The Influence of Braking Pressure on the Temperature and Stress Field of Iron-based Friction Pairs

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Abstract. The material model was established by the finite element analysis software ABAQUS. The temperature field and stress field of iron-based powder metallurgy friction pairs under the brake pressure of 0.44Mpa and 0.8MPa were calculated respectively. The variation laws of temperature and stress under two pressure conditions were compared and analyzed. The results show that with the increase of braking pressure, the stress of the friction pairs increases, but the distribution of temperature and stress fields changes little.

1. Introduction
During the braking, the temperature and stress distribution of the friction pairs are relatively complex. Scholars have conducted a series of studies using finite element software. Carlos Abilio Passos Travaglia[1] used ABAQUS software to establish a brake model, studied the factors that affect the performance of friction materials, and optimized the materials. Zhao Yuanjun[2] analyzed the temperature and stress fields of six parameters by establishing the thermal stress model of the friction pair Influence; Chu Zhengzhong[3] used ABAQUS to establish a coupling model to analyze the coupling relationship between temperature field and stress field and the change rule. For iron-based PM friction materials, its thermal stability is higher and thermal conductivity is better than that of non-metal based materials. Besides, its wear resistance is better and friction coefficient is relatively higher and remains stable. But in the process of movement, the friction and wear performance of the friction pair is easily affected, thus affecting the safe use of the friction material [4-6].Based on the fact that the influence of brake pressure on the temperature and stress field of iron-based PM friction pairs under brake condition is less, this paper analyzes the distribution of temperature and stress of friction pairs under different brake pressures by establishing the temperature and stress field model of friction pairs, and studies the influence of brake pressure on the temperature and stress distribution, so as to provide theoretical basis for the safe use of iron-based friction materials lately.

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.
Under the action of friction, the speed of the moving parts decreases until it stops. 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 $\Phi72$ mm, the inner diameter is $\Phi56$ 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 $\Phi72$ mm, the inner diameter is $\Phi56$ mm, and the total thickness is 15 mm. The structural model is shown in the figure.

![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/cm$^3$) | 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·m$^2$ | Coefficient of dynamic friction | Braking time/s |
|---------------------|---------------|-----------------------------|--------------------------------|----------------|
| 6000                | 0.8           | 0.045                       | 0.33                           | 0.3            |
| 6000                | 0.44          | 0.045                       | 0.393                          | 0.3            |

### 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 0.44MPa and 0.8MPa are 25.19°C and 76.14°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 records that the heat transfer coefficient of the inner ring surface is 5W/m2K and the outer ring surface is 20W/m2K. According to the above thermal boundary conditions, the temperature and stress fields are calculated.

3.3. Finite Element Model
In the calculation, the temperature-displacement coupling analysis step is used to divide the hexahedral mesh elements and the mesh model is generated.

4. Results and Analysis
4.1. Temperature Field
The surface pressure is 0.44MPa, and the temperature field nephogram of the moving part iron-based powder metallurgy friction plate in the brake friction pair is shown in Fig.2(a); the surface pressure is 0.8MPa, and the temperature field nephogram of the friction plate is shown in Fig.2 (b). It can be seen from Fig.2(a) that the temperature at the middle diameter of the friction contact surface is relatively high under the working condition of 0.44MPa, with the maximum temperature of 69.69°C. Along the radial direction, the inner and outer diameter of the middle radial decreases, with the minimum temperature of 55.90°C. In the axial direction, the temperature decreases from the friction layer to the steel core area; in the 0.8MPa condition, the temperature distribution is similar to that in the 0.44MPa condition, but the overall temperature increases. In the radial direction, the temperature at the middle diameter is higher, the maximum temperature is 110.1°C, the side diameter is lower, and the minimum temperature is 87.5°C.

Take the maximum temperature point at the middle diameter of the friction surface and make the temperature time curve. When the surface pressure is 0.44MPa, the temperature time curve of the node on the contact surface of the moving part iron-based powder metallurgy friction plate in the brake friction pair is shown in Fig. 3(a); when the surface pressure is 0.8MPa, the temperature time curve is shown in Fig.3(b). It can be seen from the figure that with the increase of braking time, the change trend of surface pressure 0.44MPa is the same as that of temperature 0.8MPa, which means that the temperature increases rapidly first and then significantly.

With the increase of the pressure, the temperature distribution of the friction pair changes little, but the temperature value increases accordingly. This is mainly due to the increase in pressure, the friction heat generation during friction increases and the temperature rises accordingly; The effect of the pressure on the temperature-time curve is mainly shown as the increase of the temperature, which has little effect on the change trend of the temperature with time.
Figure 2. Cloud diagram of temperature field at different surface pressures: (a)0.44Mpa; (b)0.8Mpa.

Figure 3. Temperature-time curve: (a)0.44Mpa, (b)0.8Mpa.
4.2. Stress Field
When the surface pressure is 0.44Mpa, the stress cloud of the moving part-iron-based powder metallurgy friction plate is shown in Fig.4(a); when the surface pressure is changed and the pressure is 0.8Mpa, the stress cloud is shown in Fig.4(b). Under the condition of 0.44Mpa, the stress distribution on the friction contact surface decreases from the inside to the outside along the radial direction, the stress in the axial thickness direction changes slightly along the axis, the stress at the inner ring of the friction contact surface is the largest, and the maximum stress is $1.308 \times 10^8$N. When the braking time is 0.3s, the stress is the largest and the position is shown in Fig.4(a).

With the increase of surface pressure, the stress distribution on the friction contact surface decreases from inside to outside along the radial direction, the axial stress of the moving part iron-based powder metallurgy friction plate changes slightly along the axial direction, and the stress on the steel core plate decreases from the friction contact surface to the direction of the facing surface. The stress at the inner diameter of the friction contact surface is the largest, and the maximum stress is $1.932 \times 10^8$N. This may be because the stress concentration of moving parts in the process of rotating motion is greater than that of thermal stress. When the braking time is 0.3s under the working condition of 0.8MPa, the stress is the largest, and the location is shown in Fig.4(b).

![Figure 4. Cloud image of stress field with different surface pressure: (a)0.44Mpa, (b)0.8Mpa.](image)

5. Conclusions
(1) During the friction braking process, the temperature at the inner diameter of the friction contact surface is higher. The temperature and stress of friction pairs increase correspondingly with the braking time increasing.

(2) The temperature distribution law is that 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 in the axial thickness direction.

(3) As the brake pressure increases, the stress of friction pairs increases, and the distribution law of temperature and stress distribution is unchanged.

(4) The stress distribution on the friction contact surface decreases from the inside to the outside along the radial direction. The stress of moving parts of friction pairs changes slightly along the axial direction, but the stress on the steel core plate decreases from the friction contact surface to outward.

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