The controlled growth of multiwalled carbon nanotubes on carbon fibers and the related composites.

Wei Chen, Steven R. Nutt
Department of Materials Science and Chemical Engineering, University of Southern California, 3651 Watt Way, Los Angeles, USA 90089

Introduction

Polymer composites with perfectly aligned and bonded CNTs are the ultimate form of NRPs, which will greatly facilitate experimental and theoretical work in the field. The ideal NRPs will exhibit extraordinary anisotropic properties and can be applied as ultra-high performance structural materials, flexible field-emission devices, thermal conducting pads, microelectromechanical devices, chemical vapor sensors, and switchers for ion transportation. While direct manipulation of individual CNT for bulk materials still remains to be an enormous technical challenge, few available techniques are capable of assembling macroscopic CNT performs or arrays in reasonable time frame and cost. (Figure 1.) In an effort to develop these NRPs, carbon nanotube array reinforced polymers (NARPs) and carbon nanotube array reinforced fiber composites (NARCs) are proposed recently.

In the NARP scheme, CNT arrays were synthesized and incorporated into polymer matrix through a variety of methods. In the NARC scheme, CNT arrays are either transferred or grown directly onto macroscopic fiber reinforcement or prepreg. Garcia et al. proposed the direct transfer of CNT forest between composite laminates in an effort to enhance the mode I and Mode II fracture toughness. [2] Qian et al. [3] grafted CNT forest on carbon fibers using a CVD setup by pre-depositing ion nano-particles using an incipient wetness technique. A dramatic improvement in IFSS over the grafted carbon fiber/epoxy composites was observed in the single fiber pull-out tests, but no significant change was shown in the push-out tests. Garcia et al. [4] performed direct growth of aligned CNTs on the surface of advanced fibers in a woven fabric and demonstrated a 69% increase in interlaminar shear strength and 10^6 (in-plane) and 10^8 (through-thickness) increases in laminate-level electrical conductivity.

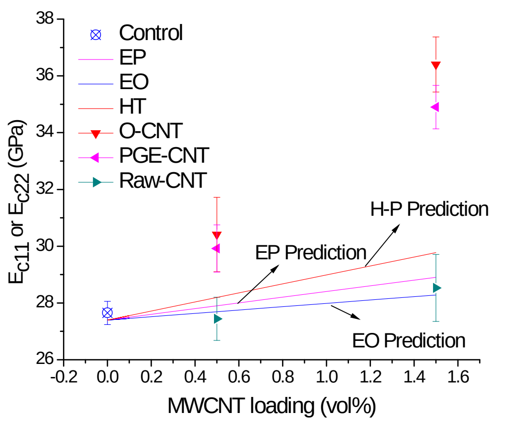

Figure 1. Effect of direct incorporation of MWCNTs into prepreg system by Chen et al. [1]

Experimental

The as-received carbon fiber fabrics were deposited with cobalt nitrate acetone solution with mole concentrations range from 0.05 to 1 mole per liter, and the depositions were freeze-dried immediately after the solution deposition. The CVD furnace was designed with a two stage heating system. And preheating temperatures ranging from 500 to 700 degree Celsius were used prior to the chemical vapor deposition process. Pure xylene was used in combination with a syringe pump at a dispense rate of 0.055ml/min. Argon was used as the carrying gas at 1000 sccm. The CNT growth was carried out at 820 degree Celsius for 5-30 minutes.

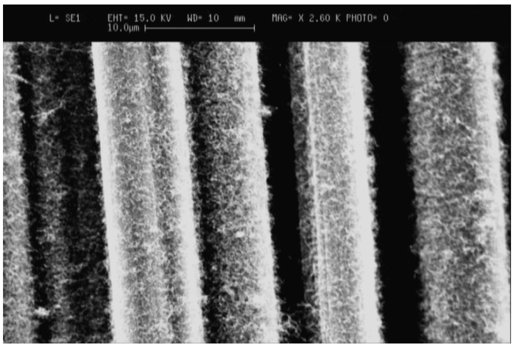

Figure 2 Sparse CNT growth on carbon fiber

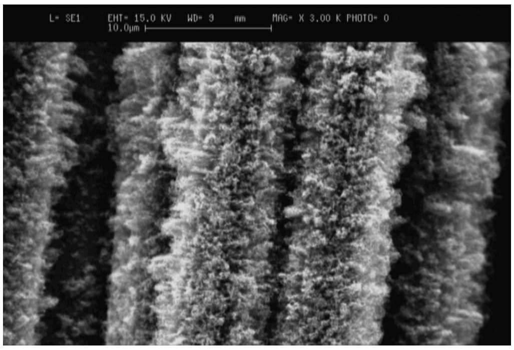

Figure 3 Dense CNT growth on carbon fiber

Results and Discussion

In this study, CVD growth of carbon nanotube forest with controlled CNT diameter, density, and length on carbon fibers was attained through a freeze-dry catalyst deposition method. Preheating temperature and catalytic solution concentration were proven to be the key parameters in determining CNT diameter and forest density respectively.

Figure2-4 indicates different CNT growth density and alignment was attained through this process.

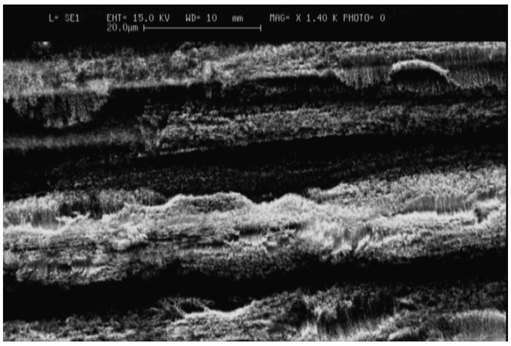

Figure 4 Aligned CNT growth on carbon fiber

Conclusion

Freeze-dry technique significantly improved the catalyst efficiency and control over the particle size deposited on carbon fiber surface and promised myriad possibility in forming hierarchical reinforcement discussed above. The incorporation of these hierarchical reinforcements into conventional fiber reinforced composites provided unprecedented capability in terms of organize carbon nanotubes in a controlled matter into macroscopic aerospace high performance materials. The hierarchical nano-structure can be incorporated into an epoxy matrix through vacuum bag technology and characterized.

References

[1] Chen, W; Shen, H; Auad, ML; Huang, CZ; Nutt, S.R. Basalt Fiber - Epoxy Laminates with Functionalized Multi-walled Carbon Nanotubes, submitted to Composites, Part A. Under review.

[2] Garcia, E.J.; Wardle, B.L.; Hart, A.J. Composites Part A: Applied Science and Manufacturing, v 39, n 6, June 2008, 1065-70

[3]Qian, Hui; Bismarck, Alexander; Greenhalgh, Emile S.; Kalinka, Gerhard; Shaffer, Milo S.P. Chemistry of Materials, v 20, n 5, Mar 11, 2008, p 1862-1869

[4]Garcia, Enrique J.; Wardle, Brian L.; John Hart, A.; Yamamoto, N. Composites Science and Technology, v 68, n 9, July, 2008, p 2034-2041