Graphene-based Composite Materials

by

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ABSTRACT

We investigated the mechanical properties, such as fracture toughness (K_{Ic}), fracture energy (G_{Ic}), ultimate tensile strength (UTS), Young's modulus (E), and fatigue crack propagation rate (FCPR) of epoxy-matrix composites with different weight fractions of carbon-based fillers, including graphene platelets (GPL), graphene nanoribbons (GNR), single-walled carbon nanotubes (SWNT), multi-walled carbon nanotubes (MWNT), and fullerenes (C60). Only ~0.125 wt.% GPL was found to increase the K_{Ic} of the pure epoxy by ~65% and the G_{Ic} by ~115%. To get similar improvement, CNT and nanoparticle epoxy composites required one to two orders of magnitude greater weight fraction of nanofillers. Moreover, ~0.125% wt.% GPL also decreased the fatigue crack propagation rate in the epoxy by ~30-fold.

The E value of 0.1 wt.% GPL/epoxy nanocomposite was ~31% larger than the pure epoxy while there was only an increase of ~3% for the SWNT composites. The UTS of the pristine epoxy was improved by ~40% with GPLs in comparison with ~14% enhancement for the MWNTs. The K_{Ic} of the GPL nanocomposite enhanced by ~53% over the pristine epoxy compared to a ~20% increase for the MWNT-reinforced composites. The results of the FCPR tests for the GPL nanocomposites showed a different trend. While the CNT nanocomposites were not effective enough to suppress the crack growth at high values of the stress intensity factor (ΔK), the reverse behavior is observed for the GPL nanocomposites. The advantage of the GPLs over CNTs in terms of mechanical properties enhancement is due to their enormous specific surface area, enhanced adhesion at filler/epoxy interface (because of the wrinkled surfaces of GPLs), as well as the planar structure of the GPLs.

We also show that unzipping of MWNTs into graphene nanoribbons (GNRs) enhances the load transfer effectiveness in epoxy nanocomposites. For instance, at ~0.3 wt.% of fillers, the Young's modulus (E) of the epoxy nanocomposite with GNRs increased by ~30% compared to their MWNTs counterpart. The ultimate tensile strength (UTS) for ~0.3 wt.% GNR composites showed ~22% enhancement compared to the MWNT composites at the same loading fraction of fillers (at ~0.3 wt.%). Our results

show that unzipping effect can be used to transform carbon nanotubes into graphene nanoribbons, which are far more effective than the baseline nanotube as a nanofiller in nanocomposites.

The mechanical properties of fullerence (C60) epoxy nanocomposites at different loading fractions (wt.%) of fullerene fillers in the pristine epoxy was also studied. Fullerene (C60) fillers demonstrated good potential to improve the mechanical properties of epoxy composites. However the required C60 loading fractions were ~1% which are still an order of magnitude higher than that for graphene platelets (~0.1%). This again illustrates the superiority of graphene as a structural reinforcement additive for epoxy polymers at low nanofiller loadings.

While the main focus of this work has been on epoxy polymers, initial results with ceramic matrix and metal (aluminum) matrix composites were also generated. These results demonstrate that GPL are highly effective in enahncing the fracture properties of silicon nitride ceramics. The fracture toughness of the baseline silicon nitride matrix increased by ~235% (from ~2.8 to ~6.6 MPa.m1/2) at ~1.5% GPL volume fraction. However the results were disappointing for aluminim matrix composites. Compared to the pure aluminum, the graphene-aluminum composites showed decreased strength and hardness. This is explained in the context of enhanced aluminum carbide formation with the graphene filler.

These results indicate that Graphene Platelets (GPL) show strong potential as a nanofiller for epoxy nanocomposites and can provide a performance comparable to other forms of nanofillers at a significantly lower nanofiller loading fraction.