Simulation Study on the Temperature Field of Iron-based Powder Metallurgy Friction Pair

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Abstract. For the iron-based powder metallurgical friction pair under high-speed braking conditions, the structural model and physical model of the friction pair were established, and the finite element software ABAQUS was used to calculate and analyze the temperature field and distribution law of the friction pair during friction braking. The results show that during friction braking, the temperature at the outer diameter of the contact surface of the friction pair is the highest, and the temperature at the inner diameter of the edge of the chip removal tank is the lowest. During braking, the temperature of friction pair increases first and then decreases with time.

1. Introduction

Friction materials are widely used in vehicles, aerospace, large equipment and other brake equipments, and the stability of their performance is the key to affect their service life. Friction heat will be generated on the contact surface of the friction pair during the friction process. Due to untimely heat dissipation and poor heat dissipation, heat accumulation will occur on the surface of the friction material, which affects the stability of performance [1-3]. The trend of using finite elements to study the temperature distribution of materials has gradually increased, and researchers at home and abroad have become more mature in their research. Dai Xinliang [4] studied the distribution rule of brake disc temperature and thermal stress during braking of ULF light rail train through ABAQUS, and Liu Hailing [5] analyzed the service life of brake disc by studying the temperature field distribution of wind turbine disc brake. During the friction process, due to the friction ring and its dual contact with each other, friction heat is generated on the friction contact surface, causing thermal deformation and thermal damage, which affects the safety of material use. Based on the research of the friction pair temperature field under high energy capacity braking conditions, a calculation model of the temperature field of friction pair was established by ABAQUS finite element software in this paper, and the temperature distribution law of the contact surface and the internal material of powder metallurgy friction pair during the braking process was studied.
2. Friction pairs and working conditions

2.1. Physical model building
The iron-based powder metallurgical friction pair is composed of a friction ring and its couple. Under the action of friction, the speed of the friction ring decreases until it stops, and the dual is fixed. In order to facilitate the analysis, the structure of the friction pair is simplified, and the simplified structure model is shown in Figure 1. Among them, the friction ring is composed of two parts, the upper layer is an iron-based powder metallurgy layer, marked as a powder metallurgy layer-friction ring, and the lower layer is a steel matrix with 65Mn material. The dual parts are divided into two parts, the upper layer is a powder metallurgy layer-dual, the lower layer is a steel core plate, and the material is 65Mn. The outer diameter of the friction ring is Φ72 mm, the inner diameter is Φ56 mm, the thickness of the core plate is 12 mm, the thickness of the powder metallurgy layer is 3 mm, the surface is uniformly distributed with 3 chip flutes, the depth of the chip flutes is 1 mm, and the width is 3 mm. The dual part is also composed of two parts, the upper layer is an iron-based powder metallurgy layer, the composition is different from the friction ring, marked as powder metallurgy layer-dual part, and the lower layer is a steel core plate. The outer diameter of the dual piece is Φ72 mm, the inner diameter is Φ56 mm, the thickness of the core plate is 12 mm, and the thickness of the powder metallurgy layer is 3 mm.

![Figure 1. Structure model of friction pairs.](image)

2.2. Thermophysical parameters
The basic performance parameters and thermophysical performance parameters of friction pairs materials are shown in Table 1.

| Friction pair          | Density (kg/cm³) | Thermal conductivity (W/(m•K)) | Specific heat (J/(kg•℃)) | Thermal expansion coefficient(10⁻⁶/K) | Elastic Modulus (GPa) | Poisson’s ratio |
|------------------------|------------------|-------------------------------|---------------------------|-------------------------------------|-----------------------|----------------|
| 65Mn                   | 7.8              | 46                            | 487                       | 11.8                                | 160                   | 0.29           |
| Powder metallurgy layer| 6.5              | 10                            | 410                       | 12                                  | 120                   | 0.3            |
| Dual material          | 7.78             | 42                            | 471.5                     | 11.69                               | 140                   | 0.3            |

2.3. Working conditions
The actual working conditions during the friction process are shown in Table 2.

| Initial temperature /°C | Rotating speed /rpm | Pressure /MPa | Moment of inertia/Kg·m² | Coefficient of dynamic friction | Braking time /s |
|-------------------------|---------------------|---------------|--------------------------|--------------------------------|-----------------|
| 60                      | 8800                | 0.8           | 0.045                    | 0.33                           | 0.3             |
3. Finite element model

3.1. Conditional assumption
The temperature distribution of the friction pair is more complicated during the friction process, and the following assumptions are made to facilitate the solution:

- The material composition in the friction layer is evenly distributed;
- During the braking process, all the heat energy is converted into kinetic energy, and the heat flux density at each point on the friction contact surface of the friction metal powder layer is averaged;
- The friction ring powder metallurgy layer and the surface of the dual powder metallurgy layer can be completely in contact;
- Due to the short movement time, the temperature rise of the material is limited, and the influence of thermal radiation is ignored.

3.2. Finite element model
In this paper, the finite element software ABAQUS is used to establish the material model. The heat conduction analysis step is selected, and the 8-node hexahedron is used as the mesh element to divide the model. The element size of the powder metallurgy layer is 1mm, and the element size of the steel core plate is 5mm.

4. Heat conduction and boundary conditions

4.1. Heat generation equation
The braking process of the friction pair is uniform deceleration, and all kinetic energy is converted into heat energy. As the braking time increases, the heat generated at the friction contact surface is transferred to the interior of the material. The heat flux density of the friction contact surface is calculated by equation (1) [6, 7].

\[ q(t) = \eta_1 \eta_2 m \frac{dv(t)}{dt} \frac{dS}{S} \]  

In the formula, \( q(t) \) is the heat flux density, and the unit is W/m². \( M \) is the braking mass. \( V_0 \) is the initial velocity of the friction ring, which is 28.45m/s. \( V(t) \) is the linear velocity of the friction ring. \( S \) is the area of the friction contact surface after removing the chip flute surface, and the unit is m². \( \eta_1 \) is the conversion rate of kinetic energy into heat energy, taking the value 1. \( \eta_2 \) is the heat flow distribution coefficient, which is calculated.

4.2. Heat distribution
The heat distribution coefficient is calculated by equation (2) [7, 8].

\[ K = \frac{q_f}{q_d} = \frac{\rho_f c_p \lambda_f}{\rho_d c_p \lambda_d} \]  

In the formula, \( K \) - heat distribution coefficient. \( q_f \) - The heat flux density distributed to the contact surface of the powder metallurgy layer-friction ring. \( q_d \) - The heat flux density distributed to the contact surface of the couple. \( \rho \) - density, \( \lambda \) - thermal conductivity, \( C \) - specific heat capacity. According to Table 1 and Equation 2, the heat generated by frictional heat generation is 30% allocated to the surface of the powder metallurgy layer of the friction ring, and 70% is allocated to the friction surface of the powder metallurgy layer of the counterpart.

The relationship between the friction distribution coefficient \( K \) and the distribution coefficient \( \eta_2 \) distributed on the friction surface of the friction ring powder metallurgy layer is shown in equation (3).

\[ \eta_2 = \frac{K}{1+K} \]
4.3. Thermal boundary condition

During the friction movement, the ambient temperature is 25℃, and the initial temperature of the friction pair is 60℃. Heat convection occurs when the inner diameter surface contacts the air, which can be assumed to be the heat exchange caused by air crossing the cylinder, and the convection heat transfer coefficient is obtained from Equation (4) [7].

\[
h = \frac{\lambda_g}{1} \left( \frac{V_{in}}{\nu} \right)^n (Pr)^{1/3}
\]

(4)

In the formula, \( \lambda_g \) - air thermal conductivity, and the value is 2.59*10^{-2} W/(m·K), \( V_{in} \) - inner ring linear velocity, \( \nu \) - air kinematic viscosity, and its value is 14.8·10^{-6} m^2·s^{-1}, \( Pr \) - Prandt constant, and the value is 0.7, \( a, n \) are constants, a value is 0.193, \( n \) value is 0.618[9]. It can be calculated by formula (5)

\[
h = 12.8879 \left( 24.89 - 6.89t \right)^{0.618}
\]

(5)

The internal plane of the chip removal tank contacts with the air, and heat exchange occurs. The convective heat transfer coefficient can be calculated by formula (6) [10].

\[
h = 0.664Re_m^{1/2}Pr^{1/3}
\]

(6)

In the formula, \( Re_m \) - Reynolds number, \( Re_m=\mu L/\nu \), \( \mu \) - speed of air movement around the friction ring, \( L \) - characteristic length.

5. Results and analysis

The temperature field cloud diagram of the friction surface and the bottom of the powder metallurgy layer of the friction ring of the brake friction pair is shown in Figure 2. It can be seen from Figure 2 (a) that the temperature of friction surface increases gradually from inside to outside along the radial direction. The temperature at the outer diameter is the highest, and the highest temperature is 374.23℃. The temperature near the chip removal groove on the friction surface is relatively low, among which the temperature at the outer diameter of the edge of the chip removal groove is the lowest, and the lowest temperature is 290.09℃. Along the axial thickness direction, the temperature decreases from the friction surface to the symmetric surface of the powder metallurgy layer. It can be seen from Figure (b) that the temperature at the bottom of the friction ring is the lowest, with the lowest temperature of 155.49℃, while the temperature at other positions ranges from 183℃ to 220℃.

Figure 3 is the position diagram of the 4 nodes taken on the friction pair, and the temperature-time curves A, B, C, D the nodes are done respectively, as shown in Figure 4. It can be seen from the figure that as the braking time increases, the temperature first increases and then decreases. When the inner diameter of the slot edge of the contact surface is at a braking time of 1.44s, the temperature reaches the maximum value of 536.83℃. When the braking time of the inner and outer diameters of the contact surface is at 1.44s, the maximum temperature is 610.53℃ and 617.09℃, respectively. The time to reach the maximum temperature in the card slot increases, and the temperature is 210.32 ℃ when the braking time is 3.25s. This is because the effect of the heat generation rate in the early stage is greater than the heat dissipation rate and the temperature rises rapidly, while the effect of the heat generation rate in the later stage is less than the heat dissipation rate and the temperature begins to decline. The delay in reaching the maximum temperature in the card slot and the lower temperature may be because the heat transfer takes some time and part of the heat is consumed.

Figure 2. Powder metallurgy layer-friction ring temperature field cloud chart: (a) friction surface, (b) friction ring bottom
The temperature field cloud diagram of the friction surface and bottom of the dual part of the brake friction pair is shown in Figure 5. It can be seen from Figure 5 (a) that the temperature at the inner diameter of the friction surface is low and the lowest temperature is 451.50°C. The temperature increases slightly from the inside to the outside along the radial direction, and the temperature at the outer diameter is the highest, which is 453.59°C. The temperature decreases from the friction direction to the steel core plate along the axial direction. It can be seen from Fig. 5 (b) that the temperature distribution of the symmetrical surface is consistent with that of the friction contact surface, and the overall temperature is maintained between 400.0°C and 412.90°C.

Take the temperature of one point on the inner diameter and outer diameter of the friction contact surface respectively, and make the temperature-time curve, as shown in Figure 6. It can be seen from Fig.6 that the temperature change trend is consistent with the change trend of the nodes on the powder metallurgy layer-friction ring. As the braking time increases, the temperature first increases and then decreases. The inner diameter is the highest when the braking time is 1.8s, which is 591.29°C, and the outer diameter is the maximum when the braking time is 1.8s, and the highest temperature is 594.43°C. The delay in the time for the powder metallurgy layer-dual member to reach the maximum temperature may be due to the larger thermal conductivity coefficient at the powder metallurgy layer-dual member, and the longer maintenance time of the previous heat production rate than the heat dissipation rate.
6. Conclusions

(1) During the braking process of the friction pair, the temperature at the outer diameter of the friction contact surface is the highest. The maximum temperatures of the powder metallurgy layer-friction ring and powder metallurgy layer-dual parts are 617.09°C and 594.43°C, respectively. The temperature at the outer diameter of the friction contact surface is the highest after braking, and the maximum temperature is 374.23°C and 453.59°C, respectively.

(2) The temperature distribution law of the powder metallurgy layer-friction ring is that the temperature increases slightly from the inside to the outside along the radial direction. Along the circumferential direction, the temperature is low near the position of the chip removal tank, the temperature at the outer diameter of the edge of the chip removal tank is the lowest, and the symmetry surface temperature decreases along the axial thickness direction from the friction contact to the powder metallurgy layer.

(3) The temperature distribution law of powder metallurgy layer-dual parts is that the temperature increases slightly from inside to outside along the radial direction, and decreases along the axial direction from friction contact to steel core plate.

(4) As the braking time increases, the temperature at each point of the powder metallurgy layer-friction ring and powder metallurgy layer-dual increases first and then decreases.

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