Influence of Aspect Ratio and Surface Chemistry of Multi-walled Carbon Nanotubes on Structures and Properties of Multi-walled Carbon Nanotube/Polymer Composite Foams

by

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An Abstract of a Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the degree of

DOCTOR OF PHILOSOPHY

Major Subject: Materials Science and Engineering

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December, 2010
(For Graduation December 2010)

ABSTRACT

The goal of this thesis is to investigate the influence of the aspect ratio and surface chemistry of multi-walled carbon nanotubes (MWNTs) on the foam morphology of the MWNT/poly(methyl methacrylate) (PMMA) nanocomposite foams, and the influence of the aspect ratio of MWNTs on the mechanical properties of MWNT/PMMA nanocomposite foams.

To investigate the influence of MWNT aspect ratio on the foam morphology of MWNT/PMMA nanocomposite foams, MWNTs with controlled aspect ratio are used to control the bubble density and bubble size of MWNT/PMMA nanocomposite foams. It is found that the nanocomposite foams filled with shorter MWNT had higher bubble density under the same foaming conditions and MWNT weight loading. Both the ends and sidewalls of carbon nanotubes can act as heterogeneous bubble nucleation sites, but the ends are more effective compared to the sidewalls. Shorter nanotubes provide more ends at constant MWNT weight loading compared to long nanotubes. As a result, the difference in the foam morphology, particularly the bubble density, is due to the difference in the number of effective heterogeneous bubble nucleation sites.

To investigate the influence of MWNTs surface chemistry on the foam morphology of MWNT/PMMA nanocomposite foams, the surface of MWNTs with controlled aspect ratio is covalently modified with glycidyl phenyl ether (GPE), and surface modified MWNT/PMMA nanocomposite foams are produced using a supercritical carbon dioxide foaming process. With the same weight percent of MWNTs, the bubble density of polymer nanocomposite foams filled with GPE surface modified MWNT is found to be several times higher than that of polymer nanocomposite foams filled with nitric acid treated MWNT. After the MWNTs are modified with GPE, the surface chemistry of the MWNT becomes the dominant factor in determining the bubble density while the MWNT aspect ratio becomes less influential.

The influence of MWNT aspect ratio on the mechanical properties of MWNT/PMMA nanocomposite foams are studied by running compression tests on pure PMMA foams and nanocomposite foams. The nanocomposite foams are filled with one weight percent of MWNTs with different aspect ratio. Foams with different density are produced by foaming under different conditions. The compressive modulus and collapse strength of pure PMMA foams and nanocomposite foams are compared. It is found that with the same density, the nanocomposite foams always have higher compressive modulus and higher collapse strength than pure PMMA foams. This is not only because of the reinforcing effect of MWNTs on the polymer matrix, which improved the mechanical properties of the solid, but also because of the cell size reduction effect by the addition of MWNTs.

With the same density and the same MWNT loading, the nanocomposite foams filled with long MWNTs always have higher compressive modulus and collapse strength than the nanocomposite foams filled with short MWNTs. However, the relative modulus, which is defined as the compressive modulus of the foam divided by the compressive modulus of the solid nanocomposites, and the relative collapse strength, which is defined as the collapse strength of the foams divided by the compressive strength of the solid nanocomposites, show a different trend. With the same density, the relative modulus and relative collapse strength of the nanocomposite foams filled with short MWNTs are higher than the relative modulus and relative collapse strength of the nanocomposite foams filled with long MWNTs. It is proposed that the difference in the relative modulus and relative collapse strength is due to the difference in the foam morphology.

A new constitutive model for predicting the compressive mechanical properties of closed-cell polymer foams is developed. The compressive modulus and collapse strength predicted by the new model fit better with the experimental results than the classic Gibson-Ashby model. The constitutive model can be used to predict the compressive mechanical properties of polymer foams with relative density lower than 0.5.