Abstract:

Composite materials play a pivotal role in industries such as automotive, aerospace, and marine, owing to their lightweight structure, high stiffness, and exceptional corrosion resistance. While carbon fiber composites offer many advantages, their lack of multifunctionality limits their broader application. Hybrid nanocomposites, integrating nanoscale reinforcements like carbon nanotubes (CNTs), address these challenges by enhancing mechanical, thermal, and electrical properties while mitigating issues such as delamination and crack propagation.

This research focuses on the fabrication of hybrid composites reinforced with carbon fiber prepreg and CNT aerogel ‘sock’ material. The multifunctional properties of these composites were evaluated through a series of tests, including three-point bending, electrical conductivity, and electromagnetic interference (EMI) shielding, with results compared to control composites. Given the structural significance of features like holes in aerospace applications, open-hole tensile tests were performed to assess damage tolerance and mechanical behavior around stress-concentrated areas. To further understand the fracture mechanisms, Scanning Electron Microscopy (SEM) was employed to analyze fracture behavior and patterns, while computed tomography (CT) scans were used to study material responses around damaged regions.

The properties of nanotube-reinforced composites were found to depend on key nanotube parameters, such as dispersion, alignment, and waviness. However, the relative significance of these parameters remains uncertain. To address this, simulations were conducted using representative volume elements (RVEs) with varying combinations of these nanotube parameters. Virtual testing and analysis of variance identified the factors influencing composite mechanical properties. Additionally, a dual multiscale simulation approach was employed, coupling local and global scale models. A digital twin approach was used to generate the local scale nanotube model, where nanotube geometries were traced from SEM images to enhance simulation accuracy. The findings reveal the excellent performance of the hybrid composite and the manufacturing/structure/property fundamental relationships, positioning CNT-reinforced hybrid composites as promising candidates for aerospace applications requiring lightweight, high-performance materials.