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Using Carbon Nanofibre Sensors for In-situ Detection and Monitoring of Disbonds in Bonded Composite Joints

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Abstract

This paper focuses on the ability of carbon nanofibre (CNF) networks to in situ monitor fatigue induced disbond damage in adhesive bonded composite joints. The inclusion of CNFs in the epoxy adhesive increases its conductivity by five orders of magnitude. The improved electrical conductivity is utilized to evaluate the ability of the CNF network to monitor and detect the fatigue induced disbond damage by measuring the *in-situ* resistance changes using a four probe setup. The changes in total resistance was a function of the bulk electrical resistivity of the adhesive and the bond dimensions, which were related to the disbond length to model and determine the size of the disbond. The simple resistivity model was in good agreement with the resistance measured during fatigue testing. Good agreement was found between the optical disbond observations and the disbond length calculated using the proposed model. Finite element simulations were performed to ascertain the range of applicability of the proposed model. The simplicity of the disbond detection technique via direct current potential drop technique enables real time monitoring of crack growth in the composite structure.

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Keywords: Carbon nanofibre, adhesive, nanocomposite, damage detection, structural health monitoring.

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1. Introduction

One of the key challenge for using composites as load-bearing safety-critical structures is the need for detecting and quantifying disbonds to ensure continuing structural integrity. While adhesively bonded joints provide many advantages such as low cost, high strength to weight ratio, low stress concentration, fewer processing requirements and good environmental resistance [1], the dielectric characteristic of existing structural adhesives means that most conductivity-based techniques, such as eddy current, potential drop, and electrical impedance, are not suitable for detection of bondline flaw or damage [2]. Recent studies have shown that conductive carbon nanofillers such as carbon nanotubes (CNTs) [3, 4] or carbon nanofibres (CNFs) [5-7] can form conductive networks in polymeric materials at extremely low weight fractions while simultaneously improving the fracture toughness. These conductive networks offer a new route for *in-situ* health monitoring of adhesively bonded structures.

Nomenclature

σ_1	conductivity of the composite substrate
σ_2	conductivity of the adhesive
Δa	disbond length
t_a	adhesive thickness
t_c	composite substrate thickness
b	width of the joint
l_b	adhesive bondline length
R	resistance
R_o	initial resistance corresponding to no disband
ΔR	change in resistance due to disbond

Recently, Lim et al. [8] reported the use of CNT networks to monitor the initiation of damage in epoxy bonded lap joints under quasi-static and dynamic tensile loading. Mactabi et al. [9] studied the electromechanical response of CNT networks incorporated in bonded lap joints under tensile fatigue loading. While a short communication by Zhang et al.[10] is the only study reported on utilizing CNT networks in epoxy polymer to monitor and predict the underlying crack growth damage during mode I fatigue testing. They successfully demonstrated that changes in resistance induced by mode I fatigue crack growth in bulk epoxy samples could be used to determine the size of the underlying damage. However, the potential application of this technique to monitor and detect fatigue crack growth in bonded composite joints has not been studied to date.

Considering that CNFs may be an excellent alternative to CNTs due to their wide availability and lower cost [11], the present study focuses on the use of CNFs to improve the electrical conductivity of an epoxy nanocomposite adhesive to enable the monitoring and detection of fatigue crack growth in bonded joints. The electrical response of the nanocomposite adhesive is measured *in-situ* during mode I fatigue crack growth using a DC potential drop technique. A simple resistivity model is developed to relate the size of the disbond with the electrical resistance. Finite element analyses are performed to verify the analytical model and to investigate the range of applicability of the simple resistivity model.

2. Materials and Experimental Details

The epoxy adhesive used for bonding composites was blend of five parts of bisphenol A ‘105’ and one part of the hardener ‘206’ (from West System). Commercially-available vapour-grown carbon nanofibres, Pyrograf® - III PR-24-HHT and supplied by Applied Sciences Inc., USA, were employed as the nanofiller. Carbon fibre composite substrates were manufactured using 12 plies of unidirectional T700 carbon fibre/epoxy prepreg (VTM 264 supplied by Applied Composites Group). The composite substrates, with dimensions of 100 mm x 100 mm x 2.5 mm, were cured and consolidated in an autoclave at 120 ^{o}C for 1 hr., in accordance with the manufacturer’s recommended cure process. The substrate surfaces were abraded using 320 grit aluminium oxide abrasive paper, cleaned under running tap water for about 2 minutes, degreased with acetone, and finally cleaned with distilled water to remove any surface