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Experimental investigation on the compression behaviors of epoxy with carbon nanotube under high strain rates

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ABSTRACT

The compressive properties of epoxy with different carbon nanotubes (CNTs) contents at quasi-static and high strain rates loading had been investigated via experiment to evaluate the compressive failure behaviors and modes at different CNTs contents and different strain rates. The results indicated that the stress train curves were strain rate sensitive, and the compressive stiffness, compressive failure stress of composites with various CNTs contents was increased with the strain rates and CNTs contents. The compressive failure stress and the compressive failure modes of the composites were apparently different as the change of CNTs contents.

1. Introduction

Fiber reinforced composites like carbon/epoxy composite have become more popular nowadays because of their low cost and high quality structures such as high strength to weight ratio and high resistance to corrosion and abrasion. The dynamic behaviors such as impact tension and impact compression properties are basic parameter for the fiber reinforced composites. Since the composites often employed in impulsive loading, the dynamic behaviors are important factors in designing because the mechanical properties of fiber reinforced composite are different under high strain rates, which also called strain rates effect. In the polymer field, epoxy presents good stiffness, specific strength, dimensional stability, chemical resistance and strong adhesion to the reinforcement [1–3]. Therefore, epoxy is a popular material to be the matrix of fiber reinforced composites. At the same time, the mechanical properties of epoxy can play a role part in the dynamic behaviors of fiber reinforced composites.

Since the synthesis of carbon nanotubes (CNTs), many researchers have been activated in the relative fields. During the past decades, carbon nanotubes have been widely used into polymers such as epoxy and polyurethane to improve the radiation resistance and mechanical properties. Gojny et al. [4] prepared the nanocomposites consisting of double-wall carbon nanotubes (DWCNTs) and epoxy matrix; they found that the mechanical properties had an obvious increasing. Thostenson and Chou [5] investigated the mechanical properties of nanotube/epoxy composites with different reinforcement fractions. The results showed that the fracture toughness increased obviously at low nanotube concentrations and the thermal conductivity increased linearly with nanotube concentration. Gojny et al. [6] observed the influence of various carbon nanotubes such as single-wall CNTs (SWCNT), double-wall CNTs (DWCNT) and multi-wall CNTs (MWCNT) on the mechanical properties of epoxy matrix composites. In their observation, the nanocomposites produced exhibited an enhanced strength and a significant increase in fracture toughness. Cooper et al. [7] employed the Raman spectroscopy to characterize the tensile deformation of a dilute dispersion of SWNTs and MWNTs in the epoxy composite and predicted the mechanical properties of high volume fraction composites reinforced with carbon nanotubes. Dassios et al. [8] investigated the compressive behavior of MWCNT/epoxy composite mats, they found that the strength, stiffness and toughness of nanocomposite were increased with the pure polymer. Loos et al. [9] prepared the epoxy resin with single walled carbon nanotubes (SWCNTs) and studied the mechanical, viscoelastic and thermal properties. The results showed that the addition of small amounts of SWCNTs to epoxy could lead slight structural change in the epoxy matrix and improve the mechanical and viscoelastic properties. Gou et al. [10] investigated the interfacial bonding of single-walled nanotube reinforced epoxy composites via computational and experimental methods. The results showed that the interface bonding of the nanotubes in the epoxy resin increased up to 250–300% and indicated that there

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Table 1
The properties of carbon nanotubes (CNTs) contents.

Property	Outer diameter (OD) (nm)	Purity (wt%)	Length (μm)	Specific surface area (m^2/g)	Ash powder (wt%)	Tap density (g/cm^3)
Index	<8	>95	10–30	>500	<1.5	0.27

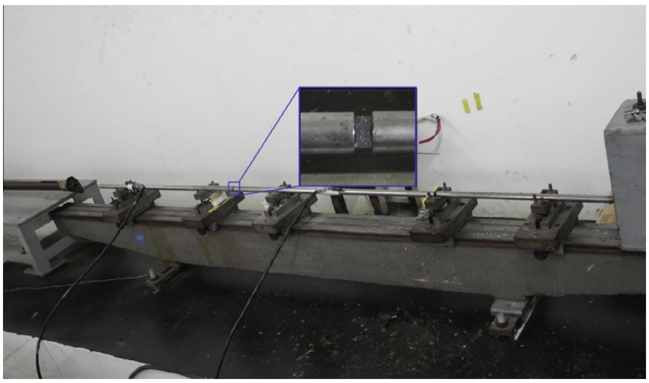

Fig. 1. Set up of split Hopkinson pressure bar.

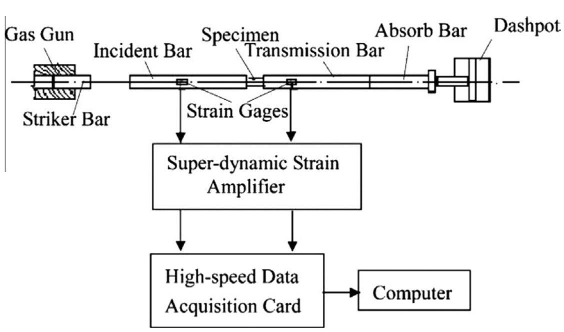

Fig. 2. Schematic of split Hopkinson pressure bar.

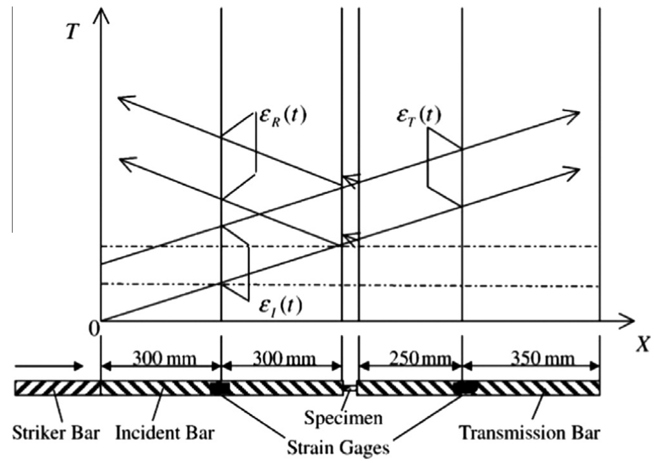

Fig. 3. Principle of split Hopkinson pressure bar.

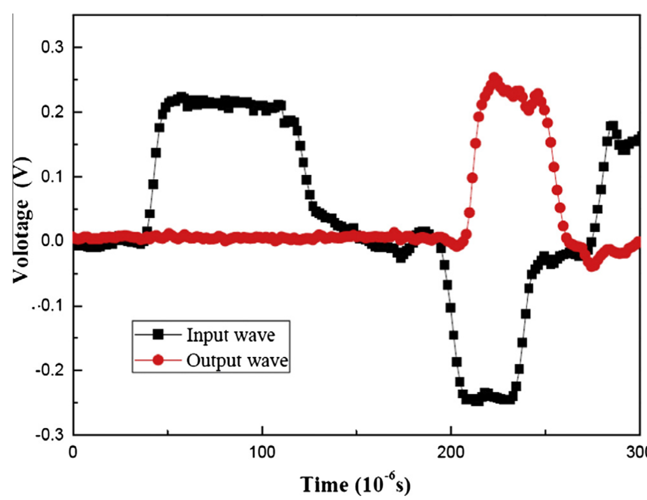

Fig. 4. Typical signals in input and output bar under compression with 1.0 wt% CNTs at strain rate of 1600/s.

could be an effective stress transfer from the epoxy to the nanotube. Shen et al. [11] discussed the reinforcement role of various amino-functionalized multi-walled carbon nanotubes in epoxy nanocomposites. They found that various kinds of amino-functionalized multi-walled carbon nanotubes would have different effects on the thermal and mechanical properties of the nanocomposites. Xu et al. [12] investigated the mechanical properties and interfacial characteristics of carbon-nanotube-reinforced epoxy tin films. The results showed that a 20% increase in elastic modulus when 0.1 wt% multiwalled carbon nanotubes were added compared to net resin thin films. Zhang et al. [13] Observed behavior of glass reinforced aluminum laminates with MWCNT modified epoxy resins via low-velocity experiments, they found that the impact resistance of composites with MWCNT was improved. Leininger et al. [14] investigated the influence of MWCNT content level on the quasi-static and dynamic tensile properties of epoxy. The results indicated that the mechanical properties were improved by the addition of MWCNTs. He and Tjong [15] analysis the correlation between state of nanotube dispersion and Zener tunneling parameters of carbon nanotube/epoxy resin composites. They found that the composites with homogeneous nanotube dispersion could exhibit larger static electrical conductivity and smaller percolation threshold han those with poorer nanotube dispersion.

Some researchers such as Zhang et al. [13] and Leininger et al. [14] investigated the dynamic mechanical behaviors of epoxy/CNT composites. However, their dynamic mechanical behaviors only focused on the low-velocity state. For the applications of impact resistance and impact protection, the mechanical parameters of the composite at high strain rates should be introduced because the composites often manifest the strain rate sensitivity. In this research, the epoxy with various content carbon nanotubes nanocomposites was prepared. The compression behaviors of the nanocomposites under quasi-static and high strain rates conditions will be presented. The compression strength, failure strain, energy absorption, compression stiffness and failure modes of various carbon nanotube contents nanocomposites under different compression strain rates also will be investigated.

2. Experimental procedure

2.1. Materials

The epoxy resin was Type 618 made by Shanghai Resin Factory of China, tensile modulus: 1.97 GPa, tensile strength: 68.10 MPa. The MWCNTs were MFG 110413 supplied by Chengdu Organic Chemicals Co. Ltd., Chinese Academy of Sciences. The properties of the CNTs have been shown in Table 1.