Mechanical Properties of Polymer Nano-composites

by

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Abstract

Thermoset polymer composites are increasingly important in high-performance engineering industries due to their light-weight and high specific strength, finding cutting-edge applications such as aircraft fuselage material and automobile parts. Epoxy is the most widely employed thermoset polymer, but is brittle due to extensive cross-linking and notch sensitivity, necessitating mechanical property studies especially fracture toughness and fatigue resistance, to ameliorate the low crack resistance. Towards this end, various nano and micro fillers have been used with epoxy to form composite materials. Particularly for nano-fillers, the 1-100 nm scale dimensions lead to fascinating mechanical properties, oftentimes proving superior to the epoxy matrix. The chemical nature, topology, mechanical properties and geometry of the nano-fillers have a profound influence on nano-composite behavior and hence are studied in the context of enhancing properties and understanding reinforcement mechanisms in polymer matrix nano-composites.

Using carbon nanotubes (CNTs) as polymer filler, uniquely results in both increased stiffness as well as toughness, leading to extensive research on their applications. Though CNTs-polymer nano-composites offer better mechanical properties, at high stress amplitude their fatigue resistance is lost. In this work covalent functionalization of CNTs has been found to have a profound impact on mechanical properties of the CNT-epoxy nano-composite. Amine treated CNTs were found to give rise to effective fatigue resistance throughout the whole range of stress intensity factor, in addition to significantly enhancing fracture toughness, ductility, Young's modulus and average hardness of the nano-composite by factors of 57%, 60%, 30% and 45% respectively over the matrix as a result of diminished localized cross-linking.

Graphene, a one-atom-thick sheet of atoms is a carbon allotrope, which has garnered significant attention of the scientific community and is predicted to out-perform nanotubes. In the last few years, work has been done by researchers to study bulk mechanical properties of graphene platelets in polymer matrix. This thesis reports the extensive improvements observed in fatigue resistance and fracture toughness of epoxy using graphene platelet as a filler in very small quantities. Though significant property improvements like 75% increase in fracture toughness and 25-fold increase in fatigue resistance were observed for graphene epoxy nano-composites, the toughening mechanisms could not be delineated without thermo-mechanical and micro-mechanical tests. In this work, the bulk mechanical properties of graphene platelet-

polymer nano-composites are studied and presented and the toughness mechanisms are identified by fractography, differential scanning calorimetry, and Raman spectroscopy; and then compared to predictions by theoretical models. Strong adherence to the matrix was found to be the key mechanism responsible for the effective reinforcement provided by graphene to the polymer. The strong graphene platelet-matrix interface also leads to extensive crack deflection, which was observed to be the major toughening mechanism in the nano-composite.

In this thesis, the bulk mechanical property results are complemented by in-depth characterization of filler-polymer interfacial interactions and interphase formation using a battery of techniques including Raman spectroscopy and atomic force microscopy. Theoretical and empirical models proposed by Faber & Evans and Pezzotti were critically studied and applied. Pezzotti's model was found to corroborate well with experimental results and provided insight into enhancement mechanisms and explains the mechanisms underpinning the toughness loss at high graphene platelet weight fraction. The thesis provides conclusive evidences for the superiority of graphene as a filler for reinforcing polymer matrices.

In conclusion, the thesis presents a thorough investigation of one- and two-dimensional carbon nanomaterials as fillers for high-performance polymer nano-composites. The extensive studies performed on graphene provide a strong foundation for graphene as a potential candidate for reinforcing polymers. The superior performance of graphene as a filler is attributed to graphene's high specific surface area, two-dimensional sheet geometry, strong filler-matrix adhesion and the outstanding mechanical properties of the sp^2 carbon-bonding network in graphene. The improved mechanical properties of the graphene-polymer nano-composites, concurrent with the cost-effective production are both vital requirements of the industry in adoption of high strength-to-weight ratio polymer composites for various structural applications.