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Mechanical and tribological properties of short glass fiber and short carbon fiber reinforced polyethersulfone composites: A comparative study

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ABSTRACT

The polyethersulfone (PES) composites incorporated with short carbon fibers (SCFs) and short glass fibers (SGFs) were manufactured, and their mechanical and tribological properties were comparatively investigated. The tensile and flexural strengths of SCF/PES composites increase monotonically with increasing the SCF content while those of the SGF/PES composites initially increase dramatically but the strengths approaches a plateau when the SGF content is over 5 vol%. The Young's and flexural moduli of both SGF/PES and SCF/PES composites exhibit a monotonic increase behavior with increasing the fiber content and achieve the maximum improvements of 128.7%, 227.2%, 165% and 234% with the introduction of 30 vol% short fibers. The addition of SGFs results in a monotonic increase of the friction coefficient and a maximum increase of 48.8% is achieved with 30 vol% SGFs. By contrary, the friction coefficient of SCF/PES composites decreases with the addition of SCFs and a maximum drop of 29.8% compared with that of pure PES is reached with the addition of 20 vol% SCFs. The wear resistance of PES composite is greatly improved by the incorporation of either SGFs or SCFs. The specific wear rates of the PES composites decrease significantly with the addition of short fibers, and the maximum reduction of 71.4% and 95.7% is achieved with the addition of 20 vol% short fibers. When cost is primary consideration while strength, modulus and tribological performance are secondary considerations for end users, SGFs are superior over SCFs; otherwise; SCFs are superior over SGFs.

1. Introduction

Polyethersulfone (PES) is an excellent high performance engineering plastic with a high T_g of 225 °C and operation temperature up to 180 °C [1]. Also, PES exhibits relatively high strength and modulus, and good fatigue resistance and dimensional stability, as well as high chemical, fire and radiation resistance, etc [1–3]. Taking the advantage of light weight and high thermal stability, PES is highly desirable as high temperature tribo-materials to replace metals or ceramics [3–5]. However, the mechanical and tribological properties of PES have to be enhanced to meet the requirements in some advanced applications, such as automotive, aerospace and microelectronics [6,7], etc.

To improve the mechanical and tribological performances of PES, various approaches including blending with other polymers, incorporation of nanofillers and fiber fabrics etc. have been proposed [1,7–12]. For example, blends of PES with a semiaromatic liquid crystalline copolyester (LCP) were obtained by injection molding across the entire composition range [13–15]. It was found that the tensile strength and modulus of PES can be improved by the blending of PES with LCP of high contents. However, the breaking properties of PES are decreased at low LCP contents due to lacking of adhesion between the two phases. In recent years, various nanofillers such as carbon nanotubes, graphene oxide (GO), silica nanoparticles and nanocellulose have also been incorporated into PES to enhance its mechanical and tribological performances [16–19]. Nano-sized GO sheets modified by 3-aminopropyltriethoxysilane as lubrication additives have been incorporated into PES matrix, which significantly enhances the tensile and thermal properties of PES. In addition, compared with net PES, the PES composite with 1.0 wt% GO exhibits a very low friction coefficient of 0.13 and wear rate of 4.68×10^{-15} m^3/Nm [20]. PES composites

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reinforced with carbon fabrics and aramid fabrics have also been reported and it was found that the wear behavior of the composites was not only related to the type, orientation and volume fraction of the fabrics but also influenced by the fiber-matrix interfacial adhesion [21–25]. However, the difficulties in dispersion of nano-fillers and pretreatment of fabrics involved in processing of PES composites dramatically hamper their large-scale production for industrial applications.

It is well known that short glass fibers (SGFs) and short carbon fibers (SCFs) are widely used in reinforcing polymers due to their superior mechanical properties [26–31]. Especially for thermos-plastics, reinforcement with SGFs or SCFs is highly attractive because the corresponding composites can be readily produced in large-scale using highly efficient conventional techniques of extrusion compounding and injection molding [32]. Very few studies on SGF/PES composites have been reported previously, and are mainly focused on tensile and flexural properties [1,8,9]. So far, rare work has been reported on tribological properties of short fiber reinforced PES composites. In particular, the differences in the mechanical properties of pure PES and PES composites reported previously are quite large between different works. The reported values for the tensile strength at room temperature of pure PES were 68 MPa [17], 83 MPa [14], 87 [18], 89 MPa [32] and 112 MPa [15]; the Young's modulus for pure PES was 2.3 GPa [14], 2.8 GPa [18,32], 3.0 GPa [17], 4.6 GPa [15] and 4.9 GPa [9]. The tensile strength of PES composites was 108 MPa with 20 wt% SGFs [12], 108 MPa with 12.5 wt % SCFs [32] and 150 MPa with 40 wt% SGFs [18]; and Young's modulus of PES composites was 5.9 GPa with 20 wt% SGFs [12], 6.0 GPa with 12.5 wt % SCFs [32], 8.3 GPa with 40 wt% SGFs [18] and 8.7 GPa with 40 wt% SCFs [9]. The tensile strength and modulus at cryogenic temperature (77 K) for pure PES were also reported by us as 120 MPa and 5.9 GPa and those for the PES composite with 12.5 wt% SCFs were 190 MPa and 9.1 GPa [3]. The mechanical properties depend not only on the properties of components but also on the processing and hence on the equipments used. These studies were conducted in different labs and it is thus not fair to make a proper comparison about the differences in the mechanical behaviors between the two SGF/PES and SCF/PES systems. Moreover, the tribological performances for SGF/PES and SCF/PES composites have been rarely investigated though they are of significance for practical applications. Compared with carbon fibers, glass fibers are relatively ductile and cheaper (over 20 times lower prices than SCFs). Thus, it is significant to systematically compare the mechanical and tribological behaviors of SGF/PES with SCF/PES systems since the knowledge obtained from the comparative study would be very informative and valuable to industries and end users.

In this work, SGF/PES and SCF/PES composites with various short fiber contents are manufactured by extrusion compounding and injection molding techniques using the same equipments. The tensile, flexural and tribological performance of SGF/PES and SCF/PES composites are comparatively investigated. It was found that both the tensile and flexural properties of PES composites are greatly enhanced by the incorporation of SGFs and SCFs, the enhancement effectiveness of SCFs on PES are obviously better than SGFs. On the other hand, the ductility of SGF/PES composites is better than that of SCF/PES composites. Moreover, although the specific wear rate of the PES composites is reduced by the incorporation of both SGFs and SCFs, their effects on the friction coefficient of PES are totally opposite. The friction coefficient of PES is reduced by incorporation of SCF attributing to the lubricative transfer film formatted in friction. Worn debris and worn surface observations reveal that the dominated wear mechanism of SGF/PES is adhesive wear, while fatigue wear and plow play a key role for SCF/PES composites.

2. Experimental section

2.1. Materials

PES micro-granules (Ultrason ®, E3010) were purchased from BASF, Germany. Short carbon fibers (SCFs) (PUT C30 S003/6) with a diameter of 7 µm and length of 6 mm were purchased from SIGRAFIL (Germany). Short glass fibers (SGFs) (552b) with a dimeter of 13 µm and length of 6 mm were purchased from ZheJiang-JuShi, China.

2.2. Preparation of composites

SGF/PES and SCF/PES composites were manufactured using the extrusion compounding and injection molding techniques. Pure PES and PES composites incorporated with 5%, 10%, 20% and 30 vol% of SGFs or SCFs were fabricated with a total weight of 700 g for each formula. Firstly, all raw materials were dried under 120°C for 3 hours. The mixture of PES with SGFs or SCFs was blended using a TSE-20/600-4-48 co-rotating twin-screw extruder (Nanjing Ruiya Extrusion System Limited, China) at a screw speed of 30 rpm and a feed speed of 6 rpm. The temperature of barrel was set as 360-365-370-375-380-380-380-375 °C from the hopper to the die of the extruder. The resultant extrudates were cooled by water and then pelletized by a breaker. Standard specimens were molded using an injection molding machine (HTF80X/1, HaiTian Plastics Machinery, China). The temperatures of barrel and injection mold were set as 350 and 180 °C, respectively. The granules of SGF/PES and SCF/PES composites were pre-dried at 130 °C for 6 h before injection molding. In addition, the specimens for tensile and flexural test were prepared according to ASTM D638-96 and ASTM D 790-03, respectively. The tribological properties of PES and PES composites were evaluated with a pin-on-disk friction and wear tester (HT-1000, Kehua Co. Ltd, China). The diameter and height of wear pin is 4.8 and 12.8 mm, respectively. A disc of steel (45#, Chinese GB) with surface hardness of HRC44–55 was used as counterpart.

2.3. Characterizations

Tensile and three point bending tests were performed on a universal testing machine (Instron 5882) with a loading rate of 2 mm/min. For each formula, more than 5 specimens were tested, from which the mean value and standard deviation (SD) were calculated. The tribological performance of PES composites was evaluated by a pin-on-disk friction and wear tester (HT-1000, KaiHua, China) at room temperature with a normal load of 800 g and a sliding speed of 364 rpm for 5 h. A disc of steel (45#, Chinese GB) with the surface hardness of HRC44–55 was used as counterpart. The specimens and pairs of friction were pre-worn with SiC grinding paper (2000#), then ultrasonically cleaned with ethanol for 10 minutes and dried at 100 °C for 3 h. Friction coefficient (µ) was calculated based on the data collected within 5 h with an interval of 2 s. The specific wear rate (w) was calculated based on the following equation:

$$w = \frac{\Delta \mathrm{m}}{\rho_t F_N L} \tag{1}$$

where Δm is the mass loss of the specimen after tribological test, ρ_t, F_N and L are the composite density, normal load and sliding distance, respectively.

The tensile fracture surface, worn surface and wear debris of the PES composites were observed with a scanning electron microscope (SEM, Hitachi S4300, Japan).

3. Results and discussion

3.1. Mechanical properties

The effects of SGF and SCF volume fraction on the tensile and