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ANN prediction model for composite plates against low velocity impact loads using finite element analysis

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ABSTRACT

In this paper, the use of Artificial Neural Networks to predict the absorbed energy in the composite plates impacted with low velocity is described. The impact response of a composite laminate depends upon various factors such as thickness, stacking sequence and number of layers. These factors are identified in an earlier study using the sensitivity analysis. These factors have the most prominent effect on the impact resistance of the composite plates. These are studied here with the help of design of experiments so that a suitable data set is obtained. The ability to solve a large number of simulations using FEA gives an advantage in the design optimization with the help of DOE (Design of Experiments). During the study different variations of these factors were tried and the response in terms of the absorbed energy was estimated. The simulation results were then used along with the ANN (Artificial Neural Networks) to fit a function to estimate the amount of absorbed energy. The results from the DOE follow the intuition that the increase of thickness and number of layers increase the performance of the composite plates. The ANN model is trained such that it is able to predict with an acceptable accuracy range the amount of absorbed energy for different configurations of input variables. The paper discusses the codification of input variables so that they can be used to train ANN model. Also, the use of differential evolution algorithm is discussed which is used to select the best possible ANN model based on the maximum error and root mean square error of the ANN models.

1. Introduction

Fiber reinforced polymers have been in use in a variety of applications from medical to engineering structures. These structures are designed to withstand loads that conventional metals cannot hold without putting the weight penalty due to their high strength-to-weight and stiffness-to-weight ratios [29]. Most of these structures are designed to take loads such as tensile loads and internal pressure, but during operational life they encounter impact loads as well. The impact behavior of metals is well defined and can be predicted accurately, however fiber reinforced composites are quite complex in behavior with regards to impact loads which can result in internal damages and loss of stiffness but the damage is often unobservable during visual inspection [1]. The impact loads results usually in delamination, fiber breakage and matrix cracking [9], the damage mechanics in fiber reinforced polymeric composites is different than conventional metals and is because of the different layered configuration and presence of heterogeneous materials. A number of studies have been performed to study the behavior of composite plates, the studies are experimental [4,8,11,14,28,30,31,33], numerical [5,16,17,31] and analytical [12] which discuss the impact behavior of different composite laminates. These studies mainly focused on the development of analytical and numerical methods to understand the impact behavior of the composite plates under low velocity impacts. These include the studying the effects of various parameters on the impact response of the composite plates. Hosseinzadeh et al. [11] studied the effects of different materials and energy levels, while Menna et al. [23] discussed the effect of thickness at various impact energies for glass/epoxy fabric laminates. Cantwell [8] studied the effects of geometry on the impact response of glass fiber reinforced composites and Karakuzu et al. [14] discussed the effects of impactor mass and velocity have on the impact characteristics of glass/epoxy composites. Similarly, Mikkor et al. [24] studied the effects on the carbon/epoxy composite system and the effects of preload, impact velocity and geometry of the specimen. Naik and Meduri [26] investigated the impact behavior of woven-fabric laminated composite plates and the effect of the fabric geometry and the effect of unidirectional at two different impact velocities. Aktas et al. [2] studied the different damage modes and the effect of different stacking sequence were studied under different impact energies.

The literature available provided an insight into how the various factors affect the impact response of the composite plates.

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Nomenclature

E_{11}	elastic modulus in longitudinal direction [N/m^2]
E_{22}	elastic modulus in transverse direction [N/m^2]
E_{33}	elastic modulus in transverse direction [N/m^2]
v_{12}	Poisson's ratio in plane containing fiber [unitless]
v_{13}	Poisson's ratio in plane containing fiber [unitless]
v_{23}	Poisson's ratio in transverse plane [unitless]
G_{12}	shear modulus in plane containing fiber [N/m^2]
G_{13}	shear modulus in plane containing fiber [N/m^2]
G_{23}	shear modulus in transverse plane [N/m^2]
X_t	tensile strength in fiber direction [N/m^2]
X_c	compressive strength in fiber direction [N/m^2]
Y_t	tensile strength in transverse direction [N/m^2]
Y_c	compressive strength in transverse direction [N/m^2]
S_{12}	in-plane shear strength [N/m^2]
G_f^t	fracture toughness in longitudinal tensile direction [J/m^2]
G_f^c	fracture toughness in longitudinal compressive direction [J/m^2]
G_m^t	fracture toughness in transverse tensile fracture mode [J/m^2]
G_m^c	fracture toughness in transverse compressive fracture mode [J/m^2]
G_s	in-plane fracture toughness [J/m^2]
NSC	normalized sensitivity coefficient [unitless]
Tp	thickness of layers
St	stacking sequence
N	number of layers

The optimization of composite plates against the impact loads is one of the primary concerns for the designers especially in the applications where during operation; structures are susceptible to impact damages such as the aircrafts, automobile parts and open air pipelines. The impact response for composite materials is not very well documented and hence novel optimization techniques like ANN (Artificial Neural Networks) along with other optimization techniques such as GA (Genetic Algorithm) are introduced. ANN models are a very powerful method since they can be applied to any generic problem with few inputs and can be trained to learn from them with the expected outputs. ANN models proved to be excellent tool in the approximation and interpolation in a variety of applications [6,7,10,13,15,18,19,21,22,27,32,34]. ANN has been used in function fitting and prediction of various mechanical properties and damage mechanisms in composite materials. Bezerra et al. [7] used ANN to predict the shear stress–strain behavior of carbon/epoxy and glass/epoxy fabric composites. The authors used the multi-layered neural network model and demonstrated that about 80% of standard error of prediction was $\geqslant 0.9$. In their study, they considered the stress as a function of the orientation angle by layers, specimen of fiber and the shear strain, while certain other factors like porosity, number of layers, matrix type and volumetric fraction of fibers were not studied. Vassilopoulos et al. [32] used ANN to model the fatigue life of multidirectional GFRP composite laminates. The benefit that ANN provided the authors was the approach saved around 50% experimental effort for the whole analysis as compared to conventional methods and that too without the loss of considerable accuracy. Jiang et al. [13] applied the ANN model to predict the mechanical and wear properties of the short fiber reinforced polyamide composites. The polyamide composites were reinforced by short carbon and glass fibers and then optimization of the neural networks was performed. The neural network was used to predict the mechanical and wear properties as a function of the content of fibers and testing conditions.

In this present work, a DOE approach is applied to generate the data to simulate experiments and generate data set for the ANN

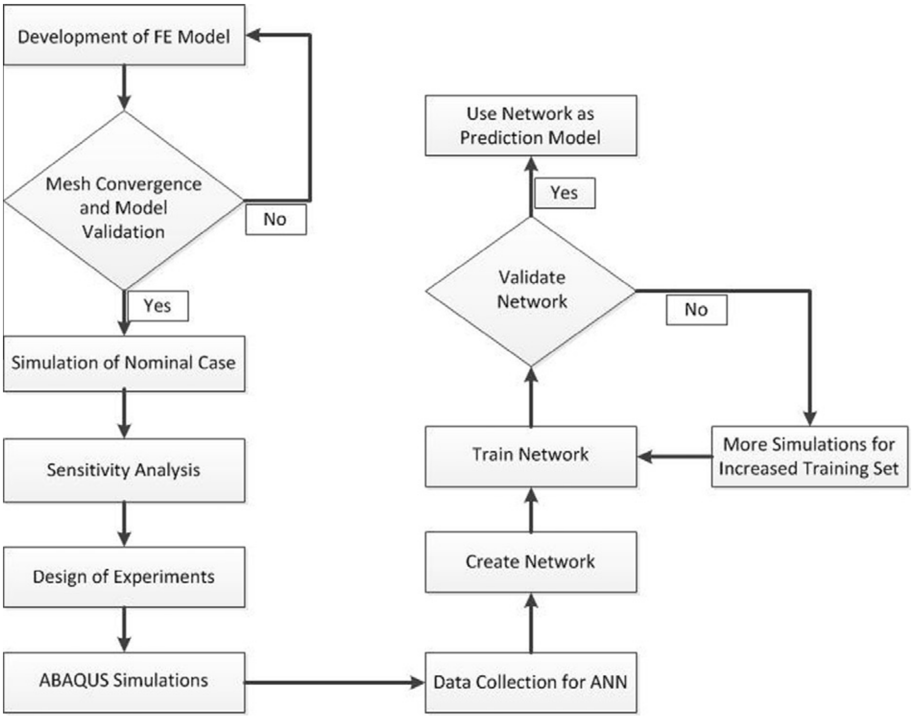

Fig. 1. Flow chart of the process for ANN modeling.