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Assessing MWCNT-graphene surface energy through *in situ* SEM peeling

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ABSTRACT

Carbon nanotubes (CNTs) are envisioned as ideal filaments for next-generation nanocomposites due to their high strength-to-weight ratios. However, while individual nanotubes are strong, interfaces between tubes cannot bear significant load due to the weak van der Waals forces that govern their behavior. Premature interfacial failure could thus counteract the inherent strength of carbon nanotubes and, in turn, prevent CNT-based composites from achieving optimal mechanical performance. To increase the load bearing capacity of these interfaces, interlayer crosslinking schemes have been proposed using chemical functionalization. For instance, introduction of hydrogen bonds or additional van der Waals bonds between tubes could improve load transfer between CNTs. While introducing chemical groups on CNT surfaces may enhance intermolecular interactions at these interfaces, a means of quantitatively evaluating changes in interlayer adhesion as a result of to these treatments needs to be defined. In addition, as sizes of CNTs will inherently vary within a composite, it is important that such energy measurements be normalized irrespective of tube dimensions.

Here we report an experimental peeling technique that can be used to measure the adhesion energy between multiwalled carbon nanotubes (MWCNTs) and graphene. Peeling tests conducted *in situ* a scanning electron microscope allow direct visualization of the nanoscale peeling process which, in turn, enables adhesion energy to be estimated through classical fracture analysis. The applicability of this analysis is validated by finite element simulations with boundary conditions derived from experiments. The effective contact width between tubes and graphene is estimated *via* atomistic simulations, providing a means to normalize interaction energy per unit area. The surface energies of bare MWCNT-graphene interfaces found in this study compare favorably with theoretical and experimental values reported for graphite. This method can serve as a foundation for evaluating the enhancements afforded by chemical functionalization, which is a critical step toward the development of strong, lightweight composites that effectively utilize the full mechanical potential of CNTs.