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Materials Science and Engineering A 404 (2005) 251–258

MATERIALS SCIENCE & ENGINEERING A

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Study on the friction and wear properties of carbon fabric composites reinforced with micro- and nano-particles

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Accepted 23 May 2005

Abstract

The carbon fabric composites filled with the particulates of polyfluo-150 wax (PFW), nano-particles of ZnO (nano-ZnO), and nano-particles of SiC (nano-SiC), respectively, were prepared by dip-coating of the carbon fabric in a phenolic resin containing the particulates to be incorporated and the successive curing. The friction and wear behaviors of the carbon fabric composites sliding against AISI-1045 steel in a pin-on-disk configuration are evaluated on a Xuanwu-III high-temperature friction and wear tester. The morphologies of the worn surfaces of the filled carbon fabric composites and the counterpart steel pins are analyzed by means of scanning electron microscopy. The effect of the fillers on the adhesion strength of the adhesive is evaluated using a DY35 universal materials tester. It is found that the fillers PFW, nano-ZnO, and nano-SiC contribute to significantly increasing anti-wear abilities of the carbon fabric composites, however, nano-SiC increase the friction coefficient of the carbon fabric composites. The wear rates of the composites at elevated temperature above 180 °C are much larger than that below 180 °C, which attribute to the degradation and decomposition of the adhesive resin at an excessively elevated temperature. That the interface bonding strength among the carbon fabric, the adhesive, and the particles is significantly increased after solidification and with the transferred film of the varied features largely account for the increased wear-resistance of the filled carbon fabric composites as compared with the unfilled one.

Keywords: Carbon fabric composite; PFW; Nano-particles; Filler; Friction and wear behavior

1. Introduction

The report of the wide use of carbon fiber as the reinforcing agent of polymers is not only attributed to its high strength and modulus but also to its excellent thermal stability [1–3]. It could be rationally anticipated that the plain carbon fabric made of carbon fiber would have better mechanical and tribological properties than the carbon fiber, owing to the orderly aligned structure, better integrity, and better load-carrying capacity of the carbon fabric than the carbon fiber counterpart [4]. This is why increased attention has been paid to the investigation on the friction and wears properties of polymer-based composites reinforced with fabrics [5–8]. As a matter of fact, the composites made of polytetrafluoroethylene (PTFE) fabric and carbon fabric have been successfully used as the self-lubricating and wear-resistant materials in the industries of aerospace, aviation, and automobile [9,10]. Unfortunately, little has been currently reported on the friction and wears behavior of the fabric composites [11–13], especially, of carbon fabric composites.

Owing to the inertia and brittleness of carbon fiber, it is imperative to modify carbon fiber and carbon fabric so as to decrease the brittleness and increase the anti-wear ability, and hence, to broaden the tribological application of carbon fabric. In other words, in order to increase the applicability of the carbon fabric composites in bearing industry where the integration and multi-functionalization of the bearings made of

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doi:10.1016/j.msea.2005.05.084

various composites are of particular interest, it is imperative to seek for the effective ways to enhance the mechanical and tribological properties of carbon fabric composite. The inorganic nano-particles, such as TiO_2, ZnO, SiO_2, and Si_3N_4 could be of significance in this respect, since they as the fillers were reported to be effective in improving the friction and wear properties of some polymer and fabric composites [11,14–18], owing to their specific properties, such as high surface activity and energy and small size effect. At the same time, the F-containing polymers, such as PTFE [11,19] and PFW as the fillers were also found to be effective in modifying the friction and wear behaviors of some fabric composites or polymer composites [11]. Therefore, nano-ZnO, nano-SiC, and PFW were selected as the fillers to modify the carbon fabric composites in the present work.

This article deals with the preparation, friction, and wear properties of the carbon fabric composites filled with PFW, nano-ZnO, and nano-SiC, respectively. The action mechanisms of the fillers in reducing the wear and friction of the carbon fabric composites are also discussed. The present work is expected to broad the application of carbon fabric composites in dry-sliding bearings.

2. Experiment

2.1. Preparation of carbon fabric composites

The carbon fabric (CF) made from polyacryl nitrile (PAN) carbon fibers was provided by Shanghai Carbon Materials Factory of China. The adhesive resin (204 phenolic resin) was provided by Shanghai Xingguang Chemical Plant of China. ZnO (diameter about 30 nm) and SiC (diameter about 50 nm) particulates were prepared at our lab. PFW (polyfluo-150 wax, diameter < 15 μm, melting point 112 °C) was provided by Micro Powder Inc., USA. The surface of the 1Cr18Ni9Ti stainless steel disc to be coated by the carbon fabric was polished with $280^{\#}$ and $350^{\#}$ sand paper to a surface roughness of $R_a = 0.45$ μm. The particle was evenly dispersed in the adhesive at proper mass fractions with the assistance of magnetically and ultrasonic stirring. Then, the carbon fabric after pre-treatment (the carbon fabric was dipped in acetone for 24 h and boiled in distilled water for 10 min, followed by cleaning with acetone in an ultrasonic bath) was immersed in the mixed adhesive to allow the coating by the adhesive mixture containing the filler. The immersing of the carbon fabric in the mixed adhesive and the successive drying of the coated carbon fabric around 60 °C were repeated to allow the generation of the carbon fabric composite about 400–450 μm thick upon the using-up of the mixed adhesive. Finally, the filled carbon fabric composites (abridged as CFC) were affixed on the stainless steel surface using the phenolic resin adhesive and cured at 180 °C for 2 h. For comparison, the unfilled carbon fabric composites wear also prepared in the same manner except that no particulate fillers were introduced in the phenolic resin adhesive.

2.2. Effect of the fillers on the adhesion strength of the adhesive

Before carrying out the adhesion test, the pure adhesive and the mixed one filled with PFW powder or the nanoparticles were used to affix two 1Cr18Ni9Ti stainless steel plates and cured at 180 °C for 2 h. The adhesion strength of the pure and filled-adhesives was determined using a universal materials test machine. The stainless steel plates affixed with the pure and filled-adhesive resin was clamped with clamp and fixed vertically, and then, were pulled at a constant speed of 50 mm/min, until the two stainless plates were pulled apart. The forces at this point was cited the pulled out force P, which was determined from the recorded load–displacement curve. The exact length L and width B of the adhered area were measured using a vernier caliper. The adhesion strength "τ" was calculated as $\tau = P/(LB)$. Five replica tests were carried out for each specimen to minimize data scattering and the averaged results of the five replica tests are reported in this article.

2.3. Evaluation of the friction and wear behaviors of the carbon fabric composites

The friction and wear behaviors of the unfilled and filled carbon fabric composites affixed on the stainless steel disc sliding against AISI-1045 steel pin of length 19 mm were evaluated on a Xuanwu-III high-temperature friction and wear tester. Fig. 1 shows the schematic diagram of the test rig. Prior to the tests, the pin was sequentially abraded with $350^{\#}$, $700^{\#}$, and $900^{\#}$ sand papers, to a surface roughness $R_a = 0.15$ um, and then, cleaned with acetone. The sliding was performed under ambient condition at a sliding speed of 0.256 m/s, a normal load within 156.8–400.0 N, and over a period of 2 h except for noting otherwise. At the end of each test, the disc was cleaned and dried, then, its wear volume loss (V) was obtained by measuring the area and depth of the wear scar using a micrometer (±0.001 mm). The wear rate was obtained from dividing the wear volume loss by the normal load and sliding distance, and it was still calculated using the same formula even the tested composite sample was

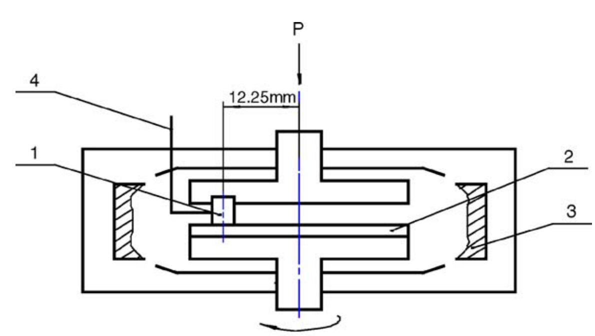

Fig. 1. Schematic diagram of the pin-on-disc (pin Ø 3.0 mm and disc Ø 44.0 mm) friction and wear tester; P, applied load; 1, counterpart pin; 2, CFC-coated stainless steel disc; 3, electric furnace; 4, themocouple.