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Effects of carbon fiber surface treatment on the friction and wear behavior of 2D woven carbon fabric/phenolic composites

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ABSTRACT

To improve the friction and wear behavior of carbon fabric reinforced polymer composites (CFRP), nano-SiO_2 was deposited on the fabric surface. The friction and wear behavior of the resulting composites were investigated on a model ring-on-block test rig. Experimental results revealed that fiber surface treatment contributed to largely improve the tribological properties of the CFRP composites. Scanning electron microscope (SEM) investigation showed that the worn surface of the surface modified CFRP composite was smoother under given load and sliding rate. Field emission scanning electron microscopy (FESEM), FTIR and X-ray photoelectron spectroscopy (XPS) studies of the carbon fiber surface showed that nanostructured Sio_2 thin film can be obtained by SiO_2 sols deposition, which improved the adhesion between the fiber and phenolic matrix and hence to improve the friction-reduction and anti-wear properties of the CFRP composite.

1. Introduction

2D woven carbon fabric (CF) reinforced polymer composites have emerged as one class of promising textile fabric constitutions, which show great potential for application in structural components [1]. Many researchers have made lots of attempts to understand the modifications in the tribological behavior of the polymers with the addition of fillers or fiber reinforcements [2,3]. Typical wear mechanisms of polymer matrix composites are: fiber breaking, fiber–matrix debonding and matrix fracture [4–9]. Other important mechanisms are fiber pull out, matrix wear related to fiber movement, peeling of the matrix, shear deformation of the fibers and deformation of the edges of the wear track [10]. The wear performance of fabric reinforced composites is a complex phenomenon. It depends on the type of fabric and matrix, fiber volume fraction, fiber–matrix interfacial adhesion, orientation of warp and weft fibers with respect to sliding direction and sliding plane, fiber architecture of the fabric [11].

Carbon fibers have the properties of small active specific surface area, low surface energy, and surface lipophobicity. The weak cohesive force between carbon fibers and the matrix make the shear strength and the bending strength of the composites low. Therefore, Surface functionalization is critical for resolving these problems, as surface-bound functional groups can enhance the wettability, dispersibility, and surface reactivity of carbon fibers surface [12]. Chemical method [13–16], electrochemical method [17–19], plasma treatment [20,21], etc., have been developed to increase the quantity of surface functional groups and thus enhance the ability to establish strong interactions between fibers and matrix.

In recent years, much research attention has been paid to nanoparticle reinforcements, which possess novel optical, electronic and chemical properties absent in bulk materials [22]. Nanoparticles most often used in plastics are carbon nanomaterials [23–25], layered clayey minerals [26] and nanoparticles of metals or their organic and inorganic compounds [27,28]. It is expected that it is still an open question to study the influence of nanoparticles on the tribological properties of filled polymers. Nano-SiO_2 is one of the most important fillers for the improvements in the friction and wear behavior of fabric composites [28]. Silicon dioxide can be coated on the surfaces of carbon fabric by sol–gel process, which has recently received a lot of attention. The SiO_2 sol–gel process has several advantages such as high purity, low temperature processing, ultrahomogeneity. The existence of a lot of silanol groups in the silica layer provides various functional groups on the surfaces of the carbon fiber and thus enhance the ability to establish strong interactions between the fiber and matrix. To the best of our knowledge, few reports have dealt with the coating of nanoparticles onto carbon fabric surface to improve the tribological properties of fabric reinforced polymer composites.

In this paper, nano-silica thin film has been deposited on the surface of 2D carbon fabric. The friction and wear properties of the resulting modified carbon fabric composites were comparatively

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Table 1
Properties of plain weave of carbon fabric.

Carbon fabric	Plain
Type	PAN
Tow	1 K
End per inch (filament/mm)	14
Pick per inch (filament/mm)	5
Warp tensile strength (N/m)	≥1000
Weft tensile strength (N/m)	≥500

investigated with that of the unmodified carbon fabric composites. The present work is expected to help understand the effects of surface modification technology.

2. Experimental

2.1. Materials

In the present study, the adhesive resin (204 phenolic resin adhesive) was provided by Shanghai Xing-guang Chemical Plant of China. CF used was supplied by Nantong Senyou Carbon Fiber Co., Ltd. (Jiangsu, China). The properties of the carbon fabric are shown in Table 1.

2.2. Carbon fiber modification

The commercial carbon fabric was dipped in acetone for 24 h, then cleaned ultrasonically in acetone for 0.5 h, finally, they were dried before being used. Because the grooves on the carbon fiber surface are the physical basis for the deposition of Sio_2 thin film, the surface morphology becomes essential. Therefore, the PAN-based carbon fabric were immersed in 10 wt.% NaOH for etching at 50 °C. The surface morphology of fibers was controlled by adjusting the etching time. After 1 h, the carbon fabric was taken out and washed with distilled water to neutrality and then dried at 80 °C for later use. The nano-silica thin film deposition has been started by sol preparation. At first, 4 g polyvinyl alcohol was added to 500 ml distilled water, the solution was heated to 85 °C and held for 30 min in order to dissolve adequately. In the second step, 3 g polyvinylpyrrolidone and 15 ml OP-10 were added after the solution cooled to room temperature, the pH was adjusted to 4 using HCl. Then tetraethoxy-silane (TEOS) was added to the solution where the volume ratio of TEOS to H_2O was 1:9. The mixed solution was stirred for 30 min to make TEOS hydrolyze adequately. After that, the hydrolytic solutions were poured into the depositing plate flat and the clean carbon fabric was immersed. The fabric was placed on a shelf after 1 h and then dried at 70 °C for 30 min. The carbon fabric was overturned and the above step was repeated so that both surfaces of the carbon fabric can be coated with a depositing layer. Finally, the carbon fabric was heated to 700 °C and held for 1.5 h so as to eliminate the organic things and make the thin film more compact.

2.3. Preparation of carbon fabric composites

The carbon fabric (350 mm × 250 mm) was put into phenolic resin solution and dipped ultrasonically for 10 min, then the fabric was put into an oven to evaporate the solvent at 40 °C. The composite was prepared by dip-coating in the phenolic resin as the adhesive. A series of repetitive immersing and coating of the carbon fabric in the adhesive were performed to allow the generation of the composite coatings. The weight percent of carbon fabric in the CFRP composites was 55%. The prepreg was cut into long pieces of 50 mm × 30 mm and put into the mould with plies orientations of [0°/0°]. The final target carbon fabric reinforced phenolic composites were obtained by heating the mould at 180 °C for 3 h. At the end of each run of heating sintering, the resulting specimens were cooled with the stove in air and then cut into pre-set sizes for friction and wear tests.

2.4. Testing procedure

After surface treatment, the carbon fibers samples were transferred in air to a VG Scientific ESCA LAB 210 spectrometer for analysis of the surface element compositions by XPS. The XPS analysis was carried out using unmono-chromated Mg Ka X-radiation using Al/Mg dual anode at 20 KV under 300 W and the base pressure in the sample chamber was about 10^{-7} Pa. In order to investigate the possible change of chemical composition of the carbon fibers after treatment, Fourier transform infrared spectroscopy (FTIR) measurements in the mid infrared were performed, which were recorded on a Bruker IFS/66 V spectrometer. The specimens for FTIR

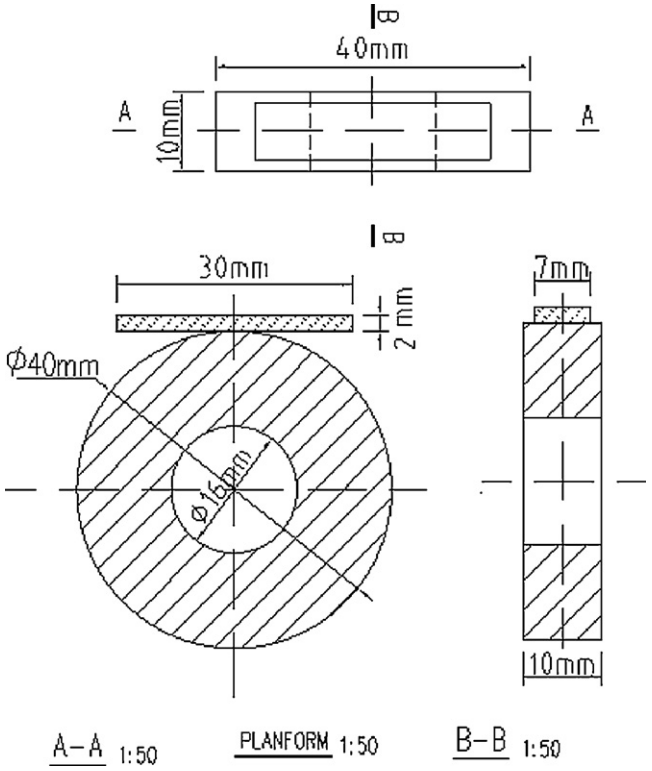

Fig. 1. The contact technical drawing for the friction couple.

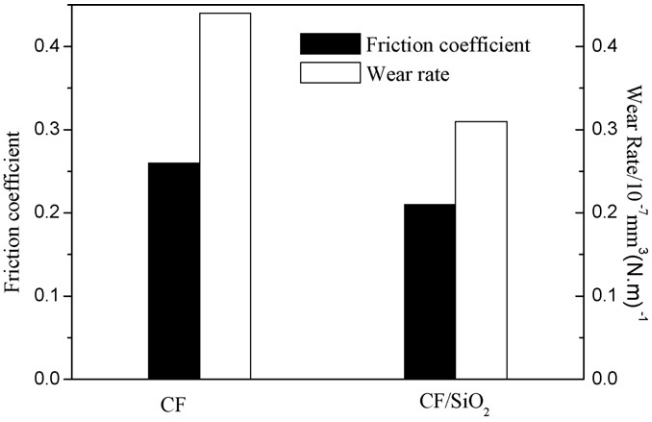

Fig. 2. Variations of the friction coefficient and wear rate of the phenolic composites reinforced with CF or CF/SiO_2 (0.431 m/s and 200 N).