



Tensile strain sensing of buckypaper and buckypaper composites

Xiaoqiang Wang^a, Shaowei Lu^{a,*}, Keming Ma^a, Xuhai Xiong^a, Haijun Zhang^a, Meijuan Xu^b

^a Faculty of Aerospace Engineering, Shenyang Aerospace University, Shenyang 110136, China

^b AVIC SAC Commercial Aircraft company Ltd., Shenyang 110136, China

ARTICLE INFO

Article history:

Received 23 January 2015

Received in revised form 7 September 2015

Accepted 8 September 2015

Available online 9 September 2015

Keywords:

Composites

Buckypaper

Sensor

Strain

Piezoresistive

ABSTRACT

The effectiveness of buckypaper as a strain sensor is investigated. The key contribution of this paper is the study of piezoresistive response of both buckypaper and buckypaper composites. In addition, the manufacture of buckypaper and buckypaper composites is mentioned. The specimen is subjected to a tensile loading, and the resistance of the buckypaper is obtained using a four-point probe method and examined as a function of applied strain. Experimental results of buckypaper and buckypaper composites demonstrate that there are two different linear change sensing stages in the resistance of buckypaper with applied strain, and the linear relationship is recoverable and stable for the first sensing stage (0 – 30,000 $\mu\epsilon$). From the results obtained, it is evident that buckypaper is very suitable for strain sensing.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Strain sensors are widely used in nuclear, space, aviation, shipbuilding and weaponry industries for monitoring the deformation and damage of structures. Conventional strain gauge is always arranged along a certain direction, and is used to measure the strain in designated directions. With the development of the engineering and science, a multidirectional sensor which can be used measure the strain is demanded.

Since the discovery of carbon nanotubes (CNTs) by Iijima [1], they have attracted remarkable attention as raw materials for the development of nanomaterials owing to their remarkable thermal and electrical conductivities, superior mechanical properties and low density [2]. Fortunately, it has been confirmed that the conductance of CNTs can be dramatically changed by changing the chirality in a single-walled carbon nanotubes (SWNTs), and mechanical strain can efficient affect the chirality [3]. All these prove that CNT-based sensors can fulfill the above mentioned engineering requirement for their properties [4,5]. Hu et al. developed a CNT-based flexible sensor which can be used to detect normal and shear forces [6]. Yimazoglu et al. raised a simple technique for integrating flexible, vertically aligned, multi-walled CNTs (MWCNTs) arrays sandwiched between carbon layers and examined the electromechanical properties of the CNT arrays for sensing pressure, tactile and vibration [7]. Lai et al. proposed a novel sensing material which was prepared by dispersing CNTs and silver nanoparticles in a polydimethylsiloxane (PDMS) polymer by using the dielectrophoresis technique [8]. Lipomi

et al. proposed a film pressure and strain sensor which was composed of SWCNTs [9].

Buckypaper (BP) is an outstanding material which contains entangled networks of CNTs formed by van der Waals interactions [10]. BP can be fabricated by using SWCNTs [11], double-walled CNTs [12], and MWCNTs [13]. A number of techniques for fabricating BP have been proposed. Hennrich et al. proposed a vacuum filtration method for fabricating large-area BP less than 200 nm thick [14]. Rigueur et al. fabricated BP by liberation of electrophoretically deposited carbon nanotubes [15]. Wang and Zhang et al. have fabricated highly oriented BP made of aligned carbon nanotubes [16–18]. Due to the component material (CNTs), microstructure and properties of BP, in the past decade, BP and BP composites have become a hot topic in the CNTs research. It is believed to be a good candidate for many engineering applications, such as electrodes, actuators, sensor, and heat conductors and as reinforcement for polymer composites [19–21]. Li et al. demonstrated the potential of carbon nanotube films in measuring strain at the macroscale [22]. Kang et al. developed a composite electrical resistance strain sensor based on SWNTs, and it was used to measure the strain of a structure at the macroscale [23]. Li et al. have studied the possibility of using multiwalled carbon nanotube (MWCNTs) films as strain sensors [24]. Gao et al. reported a simple approach to deposit multi-walled carbon nanotube (MWNTs) networks onto glass fiber surfaces achieving semiconductive MWNTs-glass fibers, along with application of fiber/polymer interphase s as in situ multifunctional sensors [25].

In this paper, we propose a simple vacuum filtration method for fabricating buckypaper and a vacuum bag molding technique for fabricating buckypaper composites. The buckypaper within the composites can be used as a sensing element for strain loading. Based on this sensing element, the tensile strain of buckypaper composites is investigated.

* Corresponding author.

E-mail address: lushaowei_sau@163.com (S. Lu).

2. Experiments

2.1. Preparation of buckypaper

The buckypaper preparation strategy was based on CNT dispersion in a solvent followed by successive filtration steps of this dispersion to form a film. 700 mg MWCNTs (10–30 nm in diameter, up to 50 μm in length and purity = 98%, Chengdu Organic Chemistry, Chinese Academy of Sciences) were ultrasonically dispersed in 1000 ml deionized water (1% Triton X-100, Tianjin Shakespeare Company) using Misonix Sonicator Q700 (USA) at 100 W (20 KHz) for 1 h. Upon completion of the dispersion process, the solution was ejected onto a 0.45 μm porous diameter filtration membrane, and filtered by a vacuum filtration setup as shown in Fig. 1(a). After filtration, the buckypaper was thoroughly washed with lots of deionized water to remove the adsorbed surfactant and dried in air. After the drying process, the buckypaper was peeled off from the filter membrane carefully and resulting in $\sim 20\ \mu\text{m}$ thick film as shown in Fig. 1(b).

2.2. Preparation of buckypaper composites

The buckypaper sensor was cut out from the buckypaper film obtained in Section 2.1 with scissors, and we ensure that the sensor has a rectangle shape with length 30 mm, width 10 mm. The sensor was located in the center of a $12 \times 2.5 \times 0.25\ \text{inch}^3$ glass fiber reinforced epoxy resin composite's (0° unidirectional composite, Weihai Guangwei composites Co., Ltd.) tensile specimen using vacuum bag molding technique for 2 h under 120°C and 0.5 MPa. The purpose of this process was to obtain a well resin infiltration into the buckypaper sensor and avoid a debonding between composites and buckypaper sensor. Subsequently, four copper wires (diameter: 0.1 mm) were fixed onto the buckypaper sensor surface using silver conductive adhesive and Fiber Bragg Grating strain sensor was used to measure the applied strain as shown in Fig. 2.

2.3. Characterization and sensing test of buckypaper

Field Emission Scanning Electron Microscope (FE-SEM) was used to get the microstructure of buckypaper, and Barret-Joyner-Halenda (BJH) method [26] was used to evaluate the pore size distribution of buckypaper. With the aim of characterizing the electric resistance response of the buckypaper sensor, a four probe methodology was employed for collecting data continuously at a sampling rate of 0.5 Hz. For the tensile testing, a MTS landmark universal testing machine equipped with 100 kN load cell was employed. The loading protocol involved incremental loading steps at load control mode with constant loading rate of 0.5 mm/min.

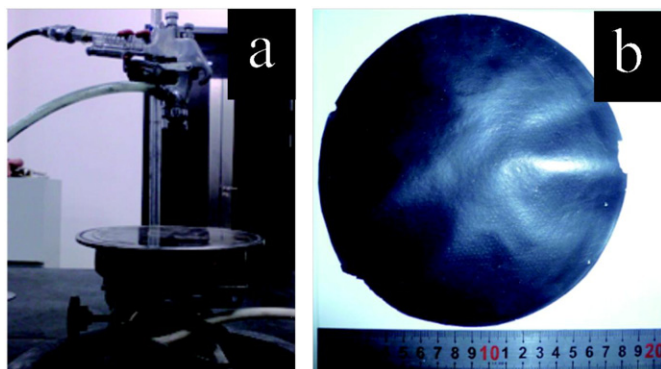


Fig. 1. (a) Vacuum filtration setup, (b) fabricated buckypaper.

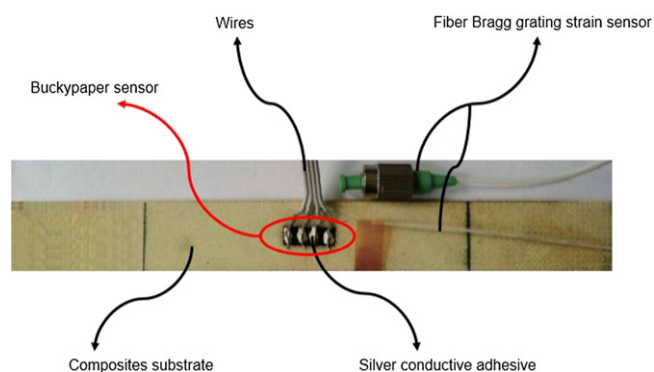


Fig. 2. Composites with MWCNT's buckypaper sensor.

3. Results and discussion

3.1. Microscopic morphology and pore size distribution of buckypaper

From Fig. 3(a), it can be seen that the SEM image of the buckypaper shows a densely packed mass of randomly oriented MWCNTs without any agglomeration, and this orientation gives rise to its isotropic

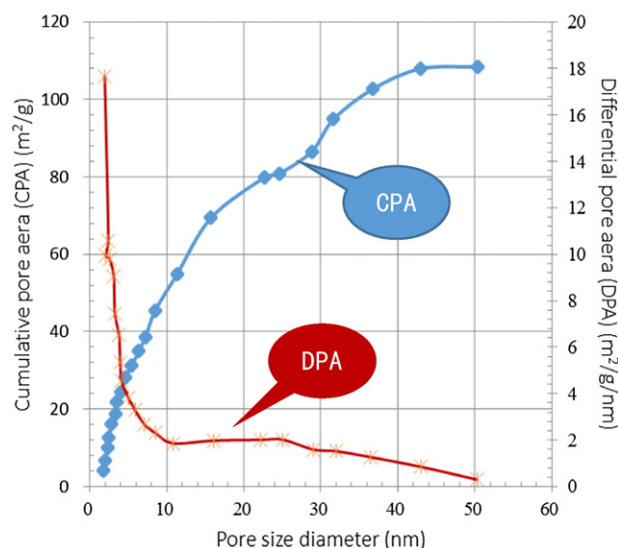
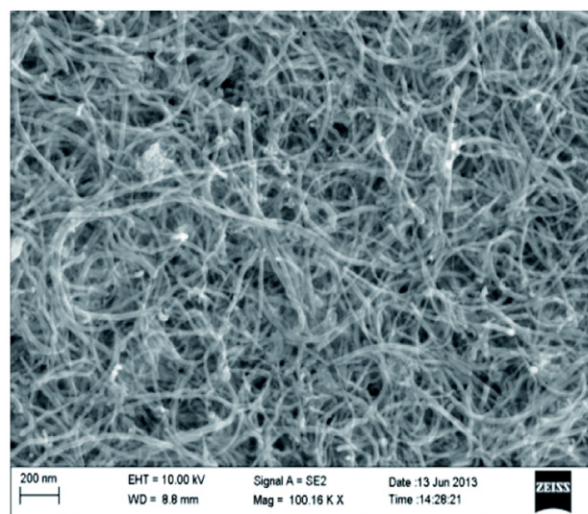


Fig. 3. (a) The FE-SEM image of a buckypaper, (b) the curve of average pore size distribution.

Download English Version:

<https://daneshyari.com/en/article/7220013>

Download Persian Version:

<https://daneshyari.com/article/7220013>

[Daneshyari.com](https://daneshyari.com)