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RESEARCH PAPER

Effects of carbon nanotube content on the mechanical and electrical properties of epoxy-based composites

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Abstract: The effects of multi-wall carbon nanotube (MWCNT) content on the mechanical and electrical properties of MWCNT/epoxy composites were investigated. Results indicate that both tensile strength and flexural modulus exhibit maxima at MWCNT contents of 0.1% and 0.25% (mass fraction), respectively. The tensile modulus increases and the strain to failuredecreases with MWCNT content, indicating a transition from plastic to brittle failure with increasing MWCNT content. The flexural strength of a sample with a MWCNT content of 0.05% is the highest. The electrical percolation threshold of the composite is found to occur at a 0.5% MWCNT addition. A good dispersion of MWCNTs in epoxy is important to improve the mechanical properties of the composites. A non-uniform dispersion leads to agglomeration of MWCNTs, which causes an early-stage failure under loading. The electrical properties of the composites are less affected by the presence of agglomerates.

Key Words: Multi-wall carbon nanotubes; Mechanical and electrical properties; Nanocomposites; Tensile properties; Stiffness; Flexural properties

1 Introduction

Polymer materials have many advantages including low weight, low cost, ease of processing and shaping and corrosion resistance[1]. Many researchers concentrated on the improvement of mechanical properties of polymers using nanoparticles as fillers. One of the famous nano fillers is carbon nanotubes (CNTs) and they are allotropes of carbon with a cylindrical nanostructure. These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. In particular, carbon nanotubes are utilized as additives to various structural materials, owing to their extraordinary thermal conductivity and mechanical and electrical properties. For instance, nanotubes form only a tiny portion of the material(s) in (primarily carbon fiber) baseball bats, golf clubs or car parts[2]. The dispersion of nano-fillers into matrix is of significant importance, and a non-uniform dispersion and defects in fabrication can cause earlier failure in the matrix and prevent from achieving required properties[3-6]. Also, the improvement of mechanical and electrical properties via adding different CNT contents into epoxy resin in some published papers have been attracted the attention of researchers [7-16].

Sandler et al.[7] used 0.1 vol. % CNTs as nano fillers into epoxy matrix to improve the electrical property and found that more conductive material can be achieved than that with carbon black in the same epoxy matrix. Yaping et al.[8] prepared some samples based on epoxy resin with different weight percentages of MWCNTs (functionalized and non-functionalized) as fillers and showed a strong influence of MWCNTs on mechanical properties of the resulting composites. When MWCNTs content was 0.6%, the mechanical properties were the best, and the bending strength and modulus were increased up to 100 and 58%, respectively. Martone et al.[9] analyzed the effect of adding MWCNTs into epoxy on the bending modulus. Bauhofer[10] reported the experimental and theoretical work on electrical percolation of carbon nanotubes in polymer composites. In their research, different parameters like CNT type, synthesis method, treatment and dimensionality as well as polymer type and dispersion method are evaluated with respect to their impact on percolation threshold, scaling law exponent and maximum conductivity of the composites. Hadavand et al.[11] modified MWCNTs by acid and then evaluated the mechanical properties of reinforced epoxy polysulfide resin by both pristine and treated MWCNTs. Arun et al.[12] studied on the processing conditions for dispersing the MWCNTs in epoxy by solvent dispersion technique with three different methods and found that the compressive strength, Young's modulus, and thermal conductivity of 0.2 mass% of MWCNTs prepared by vacuum oven method were enhanced by 39.4, 10.7, and 59.2%, respectively. Chen et al.[13] applied a novel and effective plasma method to improve the dispersion of

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MWCNTs and interfacial bonding in epoxy resin. Russ et al.[14] investigated the electrical and thermal properties of reinforced epoxy resin with different types of CNTs and found that a significant enhancement on electrical property was achieved. Khan et al[15] studied the alignment of MWCNTs in epoxy matrix with DC electric fields applied during composite curing. They reported that alignment of CNTs gives rise to much improved electrical conductivity, elastic modulus and quasi-static fracture toughness compared to those with randomly orientated CNTs.

The combination of two nano fillers like CNTs and graphene nano sheets has been attracted attention of some researchers[16-19]. Rafiee et al.[16] studied mechanical properties of epoxy nanocomposites using graphene, single-walled CNTs (SWCNTs) and MWCNTs as additives. The results indicated that graphene platelets significantly out-perform CNT additives. The Young's modulus of the graphene nanocomposite was 31% greater than the pristine epoxy while that of SWCNT nanocomposite was only 3% greater than the pristine epoxy. The tensile strength of the baseline epoxy was enhanced by 40% with graphene platelets compared with 14% improvement for MWCNTs. Yang et al.[17] demonstrated a remarkable synergetic effect between the multi-graphene platelets (MGPs) and MWCNTs in improving the mechanical properties and thermal conductivity of epoxy composites. The tensile strength of GD400-MWCNT/MGP/epoxy composites was 35.4% higher than that of the pristine epoxy while that of MGP/epoxy composites was only 0.9% higher than the pristine epoxy. Thermal conductivity was increased by 146.9% using GD400-MWCNT/MGP hybrid fillers and 23.9% using MGP fillers as compared with the pristine epoxy. Li et al.[18] dispersed hybrid fillers composed of CNTs grown on graphene nanoplatelets (GNPs) into epoxy resin and obtained remarkably mechanical properties in the CNT–GNP/epoxy composite at ultralow hybrid loading (0.5 wt.%). The tensile modulus showed a 40% increase and the tensile strength was enhanced by 36% as compared with those of the neat epoxy. Martin-Gallego et al.[19] compared the filler percolation network of MWCNTs grown by chemical vapor deposition and thermally reduced functionalized graphene sheets (FGSs) in epoxy resin. They found that FGS did not raise the viscosity of the system as much as MWCNTs, maintaining the Newtonian behavior even at 1.5 mass% FGS. MWCNTs readily formed a filler network compared to FGS, evidenced by the lower electrical and rheological percolation thresholds, and by the presence of yield stress and higher storage modulus of the dispersions than neat epoxy. On the other hand, the mechanical performance of the cured FGS nanocomposites outperformed the MWCNT nanocomposites with enhancements of 50% and 15% for Young's modulus and strength, respectively. The combination of good processing properties with the low viscosity and the enhanced mechanical properties makes FGSs ideal candidates to develop multifunctional polymer materials.

In the present research, the effects of adding different weight fractions of MWCNTs on mechanical and electrical properties of ML-526 epoxy as a polymeric matrix are investigated and the tensile, flexural and electrical properties of nanocomposites are taken into account simultaneously to find the optimum dispersion conditions.

2 Methods and experimental

2.1 Materials

Epoxy resin ML-526 is based on Bisphenol-A, a type of epoxy, in which aliphatic is applied in the structure to improve the flexibility and toughness properties. The resin was selected because of its low viscosity and extensive industrial applications. The low viscosity of the matrix makes the dispersion of additives easier. The curing agent was HA-11 (Polyamine). The epoxy resin (ML-526) and polyamine hardener (HA-11) were supplied by Mokarrar engineering materials company, Iran. The MWCNTs with commercial US4306 grade were supplied by Research Nanomaterial Institute, USA. These particles have an average outside diameter of approximately 10-20 nm, an average inside diameter of approximately 5-10 nm and a length of 10-30 microns. Fig. 1 shows the scanning electron microscopic (SEM) image of the MWCNTs.

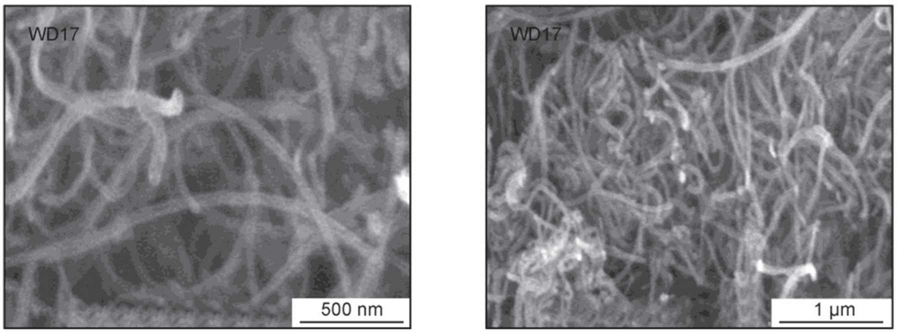

Fig. 1 SEM images of MWCNT at different magnifications.

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