Hierarchical Composite Materials: structural and multifunctional opportunities

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Many studies have reported the production and characterisation of nanocomposites; carbon nanotube (CNT) and now graphene-based systems have attracted particular attention due to the excellent intrinsic properties of individual perfect nanostructures. Although promising results have been obtained, progress has been limited by several factors, including nanocarbon synthesis (quality), dispersion, alignment and interfacial bonding. It remains challenging to exploit the intrinsic properties in macroscopic structures. One strategy is to assemble CNT-based fibres as an alternative to conventional composite reinforcements. Performance can be improved by increasing the individualization of long CNTs and modifying their mutual interactions, using new reductive chemistries which generate reactive solutions of 'nanotubide' ions. Encouraging properties, including high strain to failure and toughness can be obtained, suggesting promise as future high performance reinforcements. However, in the shorter term, the introduction of nanocarbons into conventional fibre composites, to form a hierarchical or multiscale structure, can be targeted to address critical (matrix-dominated) failure modes, notably longitudinal compression and interlaminar performance.

The presence of nanomaterials at the fibre surface is likely to enhance the fibre/matrix interfacial strength, thus improving the delamination resistance. Reinforcement radial to the fibres, extending into the surrounding matrix, will inhibit fibre microbuckling, which is the critical failure mode under compressive loading. Direct growth of CNTs on carbon fibres is appealing but requires particular strategies to avoid damage to the primary fibres, and to control the CNT length which otherwise limits fibre volume fraction. Continuous processes for CNT grafting provide larger quantities for composite testing and could be implemented in line industrially. Other platelet nanomaterials can also be assembled at the fibre-matrix interface to modulate composite failure.

Rather than locating the nanofiller at the primary fibre surface, nanotubes can be dispersed throughout the matrix. This approach is relatively simple and widely applied at low loadings; however, for higher loadings (up to 20wt% CNT in resin), we have developed a powder technique that avoids self-filtration and problems with high viscosities. Controlled heterogeneity is helpful to maximize toughness, and can be mapped using new characterization techniques. As an alternative to nanoparticle-filled systems, we have created a new hierarchical composite structure by embedding structural carbon fabric into nanostructured carbon aerogels to produce a bicontinuous monolithic nanocarbon reinforced matrix. Such motifs have provided especially effective for multifunctional structural supercapacitors, in which a structural composite component simultaneously operates as an electrochemical energy storage device. A prototype car boot / trunk lid has been fabricated, with partners, as an illustration of the potential application in electric vehicles.

Short Biography

Milo Shaffer is Professor of Materials Chemistry at Imperial College London, and co-Director of the London Centre for Nanotechnology. He has extensive experience of carbon and inorganic nanomaterials synthesis, modification, characterization, and application, particularly for nanocomposite and hierarchical systems. Key applications are in structural composites, electrochemical electrodes, and functional thin films. MS completed his PhD and a Research Fellowship at the University of Cambridge, and has previously worked as a materials technology consultant in the areas of new technology development and exploitation. He has filed around thirty patents/applications, many of which have been licensed commercially. He has published well over 160 peer-reviewed papers with a total of over 11,000 citations, h-Index 50. He was awarded the Royal Society of Chemistry (RSC) Meldola medal in 2005, a prestigious EPSRC Leadership Fellowship in 2008, and RSC Corday-Morgan medal in 2014. He sits editorial boards of Nanocomposites, Materials Today Chemistry, & International Materials Reviews, and has helped to organise a number of international nano-related meetings, including several of the Nanotube 'XX series, a Faraday Discussion on Advanced Carbon, and the CNP-COMP meetings.