Heat absorbability of single-walled, coiled and bamboo nanotube/epoxy nano-composites

K. T. LAU*
Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, People’s Republic of China
E-mail: mmktlau@polyu.edu.hk

M. LU
Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, People’s Republic of China; Department of Chemistry, Lanzhou University, Lanzhou 730000, People’s Republic of China

H. L. LI
Department of Chemistry, Lanzhou University, Lanzhou 730000, People’s Republic of China

L. M. ZHOU
Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, People’s Republic of China

D. HUI
Department of Mechanical Engineering, University of New Orleans, New Orleans, LA 70148, USA

Carbon nanotubes and nanoparticles have become attractive as nano-fillers for improving the mechanical properties and thermal stability of polymer-based nanocomposites. Most research has focused on the use of straight single-walled (SWNTs) or multiwalled (MWNTs) carbon nanotubes as ultrastrong reinforcements for epoxy-based composites. However, due to the uncertainty of the bond interface between the nanotubes and matrix, the stress transferability of these composites is doubtful [1]. The latest development of coiled multiwalled carbon nanotubes (CCNTs) provides an improvement in the stress transferability due to the generation of mechanical interlocking in composite systems [2]. However, there is no comprehensive study which has addressed the thermal properties of these nanocomposites. In this letter, we report on the thermal properties of different epoxy-based nanocomposites formed by adding 0.5 wt% of SWNTs, CCNTs (Fig. 1a), and bamboo multiwalled (BCNTs) nanotubes (Fig. 1b) to pure epoxy.

The low viscosity, commercially available ARALDITE GY 251 epoxy resin was used with CIBA HY 956 amine hardener. The sample preparation for 0.5 wt% nanotubes (SWNTs, CCNTs, and BCNTs) reinforced epoxy beam was based on four steps:

(i) Nanotubes were dispersed into acetone with strong sonication for 1 hr.
(ii) The desired amount of epoxy resin was added into the nanotubes suspension and then the mixture was sonicated for another hour.
(iii) The mixture was placed on a hot plate to evaporate the solvent for 1 hr, followed by a degassing process in vacuum for 4 hrs.
(iv) The nanotube-epoxy mixture was cast in a polypropylene mold, and then cured after the hardener was added, by first precuring on a hot plate at 50 °C for 10 min with stirring and then curing at room temperature for 24 hrs.

The three nanocomposites were heated from −50 to 250 °C at a scan rate of 10 °C min⁻¹, in a Perkin-Elmer Pyris 1 DSC apparatus coupled with an intercooler. Fig. 2 shows DSC curves for the different nanocomposites and for the pure epoxy from which the glass transition temperatures can be determined. With the DSC curve of the pure epoxy as reference, the most noticeable feature in the curves for the composites is the disappearance of the exothermic peak at 44.33 °C. This indicates that the nanotubes prevent the epoxy from releasing heat energy at this temperature. The endothermic peak located at ∼50 °C in each curve represents the glass transition temperature range for the corresponding composite. The total area under the heat flow peak, based on the extrapolated baseline at the end of the transition, is used to calculate the total heat of the transition process. The initial temperature of the transition (Tᵢ), the maximum endothermal peak temperature (Tₚ), the final temperature of the transition (Tₑ), the glass transition temperature (Tₒ), and the heat of the transition (the transition enthalpy, ΔH) for each type of composite are reported in Table I. It is clear that Tᵢ, Tₚ, and Tₑ decrease in order of SWNT/epoxy, BCNT/epoxy, and CCNT/epoxy. Compared to the pure epoxy, a shift of Tₒ to higher temperatures is observed in the composites with SWNTs and BCNTs, while there is an obvious decrease in Tₑ and ΔH in the CCNT/epoxy system. These observed changes reveal that the tubes’ surface

* Author to whom all correspondence should be addressed.
configuration plays an important role in the glass transition behavior of the epoxy. It has been demonstrated that the incorporation of carbon fillers can affect the structure of the cured epoxy by restricting the nucleophile-electrophile interaction during the curing reaction by steric hindrance. Accordingly, nanotubes with different shapes would have different steric hindrance effects on the curing reaction between the epoxy and the hardener. The helical shape of CCNTs should have a larger steric hindrance effect than the straight nanotubes, such as SWNTs and BCNTs. As a result, the curing reaction of the epoxy would be influenced more by CCNTs than by the SWNTs and BCNTs.

Also from Table I, the ΔH values for the three composites are ordered SWNT/epoxy > BCNT/epoxy > CCNT/epoxy. This ordering is consistent with that of the Tg results. Meanwhile, the ΔH value of the SWNT/epoxy composite was higher than that of the pure epoxy, while the ΔH values of the BCNT/epoxy and CCNT/epoxy are slightly, and significantly, lower than that of the pure epoxy. It is thus inferred that during the glass transition process, SWNTs can act as a heat sink to accelerate the heat absorption of the epoxy, while CCNTs can act as heat-shielding fillers and prevent the epoxy from exchanging energy with the outside system. This is because BCNTs and CCNTs are essentially multiwalled nanotubes that, in addition to the inner tube space, have extra space between the graphite layers to absorb energy. On the other hand, CCNTs should have a more effective tube length than BCNTs, and thus more space to absorb energy. In principle therefore, the sequence of endothermic ability or ΔH value should be CCNTs > BCNTs > SWNTs.