Research on the Temperature Law of Brake Disc Based on Friction

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Abstract. The temperature characteristics of the brake disc will affect the material properties and stress characteristics and affect the safe operation of the train. In order to study the temperature distribution of the brake disc during the operation, a three-dimensional finite element contact model of the brake disc and the brake pad was established by software ABAQUS, applying the initial braking speed of 80 km/h. By analyzing the simulation results, it is found that in the process of the braking, the friction between the brake pad and the brake disc surface causes the temperature rising and forms a high-temperature zone in the middle of the brake disc surface. The temperature of the node belonging to the high temperature zone on the brake disc surface increases first and then decreases. The temperature of the brake disc along the axial direction decreases, and the temperature of the back of the disc increases continuously during the braking process.

Keywords: the brake disc, the finite element, the friction method, the temperature field.

1. Introduction

The brake disc of high-speed train is the key part of the braking system, which bears the thermal load during braking. In case of emergency braking, the maximum temperature on the brake disc surface exceeds 650°C. Therefore, the brake disc must have stability, wear resistance and fatigue resistance [1-2].

Ji-Hoon Choi et al. [3] studied the transient thermo-elastic action of the brake disc, and found that the thermo-mechanical coupling would form local high temperature contact and cause material damage and thermal crack at the sliding interface. YU et al. [4] applied the finite element software to establish the brake disc and the pad models to study the influence of rotation speed on the temperature distribution of brake disc with thermal mechanical coupling method. ZHOU et al. [5] analysed the temperature and stress of the brake disc surface of the train and studied the crack growth rate and law.

Most of the researches were based on the the Energy Conversion Algorithm to simulate and analyze the temperature field of the brake disc, which is to convert the kinetic energy into heat during the braking operation and then apply it to the surface of brake disc. In this paper, a three-dimensional finite element model (FEM) of the brake disc and brake pad of high-speed train was established. By applying the initial braking speed and braking pressure to simulate the friction between the brake disc and brake pad, the transient friction method was used to study laws of temperature rise of the brake disc.
2. The FEM of the brake disc/pad

In this paper, the simplified three-dimensional finite element contact model of the brake disc and brake pad of high-speed train was established using ABAQUS software, including brake disc, brake pad and radiating ribs, as shown in Figure 1. For the brake disc and the brake pad, the outer diameter is 640mm, the inner diameter is 350mm and the thickness is 22mm. For the radiating ribs, the diameter is 20 mm and the thickness is 18 mm, which are evenly distributed on the back of the brake disc. The brake disc material is cast steel and the pad is of powder metallurgy. The relevant material parameters of brake disc and brake pad were shown in Table 1.

According to the train axle load of 17t, the braking force of 21.6kN was applied to the upper surface of the brake pad. The initial braking speed of 80 km/h was adding on the brake disc in the form of angular speed, and the braking deceleration is 1.23 m/s². According to the theory of heat transfer, the corresponding heat transfer coefficients were respectively applied to the surface and the circumference of the brake disc and the surface of the radiating ribs. The friction coefficient of the contact surface between the brake pad and the brake disc is 0.3. The initial temperature of the model is 20 °C and it is considered that 10% of the heat generated by friction is dissipated.

3. Simulation results

Figure 2 shows the temperature field of brake disc and radiating ribs under the conditions which is the initial temperature of 20 °C, the initial braking speed of 80 km/h and the braking deceleration of 1.23 m/s². In the process of braking, the friction between the brake pad and the brake disc surface causes the temperature to rise, and a high temperature zone is formed in the middle of the brake disc surface. The maximum temperature of the contact surface between the brake disc and the brake pad is about 152.3 °C. During the braking, the heat is transmitted inside the brake disc, and the maximum temperature of the back of the brake disc is about 56 °C. The maximum temperature of the radiating ribs is about 60.38 °C, which is distributed on the contact surface of the middle radiating ribs.

![Figure 1](image1.png)

**(Figure 1)** The FEM of the brake disc and the brake pad.

![Figure 2](image2.png)

**(Figure 2)** The temperature field of the brake disc.
Table 1. The material parameters of the model.

| object                   | Temperature (℃) | Thermal conductivity W/(m·k) | Specific heat capacity J/(kg·K) | Elasticity modulus (GPa) | Expansion coefficient (10⁶/K) |
|--------------------------|-----------------|-------------------------------|---------------------------------|--------------------------|-----------------------------|
| The brake disc and the ribs | 20              | 51.9                          | 462                             | 209.9                    | 10.2                        |
|                          | 100             | 45.8                          | 486                             | 201.8                    | 11.6                        |
|                          | 200             | 45.0                          | 519                             | 189.8                    | 13.6                        |
|                          | 400             | 40.1                          | 599                             | 172.1                    | 14.5                        |
|                          | 600             | 34.4                          | 749                             | 146.9                    | 14.6                        |
| The brake pad            | 20              | 74                            | 436                             | 180                      | 11.1                        |

At the high temperature zone of the brake disc, 4 nodes along the axial direction was selected, that is A, B, C, D in sequence, shown in Figure 3(a). Figure 3(b) shows the temperature-time curves of four nodes. The temperature of the nodes decreases along the axial direction in turn, which is the highest on the surface and the temperature of node in the back side is the lowest. In the process of braking, the temperature of node A (on the surface) and node B (near the surface) increased first and then decreased, while the temperature of node C and node D (far away from the disc surface) kept increasing. The maximum temperature of node A is 232 ℃, which occurs at about 7s, at the speed of 50 km/h approximately. The maximum temperature of node B is about 147.5 ℃, which occurs at 12s, at the speed of 30 km/h. The highest temperature of node C and node D occurs at the end of braking, 90 ℃ and 56 ℃ respectively.

Figure 3. The axial node position and temperature curve of the brake disc.

4. Summary
In this paper, ABAQUS software was used to establish the three-dimensional finite element contact model of the brake disc and brake pad. It is to study the temperature rise law of the brake disc at the initial brake speed of 80km/h. By analyzing the results, the following conclusions were obtained:

(1) In the process of braking, the friction between the brake pad and the brake disc causes the temperature to rise, and a high temperature zone is formed in the middle of the brake disc surface.

(2) The temperature of the nodes in the high temperature zone on the surface of the brake disc increases first and then decreases. The temperature of the inner and outer of the brake disc is lower.
(3) The temperature of the brake disc decreases in turn along the axial direction, and the temperature of the back node increases continuously during the braking process.

References
[1] Fu Rong, Song Bao-yun, Gao Fei, et al. Effect of friction conditions on friction properties of braking materials used for trains [J]. The Chinese Journal of Nonferrous Metals, 2008, (07): 1223-1230.
[2] Chen Zujun, Ren Shufang, Wang Jingbo, et al. Tribological Properties of Ti3SiC2/PM304 Tribo-pair at Elevated Temperature [J]. Tribology, 2010, 30(02): 123-127.
[3] Choi J H, Lee I. Finite element analysis of transient thermoeelastic behaviors in disk brakes[J]. Wear, 2004, 257: 47~58.
[4] Zhou Suxia, Zhao Xinghan, Sun Chenlong. Prediction of Crack Propagation Life of Cast Steel Brake Disc of EMU [J]. Journal of Mechanical Engineering, 2018, 54(24): 154~159.
[5] Yu Qi. Simulate of Temperature Field of Disk Brake in Railway Vehicle with Constant Speed [D]. Dalian Jiaotong University, 2008.