Engineering Low-Dimensional Carbon for Aerospace Composites

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Carbon nanotubes and graphene show considerable promise for composites, particularly in aerospace, due to their intriguing combination of physical properties (Figure 1). At low loadings these materials may be used as matrix modifiers, imparting electrical conductivity (e.g. for anti-static lightning strike and EM shielding applications), thermal conductivity and health monitoring. At higher loadings, these materials may act as the main structural reinforcing elements taking advantage of their high modulus (~ 1 TPa) [1]. The uptake for these materials however has been frustrated in obtaining suitable material and then formulating them into a bulk system. I will initially present our work on establishing the design rules for low dimensional carbon nanocomposites in terms of electrical, thermal and structural reinforcement and then show how these design rules can be transferred to bulk systems.

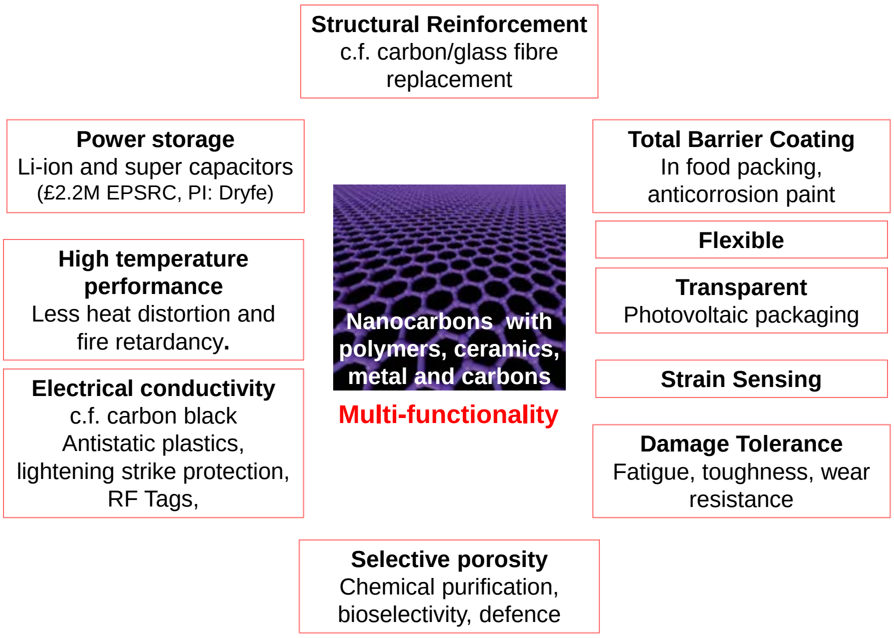

Figure 1: The potential applications of nanotubes and graphene in composites.

Carbon nanotubes are excellent fillers for electrically conducting composites, where the nanotubes form a percolated network that acts as a conducting pathway to carry current through the insulating polymer matrix. The properties of these composites are found to depend significantly on the aspect ratio and processing of the carbon nanotubes, as predicted by theory. We have found that that electrical percolation can be achieved at loadings as low as 0.0025 wt% [2] and the conductivity of such networks are high sensitive to strain as deformation pulls the networks apart, providing potential routes to health monitoring [3].

We have studied the micromechanics of graphene composites using Raman spectroscopy to map the strain in model composite systems comprising of single graphene flakes [4,5,6]. The graphene behavior in these systems can be modelled by conventional composite theory despite being an atomic layer (Figure 2). For example, graphene follows the shear lag theory for short fibers, with a critical minimum flake length of 3 microns being required for good reinforcement. We have also shown that the modulus of graphene flakes reduces with increasing thickness due to the poor internal stress transfer between graphene layers [7]. We have used this understanding of graphene micromechanics to produce bulk systems by solvent casting (PVOH-graphene composites, [8]), twin screw compounding (PMMA-graphene [9]) and hot curing (e.g. epoxy-graphene). We have explored the role of polymer-graphene interface on the properties of these composites through using different surface functionalities. The role of flake length has also been studied by using few layer graphene with controlled diameters from 100 nm to 20 microns. The 20 micron diameter, few layer thick flakes show particular promise as they are long enough to give good reinforcement, yet do not aggregate at high loadings (> 10 vol%) [10].

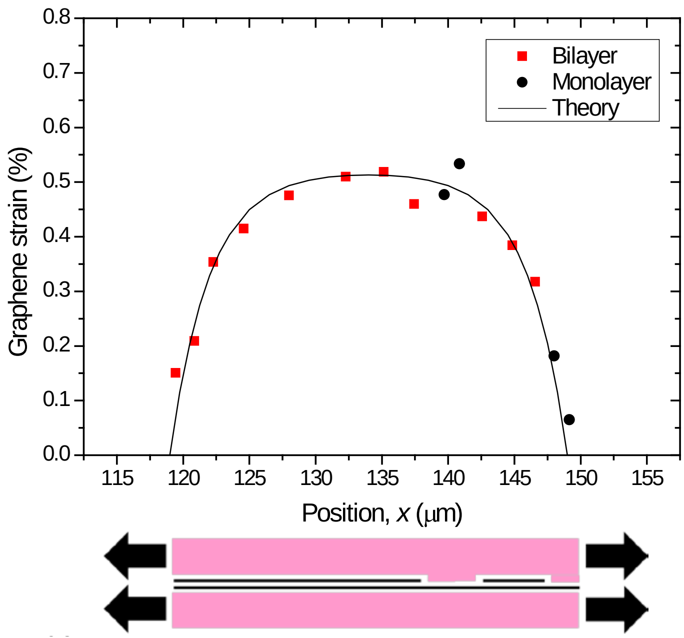

Figure 1: The strain along a graphene reinforcement in a composite measured using Raman spectroscopy. The composite has a global strain of 0.6 % and the strain in the graphene reinforcement is found to follow shear lag theory typically used for conventional macroscale fibres.

Finally, we have found that our studies on nanocarbons has allowed us to develop a new understanding of the structure and micromechanics of traditional carbon fibre, enabling us to develop new models for their performance.

References

[1] RJ Young *et al.*, Compos. Sci. Technol., 82, 1459-1476 (2012)
[2] A Moisala *et al.*, Compos. Sci. Technol., 66, 1285-1288 (2006)
[3] A de la Vega *et al.*, Compos. Sci. Technol., 71, 160-166 (2011)
[4] L Gong *et al.*, Adv. Mat., 24, 2694- (2010)
[5] RJ Young *et al.*, ACS Nano, 4, 3079-3084 (2011)
[6] A. Raju *et al.*, Adv. Functional Mat., 10.1002/adfm.201302869 (2014)
[7] L Gong *et al.*, ACS Nano, 6, 2086-2095 (2012)
[8] ZL Li, RJ Young, IA Kinloch, ACS Applied Materials & Interfaces, 2, 456-463 (2013)
[9] C Valles *et al.*, Compos. Sci. Technol., 88, 158-164 (2013)
[10] C Valles et *al.*, Faraday Discussions, FD173, Accepted