On the Contact Behavior Analysis and New Design of O-ring Seals

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This paper presents contact behavior of an Polyperfluoroalkoxyethylene(PTFE) ring seals by a non-linear finite element method using the thermomechanical analysis. PTFE elastomer was assumed as odgen model for numerical analysis in FEM commercial code because elastomer has nonlinear behaviour character. The shape effects are investigated for sealing performance of ring seal in boundary conditions which are gas pressure, groove temperature and various O-ring seal models. Also contact stress and equivalent total strain are investicated. An O-ring seals was modeled four shape which are circle, two sunflower and X. The highest contact stress occurs at sunflower-ring seal with groove deapth of 0.35mm. the equivalent total strain of sunflower-ring seal is lower than that of the others under low gas pressure condition but under gas pressure condition over 4Mpa, that of sunflower-ring seal is higher. The calculated FEM results shows that the Sunflower-ring seal with groove depth of 0.35mm has excellent performance compared with other seal models.

Keywords : Nonlinear Behavior, Odgen model, contact stress, Sunflower Shaped ring

1. INTRODUCTION

Elastomeric O-rings are used as pressure (or vacuum) seals to prevent the leakage of gas. Elastomeric O-ring seals for static and dynamic sealing functions are capable of undergoing large deformations under compression.

The leakage of elastomeric O-ring seals will occur when the pressure differential across the seal just exceeds the initial peak contact stress between two contact surfaces. Typically, an O-ring seal restrained by rectangular grooves cannot perfectly prevent the leakage of gas through the sealing interface between the surface of the O-ring and that of its groove wall. This may be explained by simulating non-even distributions of compressive stresses at the contact surface of an O-ring seal. The finite element analysis associated with the compression of elastomeric torroidal O-ring seals been studied many researchers[1-2]

The sealing performance of an elastomeric O-ring has been analyzed in terms of the gas pressure. The thermomechanical distortions that develop in compressed O-ring seals, in common case of restrained geometry, are investigated using the finite element method.

Up to now mechanical seals are used with maximum pressure of 3Mpa. Rotating shaft and conventional radial shaft seals are used under pressure condition of 1Mpa at low sliding velocity. but O-ring for static sealing can apply up to 15Mpa.[3]

So, in this study, gas pressure is up to 12Mpa as ring shape. A numerical method was used to investigate the contact stress and the equivalent total strain of a ring seal which has four design.

2. COMPUTER SIMULATION

2.1 Material Properties

The Polyperfluoroalkoxyethylene (PTFE) is resistant to most liquids and it is more stable to temperature condition among elastomer material. But it is very difficult to analyze correctly because it's behavior is nonlinear. Thus it is desirable that elastomer assumed to Mooney-Rivlin and Odgen model.

Strain energy function of Ogden model is below.

$$W=\sum_{n=1}^{N}\frac{\mu_n}{\alpha_n}[J^{\frac{-\alpha_n}{3}}(\lambda_1^{\alpha_n}+\lambda_2^{\alpha_n}+\lambda_3^{\alpha_n}-3)+4.5K(J^{\frac{1}{3}}-1)^2$$

μ_n and α_n are material constant, K is the initial bulk modulus, and J is the volumetric ratio which is defined by $J=\lambda_1\lambda_2\lambda_3$ when λ_i is equal to $1+\varepsilon_i$. N is the number of terms take into account in the Odgen models.

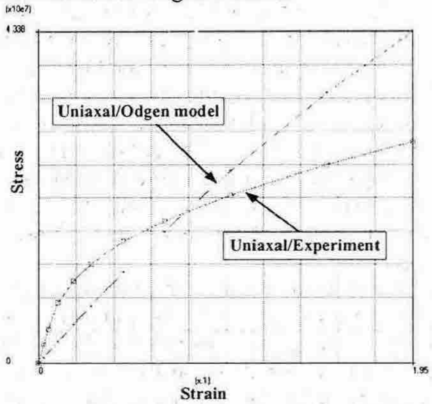

Fig. 1 Experimental stress-strain curve for PTFE and fitting curve of Odgen model with 2nd terms for nonlinear analysis for elastomer

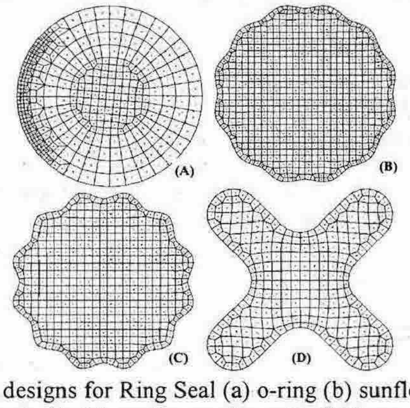

Fig. 2 New designs for Ring Seal (a) o-ring (b) sunflower-ring with 0.2mm depth (c) sunflower-ring with 0.35mm depth (d) x-ring

Fig. 1 shows the fitting curve ogden model of PTFE for nonlinear Finite element analysis. The stress-strain curve was gained from compressive experiment.[4] Experimental curve is fitted ogden 2-term material model. The uniaxial response of ogden material model is a little different from that of the experiment but it is acceptable. The ogden coefficients come in pair, the moduli, μ_i, are 3.3646e^{10}, -6.36017e^{9}, and the exponents, α_j, are 4.90239e^{-3}, 4.55973e^{-3}.

2.2 FEM Models and Boundary Conditions

Fig. 2 shows the FE meshes of the existing models and the new design for an ring seal. The element type for FE analysis is a four node, isoparametric arbitrary quadrilateral for axisymmetric incompressible application.

A ring is described by the ogden 2-term material model. Young`s modulus of PTFE ring seal is 460MN/m^2 ,thermal expansion coefficient was set to 135μmm/mm at temperature 100°C, and density is 2190kg/m^3.

The thermomechanical distortions of an elastomeric ring seal due to a gas pressure have been analyzed using a non-linear FEM program MARC[5]. A cross-section of an ring seal is about 7mm and clearance is about 0.1778mm. The compression ratio for ring seal is 10% and the temperature of a groove wall and upper plate are kept at 100℃. Gas pressure increased from 1Mpa to 12Mpa.

3. RESULT AND DISCUSIONS

In figure 3, FEM results show that contact stress distributions under high gas pressure in terms of geometries of ring seal. As a result, contact area of the sunflower-ring is smaller than that of the o-ring. Also contact area of the x-ring is as small as the sunflower-ring but the x-ring has large deformations. Thus, maximum contact stress occurred at the sunflower-ring.

In fig. 4, a contact stress of ring seal is showed in terms of geometries of ring seal and pressure conditions. The o-ring stands gas pressure of 10Mpa. The sunflower-ring stands gas pressure of 12Mpa and maintains high contact stress level. but x-ring allowed under gas pressure of 4Mpa because excessive contact occurred at edge of x-ring which is showed in dash circle in fig. 3.

In fig. 5, equivalent total strain distributions are presented in terms of geometries of ring seal. The equivalent total strain distribution of a o-ring is wide but those of the sunflower-ring and x-ring are concentrated on small contact area. So the equivalent total strain distribution of a sunflower-ring is larger than that of a o-ring. This means that the sealing performance can be improved by means of concentration of deformable area under condition of equivalent compression ratio.

4. CONCLUSIONS

The FEM results as geometries of the ring seal using thermomechanical analysis have been presented. The maximum contact stress occurred at the sunflower-ring with groove depth of 0.35mm. and the equivalent total strain distribution of that is concentrated at small area. also sunflower-ring stands gas pressure of 12Mpa and maintains high contact stress level. Conclusively, the sealing performance of the sunflower-ring is superior to the others.

5. REFERENCES

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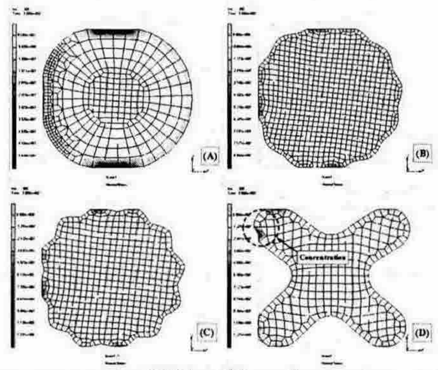

(a) o-ring ; gas pressure 10Mpa (b) sunflower-ring ; groove depth of 0.2mm, gas pressure 12Mpa (c) sunflower-ring ; groove depth of 0.35mm, gas pressure 12Mpa (d) x-ring ; gas pressure 7Mpa

Fig. 3 Contact stress distributions under high gas pressure

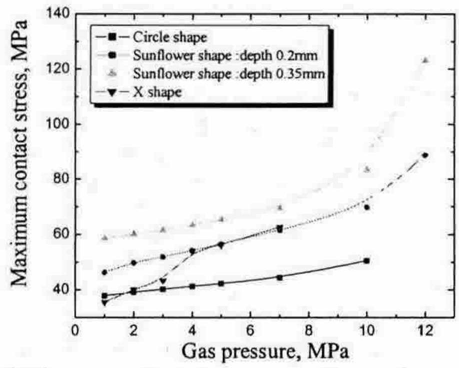

Fig. 4 Maximum contact stress on contact surface of o-ring seal as a function of gas pressure

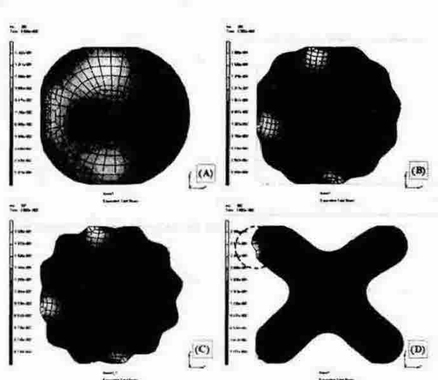

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Fig. 5 Equivalent total strain distributions under high gas pressure