Friction and Wear Characteristics of Polymer-Matrix Friction Materials Reinforced by Brass Fibers

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This study is an investigation of friction materials reinforced by brass fibers, and the influence of the organic adhesion agent, cast-iron debris, brass fiber, and graphite powder on the friction-wear characteristics. Friction and wear testing was performed on a block-on-ring tribometer (MM200). The friction pair consisted of the friction materials and gray cast iron (HT200). The worn surface layers formed by sliding dry friction were examined using scanning electron microscopy (SEM), x-ray energy-dispersive analysis (EDX), and differential thermal analysis-thermogravimetric analysis (DTA-TAG). The experimental results showed that the friction coefficient and the wear loss of the friction materials increased with the increase of cast-iron debris, but decreased with the increase of graphite powder content. The friction coefficient and wear loss also increased slightly when the mass fraction of brass fibers was over 19%. When the mass fraction of organic adhesion agent was about 10-11%, the friction materials had excellent friction-wear performance. Surface heating from friction pyrolyzes the organic ingredient in the worn surface layer of the friction materials, with the pyrolysis depth being about 0.5 mm. The surface layers were rich in iron but poor in copper, and they were formed on the worn surface of the friction material. When the mass fraction of brass fibers was about 16-20%, the friction materials possessed better wear resistance and a copper transfer film formed on the friction surface of counterpart. Fatigue cracks were also found in the worn surface of the gray cast-iron counterpart, with fatigue wear being the prevailing wear mechanism.

1. Introduction

Friction materials reinforced by asbestos fibers are a serious pollution threat to the environment and can lead to cancer in the human population. Their friction-wear performance also has a severe "heat decay" at about 240 °C. Therefore, many efforts have been made to develop new friction materials such as polymer-matrix friction materials,[1-6] metal-matrix friction materials,[7] and carbon-carbon friction materials.[8] In this study, a polymer-matrix friction material, reinforced by brass fibers, was manufactured. This composite has many advantages, such as a stable friction coefficient, excellent wear resistance, minimal environmental pollution, and minor damage to the counterpart. The friction-wear performance of this friction material mainly depends on its composition. Frictional heat and interface stress can lead to elastic deformation, plastic deformation, element interdiffusion, and material transfer in the worn surface layer. In this research, a block-on-ring tribometer was used with a sliding dry friction pair, consisting of self-made friction material and gray cast iron HT200, to study the influence of the main components of the friction material.

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The worn surface layers were examined by scanning electron microscopy (SEM), x-ray energy dispersive analysis (EDX), and differential thermal analysis-thermogravimetric analysis (DTA-TGA).

2. Experimental

The test materials consisted of gray cast iron (HT200) and a friction material consisting of brass fibers (0.18-0.20 mm in diameter by 10 mm in length), graphite powder (20-100 mesh), an organic adhesion agent, and other fillers. All the ingredients were thoroughly mixed, pressed, and solidified in the mold at a pressure of 78.4 MPa and 180 ± 5 °C for 1 h. The wear test block samples were 14 × 10 × 10 mm. The gray cast-iron ring had a 50 mm outside diameter, a 10 mm internal diameter, and a 10 mm width. Friction-wear experiments were carried out on a block-on-ring tribometer (MM200) under dry sliding conditions. The velocity of the ring was 1.05 m/s. The friction distance was 2512 m, with the normal load on the block sample being 294 N.

3. Results and Discussion

3.1 Influence of Main Ingredients on Friction-Wear Characteristics

3.1.1 Organic Adhesion Agent. An organic adhesion agent was used to bond all the ingredients of the friction material together and to bring the potential advantages of ingredients into full play. The influence of adhesion agent content

on friction-wear performance is shown in Fig. 1. It was observed that when the content of adhesion agent is in the lower range (<11%), the friction coefficient increases. The wear loss decreases with the increase of adhesion agent in this range. When the content of adhesion agent exceeds 11%, the friction coefficient decreases and the wear loss increases. When the content of adhesion agent is about 10-11%, the friction materials have their highest coefficient of friction and their lower wear-loss values.

Because the content of the adhesion agent is too low to adhere all the ingredients sufficiently, the increase of the adhesion agent content can improve the interface adhesion state between ingredients. As such, the friction coefficient increases and wear-loss values decrease. The organic adhesion agent is very sensitive to heat; the results of DTA-TGA showed that it pyrolyzes at 420 °C. Pyrolyzed organic adhesion agent is observed in the worn surface layer, with the pyrolysis depth about 0.5 mm. Pyrolysis of the adhesion agent not only decreases the bond strength between ingredients, but also prod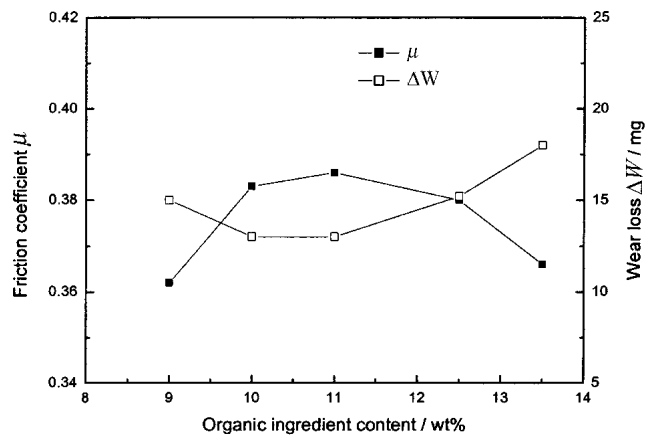uces a "tarlike" substance plus CO, CO_2, H_2, and CH_4. The tarlike substance can lubricate the interface with the evolved gases, forming a gas cushion.[9] Therefore, with the increase of adhesion agent, these processes increase, causing the friction coefficient to decrease and the wear-loss values to increase.

3.1.2 Cast-Iron Debris. Cast-iron debris is a friction agent. Figure 2 shows that the friction coefficient and the wear loss increase with an increase in the cast-iron debris content. Wear theory suggests that if friction pair materials are similar to each other, adhesive wear can occur. In this experiment, cast-iron debris in the friction material and HT200 gray cast-iron counterpart easily form adhesive junctions. Figure 3 indicates that the main composition of wear dust is iron oxide; this finding further suggests that the cast-iron debris is an important cause of accelerated wear.

3.1.3 Graphite Powder. Graphite is an anisotropic layered structure, possesses high compression strength and low shear strength, and has a friction coefficient of about 0.05-0.19.[10] Graphite is the ingredient used to reduce friction in a friction material. Figure 4 shows that the friction coefficient and the wear loss decrease with an increase in the content of the
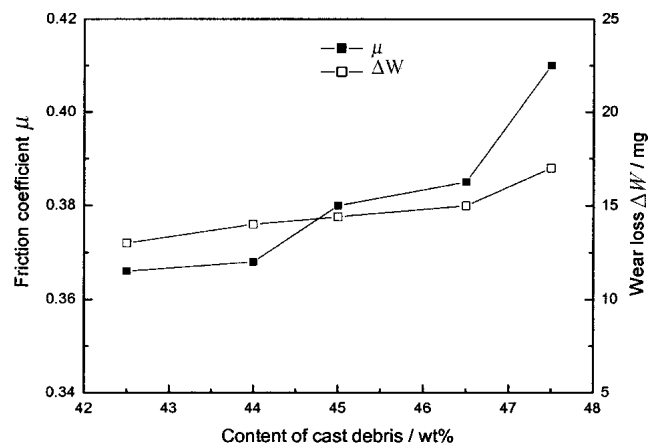

Fig. 1 Relationship between friction-wear performance and organic ingredient content

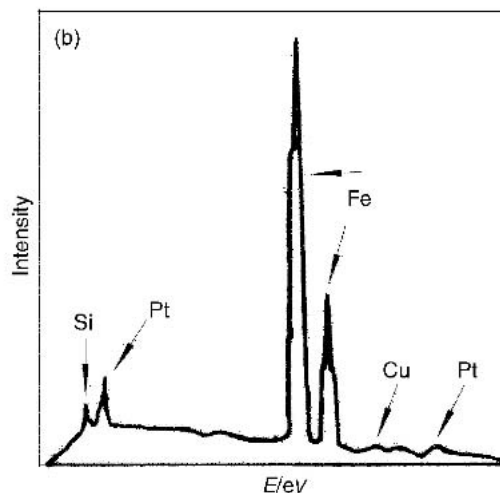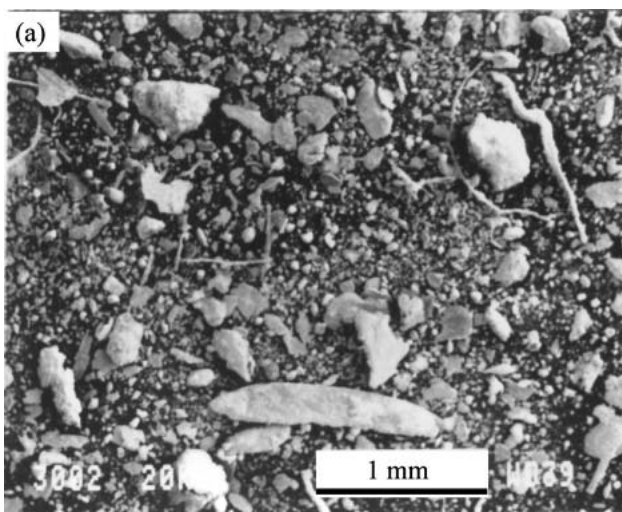**Fig. 2** Relationship between friction-wear performance and cast-iron content

Fig. 3 Main ingredients of wear dust: **(a)** wear dust, **(b)** EDX analysis of wear dust

graphite powder in the composite. During dry sliding, the graphite in the worn surface layer can be extruded into interface as a lubricant. Therefore, the friction coefficient and the wear loss decrease with the increasing content of graphite powder.
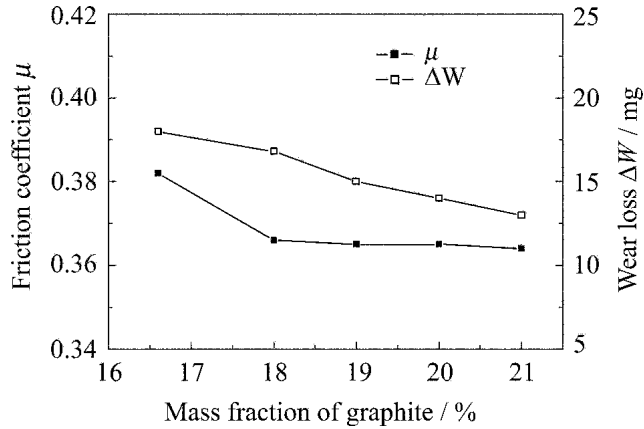

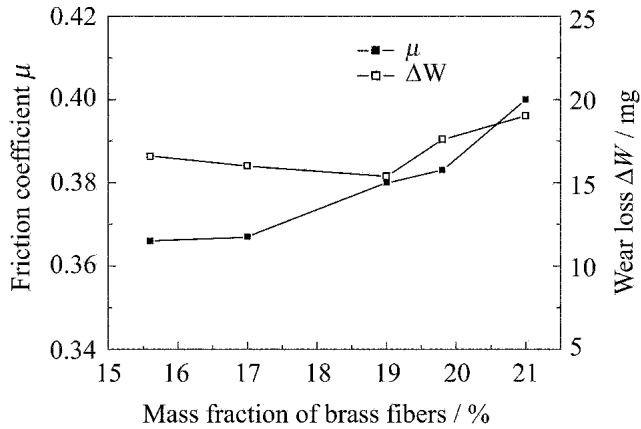**Fig. 4** Relationship between friction-wear performance and graphite content

Fig. 5 Relationship between friction-wear performance and brass fiber content

3.1.4 Brass Fibers. The brass fiber in the friction material is a structured reinforcement. Its influence on the friction-wear performance is shown in Fig. 5. When the mass fraction of brass fiber is below about 19%, the friction coefficient changes little. However, when the mass fraction of brass fiber is above 19% the friction coefficient increases.

Brass fibers have good plasticity, and during friction copper (Cu) transfer onto the friction surface of the counterpart can occur, leading to the formation of a Cu transfer film by the combined actions of frictional heating and interface stress (Fig. 6). The Cu transfer film can decrease the adhesion wear between cast-iron debris and cast-iron counterpart, leading to a stable friction coefficient and lower wear. However, when the mass fraction of brass fibers is over 19%, the distribution of brass fibers in the friction material is more inhomogeneous and dry sliding causes the brass fibers to debond from the surface (Fig. 7). The debonded brass fibers stay in friction interface and cause further damage, increasing both the friction coefficient and wear loss.
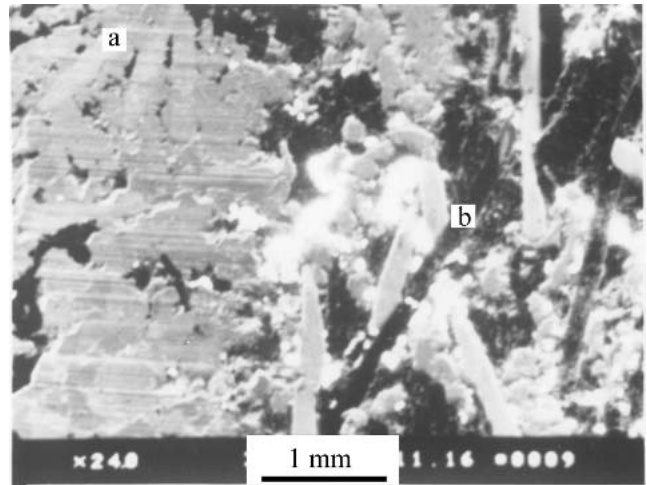

Fig. 7 Worn surface of friction material (SEM) (mass fraction of brass fiber is 21%). **(a)** Cluster of brass fibers and **(b)** mark of brass fibers falling off
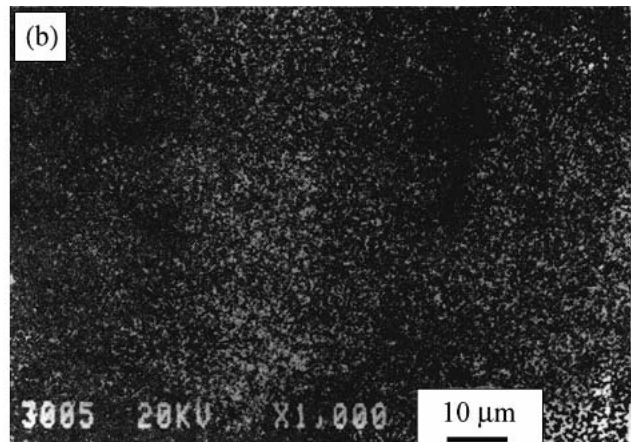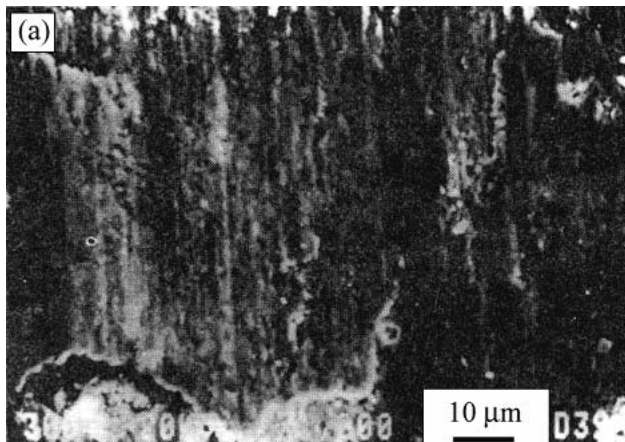

Fig. 6 **(a)** Worn surface morphology of gray cast iron (SEM) and **(b)** distribution of Cu on the worn surface (EDX)

3.1.5 Worn Surface Layers. The worn surfaces were analyzed by EDX. The results showed that the iron (Fe) content of the worn surface is about 75%, which is higher than the original content of Fe. The Cu content of the worn surface is about 9%, which is lower than the original content of brass fibers.
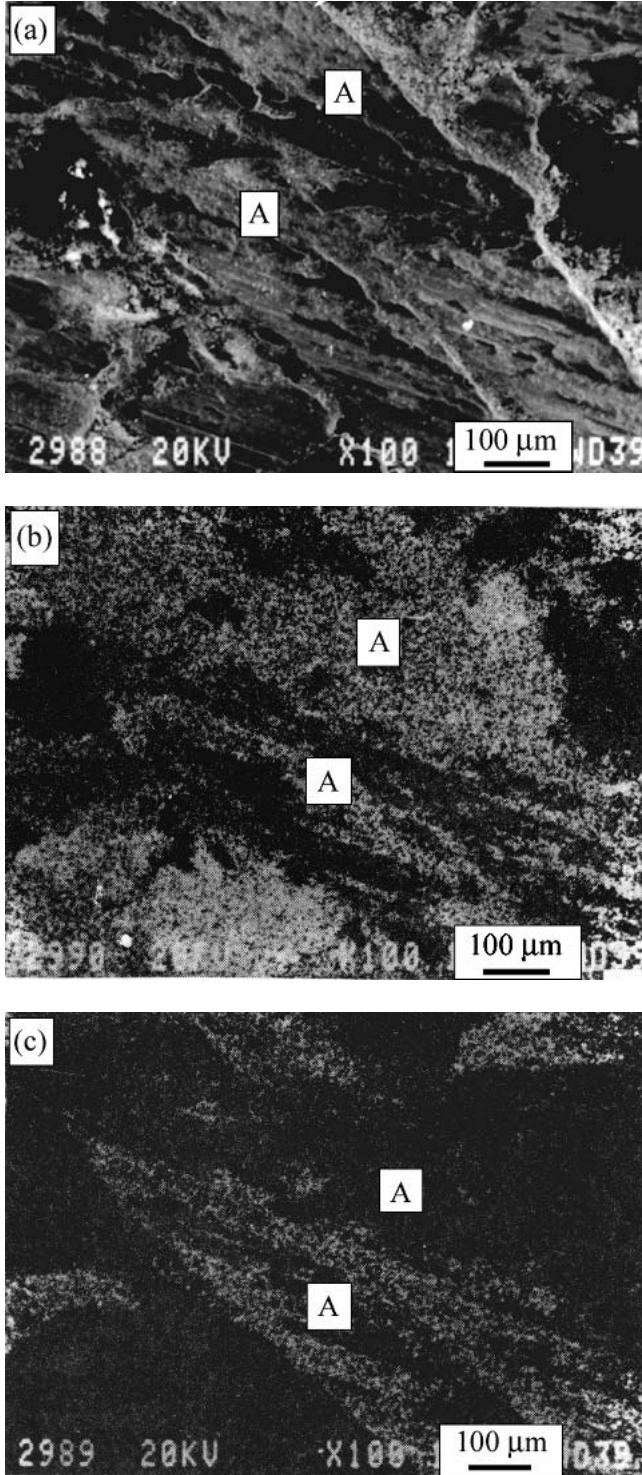
These results suggest that the surface layer, which is Fe-rich and Cu-poor, forms on the worn surface of the friction material, as shown in Fig. 8. From Fig. 8, it can be seen that Fe is found on the brass fibers. The particles of Fe and Fe oxide in the wear debris have higher hardness, and the particles can be embedded

Fig. 8 **(a)** Morphology of the worn surface of the friction material (SEM), **(b)** distributions of Fe (EDX), and **(c)** distribution of Cu (EDX). A, Brass fiber
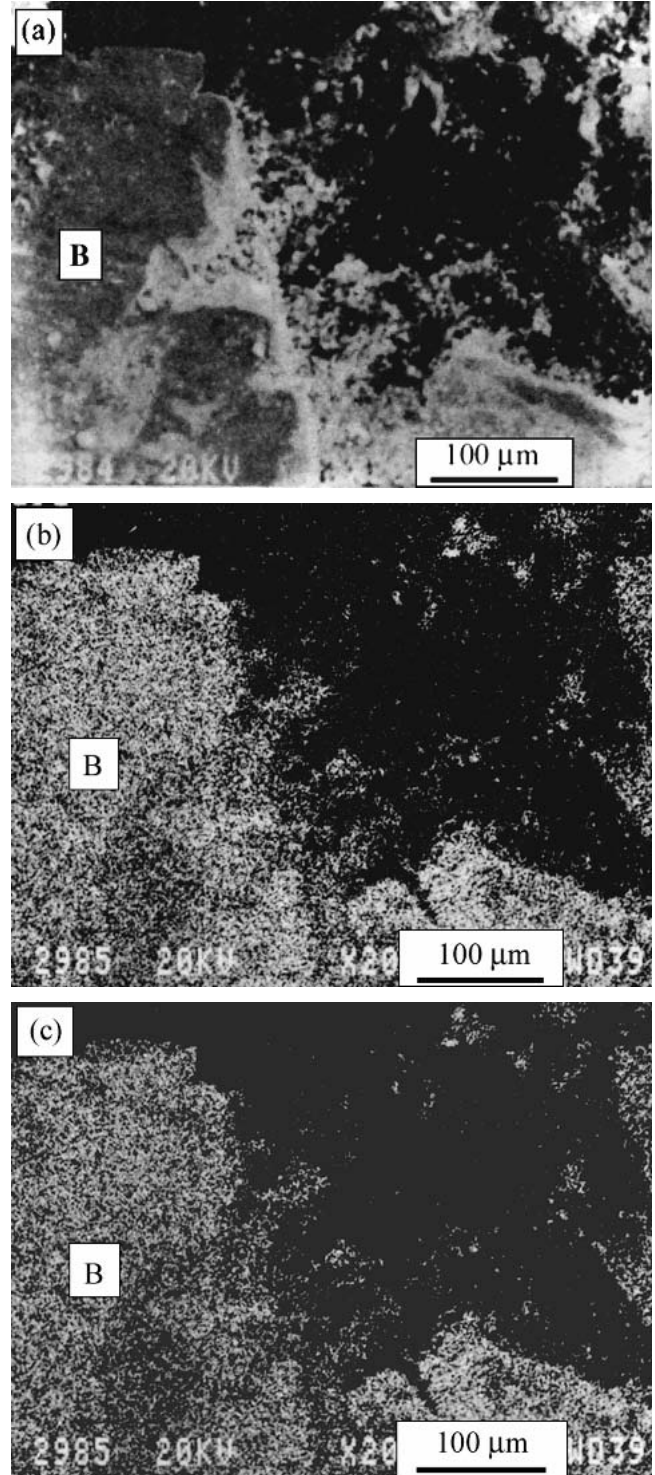
Fig. 9 **(a)** Morphology of the worn surface of the friction material (SEM), **(b)** distribution of Fe (EDX), and **(c)** distribution of Cu (EDX). B, Iron particle
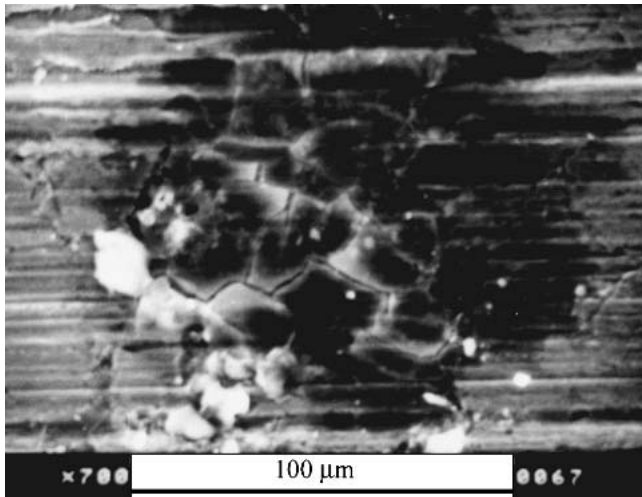
Fig. 10 Worn surface morphology of gray cast iron counterpart

in the surface of the brass fibers with lower hardness by the dry sliding action at the interface. On the other hand, microparticles of Fe oxide can be reduced into pure Fe by H_2 and CO_2 resulting from the pyrolysis of the organic ingredient. These particles of pure Fe have a high activity and easily stick onto the friction interface.[11] The prior analysis is main cause in formation of an Fe-rich and Cu-poor layer.

Figure 9 shows that there exists a certain amount of Cu on the cast-iron debris. This finding indicates that the Cu transfers onto the cast-iron ingredient, and that the amount is more extensive on the surface of the friction material after wear. These layers are produced by the transfer and smearing of Cu from counterpart to the friction materials.

Figure 10 shows the worn appearance of the counterpart. There exists some fatigue cracks on the worn surface, an indication that the prevailing wear mechanism of the counterpart is fatigue breakage.

4. Conclusions

Owing to the action of frictional heating, the pyrolysis of the organic adhesion agent takes place in the worn surface layer at 420 °C. The pyrolysis depth on the worn surface is about 0.5 mm. When the content of organic adhesion agent is about 10-11%, the friction material has a higher friction coefficient and lower wear loss value.

The friction coefficient and the wear loss increase with an increase in cast-iron wear debris in the friction material. The cast-iron wear debris is the main cause of increased wear.

The friction coefficient and the wear loss decrease with an increase in graphite powder in the friction material. The graphite powders on the worn surface layer can be extruded, thereby lubricating the friction interface.

On the worn surface of the friction material, an Fe-rich, Cu-poor layer forms, and the distribution of Cu is more extensive after wear than before. Copper can transfer onto the worn surface of the counterpart, forming a Cu transfer film that can improve the contact state of the friction interface. This makes the friction coefficient more stable and decreases wear.

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