THE INVESTIGATION OF CARBON NANOTUBES FOR LIGHTWEIGHT ARMOR MATERIALS

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ABSTRACT

Nanocomposites of multi-walled carbon nanotubes (MWNTs) in polymers are under investigation for use in lightweight personnel armor materials. Such materials are critical to the realization of the OFW vision of providing maximum protection at the individual soldier level.

1. INTRODUCTION

Carbon nanotubes are theoretically one of the strongest, stiffest materials with a calculated tensile strength of 600 megapascal and modulus of more than one terapascal (Lourie et al., 1998). If the mechanical properties of nanotubes can be effectively incorporated into a polymer matrix, composites with very high strength can be achieved (Andrew et al., 1999). Because of the large interphase volume present in nanocomposite materials, there is also the potential for enhanced dissipation of impact energy in these systems. A program is in process that investigates vapor-grown MWNTs and their functionalized homologues (Loutfi et al., 2001) are randomly and uniformly dispersed in various concentrations in several chosen polymer matrices.

2. RESULTS AND DISCUSSION

Dispersion of nanotubes free of agglomerates has been achieved by solvent mixing and dry blending as witnessed in SEM imaging. The polymers investigated to date include polycarbonate, polypara-phenylene sulfide, ultra-high molecular weight polyethylene and aliphatic ionomers (Surlyn). The structure of the polymer affects the interaction with MWNTs and the mechanical properties of the nanotube composite. An increase in compressive strength resulted when nanotubes were added to the polymers containing aromatic functionality and a lesser effect or decrease in strength resulted with the more polar polymers. It was found that MWNTs showed a stronger interaction with the lower molecular weight polycarbonate polymers, which are in the linear or extended form in dilute solution, thus presenting more surfaces for interaction with the nanotubes. The high molecular weight macromolecules unlike the lower ones are in globular or coiled forms in solution and present less surfaces for interactions with the carbon nanotubes resulting in a lower increase or even decrease of the compressive strength of the nanocomposites. The effect of the molecular weight of polycarbonate on the compressive strength of MWNT-PC composites is shown in Figure 1.

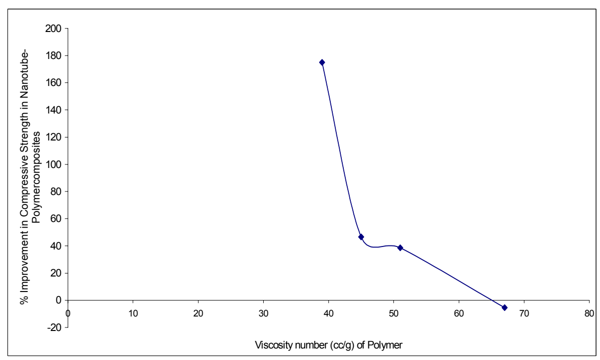

Fig. 1: Effect of PC molecular weight on the compressive strength of MWNT-PC nanocomposites

The compressive strength of the MWNT-polymer nanocomposites, particularly polymers with aromatic units along the polymer chain, such as polycarbonate and polyphenylene sulfide, increased to a maximum value of carbon nanotubes loading up to about 30%, then decreased with further loading as shown in Figure 2. The strength of these nanocomposites was further increased by blending low molecular weight and high molecular weight polymers (Figure 3), where the compressive strength peaked at a concentration of 30 parts MWNTs by weight, Figure 3.

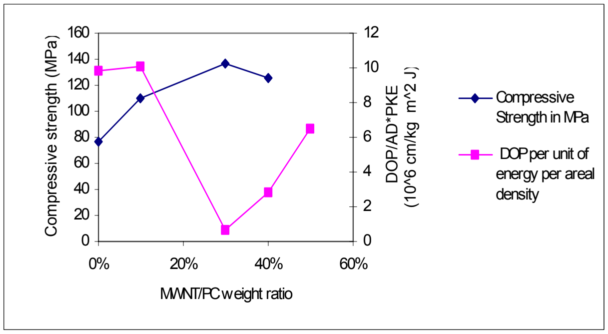

Fig.2: Changes in ballistic performance and compressive strength relative to the MWNT loading in PC.

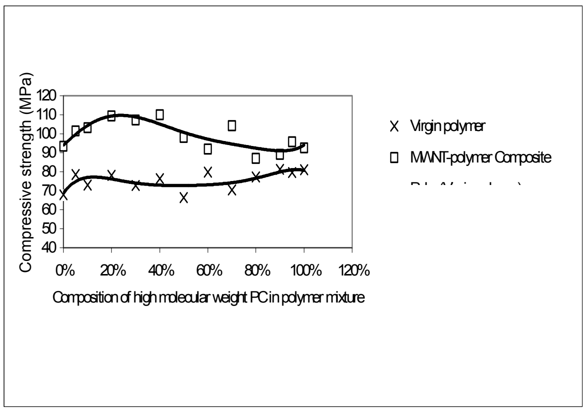

Fig. 3: Effect of blend composition on the compressive strength of virgin PC and MWNT-PC

Polycarbonate-MWNT nanocomposites have been subjected to ballistic impact testing using fragment simulating projectiles. Depth of penetration (DOP) tests were performed where the nanocomposite was supported by a semi-infinite aluminum witness plate. Initial results are shown in Figure 2. It was observed the compressive strength correlated well with the ballistic performance of polycarbonate nanocomposites (Figures 2 and 4), and this measurement can be used as a cost effective and rapid selection tool to select material formulations to produce samples for ballistic testing. It is important to use this correlation parameter only within the same family of polymers, since under ballistic impact different polymer matrices dissipate energy through different mechanisms. Polymer molecular weight and molecular structure affect differently the interaction between the polymer and nanotubes. This, as well as uniformity of dispersion of MWNTs, affect both compressive strength and ballistic performance of MWNT-polymer nanocomposites. Blending low and high molecular weight polymers with aromatic structure along the main chain improved the compressive strength of MWNT-PC composites. These composites demonstrated the highest compressive strengths and best ballistic performance. Shortening the MWNTs and functionalizing them with short polar (OH groups), and long aliphatic flexible chains were not as efficient in improving the compressive strength of MWNT nanocomposites with polycarbonate and polypara-phenylene sulfide as the as-produced carbon nanotubes. Results to date show that the addition of carbon nanotubes to polycarbonate improves its ability to absorb energy in ballistic impact under DOP test conditions.

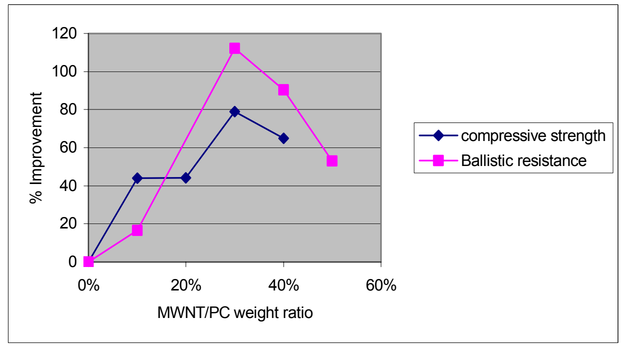

Fig. 4: Correlation of compressive strength with ballistic performance of MWNT-PC nanocomposites

3. CONCLUSION

Research to this point has shown that molecular weight and molecular structure of the polymer are important factors affecting interaction between the polymer and nanotube. Thus one can tailor the properties of composites by combining MWNTs with select polymer structures to achieve enhanced properties. This work is continuing and future plans include investigations of thermoset polymer matrices and the effects of aligned MWNTs on the high-rate impact properties of polymer-matrix nanocomposites.

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REFERENCES

Andrew, R., Derbyshire, F., Dickey, E., Fan, X., Quian, D., Tantell, T., Rao, A.M, and Vilain, F., “Nanotube Carbon-Carbon Composites,” Carbon 99, 24th Biennial Conference on Carbon, Am. Carbon Soc. Charleston, SC, pp. 194-195, July 1999

Lourie, O., Cox, D.M. and Wagner, H.D., ”Buckling and Collapse of Embedded Carbon Nanotubes,” Phys. Rev. Lett., vol 81, No. 8, pp 1638-1641, August 1998.

Loutfi, R. O., Withers, J., Abdelkader, M. and Sennett, M., “Carbon Nanotube-Polycarbonate Composites” Am. Mat. Soc. Symposium 2001.