Mechanical Engineering Thesis Defense

Electrical and Mechanical Characterization of Hybrid Buckypaper/Carbon Fiber Reinforced Polymer Matrix Composites

School for Engineering of Matter, Transport and Energy

Kartik Tripathi

Advisor: Dr. Aditi Chattopadhyay

Abstract

Carbon nanotubes (CNTs) have emerged as compelling materials for enhancing both electrical and mechanical properties of aerospace structures. Buckypaper (BP), a porous membrane consisting of a highly cross-linked network of CNTs, can be effectively integrated with carbon fiber reinforced polymer (CFRP) composites to simultaneously enhance their electromagnetic interference (EMI) shielding effectiveness (SE) and mechanical properties. In existing literature, CNT based nanocomposites are shown to improve the flexural strength and stiffness of CFRP laminates. However, a limited amount of research has been reported in predicting the EMI SE of hybrid BP embedded CFRP composites.

To characterize the EMI shielding response of hybrid BP/CFRP laminates, a novel modeling approach based on equivalent electrical circuits is employed to estimate the electrical conductivity of unidirectional CFRP plies. This approach uses Monte Carlo simulations and accounts for the effects of quantum tunneling at the fiber-fiber contact region. This study specifically examines a signal frequency range of 50 MHz to 12 GHz, corresponding to the very high to X band spectrum. The results indicate that at a frequency of 12 GHz, the longitudinal conductivity decreases to around ~3,300 S/m from an initial DC value of 40,000 S/m, while the transverse conductivity concurrently increases from negligible to approximately ~12.67 S/m. These results are then integrated into Ansys High Frequency Structure Simulator (HFSS) to predict EMI SE by simulating the propagation of electromagnetic waves through a semi-infinite composite shield representative volume element. The numerical simulations illustrate that incorporating BP allows for significant improvements in SE of hybrid BP/CFRP composites. At 12 GHz signal frequency, for example, the incorporation of a single BP interleave enhances the SE of a [90,0] laminate by up to ~64%, while the incorporation of two BP interleaves in a [90,0,+45,-45,0,90]s balanced symmetric laminate enhances its SE by ~20% . This enhancement is due to the high conductivity of BP at high frequencies.

Additionally, to evaluate the flexural property enhancements due to BP, experimental three-point bend tests were conducted on different configurations of hybrid BP/CFRP laminates, and their strength and stiffness were compared with the non-BP samples. Micrographs of failed samples are acquired using an optical microscope, which provides insights into their underlying damage mechanisms. Fractography analysis confirms the role of BP in preventing through-thickness crack propagation, attributed to the excellent crack retardation properties of CNTs.

April 12, 2024; 1:00 PM; PSH 331

Zoom Link: https://asu.zoom.us/j/83838035365

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