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Friction-wear characteristics of carbon fiber reinforced friction material

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Automotive brake materials usually consist of several ingredients which are classified as fibrous reinforcement, binder, filler and friction modifier [1, 2]. A high quality friction material must possess stable friction and low wear to satisfy the varying and rigorous service conditions. Braking hard or frequently can create a large increase in temperature due to the friction heating produced on the mating surfaces between the brake and brake friction material. The temperature can increase largely and cause the friction material to be less effective than it used to be at low temperature, reducing the brake's efficiency. When an organic friction material is subjected to such high temperatures, the normal low-temperature coefficient of friction decreases and this phenomenon is called "brake fade" or fade [1, 3].

In general, the previous friction-wear investigations of carbon composites have been mostly confined to experiments at low temperatures and most of the materials tested were binary composites [4–9]. This information may not be suitable to evaluate the applicability of carbon fiber in automotive friction material for braking purposes. In this work, a tribological investigation was conducted on a carbon-fiber-reinforced phenolic friction material using a D-MS friction material testing machine. The objective of the work described in this letter was to determine the fade characteristics of the friction materials in the devotes temperature range of 100–300 °C.

A phenolic resin is generally chosen as the binder in polymeric brake materials due to its excellent thermal stability. An acrylonitrile-butadiene rubber-modified phenolic (Heilongjiang Chemical Institute, China), was used in this study. The carbon fiber (Jilin Carton Imp. and Exp. Company), which had a Young's modulus of 50.4 GPa and a strength of 650 MPa, was used to improve the mechanical and tribological behavior of the polymer matrix. The length of the carbon fiber was in the range of 2–5 mm, its diameter was 6–8 μm. The friction modifier consisted of metallic powder (cast iron powder and copper powder) and SiO_2 powder etc. Barium sulphate was used as a filler.

The friction materials formulation consisted of about 10–20/25/15–25/40 by weight per cent of carbon fibers/phenolic resin/barium sulphate/friction modifier, respectively. The ingredients were blended in a laboratory mixer in the following sequence so as to obtain satisfactory mixing. First, the filler and the friction modifier were churned together in the mixer. Carbon fibers were added next, followed by the resin. Mixing was done for a few minutes at the addition of each component and finally for about 20 min after the addition of resin. The mixture was hot pressed at 160 °C and 3.5 MPa for about 10 min. The molded plates were postcured in an oven at 170 °C for 2 h. Specimens of size 25 mm × 25 mm were cut from the cured composite plates and ground to a thickness of about 5 mm.

The friction-wear measurements were made using a D-MS machine. Briefly, the D-MS machine consisted of a cast iron drum with a diameter of 300 mm and Brinell hardness of 170–210. A specimen was applied on the drum from it by means of a pneumatic arrangement. The drum could be rotated at a speed of 480 rev min^{-1} by a motor coupled to it through a clutch. A standard sliding speed V is 7.5 ms^{-1}. A standard dead weight of 1 MPa could be applied to the specimen. The drum temperature could rise in principle by frictional heating. Furthermore, the drum was also provided with an electric heater and air blower for controlling its bulk temperature in the range of 100–300 °C. The drum temperature was measured below the sliding surface of the drum by means of a thermocouple and a slip-ring arrangement.

The D-MS machine is generally used for the quick evaluation of brake materials by conducting a standard test, detailed by Chinese National Standard GB-5763-86.

The wear rate of a specimen was determined by weighing the specimen before and after a wear test. The frictional coefficient and wear rates of the individual wear tests were within 10% and 20% the average values, respectively.

The specific wear rate W_s due to a wear test was calculated as:

$$W_s = \Delta W/\rho P V t \tag{1}$$

where ΔW was the weight loss, ρ was the composite density and t was the total time of sliding. The effects of temperature and amount of carbon fiber on the coefficient of friction and the specific wear rate are shown in Fig. 1a and b, respectively. The coefficient of friction

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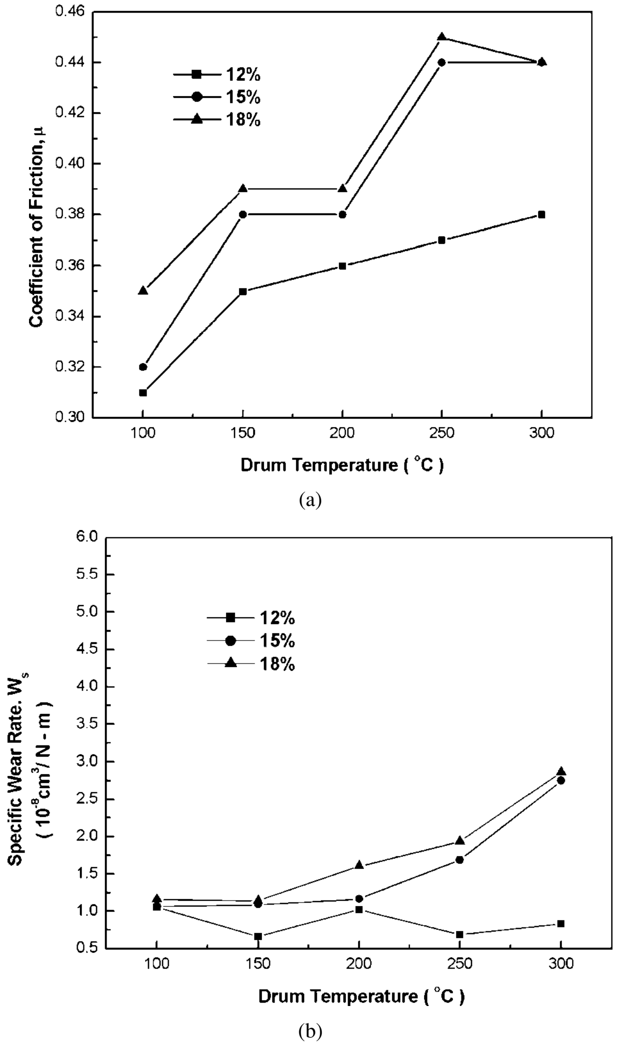
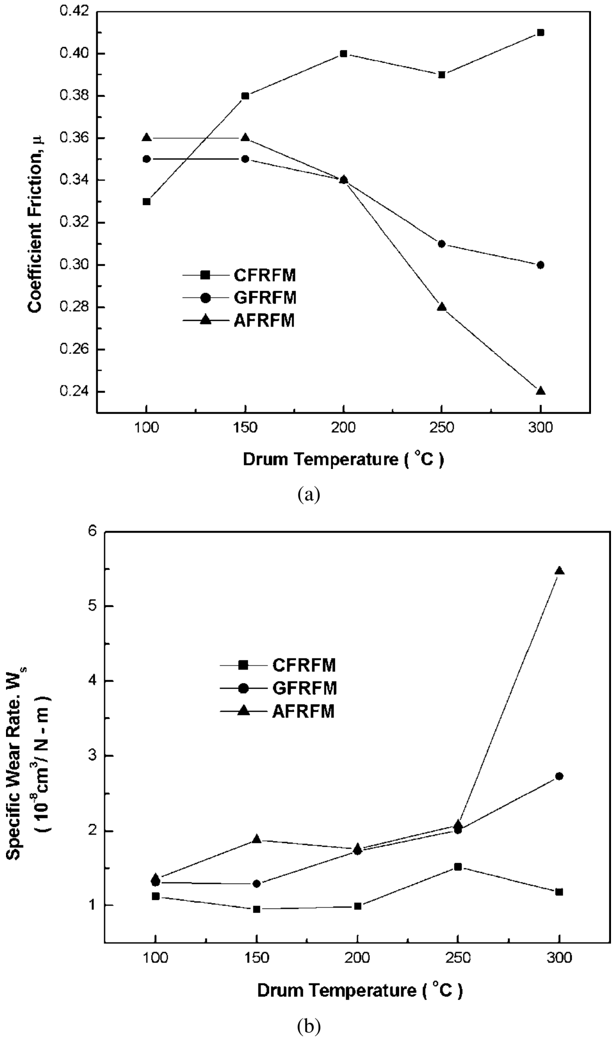


(a)

(b)

Figure 1 Effect of amount of carbon fiber on frictional coefficient and specific wear rate at 1 MPa and 7.5 ms^{-1}: (a) frictional coefficient and (b) specific wear rate.



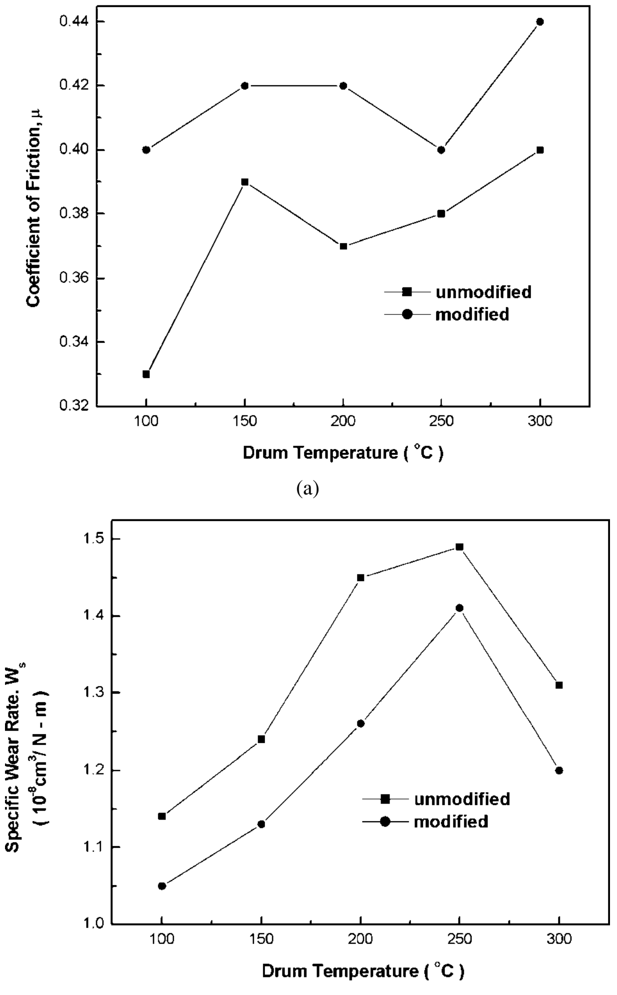
(a)

(b)

Figure 2 Effect of various reinforced fiber types on frictional coefficient and specific wear rate at P=1 MPa and V=7.5 ms^{-1}: (a) frictional coefficient and (b) specific wear rate.

increases and the specific wear rate decreases at various temperatures with increasing amount of carbon fiber, respectively. However, it is very interesting that the coefficient of friction of carbon fiber reinforced friction materials (CFRFM) with various amounts of carbon fiber increases gradually with increasing temperature, while the specific wear rate increases slightly. Carbon fiber reinforced friction materials do not appear to exhibit the fade phenomenon. This may be attributed to the better thermal stability of the binder (phenolic resin). The coefficient of friction and specific wear rates of CFRFM were compared with those of glass fiber reinforced friction material (GFRFM) and asbestos fiber reinforced friction material (AFRFM) which were fabricated using the same binder as CFRFM. The results are presented in Fig. 2a and b. The results presented in Fig. 2a reveal that GFRFM and AFRFM exhibited noticeable fade, since the frictional coefficient of GFRFM dropped slightly and the frictional coefficient of AFRFM dropped significantly with increasing testing temperature. However, the coefficient of friction of CFRFM still retains higher values, especially at higher temperatures such as 250 and 300 °C, while CFRFM provided significantly lower wear rates than GFRFM and AFRFM at various temperatures used in this investigation. The results presented in Fig. 2b were relatively unique since many previous investigations [4–9] have shown only the higher wear resistance of carbon fiber composites over glass fiber composites and asbestos fiber composites. The anti-fade phenomenon of CFRFM suggests that the carbon fiber prevents the coefficient of friction from dropping owing to its excellent mechanical and thermal properties such as high strength, high modulus and high conductivity etc. The possible reason that CFRFM possesses low coefficient of friction below 150 °C is that carbon fiber is provided with excellent self-lubricating ability at low temperature. The lubricating ability of carbon fiber, however, disappeared at high temperature [10]. Contrarily, carbon fiber acted as a friction modifier, which increased frictional coefficient of CFRFM at high temperature, while its strength value is almost the same as it is at low temperature. Actually, the friction material may undergo complicated physical or chemical changes during the wear test due to a relatively long period of sliding. Further works are still required to investigate the mechanism of anti-fade in the case of CFRFM.

The surface characteristics of carbon fiber affected the wear behavior of CFRFM. Fig. 3a and b reveal the effects of the carbon fiber modified by dipping in



(a)

(b)

Figure 3 Effect of surface modification of carbon fiber on frictional coefficient and specific wear rate at P = 1 MPa and 7.5 ms^{-1}: (a) frictional coefficient and (b) specific wear rate.

nitric acid for 48 h at room temperature and the unmodified material on the specific wear rate and frictional coefficient. The wear rate of CFRFM reinforced by modified carbon fiber was lower than that containing unmodified carbon fiber. This suggests that the surface characteristics of carbon fiber have an effect on the binding strength between carbon fiber and the binder. The unmodified carbon fiber presented inert and smooth surface, leading to reducing the binding strength between carbon fiber and the binder. In this case, the reinforced fiber tended to be pulled out from the matrix so that the excellent qualities of carbon fiber failed to be brought fully into effect. The modification makes the surface of carbon fiber surface rougher and more active, and increases the binding strength between carbon fiber and the binder. Moreover, the strength value of carbon fiber decreased slightly [11]. As a result, the wear characteristics of CFRFM reinforced by modified carbon fiber was much more improved compared to that reinforced by unmodified carbon fiber.

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