Using a Carbon Nanotube Additive to Make Electrically Conductive Commercial Polymer Composites

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Introduction

Carbon nanotubes (CNTs) have physical properties that exceed those of commonly used materials. With a tensile strength eight times that of stainless steel and with a thermal conductivity five times that of copper, CNTs are obvious choices for creating a new class of composite materials. Their inclusion in a polymer or ceramic matrix holds the potential to boost the host material's electrical, mechanical, or thermal values by orders of magnitude, well above the performance possible with traditional fillers such as carbon black or ultra fine metal powders.

But although CNTs have exceptional physical properties, incorporating them into other materials has been inhibited by the surface chemistry of carbon. Problems such as phase separation, aggregation, poor dispersion within a matrix, and poor adhesion to the host must be overcome. Zyvex has overcome these restrictions by developing a new surface treatment technology that optimizes the interaction between CNTs and the host matrix. Zyvex can create a multi-functional bridge between the CNT sidewalls and the host material or solvent.

The power of this bridge is demonstrated in Figure 1 which shows a fracture surface in a polycarbonate composite (made using Zyvex's technology). Raw nanotubes often interact poorly with a matrix—a fracture expels them and leaves behind voids in the material. **Figure 1** show that the Zyvex-processed tubes remain in the matrix even after the fracture, indicating strong interaction with the host.

Zyvex's processed nanotubes demonstrate excellent dispersion and enhanced compatibility with commercial polymers, including polycarbonates, polystyrenes, and epoxies. With this technology, manufacturers and end-users can now take full advantage of the powerful capabilities of CNTs. In this note we specifically demonstrate how polymer composites with electrical conductivity spanning the range from insulating to semiconducting can be prepared with Zyvex technology.

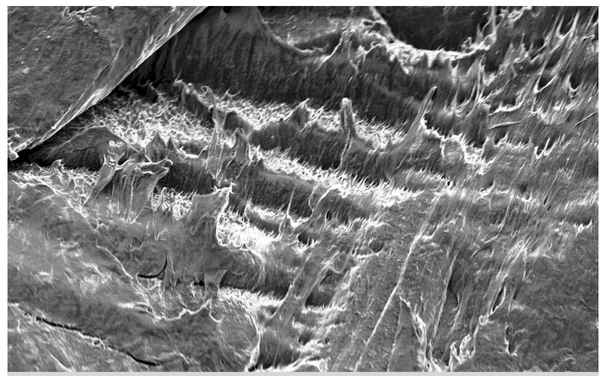

Figure 1 A field-emission SEM image of the fracture surface at the broken end of a polycarbonate composite loaded at 1 wt% with Zyvex processed SWNTs. The SWNTs appear here as white fibers retained in the matrix.

Experimental Background

The following electrical conductivity data was prepared using a solvent-based casting process. Single wall nanotubes (SWNTs) were briefly sonicated and then functionalized with Zyvex additive in chloroform. The resulting SWNT solution was mixed with polystyrene producing a homogeneous nanotube/polymer composite solution. The film was prepared on a silicon wafer with a 100 nanometer thick thermal oxide layer either by drop casting or by slow-speed spin coating. The sample was then heated to 80–90°C to remove residual solvent. This was repeated with SWNT loadings from 0.01 to 10 wt%. Resulting film thickness ranged from 2-10 microns. The SWNT mass-fraction loading values for functionalized SWNTs/host polymer composites are based on pristine SWNT material only and exclude the additive material.

Electrical conductivity measurements were performed using a standard four-point probe method. The SWNTs/polystyrene composites showed several orders of magnitude higher conductivities than neat polystyrene. As seen in **Figure 2**, Zyvex technology increases the electrical conductivity of pristine polystyrene (10^{-14} S/m) by ten orders of magnitude.

Summary of results

Because of their superior dispersion, Zyvex's processed nanotubes achieve these results at much lower loadings than other processing technologies on the market today. Previous experiments with CNTs have required loadings at up to 5-10 wt % to obtain similar conductivity values. Zyvex's processed nanotubes have demonstrated the lowest reported percolation threshold of 0.045 wt % loading in a polystyrene composite **(Figure 2)**. Low loadings are necessary to achieve conductivity levels required for various industrial applications without compromising the host polymer's preferred physical properties and lower costs.

Figure 3 illustrates the resistivity of the polystyrene composites made with Zyvex material. By comparison, recent studies of raw SWNTs in polystyrene showed no difference between the resistivities of the host polystyrene and a composite loaded with 3.5-4 wt % of these untreated CNTs. Even to achieve the modest decrease of 10^6 – 10^7 per cm required a loading in excess of 8 wt% of plain SWNTs — an amount beyond the threshold where most host materials will lose their desired mechanical properties.

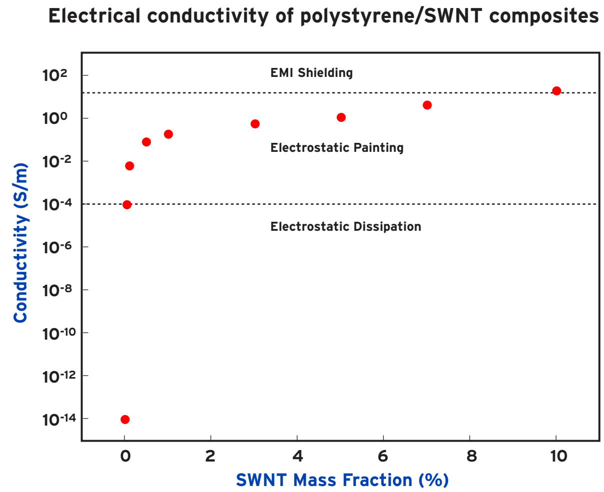

Figure 2 Electrical conductivity of polystyrene/ SWNT composites.

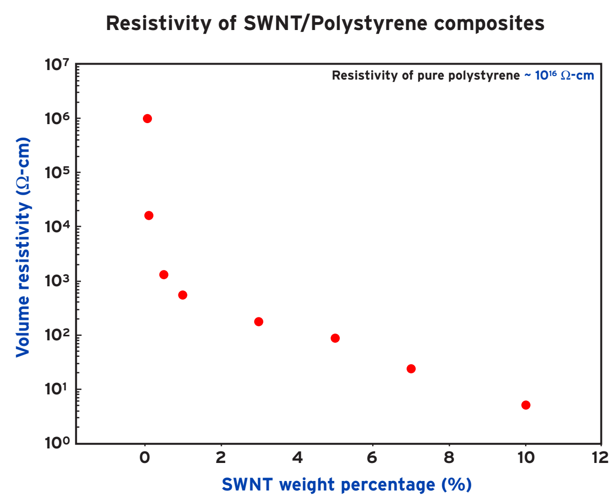

Figure 3 Resistivity of polystyrene/ SWNT composites.

By providing the necessary electrical conductivity at acceptable loadings Zyvex's technology makes possible the following commercial applications of CNTs:

- Conductive paints and inks
- Conductive coatings
- Conductive sealants, caulks, and adhesives
- Electromagnetic shielding for large structural components
- Electrostatic painting
- Electrostatic discharge
- Opto-electronic device applications

Conclusions

Zyvex's nanotechnology significantly enhances the electrical conductivity of commercial polymers. Manufacturers have the opportunity to use commodity polymers and their existing manufacturing technology to improve current composite materials. Such results are only possible with well-dispersed nanotubes that have good adhesion to the polymer matrix. These enhanced nanotubes are possible today with Zyvex's processing technology.

References

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