Research on the Mechanical and Contact Performance of Marbles Screw Loading Device in Dry Disk Brakes

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Abstract. The marbles screw loading device is an important structural part in dry disk brakes. With the increasing of braking load and temperature, the material, mechanical and contact performance become a great challenging for the brake design. To better understand the performance, the mechanical and contact performance of marbles screw loading device is investigated. The performance is investigated under different braking load. Then, the influence of typical parameters including geometrical, friction coefficient and temperature on the effective stress and strain is researched. The explicit finite element method is employed to build the numerical simulation model. Numerical simulation result shows that the contact area centre locates on the outside of the brake. The disc groove with 15°has better performance. The residual stress is an increasing with respect to the temperature for the decreasing of material performance. The marbles screw loading device could be largely improved by adjust the geometrical dimensions.

1. Introduction

With the development of vehicle and power technology, the requirement of maneuverability and velocity performance of vehicle largely increase[1]. The requirement performance gives a unprecedented demands for the brake system design. Today, not only the velocity and the maneuverability, but also the stable and lower impact loads are required. The design of brake system become a very challenging problem for vehicle engineering. The dry disc brake with larger braking power has been extensively applied on the heavy vehicle[2]. The marbles screw loading device is one of the key components to conversion device to transfer lateral load to pressure load on friction plate. This device is suffered high temperature and high load[3-4]. Till now, many researches are focused on the structural and force transmission problem of marbles screw loading device[5]. This dry disc brake has been suffered high temperature and larger load, and the mechanical and contact performance have been great influenced. However, the mechanical and contact characteristics of this device is still not clear. To better understand the performance, the performance is researched based on the explicit finite element model, and the influence of typical parameters is also researched.

2. Material and Finite Element Model

To obtain the accurate mechanical and contact performance of Ball-Plate Loading Mechanism, the commercial software LS-DYNA based on the explicit finite element method is adopted. The mechanism, material model and finite element model are given as following.
2.1. Marbles Screw Loading Device
The marbles screw loading device is a kind of device to transform the lateral load to pressing force between friction plates shown as Fig. 1. This mechanism consists of rotary disc, marble, groove and removable disc, and the groove has two parts including hemisphere groove and helical circular arc groove. The lateral load given by hydraulic cylinder is applied on the rotary disc, and it rotates about the axis of mechanism. The marble slot on the disc would force the marble to move from the slot bottom to the top. Finally, the removable disc would translate along axial direction. The marble and disc withstand harsh load for the large pressing load and severe environment. To better design and analysis the ball-plate loading mechanism, the mechanical and contact performance are the critical factors.

Figure 1. The ball-plate loading mechanism.

2.2. Constitutive Model
The material of marble and disc are GCr15 and 38CrSi, respectively. The bilinear elastic-plastic model is adopted, and the strain rate is considered based on Cowper-Symonds model shown as Eq. (1).

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\sigma_y = 1 + \left( \frac{E}{C} \right)^{1/p} \left( \sigma_0 + \beta E_p e_{eff}^p \right)
\]

(1)

Where \( \sigma_y \) is the dynamic yield stress, \( \sigma_0 \) is the material yield stress, \( C \) and \( p \) are the constants of Cowper-Symonds relation and the \( C \) and \( p \) equal 40 and 5 for steel material. \( \beta \) is a parameter to give isotropic and kinematic hardening, and material model is isotropic hardening if \( \beta \) is 1, otherwise it is kinematic hardening. \( e_{eff}^p \) is the effective plastic strain, \( E_p \) is the given by Young’s modulus and tangent modulus as Eq. (2).

\[
E_p = \frac{E E_t}{E + E_t}
\]

(2)

Figure 2. The finite element model.

2.3. Finite Element Model
To simplify the computational process, a 1/12 numerical simulation model is adopted as Fig. 2. The marble and disc are modelled with 8 node solid element. Total element number of this mechanism is 44599, that of rotary disc, removable disc and marble are 17832, 15142 and 11625, respectively.
Based on the penalty function method, the contact between disc and marble is surface to surface contact. The rotary disc is set to rotate along z-axis, and the removable disc is only allowed to move along z-direction. The pressure load is applied on the removable disc, and the rotary disc is given a rotational angular velocity. To control the hourglass energy, rigid hourglass control method is employed, and the coefficient is set to 0.05.

3. Mechanical and Contact Performance

The mechanical and contact performance are the critical factors for the marbles screw loading device, and the effect of pressure on the performance during the working process is investigated. The marbles screw loading device works under different braking condition, and different pressure load is exhibited for the ball-plate system. The braking force with 5MPa, 10MPa, 15MPa, 20MPa and 25MPa are applied on the removable disc. This pressure load is in the load between friction plates. With the numerical model, the maximum effective stresses of marble and rotary disc vs. time curves under different pressure load are given as Fig. 3. It could be seen that the stress is a linear increasing function with respect to the time during the first 0.01s. From 0.01s, the rotary disc begins to rotate with axis, and the marble is applied a larger load. The marbles move from the hemisphere groove to the helical circular arc groove. The contact surface decreased from the hemisphere to the helical circular arc groove. Consequently, the maximum effective stress quickly increases in the following short time. The contact surface becomes stable after the marble move to the helical circular arc groove. It could be seen that the maximum effective stress is an increasing function with respect to the pressure load. The applied load has great influence on the stress of marble, but negligible influence is exhibited for the rotary disc.

![Figure 3](image)

**Figure 3.** The maximum effective stress of marble (left) and rotary disc (right) under different pressure load.

The effective stress of rotary disc and marble under different pressure load are given as Fig. 4 in the 0.02s. The stress of the rotary disc and marble increases as the increasing of pressure load, and the maximum effective stress locates about the centre of contact area. The contact area also is an increasing function with respect to the load. The strain would increase with the increasing of braking force, and the plasticity deformation would occur with high pressure load. There is no plastic deformation for rotary disc and marble if the pressure is 5MPa, and the rotary disc would have plasticity if the pressure increases to 10MPa. The plasticity deformation occurs in the rotary disc and marble in the 0.0138s and 0.0128s for 15MPa and 20MPa, and the maximum values for the two parts are 0.00528 and 0.0106.

Under the same braking load, the occurrence time of plasticity strain of marble and rotary disc is 0.0358s and 0.0188s, and the maximum plasticity strain for the two parts are 0.00167 and 0.00284. It could be concluded that compare with marble, the plasticity deformation is more likely to occur for rotary disc. The occurrence time of rotary disc is before that of marble, and the plastic strain of rotary disc is also higher than that of marble. The maximum plasticity strain is on the right of centre line.
4. Influence of Typical Parameters

To better understand the performance of marbles screw loading device, the typical parameters including spiral angle, friction, dimension ratio and temperature on the mechanical and contact performance is researched.

4.1. Dimension Ratio

The dimension ratio between the spiral cylindrical and the marble is an important design parameter for this mechanism. The contact surface of the spiral cylindrical and the marble would alter if the ratio changes. As a result, the stress and strain states would also change accordingly. To better choose the best parameter, the ratios including 1.04, 1.06, 1.08 and 1.1 are chosen. The influence of ratio on the
maximum effective stress is given as Fig. 7. It could be seen that the mechanism with larger ratio would have higher maximum effective stress for the decreasing of contact surface. To better understand the pressure distribution on the disc surface, the pressure distribution along radial direction of brake. The plasticity strain and contact area are given in the Fig. 8. This shows that the centre of contact area locates on the outside of roller path, and the maximum pressure load is about the centre line. The pressure distribution area become smaller and the maximum pressure load become larger with the increasing of ratio.

![Figure 7. The influence of dimension ratio on the marble.](image1)

![Figure 8. The influence of temperature on the plasticity strain.](image2)

4.2. Temperature
The requirement of maneuverability, braking performance under emergency braking and long downhill braking is great increasing for the increasing complicated of service environment. The braking load and temperature of brake system increase lead to worse performance. The temperature has great influence on the yield stress, elastic modulus of metal material. To give a better understanding of temperature, its effect on the mechanical performance is given. Three temperature including 300°C, 400°C and 500°C are chosen. With the increasing of temperature, both of the effective plastic strain and its area increase. High effective plastic strain is exhibited for the higher temperature.

The effective stress vs. time curves are exhibited in Fig. 9. It follows that the effective stress is relatively low before the marble contact with the element, and the stress would rapidly increase if the contact is beginning. The plastic strain also occurs with the increasing of element stress. It could be
seen that the effective stress is a decreasing function with respect to temperature for the material performance is negative correlation with temperature because temperature dependent material properties are considered. The yield stress and strain decrease result in a decreasing of effective stress. However, the residual stress is an increasing function with respect to the temperature, and it is 189MPa if the temperature is 500°C.

![Figure 9. The influence of temperature on the marble.](image)

5. Conclusions
The mechanical and contact performance of marbles screw loading device is investigated, and the influence of typical parameter is given. The contact area centre locates on the outside of brake. The rotary disc, removable disc and marble have great plastic deformation under large braking load and high temperature, and high residual stress is exhibited. The mechanical performance becomes worse if the dimension ratio increases. With the increasing of temperature, the residual stress increases.

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