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Finite element analysis of different hardness O-rings

Mingjun Xu

***Abstract*—This paper uses finite element analysis software to analyze the sealing performance of O-rings with certain initial compression ratio and different rubber hardness. The relationship between the maximum Mises stress and the maximum contact stress of the O-ring in the initial state and the working pressure of 32MPa and the hardness of the material. The sealing length of the sealing ring is not affected by the hardness of the material; the greater the hardness of the sealing ring, the higher the equivalent pressure.**

***Index Terms*—Rubber hardness; O-ring; Sealing performance; Seal length;**

I. INTRODUCTION

O-rings are widely used in a variety of pneumatic devices due to their simple form. At present, the design of O-rings mostly relies on experimental formulas or empirical models, and lacks the corresponding theoretical basis. Therefore, it is necessary to analyze the sealing performance of the O-ring [1].Ferm AG and other scholars established a two-dimensional axisymmetric model of the stem seal structure. The Mooney-Rivin model was used to describe the highly nonlinear mechanical properties of the rubber, and the elastic fluid dynamic pressure model was assumed to analyze the performance in the reciprocating seal. The structural design of the rod seal provides the basis. Gadala MS uses a new method to study incompressible superelastic materials based on methods that extend to nonlinear and linear functions and can handle the constitutive relationship of superelastic rubber materials. Lemon and other scholars systematically studied the method of O-ring leakage rate in the case of multi-channel rubber seals in space environment. Lach Cynathia et al. conducted an experimental study on the sealing performance of the sealing ring under different temperature conditions [2].This study analyzes the influence of medium working pressure and rubber material hardness on the contact stress, equivalent stress and sealing length of the sealing ring in static sealing, and provides a certain theoretical basis for the sealing structure design of rubber sealing ring.

II. ESTABLISHMENT OF FINITE ELEMENT MODEL

1.1 sealing ring material selection

The sealing ring selected in this paper is an O-ring, the cross-sectional diameter of the sealing ring is 3.55mm, and the inner diameter of the sealing ring is 47.5mm, as shown in Figure 1.

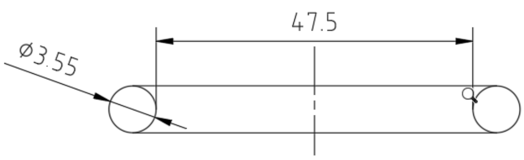


Figure 1 O-ring section

Rubber seal structure is highly nonlinear, geometric, material and contact nonlinearity. This study makes the following assumptions [3]:(1)material has a certain elastic modulus and Poisson's ratio; (2)the tensile and compressive creep properties of the material are the same; (3)the longitudinal compression of the seal is regarded as the specified displacement by the constraint boundary Caused by; (4)creep does not cause volume change. The nitrile rubber material belongs to the superelastic body and is expressed by the strain energy function. The Mooney Rivlin constitutive model is commonly used to describe superelastic materials with less than 30% deformation, and its expression is as follows [4]:

$$W = C_1(I_1 - 3) + C_2(I_2 - 3) \qquad (1)$$

Among them:W for strain potential energy;C_1 and C_2 is the material coefficient for the Mooney Rivlin model;I_1 and I_2 is the first and second strain tensor invariants.

1.2 Finite element pre-processing

A two-dimensional axisymmetric finite element model of O-rings, bushings and seal grooves was established in the finite element analysis software Abaquas. The material of the bushing and the sealing groove is 12Cr13, and the modulus of elasticity is 216000MPa. The Poisson's ratio is 0.28. The depth of the sealing groove of the model is 2.7mm, the groove width is 5mm, the groove bottom radius is 0.4mm, and the groove corner radius is 0.2mm.According to the O-ring compression rate calculation formula, the compression ratio of this model can be calculated to be 9.4%, O-ring compression ratio. The formula is:

$$\varepsilon = \frac{D-h}{D} \times 100\% \qquad (2)$$

Among them:D is the inner diameter of the O-ring;h is the height of the installation space for the O-ring.

In the static seal analysis, the axial displacement of the sleeve and the seal groove is constrained. The first step is to simulate the model assembly process during the analysis, and the second step is to apply the load to simulate the pressurization process. The contact surface of the sealing ring and the sealing groove, the surface of the sealing ring and the sleeve are set up. The friction coefficient is 0.3. The contact problem belongs to the functional extreme value problem with constraints. The penalty function is used and the friction model is the Coulomb friction model.

In order to prevent the O-ring rubber ring from being broken and causing leakage, when the medium pressure exceeds 10 MPa (dynamic seal) and 32 MPa (static seal), a retaining ring should be placed on the bearing surface[5]. There is no design retaining ring in this research model, the maximum load is not more than 32MPa, and the model is pressurized to 32MPa step by step.

2. The effect of rubber material hardness on the performance of the seal

According to the literature [6], the relationship between the elastic modulus(E) and the shear modulus(G) of the rubber material is:

$$G = \frac{E}{2(1+\mu)} \tag{3}$$

Rubber Poisson's ratio μ is 0.5 because of the incompressibility of rubber. The relationship between the elastic modulus E and the shear modulus G of the rubber material and the constant of the material is:

$$G = 2(c_1 + c_2), E = 6c_1(1 + \frac{c_2}{c_1}) \tag{4}$$

The experimental data and fitting formula of rubber hardness H_r (HIRD) and elastic modulus E are [6]:

$$l_g^E = 0.0198H_r - 0.05432 \tag{5}$$

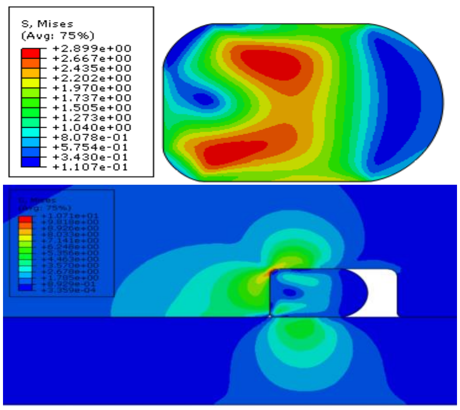
According to the fitting formula, the elastic modulus (E) of rubber materials with different hardnesses is obtained according to the fitting formula and the closest to the test. C_1 and C_2 as shown in Table 1.

Table 1 Rubber material parameters under different hardness

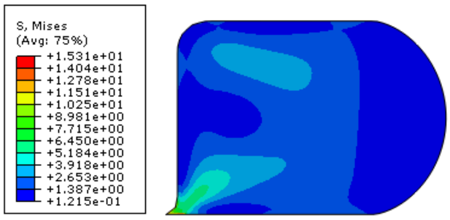
H_r(HA)	E/MPa	C_1/MPa	C_2/MPa
70	6.69	1.137	0.023
75	8.74	1.444	0.0165
80	10.98	1.833	-0.003
85	13.80	2.3434	-0.034
90	17.33	2.972	-0.082

The Mises stress reflects the magnitude of the principal stress difference on the section. Generally, the greater the Mises stress, the lower the stiffness of the rubber material and the more prone to cracking [7].The contact stress and the length of the seal reflect the sealing ability of the O-ring. The necessary condition for the seal to ensure the seal is that the maximum contact pressure is greater than or equal to the working pressure of the medium. The smaller the seal contact length, the easier the O-ring seal is invalid.

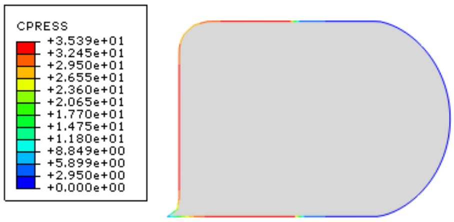
Taking the seal ring of Shore A type 70 hardness as an example, the stress distribution of the sealing ring Mises under the working pressure of the medium is shown in Fig. 3(a). The Mises stress and contact stress cloud of the sealing ring under the pressure of 32MPa are shown in Fig. 3(b). And Figure 3 (c).



(a) Mises stress distribution without medium pressure



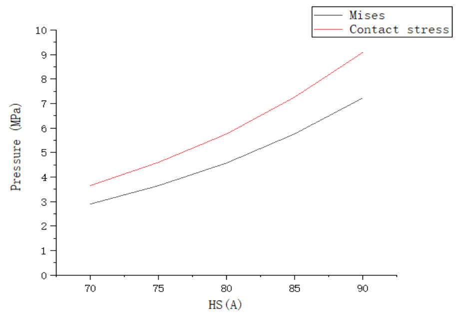
(b) Mises stress distribution at a dielectric pressure of 32 MPa



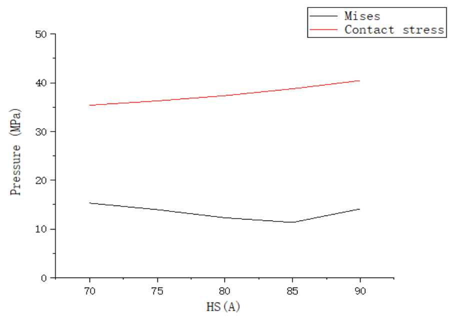
(c) The dielectric pressure is 32 MPa contact stress distribution

Figure 3 O-ring stress cloud chart

It can be seen from Fig. 3 that under the medium pressure of 32 MPa, the O-ring has a stress concentration phenomenon at the corner of the groove, where the possibility of cracking in the sealing ring is greater, and it is most likely to be sheared, affecting the O-ring. Overall sealing performance. The maximum stress curve of the O-ring under different hardness is shown in Figure 4. In the absence of pressure, the Mises and the maximum contact stress of the seal ring increase linearly with hardness; in the state of pressure (32 MPa), the hardness changes. Large, the maximum contact stress becomes larger, and the maximum Mises stress has a tendency to decrease, but the amplitude is not large.



(a) No working medium pressure



(b) Medium working pressure 32MPa

Figure 4 Stress diagram under different working pressures

Figure 5 shows the equivalent pressure diagram of different hardness O-rings under different working pressures. The equivalent pressure of the O-ring increases almost linearly with the increase of the working pressure; the greater the hardness of the O-ring, the higher the equivalent pressure.

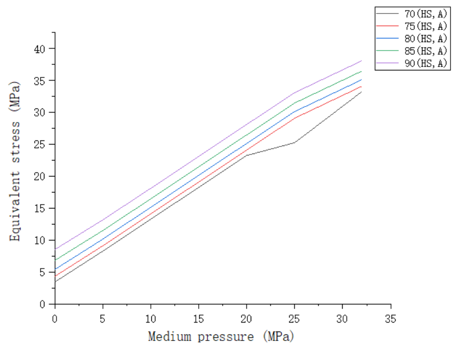


Figure 5 equivalent pressure

Taking the seal of Shore A type 70 hardness as an example, the contact stress of the O-ring and each contact surface is extracted and plotted as shown in FIG. 6 .It can be analyzed from the figure that the contact stress of each contact surface has a length greater than the working pressure of the medium of 32 MPa.

Figure 7 is a graph showing the length of seals of different hardness O-rings under pressure of 32 MPa and each contact surface. Under the same pressure, the hardness has little effect on the sealing length; the sealing length of the O-ring and the sealing groove wall surface is the longest, the sealing length of the O-ring and the sealing groove bottom surface is the shortest, and the O-ring and each contact surface can achieve the sealing purpose.

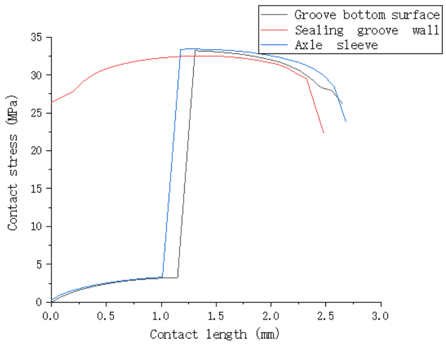


Figure 6 o-ring and stress curve of each contact surface

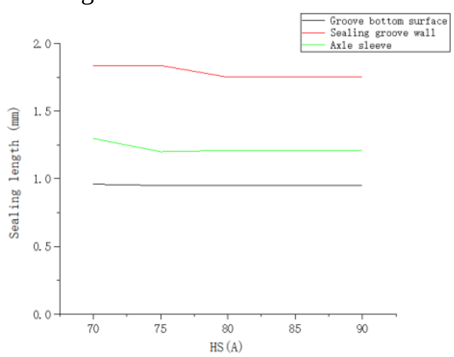


Figure 7 seal length

III. Conclusion

The finite element analysis of the mechanical properties of O-rings with different hardness was carried out by Abaqus software. The influence of different hardness on the sealing performance in static sealing was discussed. The following conclusions were obtained through analysis.

(1) When the O-ring is not under pressure, the maximum Mises stress and the maximum contact stress increase with the increase of the hardness of the O-ring. The greater the hardness, the better the initial sealing performance; the O-ring is under pressure. When the hardness has little effect on the maximum Mises stress of the O-ring, the maximum contact stress increases with the increase of the hardness.

(2) The sealing length of the O-ring when pressed is not changed with the hardness change.

(3) The greater the hardness of the O-ring, the greater the equivalent pressure.

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Mingjun Xu, master of engineering, senior engineer of oil and gas field development of CNPC; In July 1996, I graduated from China University of geosciences with a bachelor's degree in petroleum and natural gas geological exploration. In 2013, I obtained a master's degree in petroleum and natural gas engineering from southwest petroleum university and a master's degree in engineering. Since starting work, I have been engaged in oil recovery management, production management, gas recovery management and other related work, and engaged in oil and gas recovery engineering, trial production, development, production, operation management and other business. As a key member, I participated in the production capacity construction projects of key projects of the group 93 new wells in the gas field were put into operation on site, with a new natural gas production capacity of 9.24 billion cubic meters and cumulative gas production exceeding 32 billion cubic meters. Responsible for deep big north block well integrity management, the formation of "SanChao" integrity in whole life cycle of gas well control technology, establish a solid shaft integrity management idea, sets up the whole life cycle for hierarchical control, fine control pressure, points and measures to improve the level switch well, take the lead in segmentation barrier components, establish linkage mechanism, from the source, scientific analysis, accurate judgment, extend the life of the shaft safety. Won 2 provincial awards, published 1 international paper, 8 domestic core journal papers, 1 invention patent, 10 utility model patents.