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A study of tribological behaviors of the phenolic composite coating reinforced with carbon fibers

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Abstract

The nitric acid treatment was used as a method to bind acidic oxygen functional groups on carbon fiber surfaces, thereafter these fibers (CFO) and unmodified carbon fibers (CF) were incorporated into the phenolic composite coating for wear investigations. Surface analyses of the carbon fibers before and after treatments were performed by FTIR, X-ray photoelectron spectrometer (XPS). Tribological behaviors of carbon fibers filled phenolic coatings were investigated using a ring on block wear tests under dry friction condition, and the worn surfaces and the transfer films formed on the surface of counterpart ring were, respectively, studied by SEM and optical microscope. The results show that the additions of carbon fibers were able to reduce the friction coefficient of the phenolic coating and enhance the wear life of it, especially, the wear life of the phenolic coating was the best when content of carbon fibers is at 10 wt.%. Moreover, we found that the friction and wear behaviors of the phenolic coating reinforced with 10 wt.% CFO were better than those of the coating reinforced with 10 wt.% CF. FTIR and XPS analyses indicated that the oxygen functional groups, such as —OH, O—C=O, C=O, and C—O, were attached on the carbon fiber surfaces after the oxidated treatment. In both cases, appropriate treatments could effectively improve the mechanical and tribological properties in the phenolic composite coating due to the enhanced fiber–matrix interfacial bonding.

Keywords: Phenolic coating; Tribological behaviors; Carbon fiber; Nitric acid treatment

1. Introduction

Possessing of excellent mechanical and tribological properties, carbon fiber reinforced plastics are increasingly being used for many different applications [1–5]. However, carbon fibers usually perform a poor bonding behavior to polymer matrix due to their nature of smoothness and chemical inertness [6]. In order to improve the bonding properties of carbon fibers, various approaches can be applied, which were classified into oxidative and non-oxidative treatments.

In the past years, many researchers have focused on the tribological behaviors of CF filled composites in various directions. Zhang Hui et al. [7] reported that the wear resistance of air oxidative carbon fiber reinforced epoxy was significantly improved at low contact pressure, whereas that was reduced at high pressures which may be due to the damage of fiber mechanical properties after oxidation. Lu and Friedrich [8,9] studied systematically the influence of carbon fiber volume fraction of their composites on friction and wear, and declared that an optimum range for short carbon fiber in PEEK matrix is 15–25 vol.% according to the improved specific wear rate. Lancaster [10] has studied the friction and wear properties of various carbon fiber reinforced polymers sliding against metals in water, aqueous solutions and organic fluids and found that the wear of CF reinforced polymers as well as unfilled polymers under water lubrication was generally greater than that under dry conditions. Kim et al. [11] found that the wear volume of the carbon–phenolic composites saturated with oil was less than half that of the dry specimen.

There have been many research works and developments to improve the friction and wear properties of phenolic resin and its composites [12–15]. However, there is little reported work examining the friction and wear behaviors of untreated and treated CF filled phenolic coating. The objective of this work is to study the friction and wear properties of phenolic coating filled with CF or CFO. This work is believed to be helpful for

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Table 1
The chemical composition of the GCr15 bearing steel and steel 45 (in wt.%)

	C	Si	Mn	P	S	Cr	Ni	Cu	Fe
Steel 45	0.42–0.5	0.17–0.37	0.50–0.80	0.035	0.035	0.25	0.25	0.25	Balance
Bear steel	0.98–1.1	0.15–0.35	0.25–0.45			1.3–1.6			Balance

understanding the effect of the CF or CFO on the wear of the phenolic coating.

2. Experiments

2.1. Materials

In our work, a steel 45 (12.7 mm × 12.7 mm × 19 mm) was used as substrate of the composite coating. An AISI-C-52100 ring of 49.2 mm in diameter and 12 mm thick (Hardness 850 Hv) was made of bearing steel. The chemical composition of steel 45 and AISI-C-52100 bearing steel is shown in Table 1.

The phenolic binder (204 phenolic resin) was provided by Shanghai Xingguang Chemical Plant of China. POLYFLUO 150 WAX (PFW) in a diameter of approximately 3–4 μm, was provided by Mircopowder Company of USA. The carbon fibers (CF) with an average primary particle size of 10 μm were purchased from Shanghai Sxcarbon Technology Co., Ltd., China. The mixed ethanol/acetone/cyclohexanone in a volume fraction of 4:2:1 was employed in the present work as a solvent.

2.2. Surface treatment of CF

In a typical experiment, carbon fibers (4 g) were added to 60% HNO_3 aqueous solution (70 ml). The mixture was treated with an ultrasonic bath for 30 min and stirred for 5 h at reflux. Then the mixture was vacuum-filtered through 0.2-μm Millipote PTFE membrane and washed with distilled water until the PH of the filtrate was 7.0. The filtered solid was dried under vacuum for 24 h at 60 °C, obtaining CF-COOH.

2.3. Coating preparation

The manufacture process of the composite coating was as follows: first, the CF or CFO and the powder of PFW were mixed in ball mill, the quantity of the powder of PFW used was 30% of phenolic mass; second, the mixed powders were dispersed in the mixed solvent with ultrasonic stirring for 5 min and then the binder of phenolic and the mixed fillers with desired proportion were carefully mixed, respectively, by mechanical stirring and ultrasonic treatment. The surface of steel 45 substrates was rinsed with acetone and roughened by spraying corundum. The coatings on blocks were prepared by spraying the prepared mixture with 0.2 MPa nitrogen gas using spray gun. All the samples were cured following the procedures shown below step by step: 2 h at 60 °C, 2 h at 120 °C, 2 h at 150 °C and 2 h at 180 °C. The thickness of the wet coatings was controlled by regulating the spraying speed and the composition of non-volatile constituents in the coating precursors. The thickness of the cured coating was measured with a MINITEST 1100 microprocessor coating thickness gauge which works on the principle that the attractive force between a coating and a magnetic metal is inversely proportional to the distance between them. The thickness of the cured coatings was about 60–70 μm.

2.4. Characterization of coating

Fig. 1 shows the SEM pictures of the phenolic coating filled with 10 wt.% CF surfaces and sections. It is noted that the CF are seen to be well bonded with the coating matrix. However, some cavities are apparent at the surface of the coating, which might be caused by the solvent evaporation from the matrix and the poor adhesion between the fillers and the phenolic matrix.

2.5. Evaluation of the tribological behaviors

An MHK-500 ring-on-block wear tester (made by the Jinan Testing Machine Factory, China) with a similar configuration to a Timken tester was used to evaluate the friction and wear behaviors of the phenolic composite coatings. A steel ring was rotated against the phenolic composite coating at several different sliding speed and applied load. The friction forces of the specimens were measured by a strain-gage bridge which was bonded on the specimen holder. Before each test, the surface of the steel ring was polished to a roughness of about 0.1 μm. The sliding distance was calculated from the product of the sliding speed and the sliding time. The wear life of the phenolic composite coatings was calculated after dividing

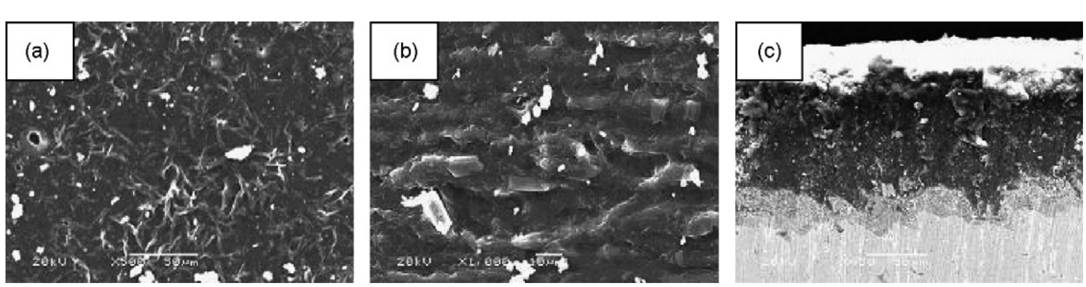

Fig. 1. The SEM photograph of the phenolic coating filled with 10 wt.% CF: (a) surface; (b) magnified view of surface; (c) section.