

Enhancement of Cup Seal Performance in Brake Wheel Cylinders by Hyper Elastic Analysis

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ABSTRACT

The shape of the cup seal that is installed in the wheel cylinder of drum brakes was examined using FEA hyper elastic analysis. The cup seal material was changed from the often used SBR to EPDM resulting in enhanced heat and wear resistance. Next, a prototype cup seal was made in a determined shape based on the results of the investigations. Various durability tests were carried out with the results confirming both enhanced durability and appropriate sliding resistance.

1. Introduction

Within the brake system of passenger cars, lip shaped packing normally referred to as a cup seal is used to seal parts that are exposed to high hydraulic pressures and sliding such as the wheel cylinder (Fig. 1).

Cup seals are mainly composed of synthetic rubber materials, and seal by completely contacting the cylinder surface (sliding surface) when fluid pressure is applied within the wheel cylinder.

In addition, there are various specifications for cup seals according to the shape and surface condition of the piston on which the cup seal is mounted and the cylinder against which the cup seal slides in order to satisfy the various functions required of brake wheel cylinders.

Thus far, the cup seal shape has generally been determined by repeatedly creating prototypes based on empirical guidelines, and then performing various tests and confirming durability. However, there are still many development issues such as the inability to observe conditions inside the cylinder during operation and the inability to measure rubber strain.

Therefore, this study conducted investigations to optimize the shape and enhance durability by hyper elastic analysis using finite element analysis (FEA).

Excellent results were obtained in durability tests using a prototype cup seal, and these results are introduced here.

2. Functions required of cup seals and materials

The cup seal in a wheel cylinder is the output portion for the hydraulic pressure inside the drum cylinder, and high durability is required. “Low strain” is generally known to be important in enhancing the durability of rubber materials.

On the other hand, it is also known from experience that there are a number of points which must be taken into consideration in terms of functions. For example, the seepage phenomenon is thought to occur when the cup seal becomes worn due to stick slip with the piston, causing brake fluid to seep around the seal. Therefore, slipping between the cup seal and the piston leads to seepage and wear, and reduces durability. The sectional shape of part A shown in Fig. 2 is formed by cutting, and is called the cut lip. It is known that an acute angle at the end of the cut lip facilitates stick slip and that the high but not-constant sliding resistance exhibited

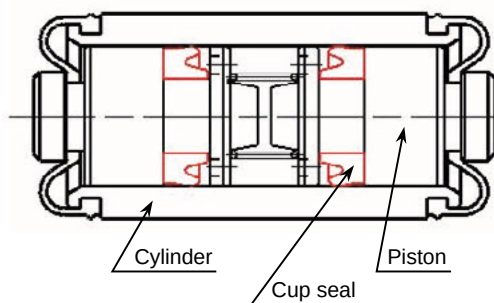


Fig. 1 Wheel cylinder

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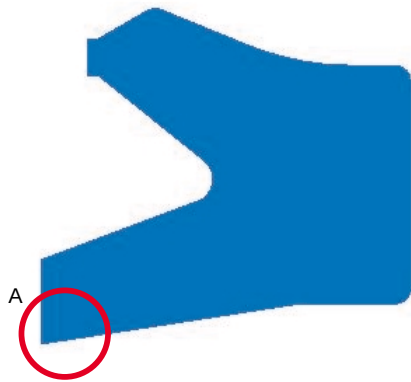


Fig. 2 Cup seal

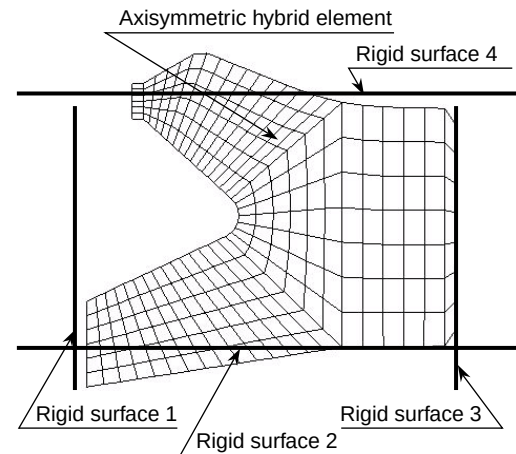


Fig. 3 FEA model

in tests results in unstable sliding resistance.

In addition, when external pressure which exceeds the frictional force is applied, relative sliding occurs between the cup seal and piston and between the cup seal and wheel cylinder, so the proper sliding resistance values must be ascertained. The wheel cylinder side constantly slides during operation, so a low sliding resistance is thought to be better. On the other hand, a high sliding resistance is desired for the piston side to prevent relative sliding when stick slip and rapid pressure changes occur.⁽¹⁾

The cup seal materials are generally rubber-like elastic solids collectively referred to as elastomers. These elastomers deform and produce strain when subjected to a load, but also exhibit non-compressive characteristics. That is to say, they are elastics but the contact portions exhibit fluid behavior. In addition, rubber materials generally experience deformation known as compression set due to macromolecular flow when subjected to stress for long periods of time.⁽²⁾

Styrene-butadiene rubber (SBR) is often used as the cup seal material. SBR is resistant to brake fluid and has excellent low temperature performance, but its physical properties can deteriorate at high temperatures (120°C or more). Therefore, this study investigated an ethylene propylene diene monomer (EPDM). EPDM features superior heat resistance, with little change in physical properties even at temperatures of 150°C or more. Furthermore, it exhibits the same low temperature performance as SBR down to -40°C, and has wear resistance superior to SBR.

3. Modeling the cup seal

The model used in this study requires advanced calculation techniques called nonlinear analysis. The cup seal is made of a hyper elastic material that experiences significant deformation which results in contact, so the correlation was expected to be poor. Therefore, the cup seal was modeled in two dimensions using axisymmetric hybrid elements as shown in Fig. 3 instead of three dimensions in order to simplify the analysis parameters as much as possible. The material characteristics were obtained from biaxial tensile tests on a test piece using the Mooney-Rivlin fixed number that corresponds to Young's Modulus for metal.

The piston and cylinder are extremely rigid compared to the cup seal, so these are modeled as rigid surfaces, and contact elements were located on the contact surface of the cup seal and each rigid surface. The coefficients of friction were calculated using the sliding resistance obtained from tests, and were $\mu = 0.135$ for the piston and $\mu = 0.205$ for the cylinder.

The condition with the cup seal assembled into the wheel cylinder is expressed by the forced displacement of the rigid surfaces in each step.

The cup seal is completely unconstrained in the initial state, so there is no balance of forces and the condition is unstable. Therefore, this study began the calculations from the condition where rigid surface 1 is already in contact with the cup seal.

A pressure load was applied to the end of the cup seal that contacts the brake fluid as shown in Fig. 4 to reproduce the deformed condition under pressure.

The sliding resistance was obtained from the fulcrum reaction force produced on the rigid surfaces corresponding to the piston and cylinder sides.

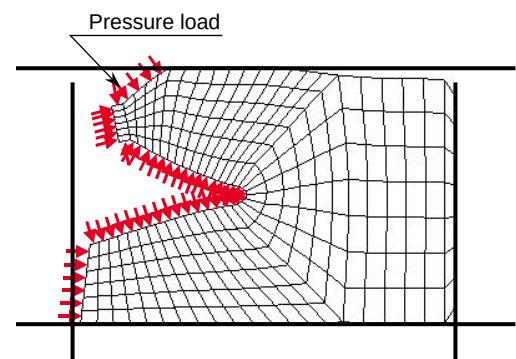


Fig. 4 Boundary condition of pressure load

4. Analysis results

Fig. 5 shows the analysis results for the stress produced on the cup seal, and Fig. 6 shows the analysis and test results for the sliding resistance produced on the piston and cylinder.

As shown in Fig. 5(b), stress was confirmed to concentrate in part B when the cup seal was assembled into the wheel cylinder. In addition, analysis showed that the sliding resistance is smaller on the piston side than on the cylinder side as shown in Fig. 6. This same tendency was also confirmed in tests.

The sliding resistance was compared through finite element analysis and tests for a number of shapes as shown in Fig. 7. These results are shown in Fig. 8. The analysis and test results correlate fairly well, thus confirming that this analysis method can be utilized for shape investigations.

5. Investigation to optimize the shape

Based on the above analysis results, investigations were carried out using finite element analysis to achieve an optimum cup seal shape that satisfies the following target performances.

- (1) Enhanced durability by reducing strain
 - There should be little strain when assembled into the wheel cylinder.
 - Stress should not concentrate locally.

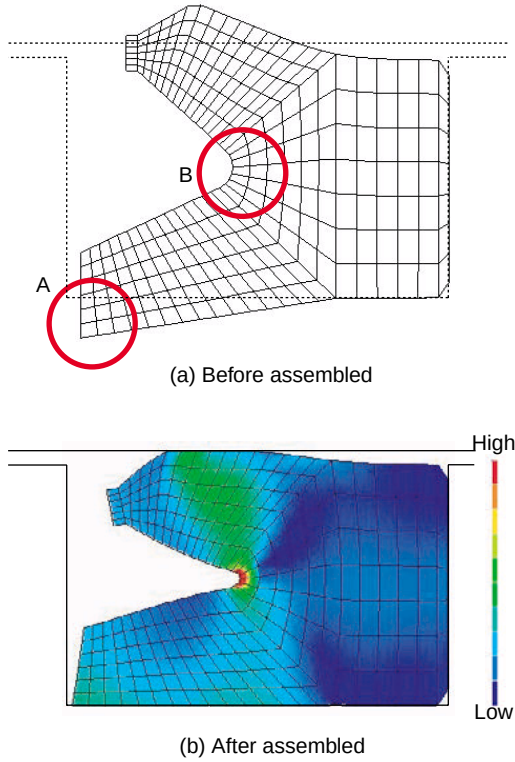


Fig. 5 FEA model of the current design and stress calculation results

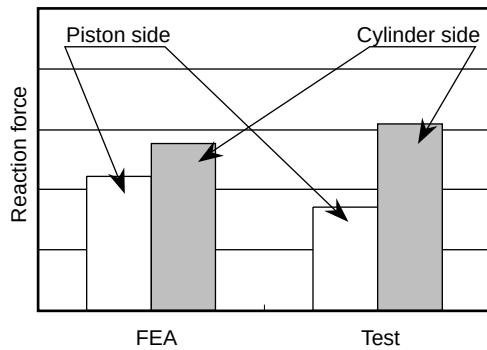


Fig. 6 Calculation result and test results of reaction force

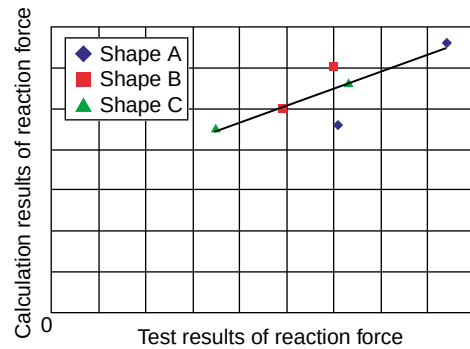


Fig. 8 Correlation of reaction force

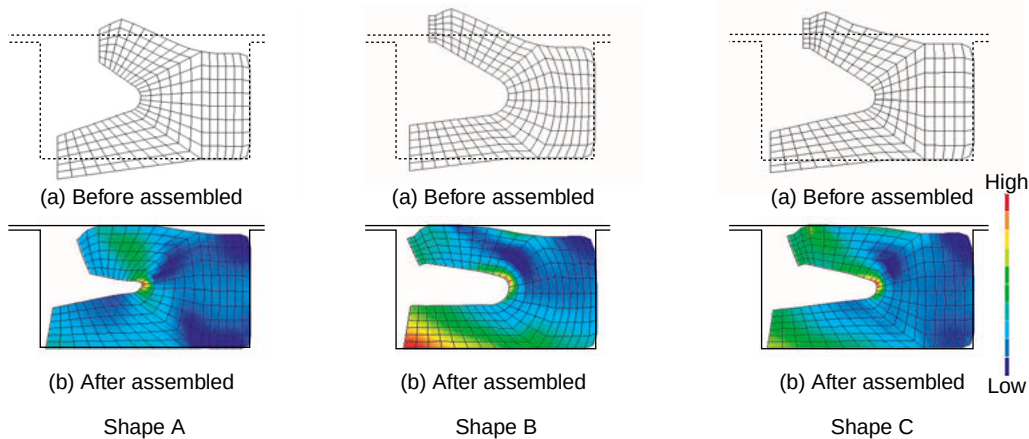


Fig. 7 FEA model of other designs and stress calculation results

(2) Appropriate sliding resistance

- Stick slip should not occur.
- The sliding resistance on the piston side should be larger than on the cylinder side.

5.1 Enhanced durability by reducing strain

When the radius of curvature is increased to reduce the strain when assembled into the wheel cylinder and disperse the stress of part B, the sliding resistance was found to drop and other required performances also could not be satisfied. Various shapes with different lip widths, for example, were investigated, and a shape joined by a large and small radius of curvature such as that shown in Fig. 9 was found to be the most effective for distributing stress.

5.2 Appropriate sliding resistance

An obtuse angle shape called a molded lip was adopted for the shape of part A as shown in Fig. 9(a) to adjust sliding resistance instability. In addition, the sliding resistance on the piston side must be relatively large, so the interference on the inner diameter of the cup seal was increased within the range allowed by the assembly performance. Conversely, the shape was changed to reduce the cup seal surface pressure against the cylinder in order to reduce the sliding resistance on the cylinder side. The analysis results confirmed that these changes achieved the target performance for sliding resistance as shown in Fig. 10. Prototypes were then manufactured based on these analysis results, and measurements performed using these prototypes showed the same tendencies.

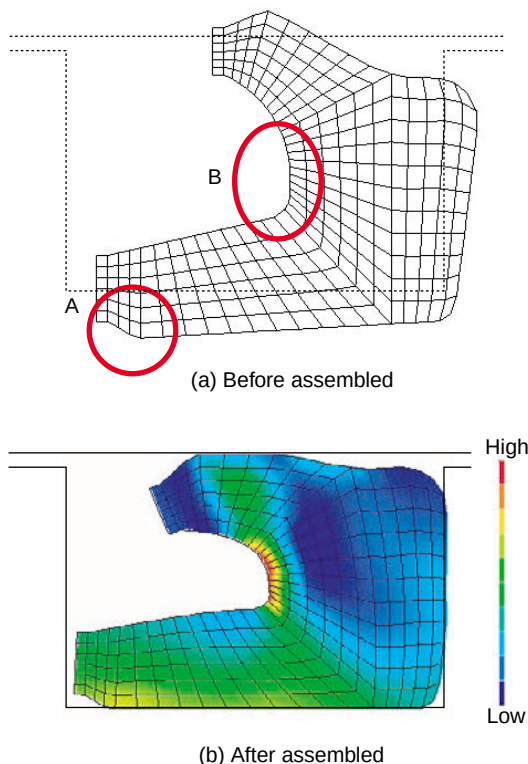


Fig. 9 FEA model of new design and stress calculation results

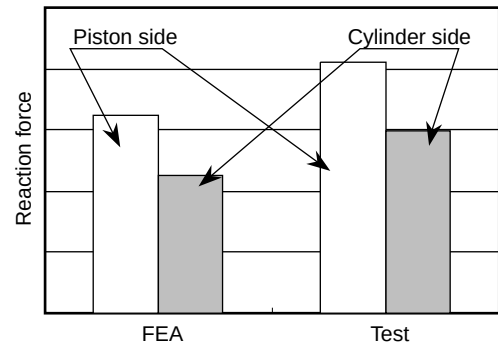


Fig. 10 Calculation and test results for reaction force

6. Confirmation of durability using prototypes

Prototypes were manufactured using the shape obtained through the above investigations, and various durability tests were carried out to compare the prototypes with the current product.

Fig. 11 shows the results of high temperature operation durability tests carried out at a test environment temperature of 120°C. These results show interference is more consistent from the initial state until the end of the test than for the current product, indicating that durability was enhanced.

Fig. 12 shows the results of bench durability tests in which the cup seal was left assembled into the wheel cylinder at a high temperature (120°C). Like the high temperature operation durability test, there was also less change in the

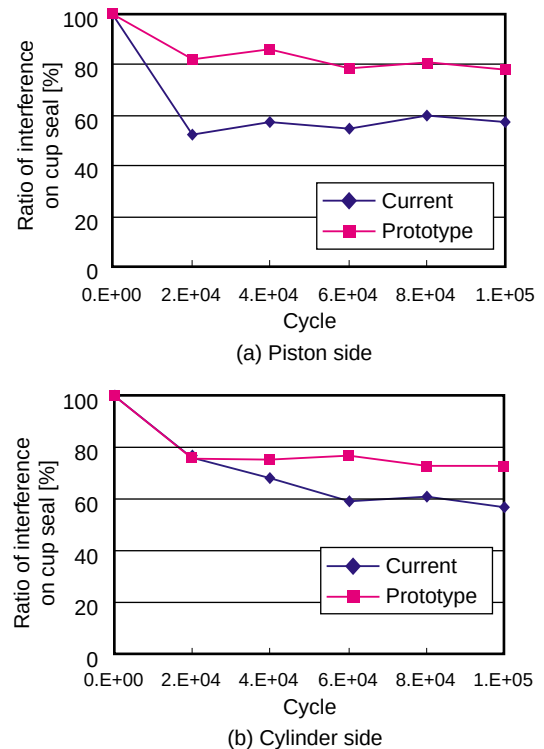
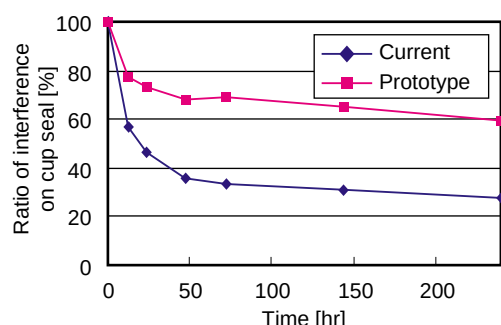
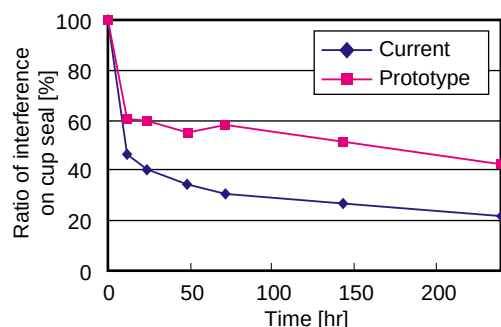


Fig. 11 Cup seal interference degradation during the high temperature cycle endurance test



(a) Piston side



(b) Cylinder side

Fig. 12 Cup seal interference degradation during the high temperature exposure test

References

- (1) Shigezo Iwanami, Norishige Chikamori: Packing Technological Manual (second edition), Tokyo, Sangyo Tosyo, p.147-190, 1981
- (2) Toshio Fujiyoshi: Plastic Processing Technological Handbook, Tokyo, Nikkan Kougyo Shinbunsha, p.143-153, 1995

interference when left for long periods, indicating that durability was enhanced.

These results confirmed that the cup seal investigated using hyper elastic analysis achieved the target performances in terms of both enhanced durability and appropriate sliding resistance.

7. Conclusion

A cup seal structure that satisfies the following target performances required by the wheel cylinders of drum brakes was investigated by hyper elastic analysis using finite element analysis.

(1) Enhanced durability by reducing strain

(2) Appropriate sliding resistance

Changing the materials from SBR to EPDM enhanced resistance to both heat and wear.

A prototype was manufactured based on the above analysis results and various durability tests were carried out. As a result, the developed prototype was confirmed to achieve the target performances.

Therefore, the proposed analysis method was found to be effective for investigating the cup seal structure.

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