Soft Materials Approaches to Carbon Nanotubes: Gels, Composites and Intracellular Reorganization

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Carbon nanotubes combine low density with exceptional mechanical, electrical, and optical properties. It is highly desired to harness these intrinsic nanoscale properties for macroscale applications. I will describe surface modification assisted self-assembly of single-walled carbon nanotubes into macroscopic, shape and size tunable, ultra-lightweight and electrically conducting networks – hydrogels and aerogels – with large surface area. The mechanical properties of these aerogels are dictated by free rotation and sliding of nanotubes about the junctions, which unfortunately make them fragile. Interestingly, coating the junctions and struts with various two-dimensional materials such as graphene and hexagonal boron nitride suppress rotation and sliding at the junctions and stiffen the struts, enhancing Young's moduli and imparting emergent superelasticity, fatigue resistance and creep resistance that is preserved over a broad temperature range (-100–500˚C). Owing to their microstructure, both uncoated and coated aerogels are suitable for diverse applications. For example, we have used these aerogels to enhance elastic modulus of thermoplastic polymers by at least 40,000%. These materials also show high capacitance that remains stable over thousands of charge/discharge cycles even at high rates exceeding 1 V/s and under 90% compression, allowing us to construct supercapacitors with exceptional volumetric capacitance. Furthermore, the aerogels can be decorated with noble metals and metal oxides to fabricate electrodes for fuel cells with high current density and stability, highly visible-light photoactive composites using ultraviolet-active photocatalysts, and pseudocapacitors without compromising the mechanical properties of the underlying scaffolds. Our fabrication process also allows densification of these aerogels to at least 400 mg/mL, reaching high Young's moduli of 0.4 GPa, while maintaining the microstructure, thermomechanical responses, and ultralow loss (≈0.01–0.04) of low density aerogels. Finally, the surface coating allows differential delivery of nanotubes inside cells, and hence intracellular reorganization.

This work has been supported by the NSF, Alfred P. Sloan Foundation, the donors of the American Chemical Society Petroleum Research Fund, the Korea Institute of Energy Research (KIER), DARPA, Army Research Office, and Bayer Materials.