



Compressive properties and thermal stability of hybrid carbon nanotube-alumina filled epoxy nanocomposites



Muhammad Razlan Zakaria ^a, Hazizan Md. Akil ^{a, b, *}, Muhammad Helmi Abdul Kudus ^a,
Muhammad Bisyrul Hafi Othman ^a

^a School of Materials and Mineral Resources Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia

^b Cluster for Polymer Composite (CPC), Science and Engineering Research Center, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia

ARTICLE INFO

Article history:

Received 17 December 2015

Received in revised form

19 January 2016

Accepted 21 January 2016

Available online 4 February 2016

Keywords:

A. Hybrid

A. Polymer-matrix composites (PMCs)

E. Chemical vapour deposition (CVD)

ABSTRACT

The multi-scale hybridisation of carbon nanotube (CNT) and alumina (Al_2O_3) was synthesised by using chemical vapour deposition. The idea of hybridisation between the CNT and Al_2O_3 particles is to prevent the agglomeration of the CNT due to van der Waals attractions. The Al_2O_3 particles work as “vehicles” for the CNTs to disperse homogeneously in the epoxy matrix and improve the particle/matrix interface. Epoxy composites with the CNT– Al_2O_3 hybrid compound were observed to exhibit an enhancement of 117% and 148% in compressive strength and compressive modulus, respectively. Similarly, thermal stability improvement has also been observed for the CNT– Al_2O_3 hybrid compound epoxy composite system.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Carbon nanotubes are regarded as seamless cylinders formed by wrapping graphene sheets with carbon atoms that are covalently bonded with each other through sp^2 hybridisation [1,2]. Over the last decades, carbon nanotubes (CNT) have progressed into one of the most intensively studied materials and they play a major role in co-triggering the polymer nanocomposites [3–7]. The use of the CNT as a filler in polymer composites has remained attractive to researchers and has been analysed for numerous applications. The CNT, with exceptional mechanical properties as well as high ratio of surface to volume, have been considered as an ideal candidate to act as a reinforcement for polymer nanocomposites [8–11]. Usually, small amounts of the CNT in polymer composites have often resulted in a significant enhancement in mechanical, thermal and electrical properties of polymer nanocomposites [12–14]. Nonetheless, full exploitation of CNT reinforcement in polymer nanocomposites has not been entirely successful because of the dispersion issue of aggregated CNT [15,16]. The CNT tend to

aggregate towards each other and form bundles that have very low solubility in most solvents because of intrinsic van der Waals forces which lead to poor dispersion in the polymer matrix [17–19]. Hence, the homogenous dispersion of the CNT in the polymer matrix as well as strong interfacial bonding between the CNT and the polymer matrix will play an important role in maximising the amazing properties of CNT reinforcement.

Recently, a great deal of research has been carried out to solve the dispersion issue between the CNT and the polymer matrix [20–23]. The hybridisation of the CNT with micro particles has been reported as one of the famous methods to solve the above obstacles [24–27]. The hybrid filler composing of the CNT and micro particles has several advantages in attaining more controllable CNT dispersion and enhanced interfacial bonding between the CNT and the polymer matrix [28,29]. These hybrid architectures were produced by directly growing the CNT on a micro-substrate surface using chemical vapour deposition (CVD) instead of simply mechanically mixing them. The multi-scale hybrid with the CNT grown on the alumina micro-substrate has been reported to be able to improve mechanical and thermal properties at low CNT content [30,31]. By growing the CNT on the alumina, this will form a network structure, which homogeneously distributes the CNT on the alumina surface and at the same time bonds strongly to the alumina. The presence of the micro-scale alumina may help to disperse the CNT in the polymer matrix where alumina works as a

* Corresponding author. School of Materials and Mineral Resources Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia. Tel.: +60 04 5996161; fax: +60 04 5941011.

E-mail address: hazizan@usm.my (H.Md. Akil).

“vehicle” for the CNT to disperse much easier than by conventional mechanical stirring. In addition, alumina is an important ceramic material that is extensively used for structural application at high temperature due to its high hardness and excellent oxidation resistance [32]. The hybridisation of alumina with the excellent thermal stability possessed by the CNT may enhance the mechanical properties of the polymer nanocomposites without reducing their resistance to oxidation [33].

In this paper, the CNT–Al₂O₃ hybrid compound was synthesised by growing the CNT on the alumina particles under methane atmosphere by using nickel as the catalyst. The characteristics of the CNT–Al₂O₃ hybrid compound were examined using a Field Emission Scanning Electron Microscope (FESEM) and a High Resolution Transmission Electron Microscope (HRTEM) to observe the morphology of the CNT structure forming on the alumina particle. The aim of this study was to investigate the effects of the CNT–Al₂O₃ hybrid and CNT–Al₂O₃ physically mixed compounds on the compressive properties and thermal stability of an epoxy nanocomposite. Compressive tests were performed on the CNT–Al₂O₃ hybrid compound filled epoxy and CNT–Al₂O₃ physically mixed filled epoxy. The dispersion states of the CNT and the Al₂O₃ were examined using FESEM and HRTEM. Thermogravimetric analysis (TGA) was used to identify the thermal stability of epoxy nanocomposites. The enhancement in the compressive properties and thermal stability of the CNT–Al₂O₃ hybrid compound filled epoxy and the CNT–Al₂O₃ physically mixed filled epoxy were also achieved. The possible explanations for the enhancement of the CNT–Al₂O₃ hybrid compound filled epoxy and the CNT–Al₂O₃ physically mixed filled epoxy are discussed.

2. Experimental

2.1. Production of CNT–Al₂O₃ hybrid powder

The CNT–Al₂O₃ hybrid compound was synthesised via chemical vapour deposition (CVD). Nickel was used as a metal catalyst to be incorporated with alumina, and this had been carried out by mixing nickel nitrate hexahydrate, Ni(NO₃)₂·6H₂O and aluminium, Al powder in distilled water. Sodium hydroxide (NaOH) was added into the mixture and it was dissolved by stirring constantly to precipitate Ni(NO₃)₂·6H₂O and Al powder. The amounts of Ni(NO₃)₂·6H₂O, Al powder, NaOH, and distilled water are presented in Table 1.

The precipitation was aged at room temperature for 24 h and a green paste of Ni(NO₃)₂·6H₂O was formed. The sample was washed and filtered by using filter paper, and followed by drying at 110 °C for 2 h. The dried precipitates were calcined at 900 °C for 10 h to oxidise NiOH and Al(OH)₃ to form a NiO–Al₂O₃ complex. The NiO–Al₂O₃ complex was then reduced at 400 °C for 2 h with the presence of a hydrogen gas atmosphere to complete the preparation of the catalyst. Later, the catalyst was placed in the custom-made tube furnace of CVD to grow the CNT on the Al₂O₃ particle. The catalyst was then reacted in methane gas as a source of carbon, and nitrogen gas as a carrier gas with ratio 1:7 at 800 °C for 30 min. CNT–Al₂O₃ was also prepared through a physical mixing method for comparison with the CNT–alumina hybrid compound. The

Table 1
Materials used for catalyst preparation.

Materials	Quantity/ratio
Ni(NO ₃) ₂ ·6H ₂ O	0.01 mol
Al powder	0.38 mol
NaOH	0.02 mol
Distilled water	1 L

purchased MWCNT and Al₂O₃ were mixed in a ratio of 12:100 by using a ball-milling machine for 48 h at 20 rpm. The ratio of the CNT and alumina was calculated quantitatively based on an energy dispersive X-ray (EDX) analysis of the CNT–Al₂O₃ hybrid compound which was reported in a previous paper [22]. Reagent grade Ni(NO₃)₂·6H₂O (99% purity), Al powder (99% purity) and NaOH (98% purity) were obtained from Merck Company. The pure MWCNT (95% purity) was purchased from SkySpring Nanomaterials Inc. and Al₂O₃ powder (98% purity) was from Sigma Aldrich.

2.2. Characterisation of CNT–Al₂O₃ filler

Micro structural characterisation of the HYB and MIX powder was examined using a high-resolution transmission electron microscope (HRTEM-Model Philip TECNAI 20 (200 kV)) and a field emission scanning electron micrograph (FESEM) (LEO SUPRA 35VP, Carl Zeiss, Germany).

2.3. Preparation of CNT–Al₂O₃ epoxy nanocomposites

The HYB and MIX were dispersed in the epoxy resin Diglycidyl Ether of Bisphenol A (DGEBA) (supplied by Eurochemo Pharma Sdn Bhd) using a QSonica sonicator machine at the frequency of 25 KHz for 30 min. The temperature was maintained between 60 °C and 70 °C during sonication. Next, the curing agent trimethylhexamethylenediamine (TMD) (supplied by Eurochemo Pharma Sdn Bhd) was added at a mass ratio of 6:10 to the epoxy resin. After that, the mixture was placed in a vacuum of 76 cm Hg pressure for 30 min to remove any trapped air. Finally, the epoxy composites were poured into a shaped silicon mould and cured at 120 °C for 1 h. In order to determine the effect of filler loading on the properties of the samples, the epoxy composites were prepared with different weight percentages of the HYB and MIX contents, i.e. 1.0 wt%, 3.0 wt%, and 5.0 wt%. Table 2 shows the descriptions of the samples.

2.4. Characterisation of epoxy nanocomposites

Compression tests of the Epoxy/HYB and Epoxy/MIX were carried out according to ASTM D695-10 [34]. Specimens were placed in a fixture as proposed in the standard and tested in a universal testing machine (Model: 5982, Instron, USA) and loaded with a constant crosshead speed of 1 mm/min until failure. Data recording and acquisition were facilitated with the Instron software. At least five specimens were tested for each case to ensure reliability of the test results. The fracture surfaces of the compressive test samples were examined by FESEM after coating with a 5–10 nm Au–Pd layer by sputtering. The morphology at a nano-scale of the HYB and MIX through the epoxy matrix was analysed using HRTEM. Samples with 50 nm of thickness were prepared by cryo-ultramicrotomy

Table 2
Descriptions of the samples.

Samples	Descriptions
HYB	CNT–Al ₂ O ₃ hybrid compound
MIX	CNT–Al ₂ O ₃ physically mix
Epoxy/HYB	Epoxy filled with CNT–Al ₂ O ₃ hybrid compound
Epoxy/HYB1	Epoxy filled with 1% wt CNT–Al ₂ O ₃ hybrid compound
Epoxy/HYB3	Epoxy filled with 3% wt CNT–Al ₂ O ₃ hybrid compound
Epoxy/HYB5	Epoxy filled with 5% wt CNT–Al ₂ O ₃ hybrid compound
Epoxy/MIX	Epoxy filled with CNT–Al ₂ O ₃ physically mix
Epoxy/MIX1	Epoxy filled with 1% wt CNT–Al ₂ O ₃ physically mix
Epoxy/MIX3	Epoxy filled with 3% wt CNT–Al ₂ O ₃ physically mix
Epoxy/MIX5	Epoxy filled with 5% wt CNT–Al ₂ O ₃ physically mix

Download English Version:

<https://daneshyari.com/en/article/7212763>

Download Persian Version:

<https://daneshyari.com/article/7212763>

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