Fracture, Tribology, and Conductivity of Electric Field-Aligned CNF/Epoxy Nanocomposites

Amit Chanda (2017MEZ8319)

Abstract

Epoxy resins have become one of the most used polymeric materials in several engineering applications such as structural composites, adhesives, and tribological coatings. This is due to their superior adhesive properties, mechanical strength, chemical resistance, and their ability to be modified. Despite these benefits, the brittleness, low fracture toughness, and low conductivity restrict its use in the abovementioned industrial applications. The use of carbon nanofillers showed possibilities of improving the performance of epoxy to some extent, however, there is a necessity for better design and development of epoxy nanocomposites for enhanced performance based on the nanofiller dispersion and directional orientation. From the above perspective, electric field-aligned carbon nanofiber (CNF)/epoxy nanocomposite was fabricated, and the fracture, tribological, conductivity as well as other multi-functionalities was investigated.

The analysis of the tensile, compressive, and thermomechanical properties of random and aligned nanocomposites revealed that the mechanical properties improved with CNF addition and their longitudinal alignment. The nonlinear tensile responses of nanocomposites were accurately captured by the finite element analysis of a three-dimensional representative volume element (3D-RVE) model, which considered fiber structure, alignment, concentration, and loading condition.

The DC electrical conductivity and thermal conductivity of nanocomposites increased with CNF addition and alignment. Electrical conductivity of 0.6 wt% aligned nanocomposites enhanced by 7 and 2 orders of magnitude, while the thermal conductivity improved by 77% and 44% compared to pure epoxy and random nanocomposites, respectively, for the same filler content. Fiber-fiber contact based sanalytical model wase developed for the electrical conductivity prediction of polymer composites, which was validated with our experimental results as well as with the literature data.

The effect of CNF alignment on the tribological behavior of epoxy nanocomposites was studied by carrying out friction and wear tests keeping the sliding direction normal to nanofiber orientation. At 1wt% CNF content, the aligned nanocomposites exhibited 25 and 7 times

improvement in wear resistance compared to pure epoxy and random composites, while the friction coefficient reduced from 0.6 for pure epoxy to 0.44 and 0.24 for random and aligned composites, respectively.

The effect of through-thickness CNF alignment was also investigated further on the enhancement of mode-I, mixed mode, and mode-II fracture toughness of CNF/epoxy adhesive joints. The CNF alignment increased the fracture toughness under all modes of fracture (increased by 195%, 20%, and 31.5% for mode-I, mixed-mode, and mode-II, respectively), however, a more profound effect was observed under mode-I. The numerically predicted load-displacement responses for all joints matched satisfactorily with experimental findings.

Finally, the electromechanical responses of bulk nanocomposites and nano-adhesive joints were investigated. The nanocomposites showed excellent strain sensing capability at all CNF concentrations, however, the highest sensing capability was observed at 0.4 wt% CNF content. Moreover, the alignment of CNF was found to enhance the crack growth sensing capability of nano-adhesive joints.

Overall, aligned epoxy nanocomposites have been designed and fabricated with excellent mechanical, electrical, tribological, and fracture behavior along with damage-sensing capability. The predictive models for mechanical and electrical properties have also been presented. The fabricated nanocomposites can be used as a matrix for structural composites, adhesives, coatings, and other load-bearing applications.