Electrical Conductivity Modeling and Validation in Unidirectional Carbon Fiber Reinforced Polymer Composites

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Abstract

Carbon fiber (CF) reinforced polymer composites (CFRP) have begun to replace Al-Zn-Mg alloys in applications which require high strength-to-weight ratios. While Al-Zn-Mg alloys have isotropic electrical and thermal conductivity, CFRP properties are highly anisotropic. The anisotropy is a result of the manufacturing process of CFRP composites which involves melt crystallized extrusion techniques that impart an inherent directionality to the CFs and hence the associated material's properties; in particular, the electrical and thermal conductivities. For example, polymer components in CFRP possess an electrical conductivity (1) of ~1x10^(-14) S/m while the CFs are a relative conductor with values (2) of 1x10^(3) S/m. The composites by themselves have electrical conductivities of ~30 S/m in the direction of the fiber, while 1x10^(-3) S/m transverse to the fiber (3) creating engineering challenges to the design, development and applications of parts constituting CFRP.

Electrical conductivity was modeled across the entire CF loading range (from neat polymer to 100% volume fraction CF) using COMSOL Multiphysics®. A representative volume element (RVE) consisting of a 100µmx120µmx100µm composite 'box' was first created. CFs were placed inside this box, parallel to the XY plane while filling the voids with polymer. A percolating model was used to simulate the higher loading values of CF. The percolating model treated the polymer as an insulator and added a contact resistance between CF as studied by Mohiuddin and Hoa (5). A non-percolating model was used to simulate the lower loading values of CF. This was achieved by treating the polymer as a semi-conducting material where the electrical conductivity within the polymer was modeled after Boggs (4). The physics was programmed into the model at the macroscopic and microscopic scale using a Java interface. Modeling results from the above approach nicely validated the conductivity reported in experimental studies across the entire CF loading range (from neat polymer to 100% volume fraction CF). The results from the RVE can be taken to model the electrical conductivity of structurally complex CFRP parts.

Reference

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