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Friction and Wear Behavior of Resin/Graphite Composite under Dry Sliding

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The friction and wear behavior of resin/graphite composite has been investigated using a pin-on-disc configuration under dry sliding condition. The results showed that the resin/graphite composite exhibited much better mechanical and tribological properties compared with the unimpregnated graphite. The friction coefficient was reduced by addition of furan resin, which could also prevent the "dusting" wear at loads more than 15 MPa. The steady and lubricated transfer film was easily formed on the counterpart surface due to the interaction of furan resin and wear debris of graphite, which was useful to reduce the wear rate of the resin/graphite composite. The composite is highly promising for mechanical sealing application and can be used at high load for long time sliding.

1. Introduction

Carbon–graphite materials have been widely used in mechanical seal due to their excellent self-lubricating, chemical inertness, high thermal conductivity and outstanding temperature stability[1]. The application of traditional carbon–graphite material is sometimes restricted by their low mechanical strength, low wear resistance and poor sealing performance, which are caused by a large portion of connected pores generated during the preparation process. To overcome these above shortcomings, some carbon–graphite composites have been prepared by infiltrating these materials in a second phase (metal, polymer, inorganic salt, etc.) at high pressure in the carbon industry[2–4].

The friction and wear properties of graphite have been widely studied[1,5–7]. For a long time, weak interplanar van der Waals interactions between planes of graphite are considered to be the origin of its low friction coefficient[8]. Nevertheless, the friction coefficient of graphite was higher than 0.5 and fluctuated greatly under vacuum or some inert atmospheres[5,9,10]. This erratic friction behavior is known as "dusting" wear owing to the rapid disintegration of graphite into a cloud of fine dust-like debris[10]. Researches show that water vapor or other condensable vapors in the environment could prevent the "dusting" wear and lead to a complete lubrication even at much lower pressure. It was clearly demonstrated that the interactions between graphite and water vapor greatly influence its tribological properties[5,11]. The widely accepted friction mechanism for carbon–graphite material inferred that the stable and complete transfer film formed on metal surface during friction against graphite could reduce the friction coefficient and wear rate, and the formation of transfer film is concerned with the structure of graphite and its interactions with the environment[1,12,13].

Compared with pure carbon–graphite, carbon–graphite composite exhibited different tribological properties owing to the multiphase structure and interaction among the phases during contact sliding. There were lots of researches on the friction and wear behavior of C/C composite[14–18] and the friction coefficient of C/C composite was relatively high owing to different properties of carbon fiber and pyrolytic carbon matrix. However, if lubricated film formed between the friction surface, the C/C composite could also exhibit better tribological properties[17]. Some investigations on metal/graphite composite had been conducted[19–21], where tribological properties of the composite were significantly enhanced by forming steady and lubricated transfer film.

It was found that the transfer film usually formed when polymers slide against a metal or polymer counterfaces to affect the friction and wear behavior of the two sliding pairs[22]. Therefore, it may be a feasible way to combine resin with graphite, by which a steady and complete transfer film would form and low friction coefficient and wear rate can be achieved. Research had found that resin/graphite composite could form lubricated film at the initial

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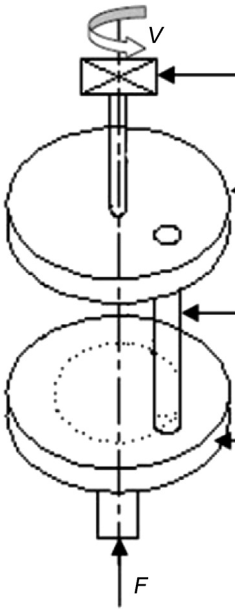

Fig. 1. Schematic of sliding friction test.

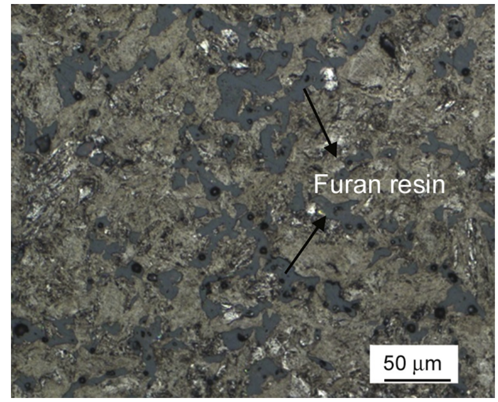

Fig. 2. Microstructure of the resin/graphite composite.

stage of the friction due to the supporting of the resin[23]. But the role of resin in resin/graphite composite is not clear during high loads friction process. In this work, a resin/graphite composite was prepared and the effect of applied loads on the tribological properties of the composite was investigated under dry sliding, which was the harshest condition for mechanical seal. Moreover, the wear mechanisms of graphite and the resin/graphite composite were discussed.

2. Experimental Work

The substrate graphite material used in this study was prepared by the traditional molding method and heat-treated at 2200 °C, and its degree of graphitization is 24.4%. The resin/graphite composite was prepared by impregnating furan resin at high pressure, and the specific method of preparation had been described in details in our previous publication[24]. The weight gain rate (resin content, %) of the composite was calculated using the following equation:

$$w = \frac{m - m_0}{m_0} \times 100\% \tag{1}$$

where w (%) is the weight gain rate, m_0 (g) is the weight before impregnation, m (g) is the weight after impregnation.

Compressive and flexural tests were performed on a universal testing machine. The open porosity (%) of the composite was measured by boiling method. Shore hardness (HS) was measured by using a shore hardness tester. The data reported here represent the average result of at least five tests.

The friction and wear tests were conducted in a pin-on-disc contact configuration (Fig. 1) under dry sliding condition at room temperature. Before test, the pin specimen (4.8 mm in diameter and 12.8 mm in length) and the counterpart disc (45 steel) were polished with No.1200 waterproof abrasive paper and ultrasonically cleaned in acetone. A thermocouple was attached on the stationary disc approximately 2 mm from the mating face, and an infrared thermal imager (Ti32, FLUKE) was used to measure the friction temperature field. The tests were carried out at normal load from 3 MPa to 20 MPa at a constant linear velocity of 0.5 m/s for 120 min. The friction coefficient was directly recorded with a testing machine. Before and after the test, the pins were ultrasonically cleaned and dried for weighing. The mass loss of the pin was measured with an electrical balance (Mettler AE240, accuracy 0.01 mg) for the specific wear rate calculation. The specific wear rate k was calculated from the following equation:

$$k = \frac{\Delta m}{\rho \times N \times L} \left(\mathrm{mm^3\ N^{-1}\ m^{-1}} \right) \tag{2}$$

where Δm (mg) is the mass loss of the specimen, ρ (mg/mm^3) is the density of the specimen, N (N) is the normal load and L (m) is the total sliding distance. The microstructure, worn surfaces of specimens, transfer film on the steel counterpart and wear debris were observed with an optical microscope (OM) and scanning electron microscope (SEM, Nova NanoSEM 430). The synchronous thermal analyses (thermogravimetry/differential scanning calorimetry/mass spectrometer, TG/DSC/MS, Netzsch 449C Jupiter/QMS 403C) of furan resin were performed in air at a ramping rate of 5 °C/min up to 300 °C.

3. Results and Discussion

3.1. Structure and properties

Some mechanical and physical properties of the graphite and resin/graphite composite are listed in Table 1. The furan resin of 6 wt% was impregnated into the graphite. The densities of the graphite and resin/graphite composite are 1.85 and 1.98 g/cm^3, respectively. The compressive strength and flexural strength of the composite are 156 MPa and 58 MPa, respectively, much higher than 101 MPa and 35 MPa for the graphite. The shore hardness of the

Table 1
Mechanical and physical properties of graphite and its composite

	Density (g/cm^3)	Resin content (wt%)	Compressive strength (MPa)	Flexural strength (MPa)	Shore hardness (HS)	Open porosity (%)
Graphite	1.85 ± 0.02	–	101	35	72	10.34
Resin/graphite composite	1.98 ± 0.02	6	156	58	76	0.73