

Synthesis & Characterization of Carbon Nanotube Polymer Composites

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Introduction



Multiwall carbon nanotubes (MWNTs) have remarkable mechanical and electrical properties. These properties offer great potential in advanced composite material applications. In this study, composite materials were fabricated using high purity MWNTs and polymer matrices. Among a host of practical challenges in fabricating these materials, uniform dispersion of the MWNTs in the composite is paramount to fully exploit the unique properties of these materials.

Effective dispersion of MWNTs is not only dependant on the technique employed but also on the method by which the MWNTs are synthesized. The MWNTs used in this study were synthesized via chemical vapor deposition. This synthesis technique produces highly aligned, highly pure MWNTs (Figure 1) that enable well dispersed nanotube/polymer composites to be fabricated.

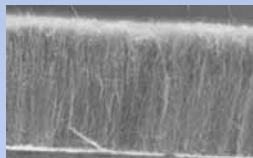


Figure 1: Micrograph of in-house produced MWNTs that shows their alignment and purity.

Experimental

As-produced MWNTs were dispersed in toluene using an ultrasonic wand set at 300 watts for 30 minutes. The MWNTs suspensions were then mixed into solutions of 30 % polystyrene (PS) ($M_w \approx 280,000$ from Scientific Polymer Products, Inc.) to prepare a series of mixtures containing from 1wt.% to 10wt.% PS / MWNTs in PS. These mixtures were homogenized in an ultrasonic bath for 30 minutes. Thin composite films were produced from these solutions using two techniques, film casting and spin casting. Composites with other polymer matrices were fabricated by the same technique. The surface resistivity ρ_s (ASTM D 257 - 83) was measured using a surface resistance indicator (PSI. 870). Die cut films were used for tensile testing on a QT / 1L Material Test System (MTS Corp.) according to ASTM D 882 - 97.

Results

The MWNTs / PS composites were examined by optical microscopy, Figure 2, and TEM, Figure 3. The micrographs show a uniform dispersion of MWNTs in the polymer matrix. This indicates that simple sonication was effective in dispersing the nanotubes without the need for surfactants or other chemical treatments. Examination of the composites' physical properties showed the following:

- Increased stiffness of the MWNT composite compared to PS. The composite film failed brittlely, showing negligible elongation at break compared to neat PS, Figure 4.
 - Experimental results show increased tensile strength and modulus with increasing MWNT loading, Figure 5.
 - Utilizing classical micro-mechanical models, MWNT composites can be approximated as randomly oriented discontinuous fiber lamina. E_c is the tensile modulus of the composite calculated according to equations (1,2 & 3) and plotted as a function of MWNTs loading, Figure 6. However, at higher loadings the experimental deviation from the model increases, signifying either model inapplicability or lessening of dispersion at higher MWNT loadings.
 - Addition of MWNTs to PS changes the surface resistivity of the polymer from $\geq 10^{12}\Omega / \text{square}$ to $< 10^3 \Omega/\text{square}$ that is from insulating (PS) to conductive (MWNT composite), Figure 7.
- The high aspect ratio of MWNTs and their metallic conductivity establish an efficient conducting network inside the polymer at lower concentrations compared to traditional fillers.

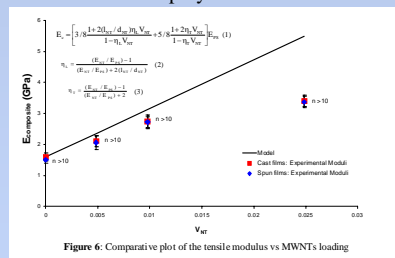


Figure 6: Comparative plot of the tensile modulus vs MWNTs loading

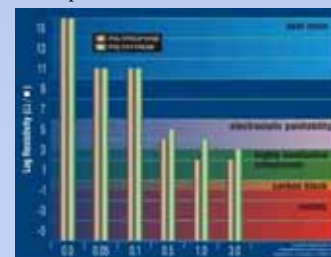


Figure 7: Surface resistivity of the prepared composites and their potential applications.

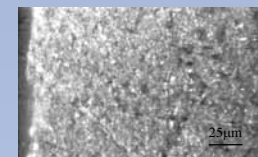


Figure 2: Picture of a section within a PS/MWNTs film which illustrates a good dispersion.

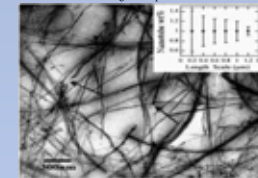


Figure 3: TEM micrograph of showing MWNTs individually dispersed in PS.

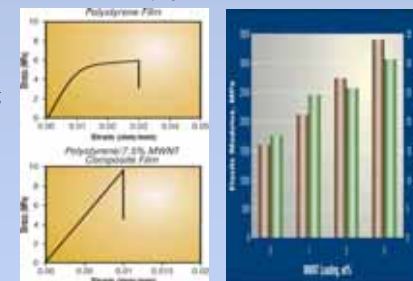


Figure 5: Experimental values of the tensile strength and modulus of PS/ MWNTs films.

Conclusions

Composite materials were fabricated using MWNTs in polymer matrices. These MWNT composites showed remarkable increases in tensile strength, modulus and electrical conductivity. More significantly, the enhanced physical and electrical properties occurred at relatively low concentrations of MWNTs in the composites. It is anticipated that these advanced composite materials will have applications for anti-static materials, electrostatic painting and protective coatings for electrical components.

Publications: R. Andrews, E. C. Dickey, D. Qian, B. Knutson, B. Safadi, B. Moore, and F. Derbyshire, Proceedings of Carbon'99, Charleston, SC, 1999, p. 258.
D. Qian, E. C. Dickey, R. Andrews, T. Rantell, Appl. Phys. Lett. **76**, 2868 (2000)
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