bond between plies may weaken and propagate, eventually leading to catastrophic failure of the structure. Such a debonding may go undetected during testing on an assembly line. One method of locating flaws is ultrasonic testing which may give only qualitative results. However, the need is to have a more quantitative approach in detecting such flaws. In an FRP laminate, internal flaws in the form of ply/fibre break, debonding or delamination are caused by various reasons like manufacturing error, exposure to unusual level of excitation or oscillating load over an extended period of time, impact of foreign objects, etc. Presence of such a delamination causes change in physical properties and usually does not affect the mass distribution but reduces the stiffness of the structure and leads to the changes in modal parameter. So, natural frequency fits as a suitable candidate parameter for detecting such delaminations.

Many early workers have used modal analysis for the purpose of correlating natural frequency with flaws such as delamination. Kulkarni and Fredrick [1] studied the variation of natural frequency with delamination in FRP laminates. Cawly and Adams [2] proposed a method to detect and locate a variety of types of damages by noticing the change in natural frequency. Mujumdar and Suryanarayan [3] reported the effect of span wise and thickness wise location of delamination on natural frequencies for a laminated beam. Tracy and Pardoen [4] reported that the presence of delamination leads to decrease in natural frequencies. Paolozzi and Peroni [5] performed finite element (FE) analysis to

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correlate the natural frequency shift with the extent of delamination damage. Natural frequency variation of damaged laminates has also been studied by Duggan and Ochoa [6] and they reported good correlation between experimental and finite element results. Manivasagam and Chandrasekaran [7] presented the correlation of damage size with natural frequency for layered beam by performing experiments as well as finite element analysis. Shen and Grady [8] evaluated the effect of inter-ply delaminations on natural frequencies and observed that frequency is very sensitive to the size and location of the delaminations.

It has been observed from the earlier works that natural frequencies are sensitive to the size and location of flaws in structural components. So the present work aims at developing an artificial neural network (ANN) model for detection of extent of delamination, its shape and location in an FRP composite laminate using natural frequencies as inputs and corresponding size, shape and location of delamination as outputs of the network. First, hundreds of finite element models have been run to generate natural frequencies up to ten modes for various combinations of size, shape and location of an embedded delamination in a laminate and these data have been used to train a back propagation neural network (BPNN) for future prediction of delamination in the laminate.

2. FE modeling

Three dimensional (3D) finite element analysis has been performed by using ANSYS 5.4A for analysing a $[0]_{20}$graphite/epoxy square plate (length = width = 100 mm and thickness = 2.54 mm, with all four edges clamped) having an embedded delamination at the interface of two $[0]_{10}$ sub-laminates as shown in Fig. 1(a). Two sub-laminates have been modelled individually and the interface between the two sub-laminates has been modelled with a thin resin rich layer (Fig. 1(b)). Eight noded isoparametric layered element (SOLID46 in ANSYS) with orthotropic material properties were employed for the analysis and in the delaminated region, corresponding nodes of the top and bottom sub-laminates are connected by contact elements (CONTAC52 in ANSYS) to simulate the contact force between the sub-laminates. First ten natural frequencies have been extracted using sub-space iteration method of modal analysis.

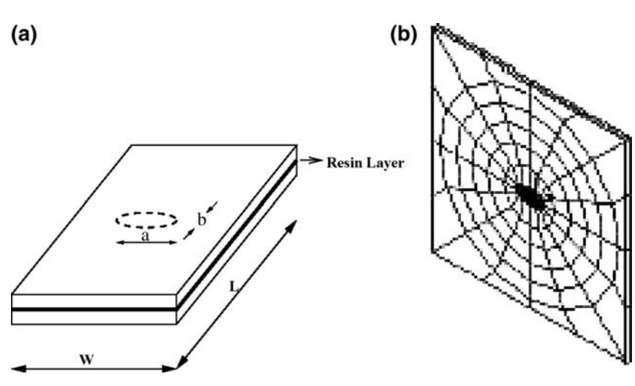

Fig. 1. (a) Laminate specimen with an elliptical embedded delamination; (b) 3D FE mesh of the laminate specimen.

3. ANN based delamination prediction

Artificial neural network architecture comprises mainly parallel adaptive processing elements with hierarchical structured interconnected networks. Each processing unit of an ANN has multiple input slots and a single output one (Fig. 2). The relation between the input and the output signals usually formulated as follows:

$$O_i = f(y_i) = 1/(1 + \exp(v_i)), \tag{1}$$

$$v_i = \sum_{i=1}^{l} w_{ij} I_i - \theta_i, \tag{2}$$

where, O_j is the output signal of the jth unit, v_j is the potential of the jth unit, $f()$ is the activation function that is a sigmoidal function in this case, w_{ji} is the connection weights between ith and jth units, θ_j is the threshold value of the jth unit and l is the number of input signals.

Fig. 2 shows a three layer neural network. All the units are formed in to a multiple layers, i.e., an input layer, a hidden layer and an output layer. The basic idea of training a neural network is as follows. First, the square error of the pth training pattern E_p is defined as

$$E_p = \sum_{k=1}^{m} \left(T_{pk} - O_{pk}\right)^2/2, \tag{3}$$

where, T_{pk} is the teacher signal (desired output) to the kth output unit for pth training pattern, O_{pk} is the output

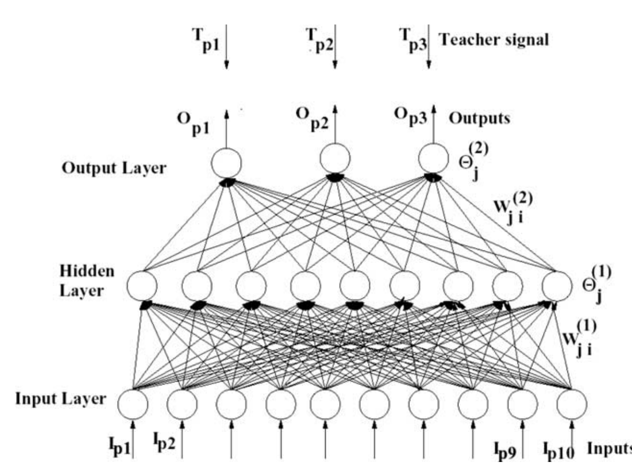

Fig. 2. Three layer back propagation neural network.