Journal of the European Ceramic Society 36 (2016) 2255–2262

Contents lists available at www.sciencedirect.com

Journal of the European Ceramic Society

journal homepage: www.elsevier.com/locate/jeurceramsoc

An experimental and numerical study on the mechanical properties of carbon nanotube-latex thin films

Long Wang[a], Kenneth J. Loh[a,*], Lucas Brely[b], Federico Bosia[b], Nicola M. Pugno[c,d,e,**]

[a] Department of Structural Engineering, University of California, San Diego, 9500 Gilman Drive, Mail Code 0085, La Jolla, CA 92093-0085, USA
[b] Department of Physics and "Nanostructured Interfaces and Surfaces" Centre, Università di Torino, Italy
[c] Laboratory of Bio-Inspired & Graphene Nanomechanics, Department of Civil, Environmental and Mechanical Engineering, Università di Trento, Italy
[d] Center for Materials and Microsystems, Fondazione Bruno Kessler, Trento, Italy
[e] School of Engineering and Materials Science, Queen Mary University of London, UK

ARTICLE INFO

Article history:
Received 1 December 2015
Received in revised form
25 December 2015
Accepted 31 December 2015
Available online 29 January 2016

Keywords:
Annealing
Carbon nanotube
Mechanical property
Nanocomposite
Numerical simulation

ABSTRACT

Multi-walled carbon nanotube (MWNT)-latex composite thin films of different MWNT concentrations were fabricated by spraying. Post-fabrication thermal annealing was then conducted on sample sets of different MWNT concentrations, and their microstructure, morphology, and mechanical properties were compared to non-annealed sample sets. The incorporation of MWNTs significantly enhanced the mechanical properties of these nanocomposites at least up to 3 wt%. In addition, annealing altered the microstructure and morphology of the latex matrix, which enhanced the interactions between MWNTs and the polymer, significantly increasing the composite ultimate failure strain and tensile strength. Furthermore, the reinforcing effects of MWNTs on the polymer matrix were investigated using numerical simulations. Stress concentrations were found to initiate at MWNT ends, thus giving rise to yielding fronts that tend to coalesce and propagate across the entire film. The enhancement of the mechanical properties of MWNT-latex nanocomposites, also verified numerically, makes them more suitable for field application as multifunctional coatings or sensors.

1. Introduction

Carbon nanotubes (NT) have received significant attention and have been studied extensively since the work by Iijima [1]. Early research has focused on characterizing individual NTs' intrinsic properties, which include their high aspect ratios, low density, mechanical [2–4], and electrical [5] properties. In addition, they have been shown to be piezoresistive [6–8] and sensitive to thermal effects [9], among others, which make them prime candidates for multifunctional materials. In fact, their peculiar properties have been leveraged for developing various NT-based sensing devices [8,10]. However, the application of individual NTs can be challenging due to their small dimension, especially when it comes to large-scale civil, aerospace, and marine structural applications.

On the other hand, NTs serve as ideal reinforcing materials for engineered composites due to their unique mechanical properties [11–13]. After NTs are incorporated within materials such as polymer matrices, they can be more readily used as macro-scale nanocomposites for structural applications. Examples include using vacuum filtration (for buckypapers) [14], layer-by-layer (LbL) deposition [15], and electrospinning [16], to name a few. Although these methods could successfully fabricate piezoresistive NT-based thin films, they suffer from limitations, including the use of complicated or time-consuming fabrication procedures, low productivity, and size constraints. In contrast, spray-coating has been investigated as a viable alternative, since it is simple, efficient, low cost, and uses readily available raw materials (e.g., latex) [17,18]. A previous study by Wang and Loh [19] showed that spray-coated, post-fabrication, thermally annealed MWNT-latex thin films exhibited improved electromechanical properties; nominal electrical resistance drifts were eliminated or mitigated, which make them more suitable for use as strain sensors for structural health monitoring applications.

The objective of the present study is to characterize how nanotube concentrations and post-fabrication thermal annealing affected the bulk mechanical properties of the aforementioned

* Corresponding author.
** Corresponding author at: Laboratory of Bio-Inspired & Graphene Nanomechanics, Department of Civil, Environmental and Mechanical Engineering, Università di Trento, Italy.
E-mail addresses: lowang@ucdavis.edu (L. Wang), kenloh@ucsd.edu (K.J. Loh), lucasleo.brely@unito.it (L. Brely), federico.bosia@unito.it (F. Bosia), Nicola.Pugno@unitn.it (N.M. Pugno).

http://dx.doi.org/10.1016/j.jeurceramsoc.2015.12.052
0955-2219/