Effect of Oil Groove Depth on Friction Performance of Copper based Friction Materials with Different Graphite Content

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Abstract. Copper-based friction materials with different oil groove depth and graphite content were prepared by powder metallurgy process. The effect of oil groove depth on the friction performance of copper based friction materials with different graphite content at different linear velocities was studied. The results show that the dynamic friction coefficient of material decreases with the increase of oil groove depth at low linear velocity of 16.5m/s, and increases with the increase of oil groove depth when linear velocity is ≥ 20m/s. With the increase of oil groove depth and graphite content, the heat resistance of the friction material increases and the wear rate decreases.

1. Introduction
The copper-based powder metallurgy friction material has a suitable and stable friction factor and high wear resistance. However, when the friction temperature is too high, the friction factor will decay and the wear rate will increase, thus limiting its application range[1-4]. The surface of copper-based powder metallurgy friction plates used in machinery is mostly open with various types of oil grooves. The type, depth, spacing and direction of the oil groove have important effects on the friction and wear performance and heat resistance of the friction plates[5-12]. After research, Yapeng Z and others[13] compared and analyzed the effect of different oil groove spacing on the friction plate under the same working conditions, and found that with the increase of the oil groove spacing, the maximum surface temperature of the friction plate decreased and the maximum stress value of the friction plate decreased. Reduce fever and extend service life. Jiasen C[14] found that under the same working conditions, the maximum temperature of the oil film of the trapezoidal oil groove is lower than that of other oil groove cross-sectional shapes. The cooling effect is slightly better than the radial groove. At present, domestic and foreign scholars have conducted many studies on the influence of oil groove structure parameters on friction performance, but there are few studies on the influence of oil groove depth on friction performance of friction plates. This paper focuses on the effect of oil groove depth on the friction performance of copper-based friction materials with different graphite contents.
2. Sample preparation
Six kinds of copper-based friction materials with different oil groove depth and graphite content were prepared by powder metallurgy autoclaving process. The main composition ratio, oil groove depth and sample number of the six kinds of friction materials are shown in Table 1. The graphite content of the friction material is 14%, 18% and 22% by mass. The groove shape of the friction surface of the sample is a spiral groove (evenly distributed), its pitch is 2.5 mm, the groove width is 1.0 mm, and the depth of the oil groove is 0.1 mm and 0.3 mm, respectively.

Sample size: outer diameter Ф146mm, inner diameter Ф121mm.

| Numbering | Composition | Oil groove depths /mm |
|-----------|-------------|-----------------------|
|           | Cu | Alloy element | SiO₂ | Graphite | |
| A1-0.1    | margin | 16 | 3 | 14 | 0.1 |
| A3-0.1    | margin | 16 | 3 | 18 | 0.1 |
| A5-0.1    | margin | 16 | 3 | 22 | 0.1 |
| A1-0.3    | margin | 16 | 3 | 14 | 0.3 |
| A3-0.3    | margin | 16 | 3 | 18 | 0.3 |
| A5-0.3    | margin | 16 | 3 | 22 | 0.3 |

3. Experiment method
The SAE NO.2 testing machine (model M1080) produced by the US Greening Company was used to test the friction and wear resistance and heat resistance of the samples. First of all, 200 times of running-in were completed under the conditions of pressure 2 MPa, speed of 1000 r/min, and inertia of 0.2485 kgm²; then the friction and wear test was carried out according to the parameters shown in Table 2, and 2000 joints were carried out under stable conditions. The volume wear rate is calculated by measuring the thickness of the friction plate before and after wear.

Under the condition of 1 MPa pressure, the dynamic friction coefficient of the test specimen when the linear velocity is increased from 20m/s to 30m/s. Under the condition of pressure 2.0 MPa, the speed is gradually increased from 2370r/min. For every 300r/min increase, 20 joints are performed until the friction pair fails; the energy load permitting value of the friction material can be calculated by the braking time and braking energy of a working condition before the friction pair fails.

| Parameter | Parameter value |
|-----------|----------------|
| linear velocity / (m·s⁻¹) | 16.5 |
| pressure / MPa | 2 |
| Oil temperature / °C | 75–80 |
| Inertia / (kg·m²) | 0.376 |
| Number of engagements | 2000 |
| Oil flow / (mL·min⁻¹·cm⁻²) | 0.37 |

4. Results and analysis

4.1. Coefficient of friction
Under the conditions of low speed and high surface pressure (linear velocity of 16.5m/s, surface pressure of 2MPa), the variation curve of dynamic friction coefficient with joint times is shown in Figure 1. It can be seen that with the increase of joint times, the dynamic friction coefficients of samples with different oil groove depths increase with the increase of the number of joints, and the change law is consistent, indicating that the depth of the oil groove has no differential effect on the dynamic friction coefficient of the friction material with the number of joints. Comparing the dynamic
friction coefficients of samples with different oil groove depths, the dynamic friction coefficients of samples with oil groove depth of 0.1 mm are all greater than those with oil groove depth of 0.3 mm. This is because, at low speeds (linear velocity of 16.5 m/s), friction generates less heat and the material properties of friction materials are more stable; the depth of the oil groove is increased, and the storage conditions of the lubricating oil on the surface of the sample are good. The lubrication effect of the friction surface is better than that of the sample with a shallow depth of the oil groove, so the coefficient of friction is low. As the graphite content increases, the dynamic friction coefficient curves of samples with different oil groove depths change uniformly, indicating that under low speed conditions, fluid lubrication is the main factor affecting the dynamic friction coefficient.

![Graphs showing dynamic friction coefficient with joint times at linear velocity 16.5 m/s](image)

Figure 1. Variation curve of dynamic friction coefficient with joint times at linear velocity 16.5 m/s

Under the condition of high speed and low surface pressure with line speed ≥20 m/s and face pressure of 1 MPa, the variation curve of dynamic friction coefficient with joint times is shown in Figure 2. It can be seen that the changing trends of the samples with different oil groove depths are consistent, and they all decrease with the increase of the linear velocity. This is because with the increase of the linear velocity, the heat of friction increases, and the material performance decreases due to the increase of temperature, which leads to the decrease of the dynamic friction coefficient. Therefore, the linear velocity has a greater influence on the friction coefficient of the friction material.

Comparing the dynamic friction coefficients of samples with different oil groove depths, the dynamic friction coefficient of samples with oil groove depth of 0.3 mm is greater than that of oil grooves with depth of 0.1 mm. This is because under the condition of high linear velocity, friction heat generation is the main factor affecting the dynamic friction coefficient. With the increase of the depth of the oil groove, the flow of lubricating oil during friction increases, the cooling effect increases, and the performance of friction materials decreases. Therefore, at the same linear velocity, the dynamic friction coefficient of the deep oil groove sample is higher than that of the shallow oil groove sample.
4.2. Wear rate

The friction and wear rates of the samples are shown in Table 3. It can be seen that the influence of the oil groove depth and graphite content on the wear rate of the sample is the same. With the increase of the oil groove depth and graphite content, the wear rate of the sample decreases. It shows that increasing the depth of the oil groove can improve the lubrication state of the friction surface and reduce the wear rate of the friction material.

Table 3 Wear rate of samples

| Sample number | A1-0.1 | A1-0.3 | A3-0.1 | A3-0.3 | A5-0.1 | A5-0.3 |
|---------------|--------|--------|--------|--------|--------|--------|
| Wear rate / (cm²·J⁻¹) | 3.6    | 3.0    | 2.84   | 2.38   | 1.5    | 1.3    |

4.3. Energy load permitting value

The allowable energy load values of samples with different oil groove depths are shown in Figure 3. It can be seen that the allowable value of the energy load of samples with different graphite content increases with the increase of the depth of the oil groove. This is due to the increase in the depth of the oil groove and the increase in the flow of lubricating oil on the friction surface, which improves the cooling effect of the friction surface, thereby improving the heat resistance of the friction material.
5. Conclusion
(1) The dynamic friction coefficient of material decreases with the increase of oil groove depth at low linear velocity of 16.5m/s, and increases with the increase of oil groove depth when linear velocity is ≥ 20m / s.
(2) With the increase of oil groove depth and graphite content, the wear rate of friction materials decreases.
(3) With the increase of oil groove depth, the heat resistance of copper based friction materials increases.

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