Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

Effect of nitrile butadiene rubber hardness on the sealing characteristics of hydraulic O-ring rod seals

Xiaoxuan LI, Bingqing WANG, Xudong PENG, Yuntang LI,
Xiaolu LI, Yuan CHEN, Jie JIN

Cite this as: Xiaoxuan LI, Bingqing WANG, Xudong PENG, Yuntang LI, Xiaolu LI, Yuan CHEN, Jie JIN, 2024. Effect of nitrile butadiene rubber hardness on the sealing characteristics of hydraulic O-ring rod seals. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 25(1):63-78.
https://doi.org/10.1631/jzus.A2200612

Theoretical models

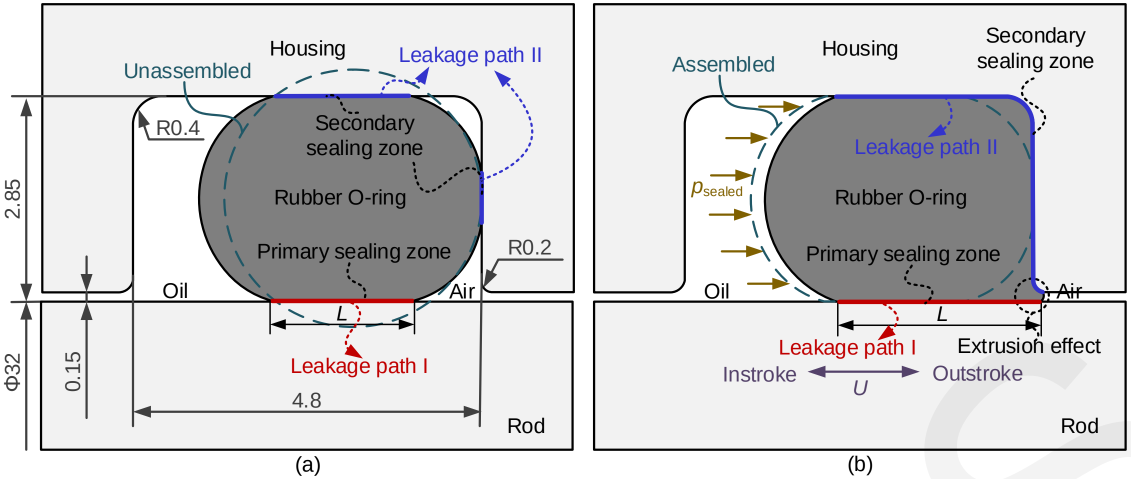
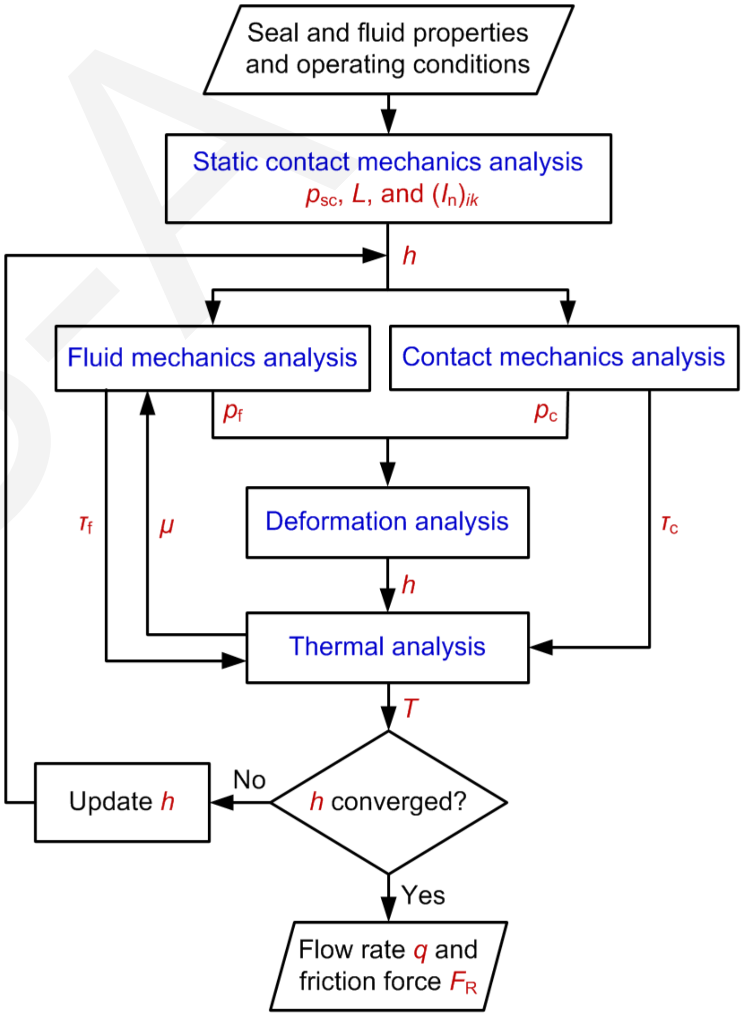


Fig. 1. Geometry of a hydraulic O-ring rod seal without (a) and with (b) sealed pressure (p_{sealed}) (Unit: mm).

Tab. 1. Mooney-Rivlin parameters of NBR under different Shore A hardnesses

H (Shore A)	E (MPa)	G (MPa)	C_{10}	C_{01}
60	3.62	1.21	0.48	0.12
65	4.44	1.48	0.59	0.15
70	5.54	1.85	0.74	0.18
75	7.08	2.36	0.94	0.24
80	9.39	3.13	1.25	0.31
85	13.23	4.41	1.76	0.44
90	20.93	6.98	2.79	0.70


Seal and fluid properties and operating conditions

Static contact mechanics analysis

p_{sc}, L, and $(l_n)_{ik}$

h

Fluid mechanics analysis

Contact mechanics analysis

p_f

p_c

τ_f

μ

Deformation analysis

τ_c

h

Thermal analysis

T

h converged?

No

Update h

Yes

Flow rate q and friction force F_R

Fig. 2. Flowchart of the mixed lubrication model.

Effect of rubber hardness on static mechanical properties

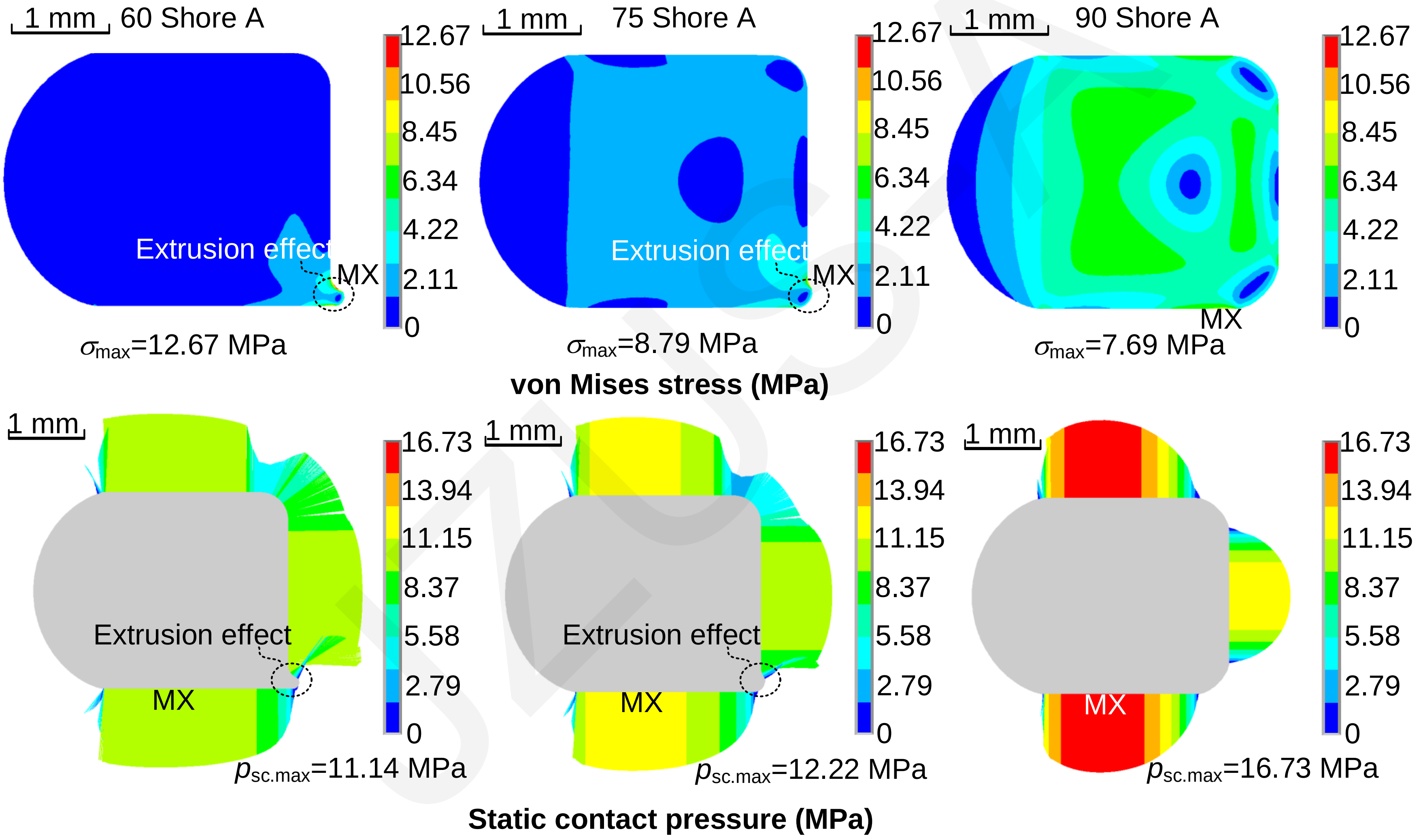
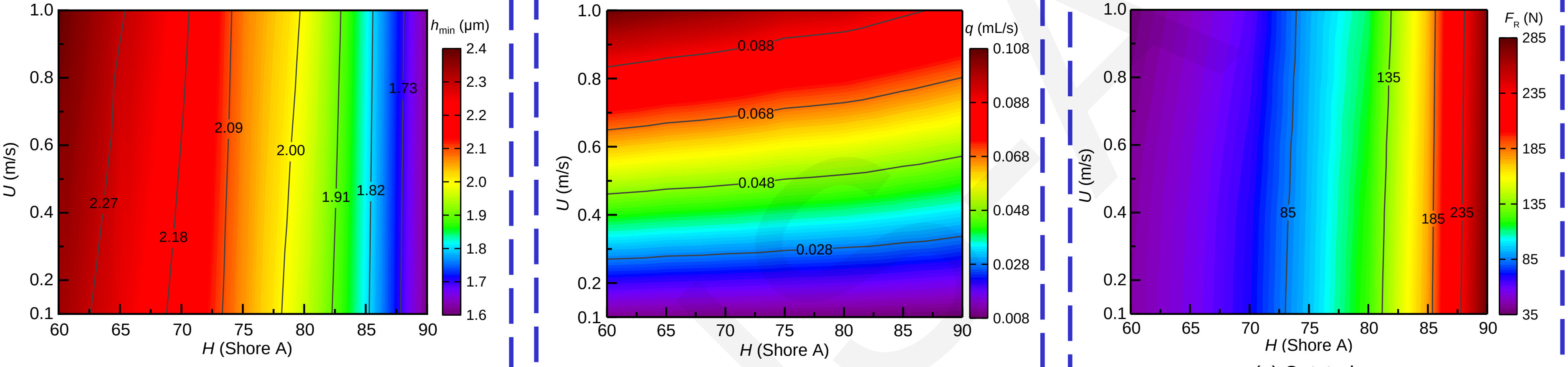


Fig. 3. The distributions of von Mises stress and static contact pressure under different rubber hardnesses.

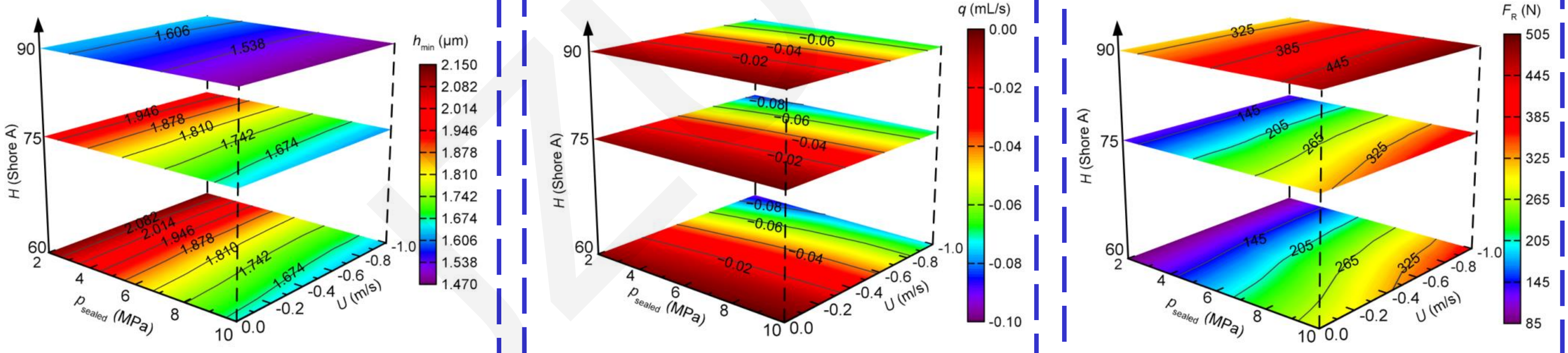
Effect of rubber hardness on dynamic sealing performances



(a) Outstroke

(a) Outstroke

(a) Outstroke



(b) Instroke

(b) Instroke

(b) Instroke

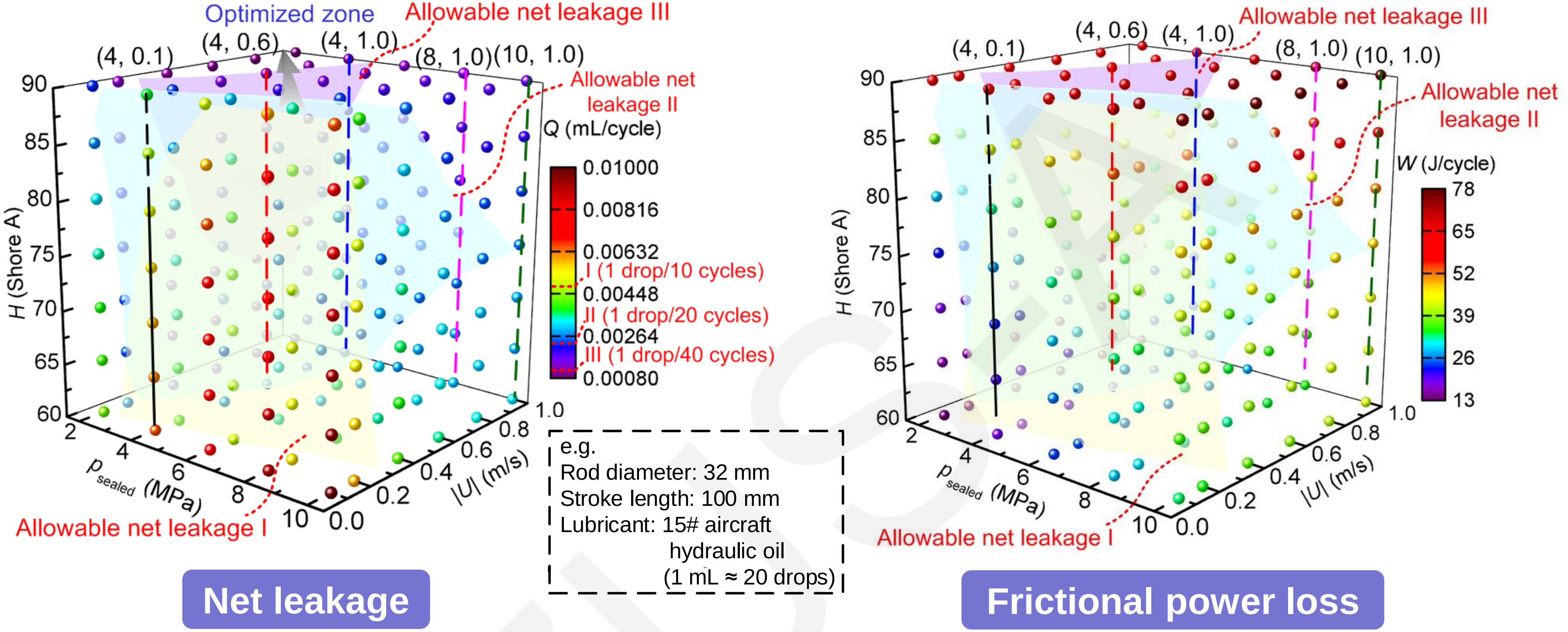
Minimum film thickness

Flow rate

Friction force

Fig. 4. Effect of rubber hardness on the minimum film thickness, flow rate and friction force during outstroke and instroke.

Optimized selection of rubber hardness



e.g.
Rod diameter: 32 mm
Stroke length: 100 mm
Lubricant: 15# aircraft hydraulic oil
(1 mL ≈ 20 drops)

Net leakage

Frictional power loss

Fig. 5. Optimized rubber hardness of allowable net leakage and minimum frictional power loss under different operating conditions.

- **the optimum rubber hardness is the minimum value meeting the leakage standard.**

Multi-component regression

$$Q = \mathrm{e}^{-1.41548} \cdot H^{-1.37225} \cdot p_{\mathrm{sealed}}{}^{0.54922} \cdot |U|^{-0.52995}$$

$$W = \mathrm{e}^{-7.59330} \cdot H^{2.43012} \cdot p_{\mathrm{sealed}}{}^{0.42556} \cdot |U|^{0.02534}$$

- **$|U|$ has the most significant effect on Q followed by p_{sealed} and H, while H has the most significant effect on W followed by p_{sealed} and $|U|$.**

Conclusions

- With the increase of rubber hardness, the resistance to deformation of the O-ring seal is enhanced, and then the static contact pressure is increased and the minimum film thickness is decreased, which is conducive to preventing leakage, but not conducive to reducing friction.

- The low rubber hardness seal is prone to the extrusion effect and induced stress concentration especially under high sealed pressure conditions and is recommend for use at high speed or on other occasions with low sealing requirements.

- The high rubber hardness seal has better dynamic and static sealing performances but with a high friction force. It is especially recommended for application under high pressure conditions. As far as possible, and under the premise of not exceeding the leakage requirements, low rubber hardness should be selected so as to reduce friction.