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Enhanced mechanical properties of short carbon fiber reinforced polyethersulfone composites by graphene oxide coating

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ABSTRACT

Polyethersulphone (PES) is an important special engineering plastic. In order to broaden its applications in automobile and sports fields etc., its mechanical properties have to be enhanced. This paper reports the effectively enhanced tensile and flexural properties of injection molded graphene oxide (GO)-coated short carbon fiber reinforced PES composites by GO coating. The GO content varies in a range of 0.0–1.0 wt%. First, the GO is employed as surface sizing agent to treat short carbon fibers (SCFs) by a facile physical absorption method. The GO-coated SCF/PES composites are extruded into pellets and then injection molded into tensile and flexural samples. It is shown that the GO coating on SCF surface leads to an obviously enhanced SCF/PES interfacial adhesion. As a result, both the tensile and flexural strengths are effectively enhanced by the GO coating on the SCF surfaces. The tensile and flexural moduli are also increased by the GO coating due to the excellent elastic modulus of GO. The optimal GO content is found to be 0.5 wt% for effectively improving the overall composite mechanical performance.

1. Introduction

Polyethersulfone (PES) is an amorphous anamber-coloured transparent special engineering thermoplastic. It belongs to high glass transition temperature polymers (Tg-225 °C), possesses relatively high mechanical strength, great dimensional stability, excellent thermal stability, and chemical resistance. In addition, it has low creep, high flame retardancy, excellent insulation property and high dielectric strength. Therefore, PES has been used in medical instruments, aviation, microelectronics, automobile, membrane separation, etc [1]. In order to broaden its applications, carbon fibers, glass fibers and graphene oxide etc. are introduced into PES to make composites with enhanced mechanical properties. Especially, carbon fiber (CF) reinforced PES composites have been widely applied in automobile, aerospace, sporting, off-shore-technology, and chemical engineering areas etc. due to their excellent mechanical and physical properties [2,3]. Conventional PAN and pitch-based carbon fibers are widely used as reinforcements in polymer-matrix composites owing to their excellent mechanical properties, high thermal and electrical conductivity, resistance to corrosive environment, low linear coefficient of thermal expansion and low density [4,5]. In particular, short carbon fiber (SCF) reinforced polymer composites are very attractive because of their ease of fabrication, economy and superior mechanical properties. They can fill the mechanical property gap between the continuous-fiber laminates used as primary structures by the aircraft and aerospace industry and the unreinforced polymers used in partial-load-bearing applications [6,7]. In addition, short carbon fiber reinforced polymer composites can be readily manufactured using highly efficient conventional techniques of extrusion compounding and injection molding etc. for polymers [8,9].

The mechanical properties of short carbon fiber reinforced polymer composites critically depend on the fiber-matrix interfacial adhesion, fiber amount, aspect ratio, orientation with respect to loading direction, etc. Among these, fiber-matrix interfacial adhesion is extremely important since carbon fibers have chemical inertness and poor wettability with most of the polymeric matrices [10]. Hence, it is necessary to improve the fiber–matrix adhesion for enhancing the mechanical properties. Many methods have been

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developed for improving the carbon fiber-polymer matrix interfacial adhesion to enhance mechanical interlocking, including electrochemical, chemical, thermal, grafting, coating (sizing) and discharge plasma treatments etc [11,12]. Graphene oxide (GO) as a potential multifunctional sizing agent can be uniformly dispersed and firmly adsorbed on the surface of carbon fibers to synthesize a new hierarchical reinforcement. And the GO has the ability to produce in large quantities at a relatively low cost [13,14] and possesses excellent mechanical properties. Meanwhile, it contains various oxygen functional groups such as epoxide, hydroxyl and carbonyl groups. It is expected that GO coating on SCFs will enhance the SCF-PES interfacial adhesion and thus the applied load can be more effectively transferred from PES to SCFs to enhance composite mechanical properties [15–17].

Huang et al. [18] employed graphene oxide (GO) as the sizing agent for continuous CF tows by an electrophoretic deposition and subsequent thermal annealing. Such reduced GO-deposited CFs exhibit a significant increase in surface roughness compared to the bare CFs, leading to an improvement in the interfacial shear strength between CFs and epoxy matrix through enhanced mechanical interlocking. Lee et al. [19] coated partially reduced graphene oxide on carbon fibers by an anodic electrophoretic deposition to increase surface energy and wettability of carbon fibers. As a multifunctional sizing agent, the partially reduced graphene oxide enhanced both mechanical and electrical properties of the carbon fiber composites. Li et al. [20] proposed a new hierarchical reinforcement consisting of GO and CFs by chemically grafting via poly(amido amine) dendrimers. They confirmed that the GO grafting significantly changes the surface configuration of CFs and predicted that the new hierarchical reinforcement has the potential to be applied in high performance polymer composites. As mentioned above, PES is one important special engineering thermoplastic. High performance SCF/PES composites are desired for applications in various fields such as automobile, aerospace and sporting industries, etc. The GO coating on SCFs is expected to enhance the SCF/PES interfacial adhesion and thus the composite mechanical performance. However, to our best knowledge, the GO-coated short carbon fiber reinforced PES composites via the conventional extrusion compounding and injection molding techniques have not been reported yet.

In this work, the GO-coated short carbon fiber reinforced PES composites are prepared using the melt blending and injection molding techniques. The tensile and flexural properties of the GO-coated SCF/PES composites are systematically investigated. The GO treatment on short carbon fiber surfaces can remarkably improve the interface adhesion of carbon fiber/PES composites due to the GO hydrophilic oxygen-functional groups in its basal plane [21]. Moreover, oxygen-based functional groups can establish the hydrogen bonding with the PES. In addition, the GO coating can promote the dispersion uniformity of GO via resting on carbon fiber surfaces in the composites [22]. Thereby, the GO-coated SCF reinforced PES composites show an appreciable improvement in the mechanical properties compared to the un-treated SCF reinforced PES composite.

2. Experimental section

2.1. Materials

Polyethersulfone (PES) granules, E3010, were obtained from BASF (Germany). Graphite powders were obtained from Qingdao AoKe ShiMo Co. Ltd, China. Short carbon fibers (SCFs, 6 mm length), C30 S003/6 APS, were provided by SIGRAFIL (Germany). N,N-dimethyl-Formamide (DMF), Ethanol, concentrated sulfuric acid, potassium permanganate and hydrochloric acid were all obtained from Beijing Chemical Works and used as-received. Sodium nitrate was purchased from Tianjin JinKe Fine Chemical Industry Research Institute. All of the raw materials were used without any further purification and treatment.

2.2. Preparation of GO and GO-coated carbon fibers/PES composites

Graphite oxide (GO) was produced through the acid oxidation of graphite powders in a way similar to the Hummers method [23]. The obtained GO was subsequently dispersed in deionized water to form a suspension of 0.2 mg/ml. The resulted suspension was treated by ultrasonic technique (1000 W) for 3 h to exfoliate the graphite oxide to layered GO and form the homogeneous GO aqueous solution [24]. Then, an appropriate amount of SCFs was added to the GO aqueous solution in the ratio illustrated in Table 1 and stirred for 24 h. After that, the resultant mixtures were dried at 100 °C to remove water and then cooled naturally to room temperature. Finally, the GO-coated SCFs were obtained. The schematic showing of GO sizing onto SCFs was presented in Fig. 1a.

The GO-coated SCFs were then compounded with PES to prepare the GO-coated SCF/PES composites extrudates using a TSE-20/600-4-48 co-rotating twin-screw extruder (NanJing Ruiya Extrusion Systems Limited, China) at a screw speed of 30 rpm and a feed rate of 6 rpm. The temperature profile of the barrel was set at 360–365–370–375–380–380–375 °C from the hopper to the die. All the materials were dried in an oven at 130 °C for 6 h prior to melting process. The extrudates were continuously cooled by water and pelletized. The as-prepared pellets were dried in an oven at 130 °C for 6 h before injection molding. Standard test bars were obtained by injection mold at the mold temperature of 180 °C using HTF80X/1 plastic-injection moulding machine (HaiTian international holding LTD. China). The tensile and flexural specimens were prepared according to the recommendation of ASTM D 638-96 and ASTM D 790-03, respectively. The formulation of SCF/PES composites was given in Table 1. The 12.5 wt% of SCFs is a typical fiber content for effectively improving the mechanical properties of polymer composites [25]. For the purpose of comparison, the pure PES, the un-treated SCF reinforced PES composite and the SCF reinforced PES composites by separately adding 0.2 and 0.5 wt% GO to PES were also prepared by the extrusion and injection molding techniques. In addition, the pure PES specimen was prepared by the injection molding technique only to examine the effect of the extrusion compounding processing on the mechanical properties of the PES matrix. The process chart for preparing the specimens was presented in Fig. 1b.

Table 1
Formulation and mechanical properties of the composites.

SCF/GO/PES (wt%)	Tensile strength (MPa)	Young's modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)
0/0/100[a]	89.01 ± 0.45	2.78 ± 0.03	126.87 ± 0.84	2.56 ± 0.02
0/0/100	86.17 ± 5.04	2.73 ± 0.10	115.21 ± 0.45	2.67 ± 0.03
0.00/0.50/99.5	93.09 ± 0.85	2.81 ± 0.16	128.77 ± 0.48	2.67 ± 0.14
12.5/0.00/87.50	106.27 ± 0.70	6.02 ± 0.22	157.95 ± 4.18	4.93 ± 0.23
12.5/0.05/87.45	111.53 ± 3.37	6.60 ± 0.12	173.70 ± 3.74	5.03 ± 0.25
12.5/0.10/87.40	116.06 ± 0.99	7.32 ± 0.11	178.48 ± 0.56	6.09 ± 0.04
12.5/0.20/87.30	117.11 ± 0.74	7.45 ± 0.37	177.58 ± 0.32	6.06 ± 0.19
12.5/0.20/87.30[b]	115.67 ± 1.33	6.99 ± 0.21	160.79 ± 0.67	5.16 ± 0.18
12.5/0.50/87.00	119.09 ± 0.54	7.79 ± 0.20	182.51 ± 1.51	6.42 ± 0.08
12.5/0.50/87.00[b]	116.41 ± 0.41	7.23 ± 0.13	179.84 ± 2.37	6.29 ± 0.05
12.5/1.00/86.50	117.39 ± 0.29	7.92 ± 0.02	180.62 ± 3.63	6.47 ± 0.08

[a] The pure PES specimens were prepared using the injection molding technique only and other samples were prepared using both the extrusion compounding and injection molding techniques.
[b] The PES composites were prepared by separately adding GO and SCFs to the PES matrix.