Materials and Design 44 (2013) 493–499

Contents lists available at SciVerse ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Effect of carbon fiber reinforcement on the mechanical and tribological properties of polyamide6/polyphenylene sulfide composites

Shaofeng Zhou [a], Qiaoxin Zhang [a,*], Chaoqun Wu [a], Jin Huang [b]

[a] School of Mechanical and Electronic Engineering, Wuhan University of Technology, Wuhan 430070, China
[b] College of Chemical Engineering, Wuhan University of Technology, Wuhan 430070, China

ARTICLE INFO

Article history:
Received 4 June 2012
Accepted 12 August 2012
Available online 23 August 2012

Keywords:
Polyamide
Polyphenylene sulfide
Carbon fiber
Mechanical
Friction
Wear

ABSTRACT

Polymer-based composite reinforced by fibrous filler has aroused wide concern in the field of tribology and material science. In this manuscript, the effect of carbon fiber (CF) as filler on the structure, mechanical and tribological properties of the polyamide6/polyphenylene sulfide (PA6/PPS) composites were investigated carefully in order to provide a practical guidance for the use of the polymer-based composites. It was found that the introducing of carbon fibers improved strength, modulus and hardness of the PA6/PPS blend apparently while breaking elongation rate and impact strength just decreased in a small degree. Average friction coefficient value of the carbon fiber-reinforced PA6/PPS composites (PA6/PPS-CF) was lower than PA6/PPS blend at the stable stage. As the content of carbon fiber increased, the wear rate of the PA6/PPS-CF composites trended to increase. Under the friction condition of high applied load or high sliding speed, the friction coefficient of the PA6/PPS-CF composites inclined to decrease while wear rate increased. When slided under a relatively high load of 20 N or high speed of 1500 r/min, the wear resistance of PA6/PPS-CF behaved was better as the content of carbon fiber increased. Scanning electron microscopy of worn surface morphology has revealed that the main wear mechanism of the PA6/PPS-CF composites were adhesive wear.

1. Introduction

In recent years, polymeric matrices reinforced with glass, carbon and aramid fibers were being increasingly used for numerous mechanical and tribological purposes, such as seals, gears, bearings and cams to replace metallic materials owning to their attractive combination of lightweight, economic fabrication, good chemical resistance and low friction coefficient [1–4]. The feature that makes polymer composites so promising in industrial applications is the possibility of tailoring their properties with functional fillers [5,6]. A great attention was given to the fibrous fillers because of the easy processing and the significant improvement in mechanical and tribological properties [7,8]. Carbon fiber reinforcement, which dominates in the high-performance applications due to its outstanding mechanical properties combined with low weight, have been widely investigated by many researchers in order to attempt to understand the modifications in the tribological behavior of the polymer matrix [9,10].

There is considerable interest and high expectation that such carbon fiber-reinforced polymer composites could be superior to the conventional polymer composites [11]. Xian and Zhang [12] investigated the tribological behavior of short carbon fiber-reinforced polyetherimide (PEI) composites. It was found that the addition of 5–20 vol.% short carbon fiber could reduce the friction coefficient, and improve the wear resistance significantly, especially at elevated temperatures. Zhang et al. [13] investigated the influence of fiber length on tribological properties of short carbon fiber (SCF)-reinforced epoxy composites, and concluded that the composites with longer SCF (nominal length = 400 μm) exhibited better wear resistance than those shorter one (nominal length = 90 μm), and the steady frictional coefficient and contact temperature were reduced slightly by longer fibers. Carbon fibers can provide a synergistic action in the tribological behavior of polymer composites incorporated with inorganic particles [14,15]. Bahadur et al. [16] reported the synergistic action in wear behavior between carbon fiber and microsize CuS filler in the nylon 11-based composites. They found that the wear rate of polyamide reduced by introducing 35 vol.% microsize CuS filler and 5 vol.% carbon fiber while an equivalent level was not achievable by using either the fiber or the filler alone. However, most of the present studies in the terms of wear resistance of carbon fiber-reinforced polymer composites were focused on the homopolymer matrix [17], very few reports dealing with the polymer blend can be published. So it is original and interesting to study the tribological and mechanical properties of the polymer blend based composites reinforced with carbon fiber.

* Corresponding author. Tel./fax: +86 27 87651793.
E-mail address: zhangqx@whut.edu.cn (Q. Zhang).

0261-3069/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2012.08.029

Polyamide (PA) is a semi-crystalline thermoplastic polymer used for numerous engineering applications. However, its heat distortion temperature is low, and it absorbs water easily for the presence of amide groups in the molecular chain, which deteriorates its mechanical properties, dimensional stability and tribological properties severely. In order to inhibit these shortages, polyphenylene sulfide (PPS), as a very well-known semi-crystalline thermoplastic polymer for its high service temperatures, low creep, fairly low water absorption, quite high chemical resistance and high rigidity, has been blended with PA to obtain a polymer alloy with outstanding properties [18]. However, the adhesion between PA and PPS phases is poor, and tribological properties of the PA/PPS blend sliding under different frictional conditions was not founded very well [17]. To further improve the quality of PA/PPS blend, the enhancing of interfacial interactions was often adopted by using functionalized modifier. Zou et al. [19] provided a newly means of manipulating the phase morphology in PPS/PA66 blends by adding a small amount of clay into the polymer matrix. It was found that the tensile and impact strength of the composites were increased obviously, and their wear resistance was greatly improved for the blend with co-continuous phase form. As to the method of improving the performance of PA/PPS blend by fibrous filler, very few references have studied its reinforcement effect on the mechanical and tribological properties of PA/PPS composites filling by carbon fiber. Therefore, studies about the effect of carbon fiber reinforcement on the mechanical and tribological properties of PA/PPS composites would be an interesting work, and it is expected to offer some useful reference for developing and producing high-quality polymer-based composites.

In this manuscript, carbon fiber was introduced to the PA6/PPS blend with a fixed ratio prepared through a Mini-twin-screw extruder and MiniJet. The effect of carbon fiber reinforcement on the structure, mechanical and tribological properties of PA/PPS composites, especially the friction and wear behaviors of the composites sliding under different time, applied load and sliding speed, were carefully investigated in order to provide some practical guidance for the use of polymer-based composites. Furthermore, the corresponding wear mechanisms of the carbon fiber-reinforced PA6/PPS composites (PA6/PPS-CF) were discussed assisting by micrographs of the worn surfaces.

2. Experimental details

2.1. Materials

Polyamide6 (PA6) and polyphenylene sulfide (PPS) were supplied by Yuyao Gaoke Modified Plastic Co. Zhejiang. Density and melting temperature for PA6 and PPS were 1.14 and 1.35 g/cm^3, 220 and 285 °C, respectively. PA6 and PPS were vacuum dried at 100 °C for 12 h prior to use. Carbon fiber was supplied by Lianyungang Zhongfu Shenying Carbon Fiber Co., Ltd., China. It was polyacrylonitrile (PAN) based T300 carbon fiber powder with the particle size of 300 mesh.

2.2. Preparation process

PA6/PPS based composites reinforced by carbon fiber were blended using Mini-twin-scew extruder (HAKKE MiniLab, Germany) at 230 °C with the rotating speed of 100 rpm for 10 min. The melting composites were constantly injected into the MiniJet (HAKKE MiniLab, Germany) at the injection temperature of 250 °C. Under the injection pressure of 700 bar for 15 s, the test specimens for mechanical and tribological tests were injection molded in the standard mold at the temperature of 80 °C. The blend composition PA6 (80 wt%)/PPS (20 wt%) was selected as the matrix to study the improve effect of carbon fiber filling on its mechanical and tribological properties. Samples with different mass percent of carbon fiber were coded as PA6/PPS, PA6/PPS-CF5%, PA6/PPS-CF10% and PA6/PPS-CF15%, respectively.

2.3. Characterization of the composites

Fractured morphology of the composites was observed on a S-3000N scanning electron microscope (SEM, Hitachi) operating at 20 kV. Prior to the observations, samples were coated with a thin gold layer.

Crystallinity and melt temperature of PA6 and PPS in the composites were determined by differential scanning calorimetry (DSC, PerkinElmer). DSC was performed in a using 10 mg nominal sample weight, at a scanning rate of 10 °C/min from 20 to 300 °C under nitrogen atmosphere. The crystallinity of PA6 and PPS in the composites was calculated as:

$$X_c = \frac{\Delta H}{\Phi \times \Delta H^0} \times 100\% \quad (1)$$

where ΔH is the apparent enthalpy of fusion per gram of composite, ΔH^0 is the heat of fusion of a 100% crystalline PA6 or PPS taken as 190.9 J/g and 80.8 J/g, and Φ is their weight fraction in the composites.

The tensile properties and blending properties were conducted on a JDL-5000N universal electronic testing machine according to GB/T 1447-2005 [20] and GB/T 1449-2005 [21], respectively. Impact strength was measured according to GB/T 1451-2005 [22] on the TF-2054 cylinder support beam impact testing machine. And rockwell hardness (HRR) was conducted according to JB/T 7409-1994 [23] on the XHRD-150 moto-driven plastic rockwell hardness.

The friction and wear test were conducted on a HT-1000 ball-on-disk friction and wear equipment consisting of a stationary ball and rotating disk at room temperature [24]. The disk was the composite specimen with the size of Φ 20 mm × 2 mm, while the counterface a chromium steel ball with the diameter of 6 mm. The friction and wear tests were carried out under three loads (10 N, 15 N and 20 N) and three rotate speeds (500, 1000 and 1500 r/min), for a duration of 40 min. Average values of friction coefficient at the last 30 min were used as the friction coefficient of the samples [9]. Weight loss measurements were made using an analytical balance with the accuracy count of 10^{-4} g. Specific wear rate was calculated using the following equation:

$$\text{wear rate} = \frac{\Delta m}{\rho \cdot N \cdot 2\pi r \cdot T \cdot V} \times 10^3 \ \text{mm}^3/\text{N m} \quad (2)$$

where Δm is the mass loss in grams, ρ the density of the test material in g/cm^3, N the load in Newton, r the rotation radius in m, T the test durations in min and V the rotate speed in r/min.

Worn surface morphology of the samples sputtered by gold was taken on a JSM-5610LV scanning electron microscope (SEM, JEOL) at an acceleration voltage of 20 kV. Its aim is to investigate the topographical attributes and wear mechanisms of the PA6/PPS-CF composites.

3. Results and discussion

3.1. Fractured morphology and crystalline structure

Fig. 1 shows the tensile fractured surface of PA6/PPS-CF composites filled with different content of carbon fiber. The fracture surface of pure PA6/PPS blend is not smooth, and some small cavitations and particulates can be seen from Fig. 1A. The compatibility between PA6 and PPS is not very well reasoned by their