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DETECTION OF MODE-I INTERLAMINAR CRACK IN CNF DOPED GFRP LAMINATES USING ELECTRICAL IMPEDANCE TOMOGRAPHY

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Abstract

Electrical impedance tomography (EIT) is an emerging structural health monitoring tool for self sensing composites using the piezoresistive effect. This work presented a novel methodology to detect interlaminar crack or delamination developed during mode I loading in carbon nanofillers doped glass fiber reinforced polymer (GFRP) composites using EIT. DCB specimens were fabricated with 1 wt% carbon nanofillers (CNF) doped GFRP laminates to produce interlaminar crack under mode I loading. The boundary voltage datasets, obtained from electrodes mounted on top and bottom surface of specimen, were used to solve EIT inverse problem to get the reconstructed conductivity change map. This methodology demonstrated that interlaminar cracks can be successfully detected using EIT.

1. Introduction

Composite laminates have superior specific strength and stiffness and are therefore increasingly used in light-weight structures. Additionally, they have good corrosion resistance, fatigue resistance, and superior design flexibility. That is why, industries like aeropace, automative and marine are using these materials. Composite materials suffer from service damages that results in matrix cracks, fiber breakage and interlaminar cracks (delamination). Most often, these damages are not visible by naked eyes. Out of these damages, interlaminar cracks or delamination is the most critical damage mode as it divides a laminate into sub-laminates and is likely to interact and propagate with other damage modes. Hence, detection of interlaminar cracks in composite materials at its nascent state is of high importance.

Damage in composites is usually detected using suitable structural health monitoring (SHM) technique. Conventional SHM involves vibration, guided wave or embedded sensor based techniques where sensors are placed on or inside the structure. The requirement of external sensors in these techniques that do not contribute to the structure in some instances reduces the mechanical performance. In this aspect, a promising alternative is to use materials that have one or more stimulus-responsive properties to sense their conditions without the use of external sensors. These materials are called self-sensing materials. For self-sensing materials based on nanofillers, peizoresistivity is used to sense changes or damages. Introduction of damage disturb the nanofiller network and afftects the tunneling resistance and thus finally results in change in conductivity of the material.

Electrical impedance tomography (EIT) is a newly emerged structural health monitoring technique based on piezoresistive effect. It is a soft-field tomographic method that recontructs the conductivity map of the domain (specimen) from a set of boundary voltage measurements. It was originally developed for geospatial imaging and later has been extensively used in medical imaging. EIT in damage detection is at the early stage and many technical challenges need to be addressed. One such challenge is the ability to detect delamination or interlaminar cracks in laminated composites. This was addressed in this work using a novel methodology in which interlaminar cracks or delamination initiation and progression in CNF doped GFRP laminates was performed by mode I frature loading. Composite laminates were fabricatd using hand layup method followed by vacuum bagging. Electrodes were mounted on the top and bottom surfaces of the DCB specimen. The boundary voltage measurements were taken before and after the advancement of crack. Open source MATLAB subroutine named EIDORS was used to solve forward and inverse problems involved in EIT and to reconstruct conductivity images.

2. Results

Mathematically, in electrical impedance tomography (EIT), the difference between numerically measured and experimentally predicted voltages is minimized. Experimentally measured voltages were obtained by injecting current between one pair of electrodes, created by applying silver paint on the top and bottom surface of the DCB specimen, and measuring voltages across the remaining electrode pairs. This process was repeated until all the electrode pairs received the current injection. Numerically predicted voltages were obtained by solving forward model which required the solution of Laplace's equation for steady-state diffusion subjected to complete electrode model (CEM) boundary conditions for a given conductivity value using FEM. The inverse problem seeks the conductivity change which when supplied to the forward model, results in matching of the numerically predcited voltages with the experimentally measured voltages. It is highly ill-posed and regularization is required to convert it into well posed problem. Here, Tikhonov regularization was used.

A number of 2D numerical simulations were performed replicating the real physical experiments. To avoid inverse crime, two different FE mesh sizes were used for forward and inverse models. A total of 18644 and 7912 elements were used for the forward and inverse model respectively. The crack length of 14 mm and thickness 0.5 mm was simulated as nearly zero conductivity elements in the mesh as shown in figure 1 (c). The stimulated specimen has the same dimensions as that of the real DCB specimen. A total of 16 electrodes of 4 mm width, equally divided on top and bottom face of the specimen were used as showm in figure 1 (b). The background conductivity and current magnitude were taken as unity. Across scheme was used for current injection and volatge measurements. On solving the forward model two sets of boundary volatges, one without crack (before damage) and one with crack (after damage), were obtained. These two sets were used to solve the inverse problem to get the EIT image using EIDORS as shown in figure 1 (d). EIT image clearly showed the crack in composite as the decrease in conductivity of the domain.

To validate this methodology, EIT was performed on real specimen. EIT measurements were taken before loading the specimen to the universal testing machine. The mode I fracture test was conducted at the constant loading rate of 1mm/min. The crack length was monitored using a travelling microscope and the test was stopped when the crack length reached to 14 mm. Again, EIT voltage measurements were taken after the crack propagation. These two sets were used for the difference imaging using EIDORS . The conductivity change map or EIT image clearely showed the crack in the form of decrease in conductivity.

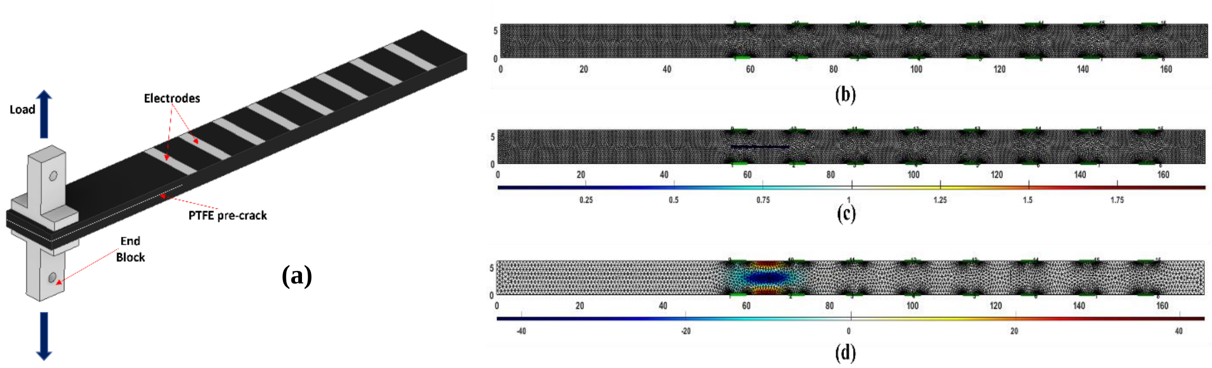

Fig. 1 – (a) Schematic showing DCB specimen with electrodes mounted on top and bottom surfaces, (b) FE mesh with no crack (before damage), each element having unit conductivity, (c) FE mesh with elements of nearly zero conducitivity at the crack position (after damage), and d) Reconstructed EIT image showing decrease in conductivity at the crack position.

3. Conclusions

This study was the first of its kind to successfully detect the interlaminar cracks or delamination produced due to mode I fracture loading in self-sensing CNF doped GFRP laminates using electrical impedance tomography. Both simulation and experiments were conducted to validate the effectiveness of the methodology.