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Characterization of enhanced interfacial bonding between epoxy and plasma functionalized carbon nanotube films

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ABSTRACT

The interfacial bonding between carbon nanotube (CNT) films and epoxy is usually fairly weak for high quality composites and difficult to be measured experimentally. In this study, the interfacial bonding strength between a CNT film and epoxy is measured using a peeling test. The CNT/epoxy interfacial bonding strength is altered by surface functionalization of the CNT film using atmospheric pressure helium/oxygen plasma. Furthermore, composites with the control and the modified CNT film impregnated in epoxy are manufactured, and their mechanical properties including peeling strengths and tensile strengths are improved remarkably due to enhanced CNT/epoxy bonding after plasma functionalization. The peeling strength between the CNT film and epoxy is increased by 156.6% and so is the fracture energy. The tensile strength of the functionalized CNT film/epoxy composites is 74.4% higher than that with original CNT film. The effect of the treatment time (0.1, 0.2 and 0.3s) is assessed by surface chemical and physical analyses, showing an improvement in the amount of oxygen-containing functional groups on CNT surface, and better dispersion of the CNTs in ethanol with increased treatment time. This benefits the wetting and infiltration into CNTs by epoxy to obtain a stronger interfacial bonding.

1. Introduction

Carbon nanotubes (CNTs) possess outstanding structural, mechanical, electrical and thermal properties [1–3]. Individual CNTs are the strongest materials reported with high tensile strengths between 10 and 100 GPa and a Young's modulus up to 1 TPa [4]. To fully utilize the excellent performance for macroscopic applications, various methods have been developed to make macroscale materials composed of pure CNTs. Currently, floating catalyst chemical vapor deposition (FCCVD) CNT film is the most efficient way to produce a 2D macroscopic carbon nanotube assembly with high quality [5]. These large scale CNT films are suitable for industrial applications with high productivity. The superior mechanical properties of CNT films make them as ideal reinforcement in high strength, lightweight polymer composites, which has been one of the most attractive engineering materials [6].

However, the challenge in manufacturing CNT reinforced nanocomposites is the weak interfacial bonding between CNTs and polymer matrix which has to be enhanced for a better composite. Virgin CNT surfaces lack oxygen-containing functional groups, leading to a feeble intermolecular force with the polymer matrix [7]. Moreover, the inherent atomically smooth surface of nanotubes limits load transfer from the polymer matrix to the nanotubes [8]. Therefore, the ability to infiltrate the polymer matrix into the CNTs with a strong interfacial interaction is the key issue in maximizing the advantage of CNT reinforcement in composites. Thus, modification of the CNT film by changing the surface chemical composition has been proven to be crucial to create a good interface between CNTs and polymer matrix. Moreover, to establish a scientific and effective interfacial bonding strength test method is equally important.

Some previous work has been done to study the macroscale CNTs materials and their composites. For example, Park and coworkers [9] reported that the tensile strength of CNT fibers could

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was improved by 40% after just 5 min oxygen plasma treatment. Jiang and Li et al. [10] used He/O_2 plasma functionalized buckypaper to make composites with phenylethynyl-terminated polyimide, and found 30% increase in tensile strength and 125% increase in tensile modulus, indicating improved adhesion between the buckypaper and the polymer. However, little has been reported on CNTs and epoxy interfacial bonding in literature. There have been published literature in direct test methods for interfacial bonding strength of CNTs and polymer matrices. Shao and coworkers [11] have investigated the interfacial shear strength between an aerogel spun CNT yarn and polyphenylene sulfide using the microdroplet test. This method pulls a single fiber out of a microdroplet of polyphenylene sulfide resin to measure the interfacial shear strength between CNT yarn and the matrix, which is more applicable for the yarn/polymer composites and the test area was relatively limited. Feng et al. [12] measured the transverse tensile strength at cryogenic temperature (77 K) as an indication for the interfacial property of carbon fiber/epoxy composites with added-in the multi-walled carbon nanotube (MWCNT). This method is particularly suitable for the cryogenic temperatures situation. So far, the existing methods for measuring the interfacial strength of CNTs reinforced nanocomposites still have certain obvious disadvantages. In this study, we try to develop a feasible method, namely peeling test of two CNT films bonded by epoxy resin, to effectively measure the interfacial bonding strength between the CNT films and the matrix. An epoxy resin is selected as the matrix because epoxy resins have the best overall properties and are used widely in applications where CNT can potentially replace traditional high performance fibers. In order to prove the effectiveness of the interfacial bonding test method, plasma treatment was utilized to alter the surface properties of the CNT films with the advantages of simplicity of operation, short treatment time and no great damage to CNTs like strong acid does [13,14]. When plasma is discharged with oxygen-containing gas, oxygen-containing functional groups would be generated on the treatment site of the CNTs surface [15], which are beneficial for improving the CNTs surface polarity and the bonding with polymers.

In this work the atmospheric pressure plasma jet was employed to treat MWCNT films. The peeling strength and tensile strength of the MWCNT film/epoxy composites were systematically investigated.

2. Experimental

2.1. Materials

MWCNT film prepared by FCCVD was supplied by Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO), Chinese Academy of Sciences. The thickness of the film was about 13.7 μm with a purity >90% and the MWCNT had a diameter of approximately 25 nm [16]. Epoxy resin (JL-235) and curing agent (JH-242) were purchased from Changshu Jiafa Chemical ltd., China.

2.2. Plasma modification of CNT films

Atmospheric pressure plasma jet Atomflo™400 (Surfx technologies, US) was used to treat the MWCNT films as shown in Fig. 1. A 13.56 MHz power supply for the discharge was connected to the

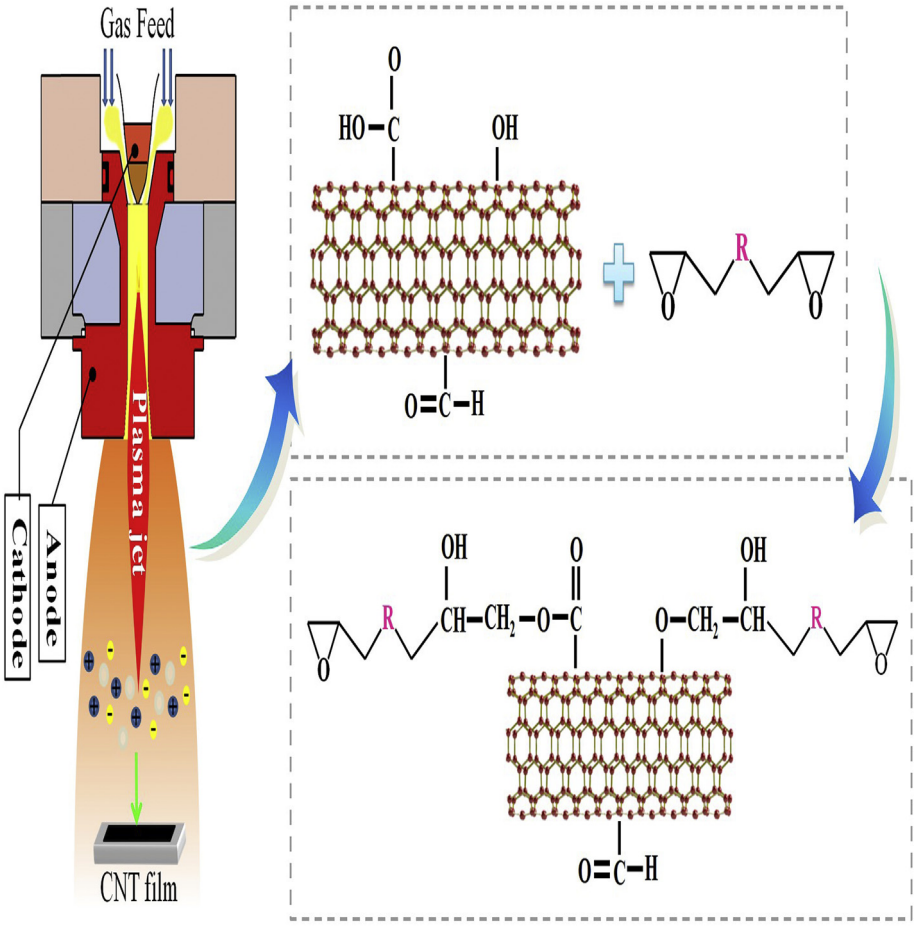

Fig. 1. Reaction scheme of CNT film plasma modification.