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Effect of aramid pulp on improving mechanical and wet tribological properties of carbon fabric/phenolic composites

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ABSTRACT

To improve the mechanical and wet tribological properties, the carbon fabric/phenolic composites containing 0 wt% (F0), 0.5 wt% (F1) and 1 wt% (F2) aramid pulp were prepared by filtration method. Subsequently, their three-dimensional surface profiles, skeletal densities, porosities and compression modules were characterized. Results show that the bridging and strengthening effects of aramid pulp can dramatically enhance the interfacial bonding. The shear and tensile strengths increase with the rise of aramid pulp content and that of F2 are 1.23 MPa and 85.19 MPa, improved by 31% and 54% compared with F0. The incorporation of aramid pulp increases the friction coefficient and decreases the wear rate.

1. Introduction

With the increasing need for safer and more stable wet transmission systems of automobile, the carbon fabric/polymer composites (CFPCs) have become attractive alternatives to conventional paper-based friction materials owing to their excellent mechanical, tribological and thermal properties [1–5]. However, one of the shortcomings for most CFPCs is weak interfacial bonding between fiber and polymer owing to the low specific surface area, surface energy and chemical inertness of carbon fiber [6–8]. The weak interfacial bonding always leads to worse stress transfer and serious physical defects and thus shortens the life of CFPCs.

There are several methods to improve the interfacial bonding of CFPCs, whose interfacial reinforcing mechanisms can be usually divided into three types: the increase of fiber surface roughness, the formation of chemical bond and the size effect of inorganic particles. The growth of inorganic nanoparticle on woven carbon fibers by hydrothermal method, freeze drying process and thermal treatment, such as carbon nanotube [9], CuO [10] and ZnO nanowires [11], can increase the surface roughness and adhesion energy of carbon fiber. The more polar components [12,13] can be introduced to woven carbon fibers by anodic oxidation, air plasma bombardment and HNO_3 etching [14], oxygen treatment [15], gamma radiation treatment [8], which can form the chemical bonds between fiber and polymer. However, these methods are relatively complex and uneconomical due to the necessity of chemical reaction and the application of expensive instruments. The nano-Al_2O_3, Si_3N_4, SiO_2, TiO_2, ZnO, $CaCO_3$ [16–18], nano-carbon black [19], micro-MoS_2, graphite [20] and micro-SiC [21] were incorporated by a dip coating process, prepreg manufacturing process or hand lay-up technique. The small size effect, large specific surface area, high surface activity and energy of these inorganic particles [22,23] can improve the interfacial bonding and then enhance the mechanical and tribological properties of CFPCs. Although being simple and economical, these methods prevent these particles from immerging into the inside of carbon fabric, which leads to the result that the internal fiber-matrix interfaces are hardly improved.

Aramid pulp has been widely used as a class of important tribo-engineering materials owing to their special surface structure and excellent grasp force in industry [24,25]. Aramid pulp has excellent compatibility with polymer, which makes it easy for more phenolic to immerge into the inside of carbon fabric. Meanwhile, the addition of aramid pulp easily results in the formation of some resin-rich zones with higher loss factor in the composites [26] and increases the interaction between fiber and matrix [27].

Hence, in this paper, the carbon fabric/phenolic composites containing aramid pulp are prepared by filtration method. Subsequently, the effects of aramid fiber content on the mechanical and wet tribological properties are investigated. Finally, the worn

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surfaces are analyzed by scanning electron microscopy with worn specimens.

2. Experimental work

2.1. Materials

In this study, plain weave (12 K) carbon-fiber fabric with an areal density of 400 g/m^2 was used as reinforcement (supplied by Jilin Jiyan High Technology Fiber Co. Ltd., Jilin, China). The warp count and weft count were 250 to ws/m and the carbon fiber diameter was 7 μm. Cashew-modified phenolic resin (PF-6291A) was used as matrix (supplied by Shandong Shengquan chemical Co., Ltd., Jinan, China). The aramid pulp was PPTA PulPs (1F538, provided by Shanghai Siju special fiber materials Co., Ltd), which were obtained by the external fibrillation of aramid fibers. As shown in Fig. 1, the diameter of aramid fiber was about 20 μm and a large number of microfibers from the fiber stems can be clearly seen, which can establish three-dimensional network structure.

2.2. Fabrication of carbon fabric composites

To remove the impurities of carbon fiber surface, the carbon fabric was dipped in acetone for 24 h, and then cleaned ultrasonically in acetone for 1 h, and finally, dried at 100 °C. In order to obtain a stable aramid pulp suspension, aramid pulp was dispersed in water and stirred for about 30 min by a beater, which can separate aramid fibers on the premise of not damaging their original structure. After that, the stable aramid pulp suspension was filtered using the carbon fabric as filter paper and hence the carbon fabric was dried around 60 °C in the oven. Subsequently, the dried carbon fabric was put into phenolic solution (dissolved in the ethanol with the mass concentration of 30%) and dipped for 30 min, then the carbon fabric was put into an oven to evaporate the solvent at 100 °C, followed by compression molding at 170 °C for about 5 min under the pressure of 5.0 MPa. Finally, the as-prepared composites containing 0 wt%, 0.5 wt% and 1 wt% aramid pulp were designated as F0, F1 and F2, respectively. The overall fabrication process was illustrated in Fig. 2(a).

In order to obtain the matrix content in each formulation, TG test was carried out in nitrogen from 40 °C to 1200 °C at a heating rate of 10 °C/min and then The ingredients of the carbon fabric composites were obtained, as shown in Table 1. As shown in Fig. 2 (b), the amounts of mass loss after 1200 °C are respectively 77%, 82% and 86% for F0, F1 and F2, which means that the matrix content decreases with the rise of aramid pulp content.

2.3. Surface structure characterization

In order to better characterize the worn surfaces of carbon fabric composites, scanning electron microscope and three-dimensional surface profiles tests were performed using a JEOL 6460 and an OPTELICS C130 real color confocal microscope. 3-D surface profiles were the height distribution of surface asperities, which can be obtained by gathering the height data of surface asperities in the measured area.

2.4. Pore structure characterization

The skeletal density and porosity were measured by mercury porosimeter (AutoPore IV 9500) under high pressure based on Washburn equation. The skeletal density was calculated by Eq. (1).

$$\rho_f = \frac{m}{V - V_p} \tag{1}$$

where ρ_f is the skeletal density of sample; m is the quality of sample; V is the volume of sample; V_p is the pore volume of sample.

2.5. Mechanical properties test

The mechanical properties of carbon fabric composites were measured with a CMT5304-30KN standing electromechanical universal testing machine under dry condition at room temperature. The average value of three specimens was reported to minimize data scattering and the representative curves were used. The tensile properties were tested at a crosshead speed of 5 mm/min, which can reflect the ability of a material to resist breaking under tensile load. The tensile specimen diagram was shown in Fig. 3(a). The shear test sample was prepared by affixing the sample between two stainless steel strips with a type of phenolic resin adhesive (cured at 160 °C and under 1.0 MPa) and tested at a constant speed of 5 mm/min until shear fracture occurs, whose test principle diagram was shown in Fig. 3(b). The compressibility and recovery properties were measured according to the ASTM F36-99 and the four repetitive loading-unloading processes were conducted under a load of 100 N.

2.6. Wet tribological properties test

The reciprocating friction method of CFT-I friction tester was used to measure the friction and wear behaviors of carbon fabric composites in oil lubricating, whose schematic diagram was shown in Fig. 4. The set value of reciprocating length was 3 mm

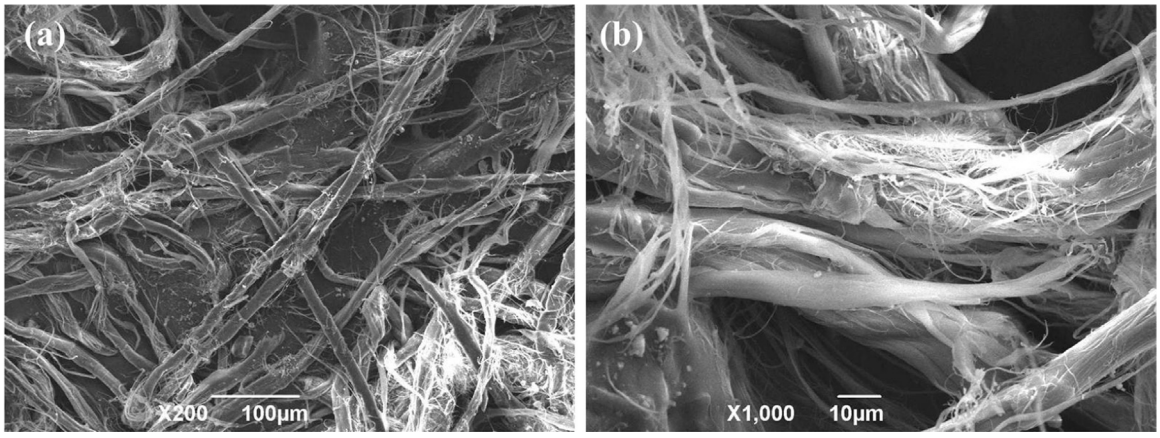

Fig. 1. (a) SEM micrographs and (b) Magnification SEM micrographs of aramid pulp.