THE DAMPING PROPERTIES OF DIFFERENT CNT FILMS CHARACTERIZED BY CYCLIC TENSILE TESTING

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ABSTRACT

The vacuum filtration CNT film (also called buckypaper) and floating catalyst chemical vapor deposition (CVD) CNT film were fabricated to study the damping properties by cyclic tensile testing with the reference of commercial damping rubber produced by 3M™. The results suggest that the CVD-grown CNT film tends to consume more energy during each cyclic tensile process, by contrast the energy consumptions of buckypaper is one order of magnitude lower than that of CVD-CNT film. The damping coefficient of CVD-CNT film is four times of buckypaper. The damping rubber consumes much less energy during each cyclic tensile process but its damping coefficient is relatively higher. The multi-cycle tensile tests indicate that the stability of CVD-CNT film is much better than that of VF-CNT film and damping rubber. However, the good stability of CVD-CNT film is limited within relatively small strain, the network will undergoe irreversible plastic deformation when the tensile strain beyond 0.25%. Additionally, the damping properties of CVD-CNT film can be tailored through changing the CNT alignment of the network. These imply that CVD-grown CNT film could be a promising damping material in complex structural systems, such as electronic devices and aerospace vehicle.

INTRODUCTION

Carbon nanotubes (CNTs), the strongest nanomaterial with tensile strength and elastic modulus up to 100 GPa and 1 TPa and extraordinary functional properties have attracted extensive attention among researchers in the field of composites since their discovery. However, the full realization of individual CNT's potential in real applications has been greatly hindered by their nanoscale size, which results in dispersion problem due to the unavoidable agglomeration of CNTs. Therefore, considerable efforts have been converted to fabricate CNT based macroscopic structures, such as CNT films and CNT fibers. CNT film as a self-supporting two dimensional network with the advantages of high CNT load and possible high CNT alignment could be directly used for composite laminate preparation. In recent years, CNT-based damping materials have attracted increasing attentions.

Generally, damping materials include metals, composite material and polymers, in which the viscoelastic polymers have been most commonly used due to their super energy absorbing capability via frictions between molecular chains. However, owing to low modulus and low strength, the damping viscoelastic polymers are always adhered to the main structure, which incurs some barriers, such as weight gain and volume penalty, inferior reliability and poor thermostability. In combination with polymer matrix, CNTs showed functions of damping properties [1-3], and great energy dissipations were resulted from slippage and friction between inter-tube and tube-matrix in the CNT composites, also from the viscoelasticity of polymer.[4] The potential applications of these CNT/polymer composites are still limited as damping material, which is ascribed to deficiencies of the polymer and rather low loading of CNTs.

Benefited from super-strong properties, flexible deformation capability, ultra-high aspect ratio and specific surface area of single CNT, its macroscopic assemblies display good viscoelastic properties.[5-7] Korathkar fabricated a macroscopic dense-packing CNT film from vertically-aligned nanotube arrays, and the CNT sheet reinforced sandwich beam manifested a high damping ratio with 0.3.[8] Another kind of three-dimensional (3D) random CNT sheet was synthesized by water-assisted chemical vapor deposition on silicon substrate, which exhibited stable damping properties at wide temperature range.[1] Actually, the self-supporting CNT sheet can be directly synthesized using floating catalyst CVD method. The latter method is increasingly attractive due to its highly efficient, continuous and easy production at engineering scale. The previous studies showed that the CVD-grown multi-layered CNT sheet had similar tensile behavior with plastic polymer,[9, 10] but few reports on the damping properties of this in-situ formed CNT sheet. In this paper vacuum filtrated (VF) CNT film and floating catalyst CVD grown CNT sheet were fabricated to study the damping properties by cyclic tensile testing with the reference of commercial damping rubber produced by 3M™.

EXPERIMENTAL SECTION

Synthesis of CVD-CNT film: The ethanol was selected as the carbon source, in which 2.0 wt% ferrocene and 1.0 wt% thiophene were dissolved. The solution was injected to the heat reaction region of tube furnace (about 1300°C) at a feeding rate of 0.15 ml min^{-1}. Ar/H_2 gas mixture (volume ratio 1:1) was flowed through the reactor tube at a rate of 4000 sccm. Under these synthesis conditions, the nanotubes spontaneously formed a continuous sock-like aerogel in the gas flow, which can be blown out with the carrier gas. The CNT aerogel was continuously winded by a rotating mandrel and it was densified by in-situ liquid-spraying of ethanol water solution. A multi-layered seamless CNT sheet was prepared after the evaporation of the liquid, and it was cut to desired size by scalpel. The as-spun CVD-CNT film was loose and sponge-like. After an in-situ liquid-spraying, the CNT film showed reduced thicknesses and densified network. Correspondingly the volume density of the CNT film was increased to 0.47 g cm^{-3} from 0.02 g cm^{-3} due to the liquid-spraying.[11]

Preparation of VF-CNT film: The VF-CNT films (i.e. buckypaper) were prepared by vacuum filtration of aqueous nanotube suspension. MWCNTs were ultrasonicated in deionized water for 2 h with the aid of dispersants of PVP. The dispersed nanotube solution was filtrated through a microporous membrane with positive pressure. The buckypaper was then rinsed by isopropyl alcohol to remove the surfactant. After drying at 80 °C for 2 h in a vacuum oven, buckypapers could be easily peeled off from the membrane. In this study, pristine MWCNTs were fabricated and supplied by Chengdu Organic Chemicals Co., Ltd. The content of MWCNTs is larger than 95% with the MWCNT diameter in the range of 10-30 nm and length of 0.2-4 μm. The dispersant PVP-k30 (Molecular weight 40,000) was purchased from Beijing Yili Fine Chemical Co., Ltd. The microporous membranes with a pore diameter of 0.45 μm were obtained from Hangzhou ANOW Microfiltration Co., Ltd.

Test on CNT films: The cyclic tensile properties of CNT films were performed using Instron 3344 at room temperature. The tensile specimens were cut into rectangle shape with a clamping distance of 20mm and width of 1mm. At least five specimens were tested for each. The length and width of the CNT films were measured by vernier caliper, and the thickness was measured by micrometer caliper.

RESULTS AND DISCUSSION

Figures 1a and 1b display the cyclic tensile curves for buckypaper, CVD-CNT film and commercial damping rubber under the strain of 0.15%. It shows that the strains obviously lag behind the stress, leading to typical hysteresis loops similar to viscoelastic polymers. From the area of the hysteresis loop the energy consumption ΔW can be estimated for each tensile cycle. The curves demonstrate that the energy consumption of every tensile cycle of CVD-CNT film is an order of magnitude higher than that of buckypaper and it is two orders of magnitude higher than the energy consumptioin of commercial damping rubber.

The loading energy W applied to the sample can be obtained from the integral of the loading curve. Then a relationship between ΔW and W is as follows:

$$\Delta W/W=2\pi \tan\delta \qquad (1)$$

wherein δ is the phase angle for the strain lagging behind the stress. Therefore, damping coefficient $tan\delta$ can be calculated in accordance to Equation 1. The data were plotted to reveal the quantitative damping properties of the two types of CNT films as well as the commercial damping rubber. In Figure 2 the energy consumed in a unit tensile cycle of buckypaper is 86 Pa, whereas that for CVD-CNT film is 325 Pa, almost 3.8 times of the former film. Nevertheless, the energy consumption of commercial damping rubber is only 2.4Pa which is 2 orders of magnitude lower than the two types of CNT films.

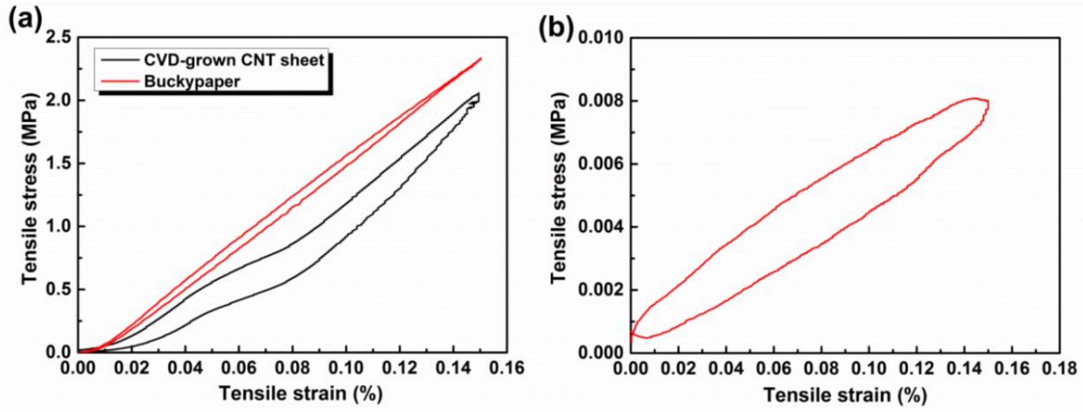

Figure 1 The cyclic tensile curves for (a) VF-CNT film and CVD-CNT film, (b) commercial damping rubber under the strain of 0.15%.

As in Figure 2, the damping coefficient of CVD-CNT film is 0.034 four times of that of buckypaper, which is consistent with the energy comsumption data for the two kinds CNT films. Moreover, the damping coefficient of commercial rubber is 0.049, close to the coefficient of CVD-CNT film. Thses different damping properties of CVD-CNT film and buckypaper should be ascribed to the structure and distribution status of the CNT assemblies. Figure 3 gives the surface morphology images of buckypaper and CVD-CNT film. One can easily find that the aspect ratios of individual CNTs in buckypaper are considerably smaller than those of CNTs in CVD-CNT film. Also the CNTs tend to coalescence into bundles in the CVD-grown CNT sheet, particularly lots of closely combined CNT intersections are formed at the iron catalyst-rich regions during the growth of aerogel. Therefore, the CVD-CNT sheet shows much higher energy consumption and damping coefficient than buckypaper.

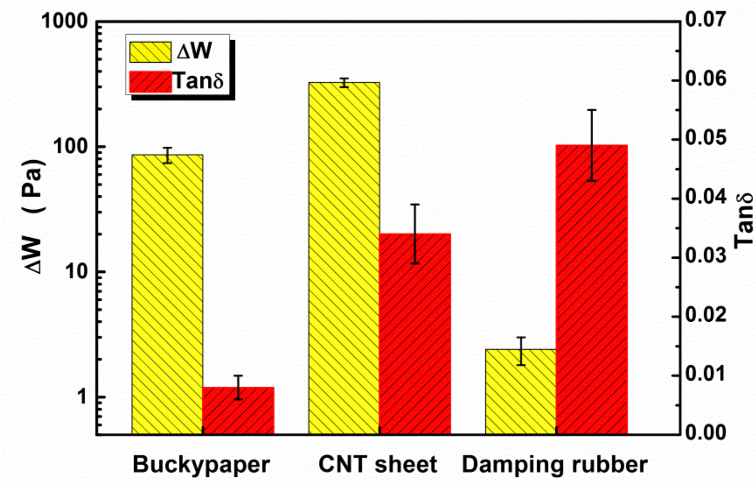

Figure 2 The damping properties of CVD-CNT sheet, buckypaper and commercial damping rubber respectively.

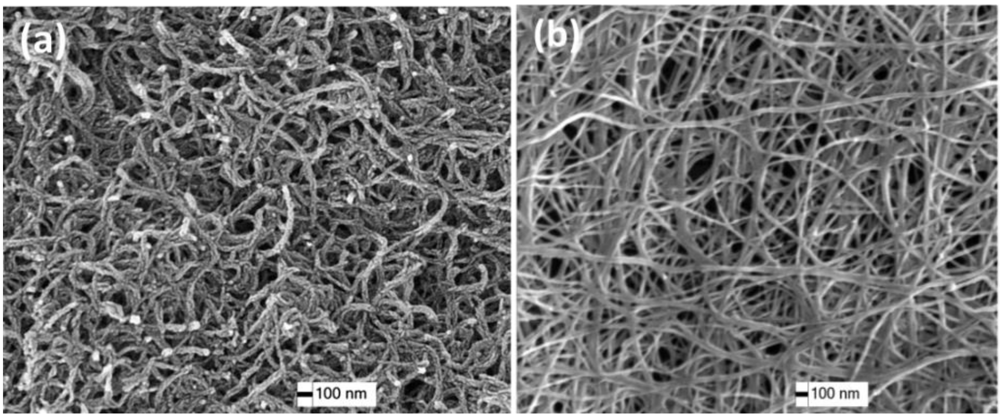

Figure 3 The surface morphology of (a) buckypaper and (b) CVD-CNT sheet, respectively.

Figure 4 displays the multi-cycle tensile curves of two types of CNT film and damping rubber, respectively. In Figure 4a the 20th cycle tensile stress-strain curve of VF-CNT film is lower that that of the 1st cycle curve and then the 40th cycle shows even lower tensile stress-strain. But in Figure 3b the tensile stress-strain curve of CVD-CNT film still repeats very well after 40 cycles especially the unloading process. However, the multi-cycle tensile curves of damping rubber show even larger deciation in Figure 4c. It indicates that under the strain of 0.15% CVD-CNT film has much better stability than VF-CNT film and damping rubber. It is noteworthy that when the tensile strain beyond 0.25% the CVD-CNT network will undergoe irreversible plastic deformation during the tensile test as shown in Figure 4d. Similar behavior has been reported by our former studies in Ref[11]. Hence, the CVD-CNT film is suitable for damping application under tension with small strain.

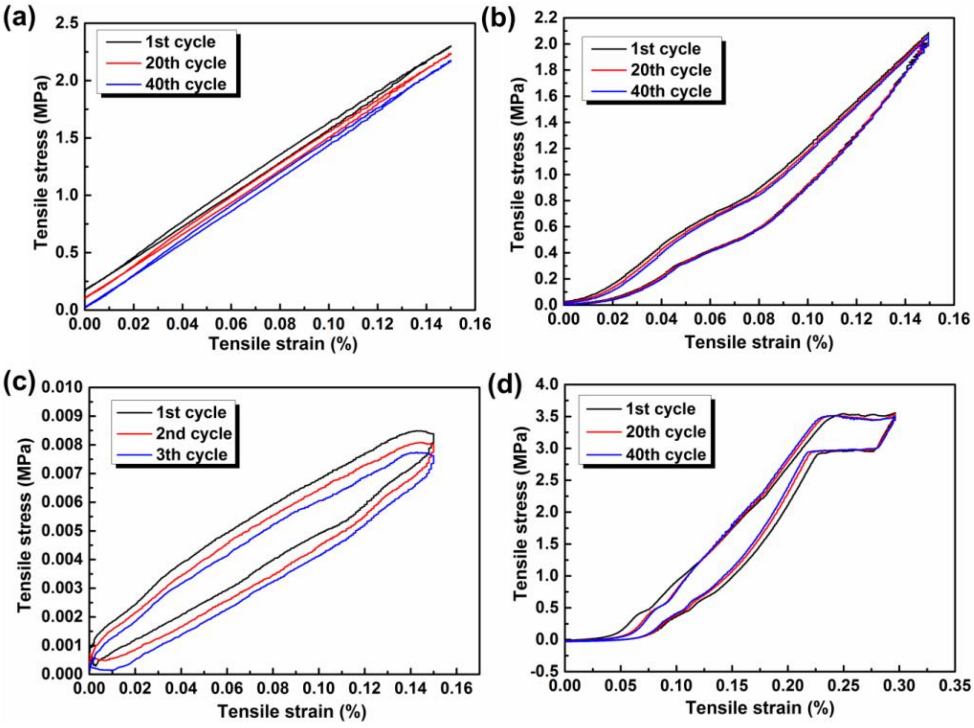

Figure 4 The multi-cycle tensile curves of (a) VF-CNT film, (b) CVD-CNT film, and (c) commercial damping rubber under the strain of 0.15%; (d) the multi-cycle curves for CVD-CNT film under 0.30% strain.

CONCLUSIONS

The damping properties of vacuum filtration buckypaper and floating catalyst chemical vapor deposition (CVD) CNT film were studied by cyclic tensile testing with the reference of commercial damping rubber. The results show that the energy consumption of every tensile cycle of CVD-growm CNT film is an order of magnitude higher than that of buckypaper and it is two orders of magnitude higher than the energy consumptioin of commercial damping rubber. The damping coefficient of CVD-CNT film is four times of buckypaper, both lower than that of damping rubber. Moreover, the multi-cycle tensile tests suggest that the CVD-CNT film posses much better stability than the buckypaper and the damping rubber. However, the CVD-CNT network will undergoe irreversible plastic deformation during tensile test when the strain beyonds 0.25%. Additionally, the damping properties of CVD-CNT film can be tailored through changing the CNT alignment of the network. The results imply that CVD-grown CNT film could be a promising damping material in complex structural systems, such as electronic devices and aerospace vehicle.

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