Wear Mechanism of Copper-based Powder Metallurgical Friction Materials with Different Graphite Content

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Abstract. Copper-based friction materials with different graphite contents were prepared by powder metallurgy process. The influence of graphite content on the surface hardness of friction materials was studied by Bush hardness tester. By means of scanning electron microscope (SEM) and energy dispersive spectrometer (EDS), the wear morphology and composition of friction materials were studied, and the wear mechanism was analyzed. The results show that the graphite content has little effect on the surface hardness of friction materials, and the surface hardness mainly depends on the copper matrix and its alloy elements. The main wear mechanism of copper based friction materials is plough type abrasive wear. Graphite has good lubricity and can reduce the wear.

1. Introduction
Copper has good thermal conductivity and the temperature of the friction surface rises slowly, it is not easy to adhere to the couple material, prolongs the service life of the friction pair, and has good corrosion resistance compared to iron-based powder metallurgical friction materials. Therefore, copper-based powder metallurgical friction materials are widely used in the field of friction braking. However, the copper-based powder metallurgical friction plate also has the problems of low heat resistance and wear resistance under heavy load conditions. Therefore, the composition of copper-based powder metallurgical friction materials needs to be further optimized. Graphite is one of the important lubricants in powder metallurgical friction materials. Its special crystal layered structure, the crystal planes can easily slide with each other without being destroyed [1-6]. As a solid lubricant, it can improve the friction of friction materials Wear performance. At present, the wear mechanism of copper-based friction materials mainly includes abrasive wear and adhesive wear [7-9]. Abrasive wear is the loss or material loss caused by the hard particles or the hard micro-convex body on the surface of the friction pair to squeeze and move along the surface. It is a common type of wear [10]; adhesive wear is the contact of the friction pair during friction Local metal adhesion occurs on the surface. In the subsequent relative sliding, because the adhesion is destroyed, metal particles are pulled down from the part surface or the part surface is abraded. However, different graphite contents have different effects on the wear mechanism of friction materials. This article systematically studies the effect of graphite content on the wear mechanism of copper-based powder metallurgical friction materials.
2. Experimental Methods

2.1. Materials
The powder metallurgy sintering process was used to prepare 4 kinds of friction materials with different graphite contents. The material distribution ratios are shown in Table 1. The sample is a double-sided metallurgical layer as shown in Figure 1. The friction layer is Ф145 × Ф120 × 0.5 mm. The groove type is a spiral groove with 4 radial grooves (uniformly distributed), a pitch of 3 mm, a groove width of 1 mm, and a radial groove width of 3 mm. The preparation process is mainly composed of pressing, sintering and machining.

| Table 1. Sample number and formula. (% by mass) |
|-----------------------------------------------|
| Numbering | composition | Cu | alloy element | SiO₂ | graphite |
| A1        | margin      | 16 | 2–6           |     | 10       |
| A2        | margin      | 16 | 2–6           |     | 12       |
| A3        | margin      | 16 | 2–6           |     | 16       |
| A4        | margin      | 16 | 2–6           |     | 20       |

Figure 1. Structural diagram of copper-based powder metallurgy friction plate and technical requirements of test piece.

2.2. Test
Friction and wear tests were carried out on friction and wear testing machine. Bush hardness tester is used to measure the surface hardness of friction materials, and the diameter of the ball is Ф 2.5mm, and the pressure is 62.5kgf (612.9N). The surface morphology and composition of the friction materials were analyzed by SEM and EDS.

3. Results and Analysis

3.1. Component Analysis
The energy spectrum analysis of the A4 sample is shown in Figure 2. In the figure, the black A area is element carbon, which is the graphite of lubricating component. The bright gray area B is copper and alloy elements, which are copper matrix. The dark gray C area is silicon and oxygen, and it is the friction component SiO₂.
3.2. Analysis of Hardness
The hardness values of the four friction materials are shown in Table 2. It can be seen that the surface hardness of these materials is relatively close, and there is no obvious difference, indicating that the graphite content has little influence on the surface hardness of the friction materials. This is because the composition of copper base is the same, so the hardness difference is small. The hardness of friction material mainly depends on the hardness of copper matrix.

Figure 2. Energy spectrum analysis of friction components: (a) Microstructure; (b) A-point energy spectrum; (c) B-point energy spectrum; (d) C-point energy spectrum.
### Table 2. Surface hardness of friction materials.

| Sample number | A1  | A2  | A3  | A4  |
|---------------|-----|-----|-----|-----|
| Hardness value /HBS | 69.35 | 69.50 | 70.55 | 69.60 |

3.3. Analysis of Wear Mechanism

The friction surface morphology of the material is shown in Figure 3. It can be seen that there are scratches and furrows along the friction sliding direction on the friction surfaces of the four kinds of friction materials, and the main wear mechanism is furrow abrasive wear. The number and depth of furrows on the friction surface vary with the graphite content. With the increase of graphite content, the furrow on the friction surface becomes shallower. This is because graphite will form a layer of graphite film on the friction surface in the process of friction, which can play a role of lubrication and reduce the wear.

![Figure 3](image)

**Figure 3.** Surface morphology of friction material: (a) A1; (b) A2; (c) A3; (d) A4.

The surface morphology of A3 friction material after heat-resistant test is shown in Figure 4. It can be seen that copper matrix and graphite are rolled and applied on the friction surface under high temperature, and there is no obvious interface between graphite and copper matrix. There are a lot of pitting pits on the surface of copper matrix under high temperature, which show the characteristics of adhesive damage and ablation.
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5. Conclusions
(1) With the increase of graphite content in copper based friction materials, there is no obvious change in the surface hardness of friction materials, which shows that the change of graphite content has little effect on the hardness of friction materials. The surface hardness mainly depends on the copper based matrix and its alloy elements.

(2) The main wear mechanism of copper based friction materials is plough type abrasive wear. With the increase of graphite content, the plough on the friction surface will gradually become shallow, which shows that graphite has good lubricity and can play a role in reducing wear.

6. References
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