The Effect of Rotation Speed on the Temperature and Stress Field of Iron-based Friction Pairs

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Abstract. In view of the iron-based powder metallurgy friction pairs under braking conditions, the temperature field and stress field of friction pairs under different rotation speeds were calculated by using the finite element software ABAQUS through building the structure and physical model of friction pairs. The temperature and stress distribution of the friction pairs under different rotation speeds were studied. The results show that in the process of friction braking, the temperature at the middle diameter of the friction contact surface is higher, and the stress at the inner diameter of the friction contact surface is the largest. With the increase of rotation speed, the distribution of temperature and stress is not changed.

1. Introduction

The braking system is the most important part of the operation of vehicles such as automobiles, high-speed rails and airplanes. The friction performance of the friction pair directly affects the length and reliability of the braking distance. In the process of friction, the heat distribution on the surface of friction material is uneven, affected by thermal stress, it is easy to initiate cracks, or even crack and fracture, which seriously affects the safe use of friction pairs\textsuperscript{[1-2]}. The distribution of temperature and thermal stress in the process of friction braking is rather complicated. The temperature field and stress field of the friction pair are calculated by the finite element methods such as ABAQUS and ANSYS at home and abroad. Han Jianhui\textsuperscript{[3]} and others used CATIA software to establish the transient temperature field and thermal stress simulation model of aircraft brake discs, and studied the relationship between the distribution characteristics of thermal stress and temperature gradient. Feng Shibo\textsuperscript{[4]} applied ABAQUS to study the effect of thermal stress on brake discs. For friction pairs made of iron-based powder metallurgy materials, due to uneven heat distribution on the friction surface during friction braking, it is easy to cause thermal deformation damage to the powder metallurgy friction pairs\textsuperscript{[5-7]}. There are few studies on the coupling of temperature field and stress field of iron-based powder metallurgical friction pairs under braking conditions. In this paper, the temperature and stress field structure model and physical model of friction pair are established to analyze the characteristics of friction pair temperature and stress distribution during friction.
2. Friction Pairs and Working Conditions

2.1. Structure Model

The iron-based powder metallurgy brake friction pairs are composed of moving part and fixed part. In order to facilitate the analysis, the structure of the friction pair is simplified. The simplified structural model is shown in Figure 1. The moving parts are composed of two parts: the upper layer is iron-based powder metallurgy layer and the lower layer is 65Mn steel core plate. The outer diameter of the moving part 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; the outer diameter of the fixed part is Φ72 mm, the inner diameter is Φ56 mm, and the total thickness is 15 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•°C)) | Thermal expansion coefficient (10⁻⁶/K) | Elastic Modulus (GPa) | Poisson's ratio |
|------------------------|------------------|-------------------------------|---------------------------|---------------------------------------|-----------------------|----------------|
| 65Mn                   | 7.8              | 51                            | 460                       | 10.6                                  | 206                   | 0.3            |
| Powder metallurgy layer| 6.5              | 50                            | 400                       | 12                                    | 200                   | 0.3            |

2.3. Working Conditions

The specific braking conditions during the simulation process are shown in Table 2:

| Rotating speed /rpm | Pressure /MPa | Moment of inertia /Kg·m² | Coefficient of dynamic friction | Braking time /s |
|---------------------|---------------|--------------------------|--------------------------------|-----------------|
| 6000                | 0.44          | 0.045                    | 0.393                          | 0.3             |
| 7500                | 0.44          | 0.045                    | 0.309                          | 0.2             |

3. Physics and Finite Element Model of Friction Pairs

3.1. Heat Distribution

The friction distribution coefficient is calculated by the formula (1) [8]. 46% of the heat generated by friction heat is distributed to the surface of the powder metallurgy layer of the moving part, and 54% is distributed to the friction surface of the fixed part.
In the formula: $K$-heat distribution coefficient, the subscripts "f" and "s" respectively represent the powder metallurgy layer of the moving part and the fixed part. $q_f$-heat distributed to the contact surface of the powder metallurgy layer of moving parts. $q_s$-the heat distributed to the contact surface of the fixed parts. $\rho$-density, $\lambda$-thermal conductivity, $C$-specific heat capacity.

3.2. Boundary Conditions
The initial temperatures of the friction pairs at 6000 rpm and 7500 rpm are 25.19°C and 133.0°C respectively. The average convective heat transfer coefficient of the model is 50W/m²k, and the ambient temperature is 20°C. As the heat will be dissipated during braking friction, the heat transfer coefficient of the inner and outer annulus of the friction plate is in the range of 5-20w/m²k according to the literature. Then this paper chooses that the heat transfer coefficient of the inner and outer annulus is 5W/m²k and that of the outer annulus is 20W/m²k. According to the above thermal boundary conditions, the temperature field and stress field are calculated.

3.3. Finite Element Model
In the calculation, hexahedral elements are used to mesh and the mesh model is generated.

4. Results and Analysis

4.1. Temperature Field
When the rotation speed is 6000rpm, the temperature field cloud diagram of the moving part-iron-based powder metallurgy friction plate in the brake friction pair is shown in Fig.2. It can be seen from the figure that the temperature at the mid-diameter on the frictional contact surface is higher and the highest temperature is 69.69°C; the temperature at the inner-outer diameter of the mid-radial along the radial direction decreases, and the lowest temperature is 55.0°C. Along the axial thickness direction, the temperature decreases from the friction layer to the steel chip area. Take the temperature of a point on the friction surface at the middle diameter, inner diameter and outer diameter respectively, and make the temperature time curve, as shown in Fig.3 (a), (b) and (c). It can be seen from the figure that as the braking time increases, the temperature first rises rapidly and then rises significantly.

![Figure 2. Cloud chart of temperature field at 6000rpm](image)
Figure 3. Temperature-time curve of powder metallurgy layer: (a) Mid-diameter; (b) Inner; (c) Outer.

At a speed of 7500 rpm, the temperature field cloud diagram of the friction plate is shown in Figure 4, and the temperature-time curve of the node at the inner diameter of the contact surface is shown in Figure 5. The temperature at the median diameter of the friction surface is the highest, with the highest temperature being 182.2°C. The temperature distribution law is consistent with the 6000 rpm distribution law. As shown in Figures 2 and 4, as the speed increases, the maximum temperature of the material increases. As can be seen from Figures 3 and 5, the temperature change trend has nothing to do with the speed change. The temperature-time curve shows a small increase in the early stage and an increasing trend in the later stage.

Figure 4. Cloud chart of temperature field at 7500rpm

Figure 5. Temperature-time curve of powder metallurgy layer: (a) Mid-diameter; (b) Inner; (c) Outer.
4.2. Stress Field
At 6000 rpm, the stress field cloud diagram of the iron-based powder metallurgical friction plate in the brake friction pair is shown in Fig.6, and a point at the inner diameter of the friction contact surface is taken to make a stress-strain curve. The curve is shown in Fig.7. At a rotation speed of 7500 rpm, the stress field cloud diagram of the friction plate is shown in Fig.8, and the node stress-strain curve on the contact surface is shown in Fig.9. It can be seen from Figures 6 and 8 that the stress distribution on the friction contact surface decreases from the inside to the outside in the radial direction, and decreases from the friction layer to the steel chip area in the axial direction. The stress at the inner diameter of the friction contact surface is the largest, and the maximum stress is $1.308 \times 10^8$N and $1.533 \times 10^8$N. The increase in rotation speed does not change the stress distribution of the material; the stress-strain curves obtained from Figures 7 and 9 are smooth, and the stress gradually increases as the strain increases.

5. Conclusions
(1) During the friction braking process of friction pairs, the temperature at the mid-diameter of friction contact surface is higher. The stress at the inner diameter of friction contact surface is the largest.

(2) The temperature decreases from the middle diameter to the inner and outer edges along the radial direction and from the friction layer to the steel chip area along the axial direction. The stress decreases from the inside to the outside along the radial direction and from the friction layer to the steel chip area along the axial direction.

(3) With the increase of rotation speed, the distribution rules of temperature field and stress field remain unchanged, and the values of temperature and stress increase overall.
6. Acknowledgement

This paper is supported by The Innovation Program (237099000000170008).

7. References

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