Study on Sealing Performance of Double Main Sealing Structure Premium for Threaded Connection

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Abstract

Aiming at the demanding requirements of sealing performance in ultra-deep oil and gas wells, a double main sealing structure consisting of conical surface to conical surface and cylindrical surface to spherical surface was designed based on the special thread sealing mechanism. Using numerical simulation method, the changes of contact stress and the contact length of the sealing surface under the four conditions of tensile, compression, tension and internal pressure, tension and internal and external pressures were analyzed. The results showed that the seal of the threaded joint under the limit load performance, get the joint sealing ability with different load changes. The full-scale test results show that the sealing performance of the double main seal premium threaded joint meets the application requirements.

Keywords

premium threaded; contact stress; sealing structure; sealing performance; full-scale test.

1. Introduction

With the development of oil extraction technology, premium threaded oil casing Connections have been widely used in the development of deep wells, ultra-deep wells and high-pressure gas wells at home and abroad [1]. The design of special connection s overcomes the limitations of the API connection 's own performance by using multi-level sealing with anti-rotation shoulders and independent sealing surfaces[2], thus providing better sealing performance. The common air seal structure of premium threaded is mainly spherical to cylindrical, conical to conical, conical to spherical and spherical to spherical in all 4 structures. Due to the complicated structure and variety of seals, the current researches on the sealing performance of metal-to-metal seal structures mainly use theoretical research [3-6], finite element method [7-10] and experimental method [11-14]. In the existing research, the contact gas pressure distribution of the premium thread sealing surface is mainly used to describe the performance of the thread gas sealing by means of the finite element method, however, the full-size test result is lacking to verify its accuracy, research is focused on the single main seal structure, the study of multi-level seal is less.

For this reason, a double main sealing structure consisting of conical surface to conical surface and cylindrical surface to spherical surface was designed based on the special thread sealing mechanism. Using numerical simulation method, the changes of contact stress and the contact length of the sealing surface under the four conditions of tensile, compression, tension and internal pressure, tension and internal and external pressures were analyzed. The safety of the threaded connection under the limit load is studied. Finally, the gas seal performance of the double main seal special threaded joint was verified through full-scale test, and the research content provided reference value for the design and application of multi-level sealing premium threaded connection.

2. Seal theory

According to the fluid mechanics, fluid passes through the gap produced by the local resistance depends on the leakage path length and cross-sectional area clearance, when the greater the contact area of the contact stress, the cross-sectional area of the gap is, the smaller [15], can be expressed as

$$\Delta R \propto \int p_c dl \tag{1}$$

The resistance is equivalent to the cumulative contact stress along the leakage path l.

Therefore, the critical sealing pressure of the contact surface p_{cr} can be expressed as

$$p_{cr} \leq K \int p_t dl \tag{2}$$

Under the condition that the metal-to-metal sealing surface is completely smooth, the condition of preventing internal fluid leakage is that the contact pressure on the sealing surface is greater than the pressure of the internal fluid. However, under the influence of actual metalworking, it is difficult to ensure that the sealing surface is completely smooth, so there is still a slight gap between the sealing surfaces even when interference fit is achieved [16]. From equation (2), it can be concluded that the critical sealing pressure at the contact surface is proportional to the contact pressure and the length of the leakage path. Therefore, maximizing the sealing surface of the contact pressure and contact area to improve the sealing performance. But the increase of contact stress easily leads to the sealing surface stress exceeding the yield limit of the material, resulting in plastic failure or stress corrosion; as the contact area increases, the contact stress decreases, and the sealing effect of the connection under complicated conditions is difficult to guarantee. Therefore, it is of great significance to study the performance of metal sealing surface under different loads.

3. Finite element modeling

3.1 Geometric model

Premium threaded connection for the specifications of φ88.9mm × 6.45mm, and thread is carrying surface modified buttress thread for -5 °. Due to the smaller helix angle of the connection, ignoring the influence of the helix angle on the calculation results, the two-dimensional axisymmetric model was used for the finite element modeling [17]. In order to ensure the accuracy of the calculation, considering the Saint-Venant effect, the model takes the distance from the small end of the pipe body to the vanishing point of the pipe as the length of the pipe body. Double main seal connection modeling is shown in Fig. 1.

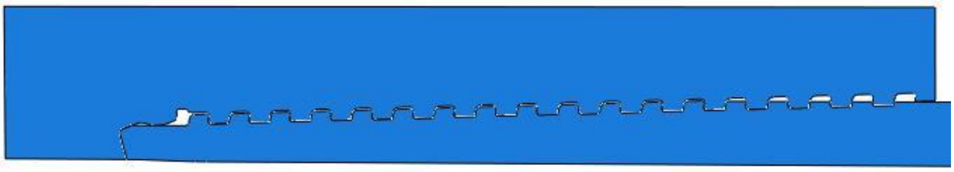

Fig. 1. Geometric model of double main sealing connection

The grid uses CAX4I four-node bilinear axisymmetric quadrilateral solid elements to divide the model and refine the grid on the double main sealing surface, the anti-torque shoulder and the threaded connection. The detailed double main sealing surface partial meshing is shown in Fig. 2.

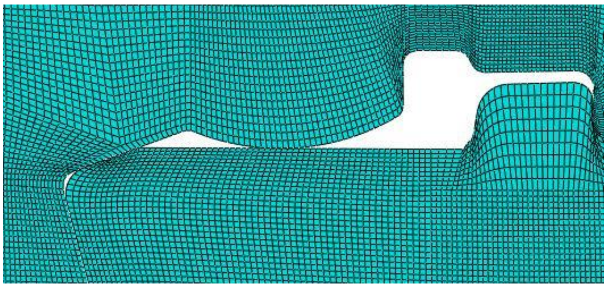

Fig. 2. Partial meshing of sealing surface

3.2 Material properties

The connection is made of 2Cr13 material and heat treated to API L80 grade. The samples treated with the furnace were measured to obtain the tensile strength, yield strength and elongation, the results are shown in Table 2. It can be seen from "Mechanical Design Handbook" that the elastic modulus of alloy steel 2Cr13 is 206GPa and the Poisson's ratio is 0.3. Coulomb friction is used for the contact between the metal sealing surfaces in the model, and the friction coefficient is 0.02 [18].

Table 1 Mechanical properties of materials

Yield strength σ_s /MPa	Tensile strength σ_s /MPa	Elongation δ / %
618	750	20

3.3 Boundary conditions

According to the symmetry of the threaded connection, the axial displacement of the symmetry plane of the connection is zero, so the axial displacement constraint is imposed on each node of the symmetry plane of the joint, which is radial free. The working conditions of the oil well are complex. The load on the threaded connection under different conditions is also different, which affects the sealing performance of the connection. On the basis of effective simulation of connection, the axial compression load, axial tensile load, axial tensile load + internal pressure, axial tensile load + internal pressure + external pressure in 4 conditions are analyzed. Table 2 shows the specific loading conditions.

Table 2 Loading conditions

Condition	Number	Axial load F_a/kN	Internal pressure p_1 /MPa	External pressure p_0 /MPa
1	1	300	0	0
	2	600	0	0
	3	900	0	0
2	4	-300	0	0
	5	-600	0	0
	6	900	10	0
3	7	900	30	0
	8	900	50	0
4	9	900	70	0
	10	900	50	50

4. Calculation results and analysis

4.1 Sealing performance analysis under axial tensile load

In service underground, the tubing joint will be subjected to greater tensile loads, increasing the possibility of leakage of the threaded joint seal. After the connection was made-up, the double main sealing surface of the connection was applied to three kinds of 300,600,900kN tensile loads in working condition 1 respectively in the axial direction, the contact stress and the contact length distribution curve between the cylindrical surface and the conical surface are obtained, as shown in Fig. 3 and Fig. 4.

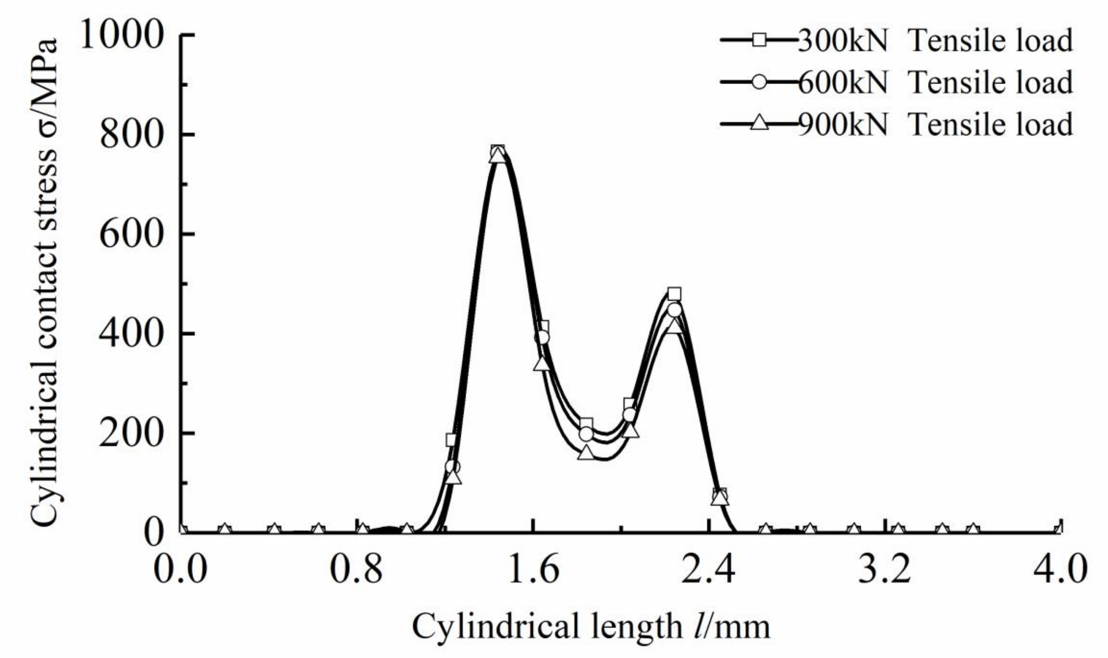

Fig. 3. Cylindrical contact stress distribution under tensile load

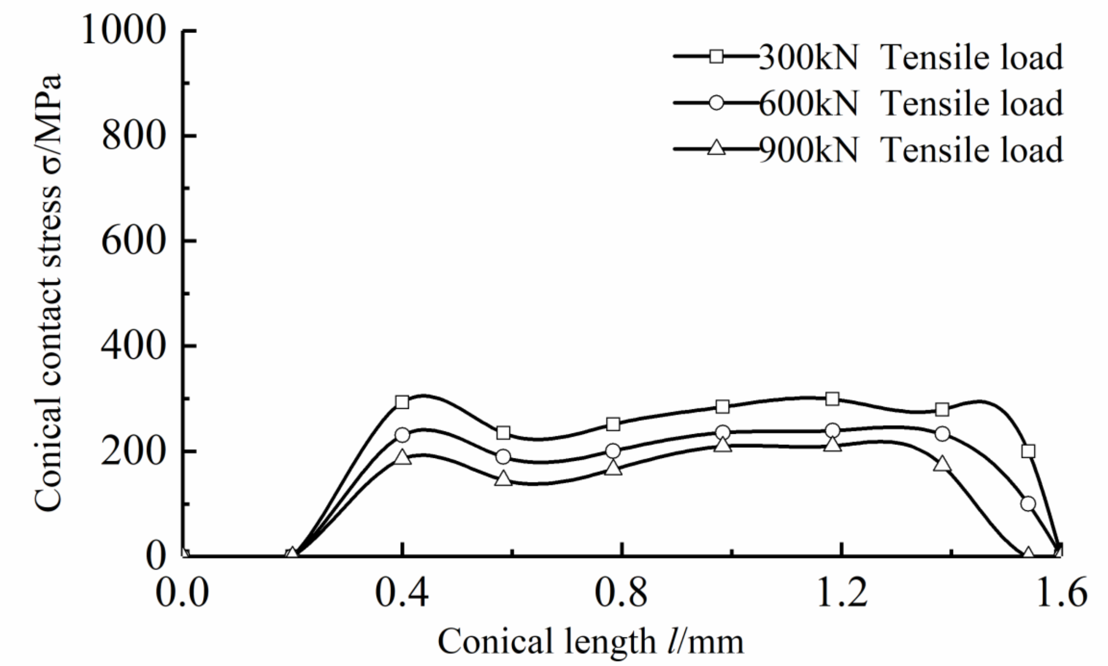

Fig. 4. Conical contact stress distribution under tensile load

As shown in Fig. 3, while the axial tensile force increases, the contact stress and contact length of the cylindrical seal to the spherical seal slightly decrease. Under 900kN axial tension, the maximum contact stress of the cylinder seal is 411.2kN, which is 85.8% of the maximum contact stress (479.2kN) of the cylindrical seal under 300kN tension; and the contact length (1.2mm) is basically consistent with the contact length under 300kN tension.

As shown in Fig. 4, the contact stress and contact length of the conical surface to the conical sealing structure decrease with the increase of the axial tensile load. However, the conical surface contact stress and contact length decrease faster than the cylinder. At 900kN axial tension, the maximum contact stress of the conical seal was 210.3kN, which is 70.3% of the maximum contact stress (299.2kN) of the tapered seal at 300kN tension; and the contact length (0.98 mm) is the contact at 300kN tension 85.9% of length (1.14mm). Conical seal contact stress and contact length in the axial pull down faster, and its lower sealing reliability.

4.2 Sealing performance analysis under axial compressive load

From the analysis of the string mechanics, it is concluded that the tubing connection has complicated forces in the well, the axial tensile load of the connection at the well head and the axial compressive load of the connection at the bottom of the well. In accordance with the requirements of condition 2, the double main sealing surface of the connection are respectively subjected to an axial compressive load of 300,600kN, the contact stress and the contact length distribution curve between the cylindrical surface and the conical surface are obtained, as shown in Fig. 5 and Fig. 6.

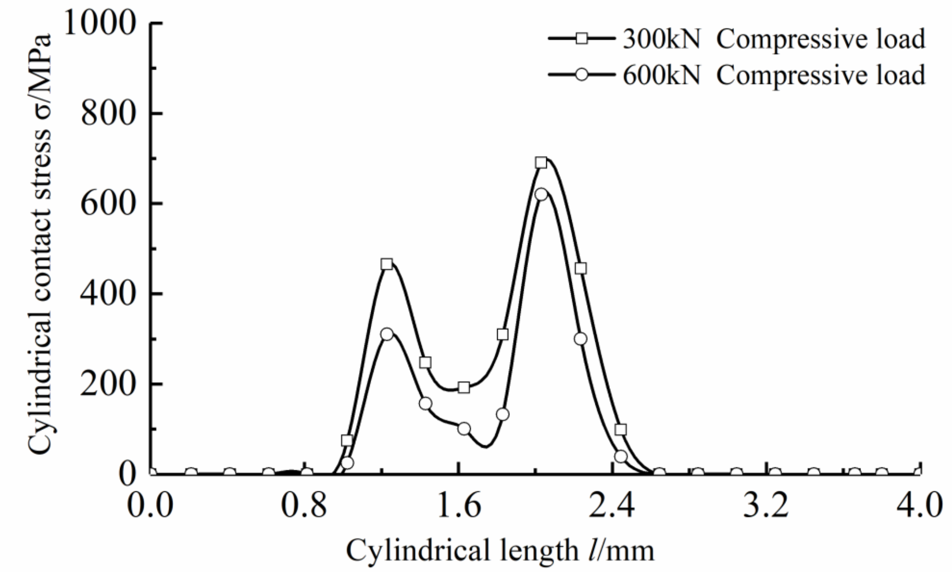

Fig. 5. Cylindrical contact stress distribution under compressive load

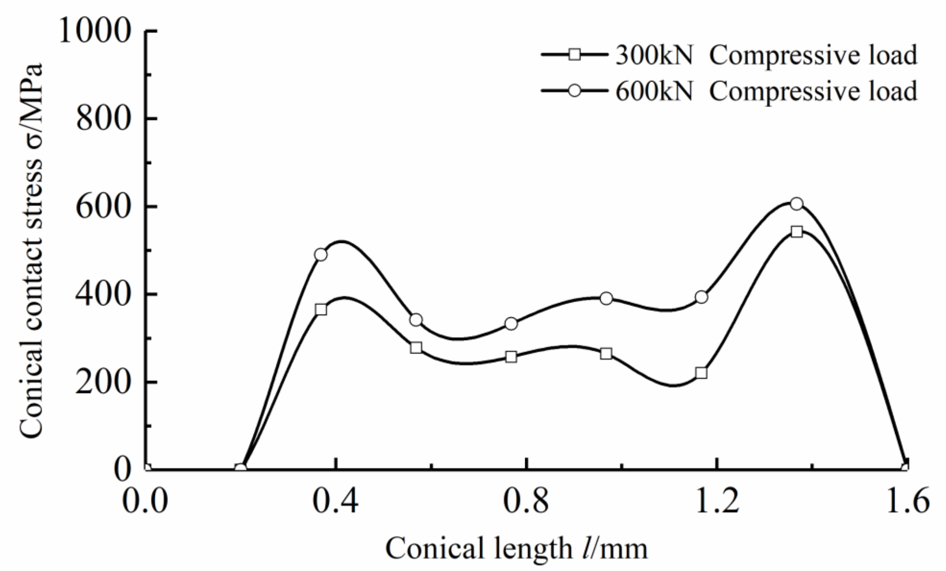

Fig. 6. Conical contact stress distribution under compressive load

As shown in Fig. 5, the contact stress and contact length of the cylindrical seal decrease with the increase of the axial compressive load. When subjected to compressive load, the contact stress of the cylinder seal increased sharply with the increase of the distance from the cylinder surface, then rapidly decreased and then rapidly increased, finally dropped to 0, the stress curve showed two obvious peaks. Under 600kN compressive load, the cylindrical seal contact length of 1.4mm, the maximum contact stress of 620MPa, which exceeds the yield limit of the material and is prone to bonding.

As shown in Fig. 6, the contact stress of the conical seal increases with the increase of the axial compressive load, and the maximum stress of the conical contact occurs at the sealing surface far away from the shoulder. Under 600kN compressive load, the maximum contact stress of the conical seal is 605MPa, close to but not exceeding the yield limit of the material, the sealing surface has not failed.

4.3 Sealing performance analysis under axial tension and internal pressure

According to the requirements of the working condition 3, the double primary sealing surface of the connection is first subjected to an axial tensile force of 900kN, and then the pressure of 10, 30, 50 and 70 MPa respectively is applied on the inner surface of the connection, the contact stress and the contact length distribution curve between the cylindrical surface and the conical surface are obtained, as shown in Fig. 7 and Fig. 8.

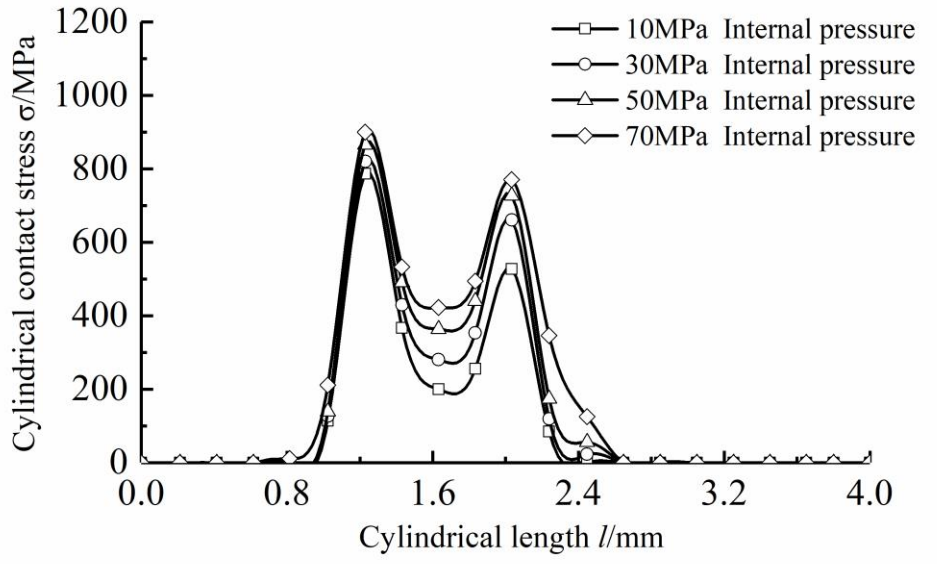

Fig. 7. Cylindrical contact stress distribution under compressive load and internal pressure

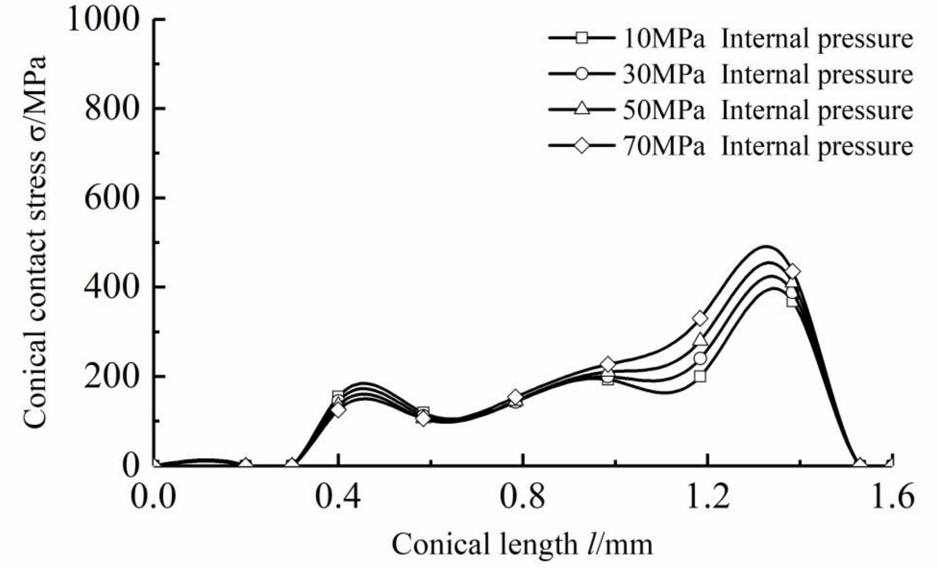

Fig. 8. Conical contact stress distribution under compressive load and internal pressure

As shown in Fig. 7 and Fig. 8, both the contact stress and the contact length of the cylindrical and conical sealing structure increase with the increase of internal pressure. Under the high pressure of 70MPa, the peak value of the contact stress of the cylinder seal is 900MPa and the sealing surface is more likely to bond; the contact length of the conical seal is 1.2mm and the maximum contact stress is 434MPa, far below the yield limit of the material. Therefore, the double main seal joint has good sealing performance when the axial tensile load and the internal pressure load act together.

4.4 Sealing performance analysis under axial tension and internal and external pressure

According to the requirements of working condition 4, firstly apply 900kN axial tensile load to the double main sealing surface of the connection, and then apply internal pressure and external pressure of 50MPa to the pipe body, the date of the cylindrical-to-spherical and Conical -to- Conical sealing surface is obtained. The data obtained in case 4 and the data obtained in cases 3-8 are plotted on two curves according to cylinder and cone respectively, as shown in Fig. 9 and Fig. 10.

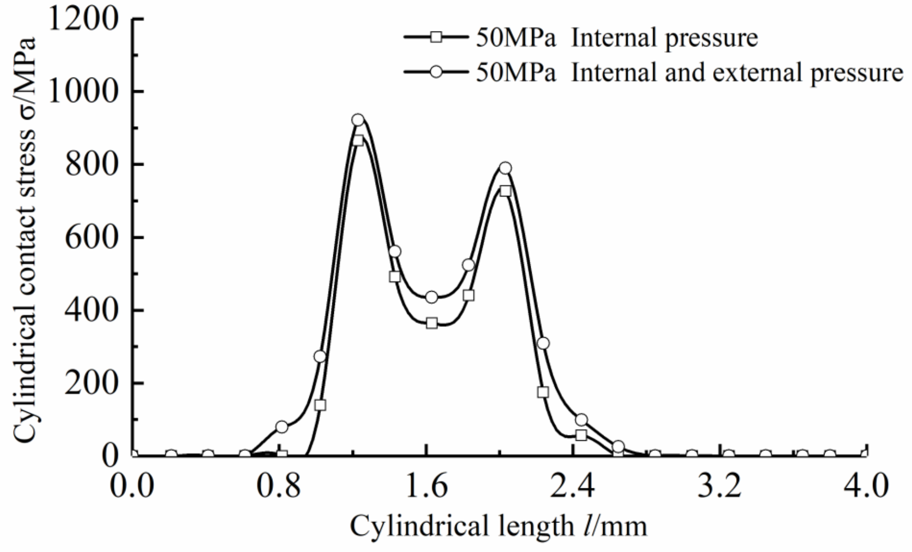

Fig. 9. Cylindrical contact stress distribution under compound load

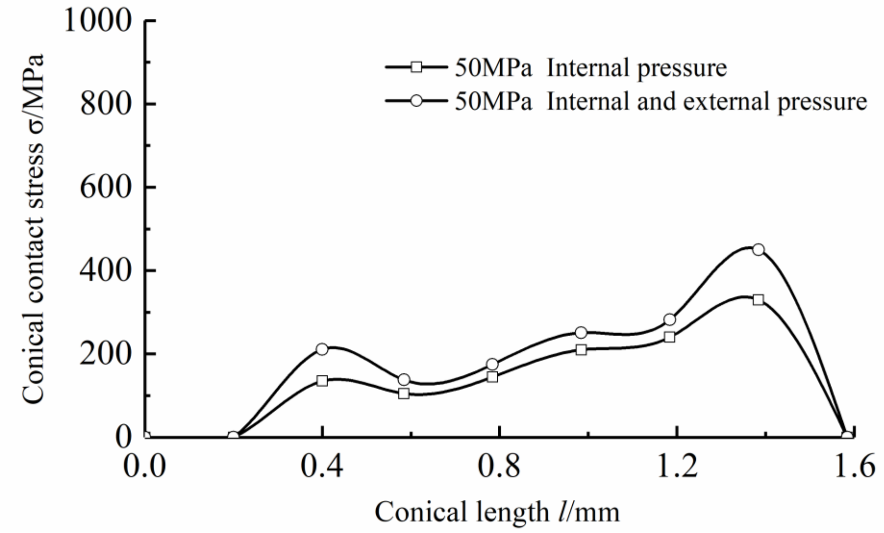

Fig. 10. Conical contact stress distribution under compound load

From Fig. 7, 8, 9 and 10, it can be seen that under the action of external pressure, the contact pressure and the contact length of the sealing surface of the double main sealing connection cylinder and the conical surface both increase. Under 900kN axial tension and 50MPa internal and external composite load, the cylindrical seal contact length is 1.8mm, about 1.24 times the contact length (1.45mm) under 900kN axial tension and 50MPa internal pressure composite load; the conical length (1.38mm) is about 1.2 times the contact length (1.16mm) under 900kN axial tension and 50MPa internal pressure combined load. Under the compound load, the maximum contact stress of cylinder seal is 921MPa, which exceeds the yield limit of the material. The maximum contact stress of the conical seal is 450MPa, far less than the yield limit of the material. In summary, the composite main seal joints have longer seal length and lower peak stress under combined axial and internal pressure loads, which not only ensures excellent sealing performance but also reduces the possibility of galling.

5. Full-scale test

The use of special CNC machine tools, processed out of this composite main seal threaded joints, randomly selected three samples for gas seal test, in strict accordance with the APIRP5C5 standard specimen selection.

The main contents of the test threaded parameters testing, geometry measurement, on the shackle test, gas seal test. The hydraulic tongs were used for 10 cycles of unloading, then the gas seal test was performed on the joints according to the APIRP5C5 standard.

Fig. 11 shows the morphology of samples after testing of the connection. The test results show that the connection of the two main sealing surface are not bonded phenomenon, while the gas sealing performance to meet the APIRP5C5 standard requirements, the maximum test pressure reaches 72MPa.

Fig. 11. The morphology of samples after testing

6. Conclusion

A double main sealing structure consisting of conical surface to conical surface and cylindrical surface to spherical surface was designed. Finite element analysis shows that the axial tensile load has no obvious effect on the cylinder seal, but it will significantly reduce the sealing performance of the cone seal; axial compressive load can reduce the sealing performance of cylinder sealing, but can improve the sealing performance of cone sealing; to a certain extent, the internal pressure and external pressure can enhance the sealing effect of cylindrical and conical sealing surface, but result the cylindrical seal in yield failure possibly.

Double main seal premium threaded connection in the axial tensile, axial compression, axial tensile + internal pressure, axial tensile + internal and external pressure four conditions, the contact stress distribution of the sealing surface is even, the contact length is long, the contact stress peak is small, the sealing surface is not easy to produce the adhesion failure and the seal is reliable.

The conclusion of the finite element analysis is verified by the full-size test, which proves that the double main seal connection has good gas sealing and anti-stickiness performance.

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