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On the friction and wear behavior of PTFE composite filled with rare earths treated carbon fibers under oil-lubricated condition

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Abstract

Carbon fibers (CF) were surface treated with air-oxidation, air-oxidation followed by rare earths (RE) treatment and RE treatment, respectively. The friction and wear properties of the polytetrafluoroethylene (PTFE) composites filled with differently surface treated carbon fibers, sliding against GCr15 steel under oil lubrication, were investigated on a reciprocating ball-on-disk UMT-2MT tribometer. The worn surfaces of the PTFE composites were examined using a scanning electron microscopy (SEM). Experimental results revealed that surface treatment of carbon fibers reduced the wear of CF-reinforced PTFE composites. Among all the treatments to carbon fibers, RE treatment was the most effective and lowest friction and wear rate of CF-reinforced PTFE composite was exhibited, owing to the effective improvement of the interfacial adhesion between the carbon fibers and PTFE matrix.
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Keywords: PTFE composite; Carbon fiber; Rare earths; Surface treatment; Friction and wear; Oil lubrication

1. Introduction

Polytetrafluoroethylene (PTFE) is a kind of perfect self-lubricating material due to its very low friction coefficient, good high-temperature stability and chemical stability. Yet, it cannot be used as anti-wear material alone because of its poor mechanical properties, bad thermal conductivity and high wear rate. Therefore, various reinforcement and modification of PTFE have been tried [1,2]. Carbon fibers (CF) made by pyrolysis from pitch and polymers are widely used as fillers in composite materials, particularly lightweight polymer–matrix composites, due to their higher stiffness, excellent electrical and thermal conductivity, and high resistance to fatigue and creep. Carbon fiber-reinforced PTFE composites are a class of advanced materials that are being used in applications requiring low friction and wear situations. The tribological properties of carbon fiber-reinforced PTFE composites have been studied by many investigators [3–5].

The properties of fiber and matrix make a critical contribution to the quality of a fiber-reinforced composite. In addition, the physical–chemical interaction at the fiber–matrix interface plays an important role in improving the mechanical properties of a fiber-reinforced composite [6]. Carbon fibers are chemically inert and it is difficult to arrange for them to interact with the resin [7]. Carbon fibers, when used without any surface treatment, produce composites with low interlaminar shear strength which, in turn, affects most of the other mechanical properties [8].

Surface treatment of carbon fiber (e.g. air-oxidation [9] or by using ozone [10], silane [11], glutaric dialdehyde [12], electron beam [13], aqueous ammonia [14], plasma [15] or acidic anode [16]) is useful for improving the fiber–matrix adhesion, interfacial shear strength, etc. However, the interfacial adhesion between carbon fiber and the matrix was not strong enough, which affected the friction and wear properties of the composites. Also, for the most part, an improvement of the coupling often causes a decrease in impact strength, and makes the composite more brittle [8].

Our previous work found that rare earths were superior to the silane coupling in promoting the interfacial adhesion and interfacial toughness between glass fibers and PTFE, and largely enhance the tensile properties and tribological properties of glass

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Table 1
Properties of carbon fibers used in PTFE composites

Filament diameter (μm)	7
Tensile strength (ASTM D-3379) (MPa)	2400
Tensile modulus (ASTM D-3379) (GPa)	190
Density (ASTM D-1505) ($g\,cm^{-3}$)	1.77
Carbon content (vol.%)	20

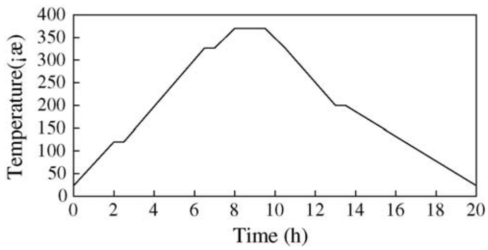

Fig. 1. Sintering process of CF/PTFE composites.

fiber-reinforced PTFE composites [17]. In the present work, rare earths are applied in the carbon fiber modifiers, and their effects on the tribological properties of PTFE composites have been evaluated.

2. Experimental procedure

2.1. Materials

PTFE powder with a grit size about 65.0 μm was used as matrix resin of the composites. Lead (Pb) powder of about 45.0 μm was used as additive to the matrix. The carbon fibers were polyacrylonitrile (PAN) based, unsized, and of length about 75 μm, as obtained from Shanghai Xinxing Carbon Co. Ltd. The fiber properties are shown in Table 1. Rare earth compound LaCl3 purchased from Shanghai Yuelong New Materials Co. Ltd., was used as main component of rare earths applied in surface modification solution.

Three types of surface treatment for carbon fibers were used. The first was air-oxidation: carbon fibers were heated at 450 °C for 40 min in a box furnace followed by cooling down to a room temperature in a furnace. In the second method, carbon fibers were dipped into the alcoholic solution of LaCl3 (0.3 wt.%) for 3 h followed by drying in oven at 800 °C for 4 h. The third method included combination of both, air-oxidation followed by LaCl3 treatment.

CF-reinforced PTFE (CF/PTFE) composites with 20 vol.% carbon fibers and 5 vol.% Pb powder were manufactured. The pre-treated carbon fibers, Pb powder and PTFE powder were mechanically mixed in a three dimensional mixer (Model SYH-1, Shanghai Yinsha Machine Making Co. Ltd.) for 30 min, and then, put into a stainless steel mold (inner diameter: 120 mm). The mixed materials were then transformed into sheets of 5 mm thick by compression molding under 35 MPa for 5 min at room temperature. Finally, the materials were sintered in a high-temperature oven and carefully cooled down to room temperature to get CF/PTFE composites. The heat process of sintering PTFE composites is shown in Fig. 1.The specimens, cut from the above sintered composites, were 30 mm in length, 20 mm in width and 5 mm in thickness. For comparison, PTFE composite filled with untreated carbon fibers was also manufactured in same way.

The composites for test were coded as follows:

A: PTFE composites filled with untreated CF;
B: PTFE composites filled with air-oxidated CF;
C: PTFE composites filled with air-oxidated and rare earths treated CF;
D: PTFE composites filled with rare earths treated CF.

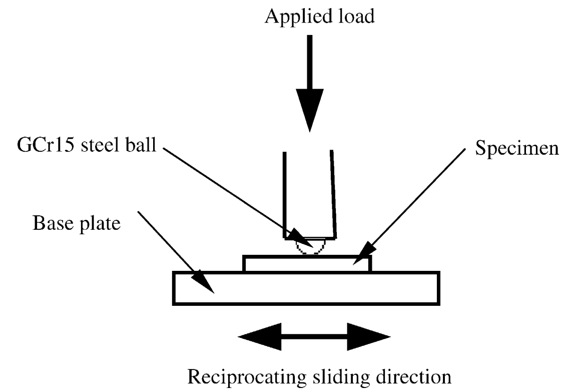

Fig. 2. Sketch of the friction pair for the reciprocating sliding contact.

2.2. Friction and wear tests

Friction and wear tests were performed on a reciprocating ball-on-disk UMT-2MT tribometer (Center for Tribology, Inc., CA, USA). The specimen was fixed on a base plate and reciprocatingly moved with a stroke length of 5 mm with the plate, as shown in Fig. 2. The counterpart was a GCr15 steel ball of hardness HRC61 and surface roughness Ra about 0.05 μm with a diameter of 3 mm. Four loads, 6 N, 9 N, 12 N and 15 N, were applied. The reciprocating sliding frequency ranged from 10 Hz to 25 Hz, which corresponds to

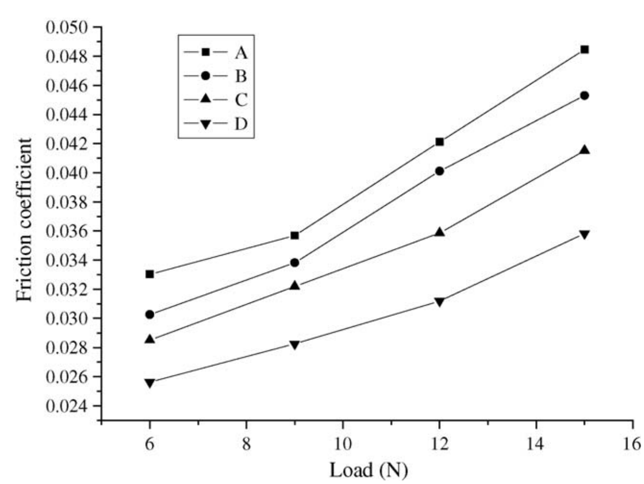

Fig. 3. Variation of friction coefficient with load for the PTFE composites (reciprocating sliding frequency: 20 Hz).

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