Self-Sensing Carbon Nanotube Composites: Synthesis and Characterization

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Key words: Multifunctional Composites, Carbon Nanotubes, Electrophoretic Deposition, Sensing, Structural Health Monitoring.

Summary. *This presentation highlights recent research in the development of multi-scale hybrid composites for applications for in situ self-sensing of mechanical and thermal loading in advanced fiber composites.*

1 INTRODUCTION

As the field of composite materials based on nanoscale reinforcements continues to mature, recent attention has been given to multi-scale hybrid composite material systems, where nanoscale reinforcements are combined with traditional continuous fibers [1]. Through the nanoscale hybridization new functionality can be imparted to existing advanced composite systems. Recently the authors have established a novel and scalable technique towards hybridization of carbon nanotubes with carbon and glass fibers using an electrophoretic deposition technique. Integration of nanotubes into the fibers can result in the formation of nerve-like electrically conducting networks that surround the advanced fibers. Because the conductivity of the network is dominated by the nanotube/nanotube tunneling resistance this has opened-up opportunities for sensing. Mechanical and chemical changes that

2 SYNTHESIS AND PROCESSING OF MULTI-SCALE COMPOSITES

Electrophoretic deposition (EPD) is an industrially-scalable coating process that is utilized in applications ranging from automotive to electronics production. Key benefits of the process include low-energy use and the ability to homogenously coat complex shapes. This technique has been extended to deposit nanotubes onto carbon [2] and glass [3] fibers by first creating an aqueous suspension of carbon nanotubes with ozone/polyethyleneimine (PEI) surface functionalization. The PEI results in both a highly stable dispersion but also facilitates bonding between the carbon nanotube and the epoxy polymer matrix. Carbon nanotube modification results in significant increases in matrix-dominated mechanical properties and laminate electrical conductivity. As-produced composite laminates also show electrical anisotropy due to preferential deposition of the carbon nanotube film in the fiber direction.

3 IN SITU SENSING OF STRAIN, DAMAGE AND THERMAL TRANSITIONS

One of the unique properties of carbon nanotube-based composites is the formation of electrically conductive networks at relatively low carbon nanotube concentrations. This unique ability has enabled the use of nanocomposites as sensors where their piezoresistivity, the change of resistivity/conductivity with applied dimensional change, can be exploited.

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Recently we have developed both DC and AC approaches to sensing of deformation and damage in fiber composites [4]. As cracks form in the advanced fiber composite containing carbon nanotubes the percolating network severs conducting pathways resulting in permanent changes in electrical properties. Opportunities for structural health monitoring will be discussed.

Since the nanocomposite bulk resistivity is dominated by the tunneling resistance at nanotube/nanotube junctions the nanotubes effectively act as a network of sensors that can detect thermal transitions and other thermochemical changes in situ. Changes with temperature result in both volumetric thermal expansion as well as physical changes in the polymer. The nanocomposite thermoresistive behavior is, therefore, strongly dependent on the nanotube concentration, thermal expansion and polymer segmental motion. Recent research has shown that we can utilize the distributed network of sensors to sense changes in the cure of the polymer matrix and also key thermal transitions. The thermoresistive behavior of the composites is highly non-linear and local inflection points during combined thermoresistive and thermomechanical characterization correspond directly to the glass transition temperature of the polymer matrix.

4 ACKNOWLEDGEMENTS

This research is funded by the National Science Foundation Grant #1254540, (Dr. Mary Toney, Program Director), Air Force Office of Scientific Research (AFOSR) Young Investigator Grant FA9550-09-1-0218 (Dr. Byung-Lip Lee, Program Director) and the US Army Program Executive Office: Soldier and the Army Research Laboratory under Cooperative Agreement Number W911NF-06-2-011.

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