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Multi-Scale Mechanics and Electrical Transport in a Free-Standing 3D Architecture of Graphene and Carbon Nanotubes by Pressure Assisted Welding

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Abstract

A free-standing three-dimensional hybrid was fabricated by welding graphene nanoplatelets and carbon nanotubes by *high temperature and high pressure assisted sintering*. A hierarchical architecture was formed, comprising of multiple layers of graphene with a network of nanotubes occupying the inter-layer space. Multi-scale mechanics of the nanohybrid was probed by nanoindentation, micro-indentation and dynamic mechanical test. *In situ* indentation was performed inside a scanning electron microscope to observe deformation of the 3D hybrid in real time. CNTs act as anchors between graphene layers and resist the pull out of graphene flakes, thereby arresting crack nucleation and propagation. Dynamic mechanical testing of the 3D material revealed damping capability, with impressive loss tangent values (as high as 0.8). Damping behavior of the 3D hybrid is ascribed to rippling, inter-layer van der Waals spring like action, buckling of CNTs and sliding of graphene layers. Electrical transport phenomena were also probed for potential device application of this 3D nanohybrid material. Anisotropy in current-voltage characteristics was observed, with superior conductivity (more than 10 times) along the graphene layers. Nevertheless, out of plane electrical conductivity was higher than pure graphene monolith fabricated by the same technique, as CNT pillars connecting the adjacent graphene layers act as conduction pathways. Therefore, increasing CNT content in the hybrid can help compensate for anisotropy in graphene's properties. This study reports an effective strategy to engineer robust and effective load bearing large-scale 3D nanoarchitectures for multifarious applications, such as in turbomachinery, nano-microelectromechanical systems, scaffolds for tissue engineering, sensors, precision systems, acoustic devices etc.

Keywords: Graphene, Carbon Nanotube, Welding, 3D architecture, Multi-scale mechanics, Electrical transport