

Insights into unique strengthening mechanism of electrostatically tethered nanoplatelets and multi-walled carbon nanotubes in epoxy

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Abstract

A number of recent studies have shown that plate-like and rod-like nanoparticles can be co-dispersed to prepare polymer nanocomposites with “synergistically improved” bulk properties, even at low particle concentrations. We previously reported that multi-walled carbon nanotubes (MWCNTs) dispersed using α -zirconium phosphate (ZrP) nanoplatelets in a glassy epoxy show a unique improvement in strength and ductility that could not be explained based on continuum-level descriptions of particle-level reinforcement. In this work, we have used rheology as a microstructural tool to probe the microstructure and interactions for this hybrid system in an uncured epoxy pre-polymer fluid. The results are compared to recent studies of model suspensions containing the same independent nanoparticle fillers to more clearly differentiate between particle-level and mesostructural processes. The linear viscoelastic results show that the ZrP-assisted dispersion approach fully disentangles and stabilizes the MWCNTs in epoxy. When subjected to large amplitude oscillatory shear or steady shearing, the hybrid suspensions show pronounced strain-hardening and shear thickening behaviors, respectively, that were not observed with suspensions containing either individual component. The non-linear behavior suggests that the ZrP nanoplatelets are directly tethered to the disentangled MWCNTs and serve as mechanically robust junctions that inter-connect the system. In the solid state, this hybrid network is proposed to have sufficient mechanical integrity to delocalize stress concentrations near flaws and cracks in the epoxy matrix, which would account for the unique strengthening behavior observed in this system. The model provides several potential design considerations to optimize this hybrid particle approach for preparation of high-performance nanocomposite materials.