Analysis of the structure and thermal coupling of the brake pads of the automotive disc

Ningqiang Wu[1], Yanxia Wang[2] and Bo Zhao[1]

[1]School of Vehicle Engineering, Xi'an Aeronautical University, Xi'an, China;

[2]Numerical Control Engineering Institute, Shaanxi Polytechnic Institute, Xian yang, China

xutwnq@163.com

Abstract

The brakes are the most important component of the braking system, and the advantage and disadvantage of the brakes determines whether the car has good braking performance. In this paper, the structural thermal stress caused by uneven temperature field during braking work of disc brakes, the performance change of materials due to temperature influence in high temperature environment, etc. the result values such as brake disc node temperature, displacement, thermal stress, etc. are analyzed and compared by ANSYS Workbench software. The relationship between the results and the safety and braking efficiency of improving the brake mechanism are comprehensively analyzed.

Keywords

Disc brakes; ANSYS Workbench; FEA.

1. Introduction

In recent years, due to the rapid development of China's highway network, driving speed and density are also increasing, and traffic conditions are more complex. Cars have brought convenience to people's life, but also brought a series of traffic safety problems, so traffic pressure is increasing and traffic accidents occur frequently. Vehicle factors affecting traffic safety include vehicle electrical system, vehicle braking system, vehicle steering system and vehicle driving system.

This paper focuses on the research and analysis of disc brakes. The principle of disc brakes is to use the friction generated when the static friction pad clamps the brake disc to brake, which can achieve to decelerate. With the improvement of the driving speed of the car, the brake performance requirements are getting higher and higher. The brakes bear a huge mechanical load and thermal load in the car brake braking process, and the heat generated by friction will also lead to thermal deformation and thermal stress of the brake disc, the braking process is accompanied by thermal conduction, thermal radiation and other physical phenomena. Therefore, using the transient analysis module in ANSYS software, it is of great significance to study and analyze the thermal fatigue of brake disc static, thermal stress and temperature field to brake disc during the braking process, which is of great significance for preventing or reducing brake disc cracks causing brake failure and the material selection and structural improvement of the brakes.

2. Brake disc and friction pad condition simulation and material property setting

In this paper, the structure of the front wheel disc brake of a car is taken as an example, the brake disc is made of ZG1Cr13 and the friction sheet material is a resin-based composite material. The parameters required for computational analysis can be found in Table 1, and the material is set up in The Engineering Data.

Table 1 Characteristic parameters of friction submaterials

Feature parameters	Brake disc	Brake pads
Thermal conductivity $\lambda/\left(W\cdot m^{-1}\cdot K^{-1}\right)$	48.46	1.212
Density $\rho/\left(kg\cdot m^{-3}\right)$	7228	2595
Than the heat capacity $c/\left(J\cdot kg^{-1}\cdot K^{-1}\right)$	419	1465
Thermal expansion coefficient（α / K^{-1}）	11×10-6	30×10-6
Elastic modulus E/Gpa	175	1.5
Poisson μ	0.3	0.25
Coefficient of friction	0.3	

3. Contact settings and grid division

Because friction is required when the brake discs and friction pads are engaged when the brakes are actually working, the friction contact model in ANSYS is used to analyze the thermal-structural coupling of disc brakes, which allows both a rhythmic separation and a tangential sliding. When a tangenting sliding occurs between two objects, a sliding friction occurs between the two contact surfaces, and the size of the value is calculated according to the positive pressure and coefficient of friction, with the contact type selected as "Frictional" and the coefficient of friction taking 0.3.

4. Brake disc modal analysis

4.1 The principle of modal analysis

The structure is modal analysis, which is used to analyze the vibration characteristics of the brake disc emergency braking, in other projects, modal analysis can simulate the force condition of the structure in advance, and by analyzing the frequency map of the structure, resonance can be avoided by optimizing the structure in advance.

The free vibration equation for modal analysis is as follows:

When damping is ignored and the structure is free vibration available:

$$[M]\{\ddot{u}\}+[K]\{u\}=\{0\} \tag{1}$$

When harmonic vibration occurs, $u=U\sin\left(\omega t\right)$ immediately, available:

$$\left([K]-\omega_1^2[M]\right)\{\phi_i\}=0 \tag{2}$$

ω_i represents the circumference frequency, ϕ_i represents the vibration, ω_i^2 is the root of the matrix equation, that is, the feature value, “i”is the value range from 1 to the degree of freedom, the corresponding vector is $\{u\}$, that is, the feature vector. ω_i is the square root of the feature value, expressed as the structure's natural circular frequency (rad/s), which in turn gives the natural frequency $f_i=\omega_i/2\pi$ (circles per second), $\{u\}_i$ represents the vibration type.

4.2 Modal Analysis Results

Modal analysis is carried out after loading the load according to the static analysis method, and the command flow option is suppressed. The "Max Depth Depth" order is set to 10 thill and then the brake disc is analyzed by modal analysis, the resulting vibration pattern is as follows:

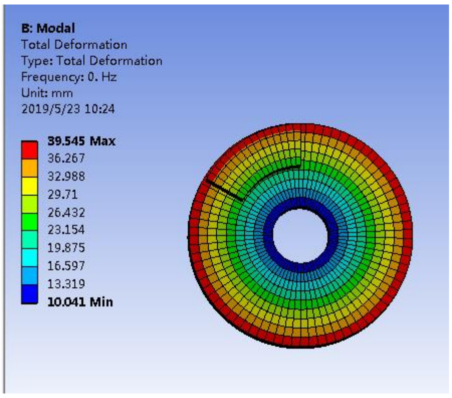


Fig. 1 Brake disc vibration pattern

As can be seen from Figure 1, the edge part of the brake disc vibration frequency is the highest, which is the maximum force in the actual operating conditions, that is 39.545Hz.The vibration type results in the figure above can help us to better understand the vibration of the structure, but the deformation value does not represent the actual displacement.

5. Thermal Structure-Coupling Analysis

5.1 Heat flux in the brake disc

Throughout the braking system, mechanical energy is converted into heat energy, which is expressed in the total heating of discs and plates during braking, and the energy loss of energy that disappears in the form of heat can produce temperature increases ranging from 300 to 800 degrees Celsius in the form of heat. The heat in the contact area is the result of a plastic micro-deformation caused by friction. The thermal conductivity of the material of the brake lining block is less than that of the brake disc (kp<kd), for the convenience of research, we can assume that the heat generated will be fully absorbed by the brake disc, and the heat flux generated on the surface of the brake disc is equal to the frictional power. The initial heat flux into the brake disc is calculated from the following formula:

$$q_0 = \frac{(1-\phi)}{2}\frac{mgvz}{2A_d{}^{\varepsilon}{}_p} \tag{3}$$

Where q_0 is heat flux, the rate distribution of braking force, m is vehicle mass (kg), g is gravity acceleration, v is the vehicle's initial speed (m /s), z is braking efficiency, A_d is the basic area of brake pad sweep, and the radiation coefficient.

5.2 Thermal stress field distribution characteristics of brake discs

The distribution of thermal stress is solved in transient analysis, and the thermal stress distribution of the brake disc can be solved by inserting the command flow in the transient analysis before thermal stress calculation is performed, as shown in Figure 2:

As can be seen from the line chart, the equivalent stress of the brake disc during the entire braking process shows the tendency of increasing rapidly and then decreasing. In the initial stage of braking, the equivalent stress mainly occurs at the combination of the friction pad and the brake disc, and as the braking time increases, the equivalent stress is gradually transferred to the entire brake disc with the rotation of the brake disc, and there is a tendency to distribute gradually and evenly, and in the t-1s, the brake disc reaches the maximum equivalent stress in the entire braking process. Its value is 29.822MPa.

5.3 Distribution characteristics of the brake disc temperature field

The braking process of the brakes is mainly through friction pad contact with the brake disc to produce friction, friction force to reduce the wheel speed, and ultimately reduce the speed of the vehicle. There is bound to be a large amount of heat during friction, which will cause the temperature of the brake discs and friction pads to rise rapidly, which greatly affects the braking efficiency of the brakes. In order to understand the temperature field change law during braking, this function can be achieved by thermal-structural coupling analysis, so the temperature field during braking is analyzed.

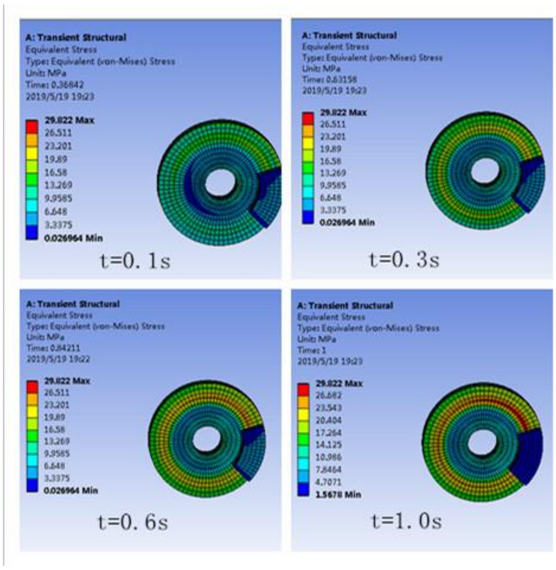


Fig. 2 Thermal stress distribution for different braking times

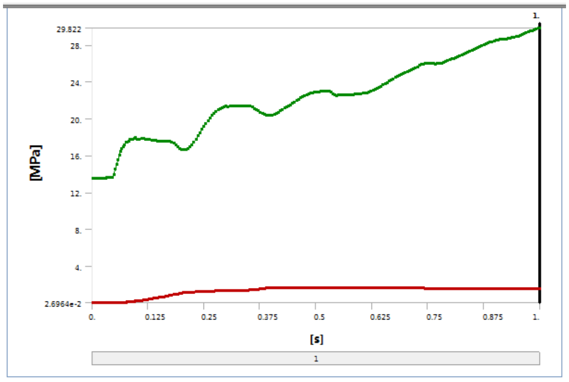
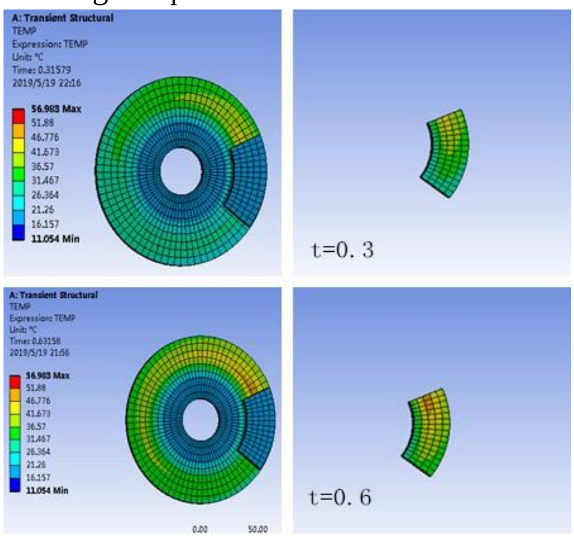


Fig.3 Equivalent Stress Line Chart



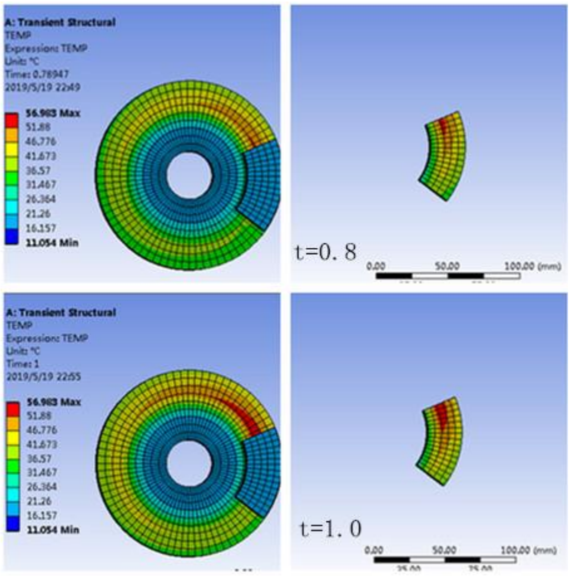


Fig. 4 Temperature field distribution cloud map of brake discs and friction pads for different braking times

Figure 4 shows a cloud of temperature field distribution at different times of the entire disc brake during braking, As can be seen from the figure, the brake in the early stage of the braking process, the temperature rise area first appears at the brake disc and friction pad joint exit, the temperature of the instantaneous growth rate is extremely fast, but with the progress of braking, the temperature growth rate gradually slowed down, braking time is 1s, the highest temperature in the high temperature area is 56.983 degrees C. The temperature field distribution of the brake disc is analyzed, it can be found that the temperature distribution of the brake disc is not axis symmetry in the whole braking process, there is a certain degree of temperature gradient in radial, peri-directional and axial, and the temperature gradient is relatively small compared to radial and axial. The main reason is that the heat generated by the high-speed friction between the brake disc rotation and the friction pad is much higher than the heat transfer speed inside the brake disc, resulting in a large amount of heat accumulated on the brake disc surface, which causes the brake disc surface temperature to rise sharply.

6. Conclusion

In this paper, a finite element model is established for disc brakes, and a systematic study of the emergency braking situation by direct coupling is used, and the following conclusions are drawn through the study of its stress field and temperature field:

(1) The start of the brake phase, the temperature of the brake disc rises rapidly, with the increase of braking time, the temperature rise speed is gradually slow, and then, the temperature field distribution gradually tends to be even.

(2) By comparing the stress field with the temperature field, it is found that the change trend between the two is very similar, because the main stress of the brake disc is thermal stress. The force that causes the thermal crack of the brake disc to expand along the radial direction is mainly the peripheral stress, which is also the largest of the three stresses on the brake disc. From the results of the analysis, it can be concluded that the "hot spot effect" of the stress field is more obvious than that of the temperature field in transient.

Acknowledgments

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