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An artificial neural network for the fatigue study of bonded FRP–wood interfaces

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Abstract

The objective of this study is to explore the development of an artificial neural network (ANN) method for the analysis of load ratio effects on fatigue of interfaces for phenolic fiber reinforced polymer (FRP) composite bonded to red maple wood. Experiments were performed with a contoured double cantilever beam (CDCB) specimen under load control, and the crack propagation rate was obtained by the compliance method. Using linear elastic fracture mechanics, the influence of load ratio on fatigue crack growth rate was studied; leading to a modified Paris Law equation based on strain energy release rate range, ΔG, and mean value of strain energy release rate, G_{mean}. By constructing suitable network architectures, an ANN can be defined and trained using existing experimental data sets, to provide in turn output fatigue data sets for new input parameters. The crack growth rate as predicted by the ANN approach is compared with the experimental output and theoretical prediction from a modified Paris Law equation. It is shown that the proposed neural network model is able to predict valuable fatigue responses, such as crack growth rate, that would facilitate the development of design guidelines for hybrid material bonded interfaces.
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Keywords: Fatigue; Interface bond; ANN; Crack growth rate; FRP; Wood; Load ratio

1. Introduction

There is a worldwide need to rehabilitate civil infrastructure. New materials and methods are being broadly investigated to alleviate current problems and provide better and more reliable future services. Fiber-reinforced polymer/plastics (FRP) composite materials have emerged as promising candidates to partially meet these needs. Several studies have demonstrated that FRP-strengthened concrete and wood structures have attained significant increases in strength, stiffness, and durability. However, in design applications of FRP–reinforced materials, the response of the interface bond under cyclic loading is not yet fully defined. Thus, fatigue test studies are highly desirable to characterize the long term performance of bonded interfaces, from which design guidelines can be developed.

Often used approaches to evaluate fatigue crack response of materials are based on fracture mechanics [1,2] and damage mechanics [3]. Numerous analytical and empirical methods have been developed to explain fatigue crack growth and predict fatigue life, and most of these methods generally require extensive fatigue test data [4]. Fatigue tests are difficult, time-consuming and costly, and in general there are no accepted criteria that can satisfy design requirements. In recent years, an artificial neural network (ANN) has emerged as a new branch of computing, which tries to mimic the structure and operations of biological neural systems. An ANN is able to learn by example and does not have to know the theory behind a phenomenon. This quality is useful to describe problems where the relationships of inputs

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and outputs are not clear enough or the solutions are not easily formulated in a short time.

From a recent research on fatigue behavior of bonded phenolic FRP to red maple wood interfaces by Jia [5], it is apparent that the problem is quite complicated both experimentally and analytically. In this study, we propose to develop an ANN method that can analyze fatigue behavior of interface bonds for dissimilar materials. A modified Paris Law equation based on strain energy release rate range, ΔG, and mean value of strain energy release rate, G_{mean}, is defined in this study for load ratio effect on crack growth rate, da/dN. A comparative study of crack growth rate prediction by ANN with experimental and theoretical results is presented. It is shown that the proposed ANN model is able to predict crack growth rate. The proposed approach can further be extended to characterization of other bonded interfaces for hybrid materials. An extensive study on fatigue behavior of FRP–wood interfaces has been carried out by the authors [5], and it appears that there has not been much effort devoted to ANN application to fatigue failure or behavior, especially for dissimilar material bonded interfaces. A summary of current studies on application of ANN to fatigue failure or behavior of materials is given in Section 2.

2. Literature review

Pidaparti and Palakal [6] developed an ANN model to represent the fatigue crack growth behavior under spectrum loading. The inputs were information about the features in the spectrum loading and crack growth behavior, and the output was the corresponding loading cycles. A material parameter network for modified Paris Law was also developed in their study. Haque and Sudhakar [7] described an ANN model to analyze corrosion fatigue crack growth rate in dual phase steel. The inputs were the stress intensity factor range, ΔK, and volume percent of martensite content and outputs were crack growth rate. Six groups of da/dN versus ΔK relationship corresponding to different martensite contents were trained, and the neural network (NN) analysis provided a good match with the experimental data. Aymerich and Serra [8] used a neural network to predict fatigue strength of a graphite-peek composite with 63% of fiber content. The input parameters were the number of cycles at failure and the stacking sequence of the laminate. The neural network used showed the capability of predicting fatigue life for laminated composites.

Lee et al. [9] investigated the feasibility of using ANN to predict fatigue lives of five carbon and one glass fiber-reinforced laminates. A three-parameter Weibull distribution was used to estimate the number of cycles for various levels of failure probability from experimental data. The peak stress, minimum stress and the failure probability level were the most appropriate inputs from the root-mean-square trials. They applied ANN to train fatigue data for four CFRP systems to predict the response of HTA/982. The results showed the log-life was well within the normal experimental spread of data for composite materials. Artymiak et al. [10] applied ANN to estimate finite life fatigue strength and fatigue limit. The notch factor, tensile strength, yield strength and nominal stress were employed as input parameters. The output parameter was the endurable number of load cycles. The results showed that NN was capable of describing the expected S–N curve. Pleune and Chopra [11] studied the effect of light water reactor coolant environments on fatigue resistance of plain carbon steel and low alloy steel using ANN. The authors showed that ANN had a great potential of predicting environmentally influenced fatigue. The ANN output of the effects of sulfur content, strain rate and temperature on the fatigue lives in air showed good agreement with the statistical model.

Venkatesh and Rack [12] developed an ANN for predicting the elevated temperature creep fatigue behavior of Ni-based alloy INCONEL 690. Five extrinsic parameters (strain range, tensile strain rate, compressive strain rate, tensile hold time, and compressive hold time) and one intrinsic parameter (grain size) were training inputs. Fatigue life defined by complete fracture of the specimen was the predicted output. Close agreement between experimental and predicted life for the test points was observed with the NN approach. Fujii et al. [13] used a Bayesian NN for analysis of fatigue crack growth rate of nickel-based super-alloys. The database consisted of 1894 combinations of fatigue crack growth and 51 inputs. The output was the logarithm of fatigue crack growth rate. A group of seven of the best models showed minimum test error and provided a close agreement with experimental data. This NN method demonstrated the ability of revealing new phenomena in cases where experiments cannot be designed to study each variable in isolation.

Biddlecome et al. [14] developed an optimization based NN method to predict fatigue crack growth and fatigue life for multiple site damage panels. In the NN optimization each neuron represented a hole and contained pertinent information relevant to existing crack conditions. As the crack extended, the neuron gained energy. A set of energy functions was developed to define how the neurons gain energy as the system begins to converge to an optimal solution. The proposed NN was able to detect a panel failure and provide the path of crack propagation. Kang and Song [15] determined the crack opening load the input of 100 data points of the differential displacement signal on the loading stage. The accuracy and precision of the prediction of crack opening point by the NN were estimated for 42

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