SPM probing of interfacial strengths of individual carbon nanotubes in a polymer matrix

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The discovery of the outstanding mechanical properties of carbon nanotubes has led to an investigation of their inclusion as additives in ultra-strong nanocomposites. Notwithstanding bulk measurements of the properties of such nanocomposites, prior to this work the detailed microscopic understanding of the nanotube/polymer interfacial strength was left to the realm of theoretical predictions. We have developed two novel SPM-based techniques which measure, for the first time, the direct pull-out forces of individual nanotubes in a polymer matrix.[1,2] In one approach, the nanotubes are mixed into an epoxy resin using a procedure which results in a porous structure with nanotubes bridging the pores and embedded into the polymer matrix. The SPM tip is used to drag these nanotubes out of the film, while simultaneously measuring the force, whereas embedded length is measured with the aid of TEM. In the second approach, a nanotube attached to a Si SPM probe was pushed into a polymer melt, and pulled out from the hardened polymer after cooling. Here, the SPM measurement was used to evaluate both the forces and embedded length.

Our results verify the predicted high nanotube-polymer interfacial strength, while revealing interesting behavioral trends. For instance, unit interfacial strength drops with embedded length, as seen in composites of macroscopic fibers.

Figure 1 shows an example of a pullout trace, obtained according to the second approach. We can see that the trace reaches a maximum pullout force and then follows a regular monotonic decrease. This is very different from the behavior seen in engineering composites, where the fibers have rough surfaces. Here, the separation is moderated by the atomically smooth surface of the nanotube. Thus, experimental nano-mechanical processes can be measured.

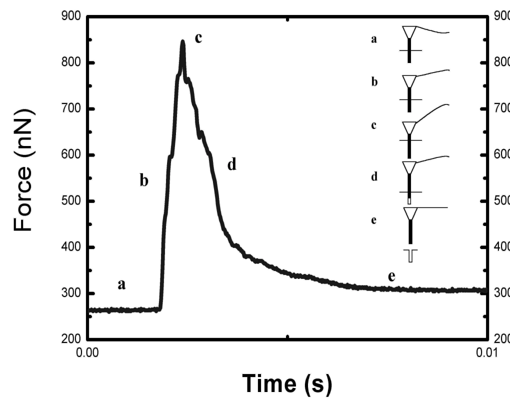

Fig. 1 *Typical pull-out curve of force vs. time for nanotube pulled from thermoplastic polymer. As the tip and surface are separated, the cantilever bending increases, increasing the outward force until at the apex the nanotube begins pulling out. Most of the pullout process occurs over a 2 ms time span.*

The outstandingly robust interfacial strengths measured here support the use of carbon nanotubes as polymer reinforcements.

References

[1] C. A. Cooper, S. R. Cohen, A. H. Barber, and H. D. Wagner Appl. Phys. Lett. 81, 3873-75 (2002).

[2] A. H. Barber, S. R. Cohen, and H. D. Wagner Appl. Phys. Lett. (in press).

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