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Original

Experimental investigation for graphene and carbon fibre in polymer-based matrix for structural applications

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Abstract

The present paper investigates the behaviour of a polymer matrix beam reinforced with graphene and carbon fibres at nano and micro level reinforcements, respectively, to study mainly the strength aspects for structural applications. However an attempt has also been made to use a combination of both micro and nano level fillers in both individual and combined forms as reinforcements. The addition of graphene and carbon fibres in the control beams was varied from 0.1 to 0.4% percent by weight of polymer matrix. Dispersion of graphene was carried out using ultrasonic energy. Composite beams were tested under flexural in order to evaluate their mechanical property such as load-deflection criteria. These results were then compared with those obtained from plain polymer beams. The present work also investigates the optimum percentage of graphene and carbon fibres as individual and combination fillers that gave the best results in terms of enhanced mechanical properties and economical aspects as well. Scanning electron microscopy and energy dispersion X-ray spectroscopy was conducted to examine the interfacial surface adhesion between the fillers and the polymer matrix. Reinforcement of polymer beams with graphene alone by weight of the polymer matrix showed enhanced results when compared to carbon fibres alone while the use of combined nano and micro reinforcements showed performance lying in between nano and micro fillers in the polymer. Flexural strength is enhanced by 35% compared to plain control beams when graphene was used as reinforcement fillers in the polymer matrix.

Keywords: Epoxy resin; Three-point loading; SEM; Sonication; Graphene; Carbon fibre

1. Introduction

GA has been considered as one of the effective reinforcement nanoparticles for polymer-based composites owing to their outstanding mechanical properties as well as their high surface area (Wong, Sheehan, & Lieber, 1997; Yu et al., 2000). However, reinforcing them in a polymer matrix so far has no yielded good results as revealed by many researchers and this could be due to two main issues: (1) the difficulty of dispersing nano fillers in the polymer matrix, and (2) interfacial adhesion between the fillers and the polymer matrix. It has been identified since long time that the mechanical properties of polymer materials can be enhanced by fabricating composites that are imbibed with different volume fractions of one or more reinforcing phases. Recently, the practical realization of composites for structural applications with use of nano-scale reinforcement is gaining prominence when compared to micro-scale fillers. This is mainly because of the unique blending of mechanical, chemical and physical properties associated with the use of nano-fillers fillers preferably with a characteristic dimension typically below 50 nm. Apart from this, study on the combination of fillers usage at both micro and nano level is scantily reported in the literature and this area

Abbreviations: Ga, Graphene; CFs, Carbon fibres.

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needs to be rigorously explored to realize the benefits of such reinforcements. The idea of dispersing nanoparticles is mainly due to their large enhancement in the specific surface area and interfacial area they provide to the matrix phase.

As traditional composites with natural fibre reinforcement use over 35 wt% of reinforcing phase, the dispersion of just a few milligrams of nanoparticles into polymeric matrix could lead to drastic changes in their mechanical properties with added functionalities. Increase in the viscosity of the holding matrix because of micro scale fillers can be greatly reduced by using nano scale fillers leading to the reduction in the brittlement of the holding matrix. Fibre-reinforced composites have emerged as a major class of structural materials and are either used or being considered as substitutions for metals in many weight-related critical components in aerospace, automotive and other industries. In this work, a method has been proposed to reinforce the adhesive layer through the homogeneous dispersion of only a small fraction of GA. Carbon fibres are regarded as one of the most promising reinforcement materials for the next generation of high-performance structural and multifunctional composites (Endo, Hayashi, Kim, Terrones, & Dresselhaus, 2004). These molecular scale platelet areas of GA have outstanding mechanical, thermal and electrical properties. In fact, some GAs are stronger than steel, lighter than aluminium and more conductive than copper as reported by Moniruzzaman and Winey (2006). Theoretical and experimental studies have shown that GA exhibit extremely high tensile modulus (>1000 GPa) and strength (>5 GPa). In addition, CFs can exhibit high flexibility, low density (0.231 g/cc) and large surface area (323–600 m^2/g). Because of this unique combination of physical and mechanical properties, GAs have emerged as excellent candidates for use as reinforcing agents in polymeric materials to yield the new generation nanocomposites. Perhaps the most remarkable improvement in the tensile modulus and yield strength of a polymer through the dispersion of GA was reported by several investigators (Liu, Phang, Shen, Chow, & Zhang, 2004). By dispersing only 2 wt% of carbon fibres in a polymer matrix an increase of approximately 214% in the tensile modulus and 162% in the yield strength was reported. They attributed these impressive improvements in the stiffness and strength due to a uniform and fine dispersion of the carbon fibres and good interfacial adhesion between the GA and matrix which were assessed using SEM. Lu, Liang, Gou, Leng, and Du (2014) reported an effective approach of significantly improving electrical properties and recovery performance of shape memory polymer (SMP) nanocomposites with reduced graphene oxide (GOs) self-assembled and grafted onto carbon fibre in order to enhance the interfacial bonding with the SMP matrix via van der Waals force and covalent bond, respectively. In the work reported a layer of Ag nanoparticles synthesized from Ag+ solution was chemically deposited onto GO assemblies. From the experimental results it was reported that the electrical conductivity of the SMP nanocomposite significantly improved. The study focused on the electrically induced shape memory effect of the SMP nanocomposites in which the temperature distribution in the SMP nanocomposites was recorded and monitored. Lu, Yao, Huang, and Hui (2014) discussed an effective approach to significantly improve the electrical properties and recovery performance of shape memory polymer (SMP) nanocomposites that show Joule heating triggered shape recovery. In the work presented, reduced graphene oxide (GO) was self-assembled and grafted onto the carbon fibres to enhance the interfacial bonding with the SMP matrix via van der Waals and covalent crosslink, respectively. From the exhaustive experimental results, it is reported that the electrical properties of SMP nanocomposites were significantly improved via a synergistic effect of GO and carbon fibre. A simple method was demonstrated to produce electro-activated SMP nanocomposites that are applicable for Joule heating at lower electrical voltages.

Table 1
Properties of the GA used for study.

Specifications	Dimensions
Diameter	10–20 (micron)
Purity	96–99%
Surface area	323–600 m^2/g
Bulk density	0.231 g/cc
Fibre thickness	3–6 nm
Oxygen content	<4%

Table 2
Specimen characteristics utilized for experimental work.

Characteristics of specimen	Particulars
Size	40 (mm) × 12 (mm) × 6 (mm)
Epoxy resin	L-12
Hardener	K-6
Amount of carbon fibre	0.1, 0.2, 0.3, and 0.4% by weight of epoxy
Amount of graphene	0.1, 0.2, 0.3, and 0.4% by weight of epoxy

Several research investigations have been reported in the literature regarding the use of different polymer systems with various reinforcements in micro, nano and combination of micro-nano fillers to develop polymer-based composites. However, the reinforcement of fillers like graphene (nano) and carbon fibre (micro) in polymer-based matrix for structural applications has been less investigated. In the present work, the mechanical performance of a polymer beam reinforced with graphene, carbon fibres, a combination of graphene and carbon fibres is studied and the results were compared with that of plain beams such as load v/s deflection criteria. From the exhaustive study based on the performance it can be concluded that the polymer reinforced beam yielded best results as compared to plain beams. This could be due to the high strength offered by GA at the polymer interface.

2. Experimental programme

The properties of the GAs used in this case are given in Table 1 and they were of industrial grade with a purity greater than or equal to 95 percent. The specimen characteristics are mentioned in Table 2. The specimen reference has been mentioned in Table 3. Uniform dispersion of carbon fibre against their agglomeration due to Vander Waals bonding is the first step in the processing of nano-composites. Dispersion is a critical issue while mixing carbon fibres in either water or organic solvents.

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