

Mechanical and Thermal Behavior of a Polymer Composite Reinforced with Functionalized Carbon Nanotubes

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Abstract: In this paper, the effects of MWNT loading, surface functionalization on the mechanical and thermal properties of an epoxy based nanocomposite system were investigated. Chemical functionalization of MWCNT by sonicating with nitric and sulfuric acids, was used to fabricate a MWNT/epoxy composite. There are two reasons for functionalizing the MWNTs, they are (i) to improve the dispersion of the MWNTs in polymer, and (ii) to improve the interfacial bonding properties between the MWNTs and polymer matrix. Tensile property test and thermal conductivity test was carried out to examine the mechanical and thermal properties of the composites with different MWNT contents (0, 0.03, 0.05, 0.1, 0.2, and 0.3 V_p %). A comparison of the composites with functionalized (f-CNT) and un-functionalized (u-CNT) MWNTs were given to elaborate the effect of nanotube functionalization.

Keywords: Carbon nanotube, Functionalization, Composite, Mechanical properties, thermal properties.

I. Introduction

Carbon nanotubes (CNTs) are currently regarded as promising nanoscale fillers for polymer composite materials. Their low density, high aspect ratio, and extraordinary mechanical, electrical and thermal properties makes them a perfect candidate in polymer composites applications where a weight reduction is crucial, such as in aerospace and automotive composites [1,2]. The performance of a CNT/polymer nanocomposite depends on the dispersion of CNTs in the matrix and interfacial interactions between the CNT and the polymer. The main issue in preparing nanocomposites is the uniform dispersion of fillers in the polymer matrix. Because of the high aspect ratio and van der Waals attractive forces, MWCNTs form bundles or agglomerates [3]. To overcome the difficulty of dispersion, mechanical/physical methods such as ultrasonication, high shear mixing, surfactant addition, etc. have been used, however, successful dispersion remains elusive [4].

As a result, significant effort has been oriented towards investigating new ways of processing CNTs to improve their integration into polymer matrices. The objective of this study is to investigate the effect of functionalization on the mechanical and thermal properties of CNT/epoxy composites. The CNTs were chemically functionalized, and dispersed into epoxy by different V_p % loading. The stress-strain behavior and thermal conductivity were evaluated.

II. Experimental

2.1. Materials

The polymer matrix consisted of part A epoxy resin (Quickmast 105) and part B hardener (poly amine) Epoxy polymer matrix was prepared by mixing 1:3 parts by volume of epoxy resin (Quickmast 105) with hardener (amine). Two different types of MWCNTs, pristine MWCNT and functionalized MWCNT, were used in this work. The MWCNTs employed in this study were supplied by Materials and Electrochemical Research (MER) Corporation and its purity was higher than 95%. The MWCNTs had diameter of (140 \pm 30 nm), and the length ranging of (7 \pm 2 μ m). Epoxy resin and hardener having the density of 1.04 g/cm³. The volume fraction (V_p) of the carbon nanotubes ranged from (0.03, 0.05, 0.1, 0.2 and 0.3 V_p %).

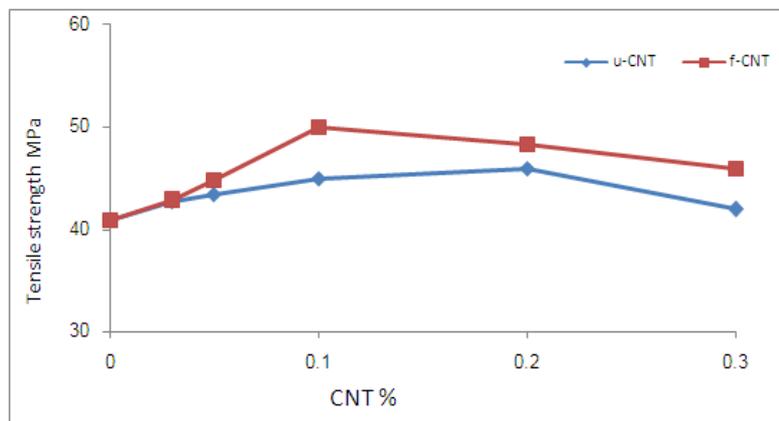
2.2 Nano composite preparation

In order to study the effect of CNTs in the polymer matrix, pure epoxy, MWNT/epoxy (u-CNT /epoxy) and functionalized MWNT/epoxy (f-CNT/epoxy) composites were fabricated separately with volume fraction of the carbon nanotubes ranged from (0.03, 0.05, 0.1, 0.2 and 0.3 V_p %). The u-CNT /epoxy composites were prepared by dispersion a desired amount of u-CNTs kinetically by ultrasonication. To achieve better state of dispersion first the nanotube were treated with acetone in an ultrasonic bath at room temperature for (2 h) for the demarcation of the tube bundles, in order to evaporate the acetone, the mixtures are treated in a vacuum oven at (70 °C) for (1 h), then the treated tubes added the epoxy resin and sonicated for (1h) at room temperature. Were MWCNTs functionalized by acid treatment of MWCNTs, typically, 7.7g of MWCNTs, 64 ml of 60% HNO₃, and 193 ml of 98% H₂SO₄ was added into 1000ml flask equipped with a condenser with vigorous stirring. The flask was then immersed in a sonication bath (40 kHz) for 10 min. Details of

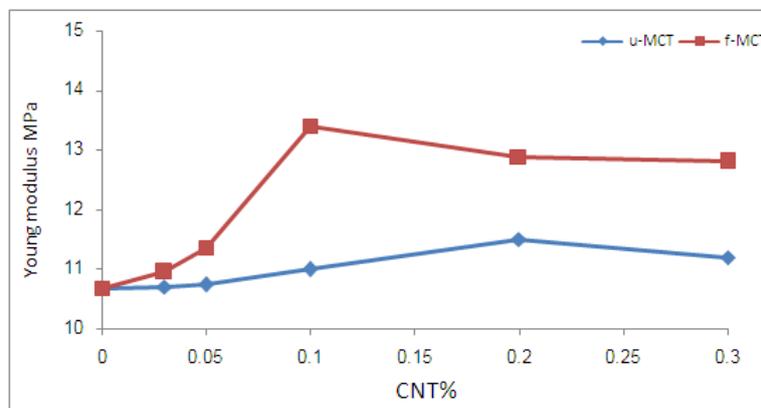
functionalization can be found in ref. [5]. Then both mixture cured under by hardener addition (resin / hardener ratio 3:1) and sonicated for 3 mints in water bath for homogenization. The resultant mixture was cast in to mould, the mould is smeared by wax paper before the mixture was poured in to the mould. The tensile strength, tensile modulus and % elongation at break of neat epoxy and nanocomposites sample were measured using a (Instron-1195) Universal Testing Machine (UTM) according to ASTM D 638. Lee's disc was the instrument used in order to examine the thermal conductivity (k-value) for samples pure, u-CNT, and f-CNT loading epoxy composites respectively.

III. Results and discussion

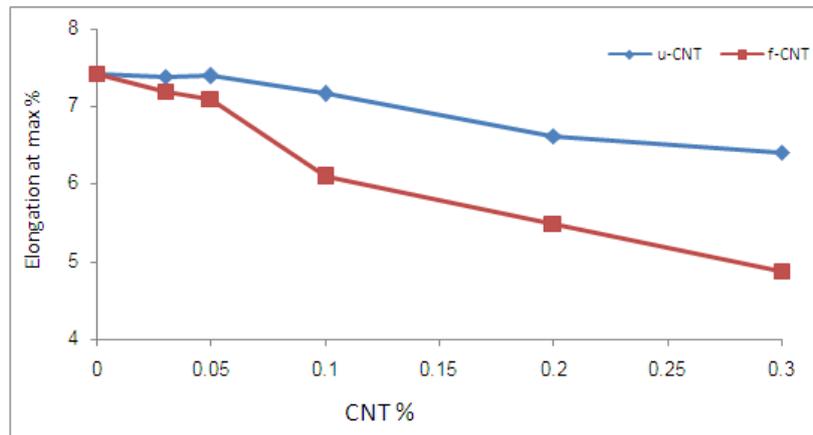
Tensile strength, Young modulus (tensile modulus) and elongation at maximum force for the performs, pure epoxy resin and two types of MWNT (u-CNT and f-CNT)/epoxy composite with different volume fraction of MWNT are shown in Fig.(1), Fig(2) and Fig.(3) respectively. The tensile strength of the epoxy composites shows the favorable effects of both u-CNT and f-CNT on the reinforcement of epoxy resin. The tensile strength increases when increasing the MWNT loading up to 0.1 V_p % for f-CNT, 0.2 V_p % for u-CNT composites and decreases as the loading increase, which is increased and 17.9% (for average) larger than that of neat epoxy (40.91 MPa). The Young's modulus show the same trend as the tensile strength, but the elongation at maximum force of composite was lower than neat epoxy, this is due to interfacial bonding between CNTs and the matrix. While, the elongation at maximum force of f-CNTs composites is lower than that u-CNTs composites due to that the interfacial bonding between f-CNTs and the matrix is more than that between u-CNTs and matrix. Similar results reported in the literature[6-7]. Moreover, tensile properties decreases slightly when the addition is over 0.1 V_p % and 0.2 V_p % for u-CNT/Epoxy and f-CNT/Epoxy composites respectively, this means that the MWNT did not disperse uniformly and they formed agglomerations in the polymer matrix at high CNTs loading[8]. However, the addition of any type generally increases the tensile properties (Young's modulus and tensile strength). Whereas, the nanocomposites reinforced with f-CNTs has higher tensile properties compared with that enhanced with u-CNTs, due to the poor interaction between u-CNTs and epoxy.



Fig(1) Tensile strength of the composites with different V_p % of MWNT



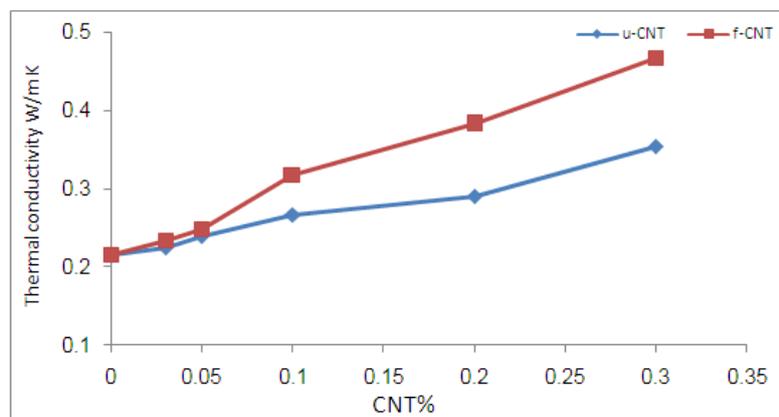
Fig(2) Young modulus of the composites with different V_p % of MWNT



Fig(3) Elongation at maximum force of the composites with Different V_p % of MWNT

The Young's modulus with a f-CNT loading is higher than that of pure epoxy and u- CNTs composites respectively, which arises from the stiff interfacial layer formed between f-CNTs and epoxy with difficulty to achieve polymer deformation[9]. This means that The functionalization process improves moderately the interface between load and matrix. Since the functionalization-induced polarity groups, may react with epoxy resin during composition curing [10-11], resulting in stronger interface bonding between f-CNTs, and epoxy resins, and better dispersion of f-CNTs in the epoxy matrix which activates effective mechanisms of load transfer.

Figure (4) shows the thermal conductivity of both CNT/epoxy composites as a function of the volume fraction of the CNTs. The thermal conductivity of these two kinds of composites increased with CNT concentration, Similar results have also been reported by Gojny et al.[12] and Ma et al [13] . On the other hand; Yuen et al. [14]reported no significant improvement in thermal conductivity by adding CNTs to the epoxy matrix. The neat epoxy showed a thermal conductivity of 0.216 W/mK. Since Carbon nanotube, which is known to be a good thermal conductor's is seen to enhance the thermal conductivity when its volume fraction is increased[15-16]. So, all composites reinforced with carbon nanotubes exhibit the highest thermal conductivity values than pure epoxy. It is clear from the figure the thermal conductivity values of u-CNT composites were slightly enhanced (as compared to the neat) with increasing volume fraction of CNTs, this slightly increments in u-CNT composites can be explained by considering various factors which affect heat flow in CNT/polymer composites. A boundary resistance(weak coupling) between the two phases acts as a barrier to the heat flow and thus decreases the overall conductivity [17] have given a comprehensive overview of the role played by the boundary resistance in determining the thermal properties of CNT/polymer composites, they show that there is a weak coupling between the phonon spectra of the CNTs and the polymer matrix. Since phonons dominate heat transport in CNTs, this weak coupling produces a backscattering of phonons at the interface causing a drop in temperature there and giving rise to a boundary resistance. Apart from the interfacial resistance, a non-uniform dispersion of CNTs in the polymer matrix may also significantly affect overall behavior.



Fig(4) Thermal conductivity of the composites with different V_p % of MWNT

Also, it can be seen from this figure that the thermal conductivity values of f-CNT/epoxy composites is higher than that of u-CNTs composites this is may be attributed to:

1- This increase for f-CNTs load can be explained considering a more efficient dispersion of functionalization nanotubes. According to Chen et al [18] the more uniform the dispersion of f-CNTs, the higher thermal conductivity of the composite.

2- Another reason to enhance thermal conductivity is that the functionalization process improves moderately the interface between load (f-CNT) and matrix (polymer) which can be expected to reduce the thermal boundary between the filler particles and the matrix, thereby increasing the effective thermal conductivity of the composite [19].

IV. Conclusions

The mechanical and thermal properties of epoxy, f-CNT/epoxy and f- CNT/epoxy composites were evaluated. The f-CNT/epoxy composite shows a significant improvement in the Young's modulus and tensile strength when compared to the other two composites. Functionalization enhances the dispersion and interfacial bonding between CNTs and polymer matrix. It is suggested that, functionalization of CNT can play an important role for the further development of CNT composites.

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