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Effects of Modified Polytetrafluoroethylene (PTFE) on the Performance of Pan-plug Seal at Different Temperatures

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Abstract: Tensile and compression tests on pure PTFE, 10% carbon fiber PTFE and 20% carbon fiber PTFE were carried out on the universal material testing machine at three temperatures of 20°C, 60°C and 90°C, accepted the tensile elongation and tensile strength of this material at different temperatures. Finite element analysis is performed on pan plug seals made of three materials at different temperatures and 105 MPa. The simulation results show that when the maximum Mises stress of the outer lip of the three materials increases to a certain amount, an inflection point will appear, and the maximum Mises stress increase before the inflection point is large after the inflection point, the Mises stress increment gradually decreases. The higher the carbon fiber content, the greater the maximum Mises stress value of the lip; as the temperature increases, the seals of the three materials are less prone to tensile failure; the material with less carbon fiber content, the less stretched. When the valve stem moves up and down, the stress value of the inner lip changes more than the stress value of the outer lip; the upward stroke is conducive to the realization of the seal; the part near the end of the inner lip is more affected by the movement of the valve stem. This article provides a certain basis for the selection of pan plug seals.

Keywords: Carbon Fiber PTFE, Tension and Compression Test, Pan Plug Seal

1. Introduction

Since it was put into industrial production in the 1950s, polytetrafluoroethylene (PTFE) has been widely used in machinery, petrochemical, aerospace and many other fields with its excellent properties [1]. Polytetrafluoroethylene (PTFE) is an important organic fluorine material and has the title of "Plastic King" [2]. The molecular structure of polytetrafluoroethylene (Figure 1) is a completely symmetrical linear, unbranched, non-polar polymer, and its structure and constituent elements determine the excellent properties of polytetrafluoroethylene. Polytetrafluoroethylene has a high degree of chemical stability, is inert to almost all common chemicals, and has a wide applicable temperature range (it can be used in the temperature range of -190°C~260°C, even at the ultra-low temperature of minus -190°C, it still has a certain degree of flexibility), extremely low surface tension, the surface energy of PTFE is the smallest among all currently known solid materials, and its surface tension is only 0.019N/m, excellent lubricity, excellent Anti-aging performance and anti-radiation performance, excellent thermal stability [3-10].

Teflon itself also has some shortcomings, such as poor thermal conductivity, easy cold flow, and insufficient tensile and compression resistance. By adding modification to improve the overall performance of PTFE, so that it can be widely used in more complex working conditions. Through the method of compounding principle, PTFE is compounded with other materials to improve the deficiency of PTFE. The main methods of modification are: surface modification, filling modification, blending modification, etc. [11]. Carbon fiber (CF for short) is a new type of fiber material with high strength and high modulus fiber with a carbon content of more than 95% [12-14]. Because of its high strength, high hardness, good shock absorption performance, and physical Stable performance and other characteristics, often used to fill PTFE materials. Domestic scholar Shi Yanling came to the following conclusions after research:

(1) With the increase of carbon fiber filling, the tensile strength and elongation of PTFE have decreased, and the hardness and compressive strength have increased.

(2) With the increase of carbon fiber filling, the friction coefficient of PTFE decreases slightly, and the width of wear scars decreases.

(3) Carbon fiber-ink filled PTFE, carbon fiber filling content of about 15%, graphite filling content of 3% ~ 5% production of composite materials, used to make composite seals, guide support rings, etc., used in reciprocating and rotating conditions, It is superior to other PTFE composite materials under water lubrication conditions [15].

Carbon fiber modified polytetrafluoroethylene materials have greater strength while retaining the advantages of pure polytetrafluoroethylene, high and low temperature resistance, low friction, and chemical inertness [16-17]. This paper studied the influence of pure PTFE, 10% carbon fiber PTFE and 20% carbon fiber PTFE as sealing materials on the sealing of pan plug seals at different temperatures. First, the constitutive model of PTFE and its modified materials is determined through uniaxial tension and compression tests, and then the Abquas finite element numerical simulation method is used to simulate the sealing performance of the pan plug seals of different materials at a pressure of 105MPa and different temperatures.

2. Uniaxial Test

In the tensile test, the equipment is a universal material testing machine, a constant temperature heating furnace, an infrared thermometer, etc., as shown in Figure 1. The universal material testing machine model is CTM6104, the maximum load is 100KN, the relative error of large deformation is within 0.50%, the vertical movement speed of the beam is between 0.001~500mm/min, and the speed accuracy is within 0.1% of the set value.

Figure 1. *Experiment apparatus.*

Tensile tests were conducted under the conditions of 20°C, 60°C and 90°C. The test materials were pure polytetrafluoroethylene (PTFE), 10% carbon fiber modified polytetrafluoroethylene (10C-PTFE) and 20% carbon fiber modified polytetrafluoroethylene (20C-PTFE), three samples for each material are prepared at each temperature, the test piece was made into a dumbbell shape according to the national standard, the tensile speed was 100mm/min, and the test would stopped when the test piece was broken.

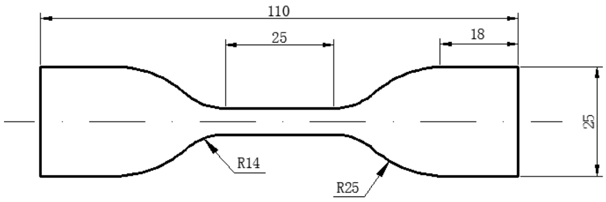


Figure 2. *Tensile Size.*

Figure 3. *Tensile specimens.*

Table 1 shows the elongation at break and tensile strength of the three materials at different temperatures. It can be seen from the table that as the temperature increases, the elongation at break of PTFE and its modified materials will increase but the tensile strength will decrease. Among them, pure PTFE materials are the most obvious. The material performance parameters of PTFE itself, such as tensile strength, elongation, and thermal expansion coefficient, will change with the change of temperature, showing a kind of rheology [18], a seal made of PTFE There will be corresponding results. At 90°C, 10% carbon fiber modified polytetrafluoroethylene has the largest elongation at break and tensile strength.

Table 1. *Material tensile strength and elongation at break at different temperatures/.*

	20°C	**60°C**	**90°C**
PTFE	28.2MPa 81%	25MPa 253%	22.3MPa 266%
10C-PTFE	26.1MPa 184.2%	24.6MPa 274%	23.0MPa 297%
20C-PTFE	25.85MPa 83.95%	21.7MPa 205%	21.0MPa 226%

The universal material testing machine can also do uniaxial compression test. When the stress reaches 120MPa (higher than 105MPa sealing pressure difference), the pressure would stopped. No signs of damage can be observed except for the flattening of the specimen. It can be known that all three materials are Very pressure resistant.

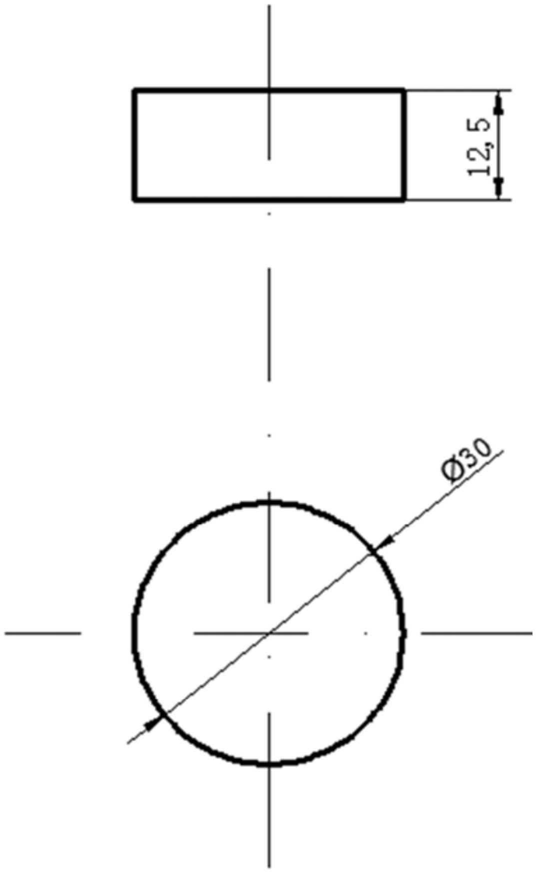


Figure 4. *Compressed specimen size.*

Figure 5. *Before and after compression of test piece (from left to right are PTFE, 10C-PTFE, 20C-PTFE).*

3. Finite Element Analysis

3.1. Finite Element Modeling

The pan-plug seal in this article is applied to the stem of a flat valve, and an axisymmetric simplified model is used in the finite element analysis. In order to make the simulation easier to converge, the real cross-sectional model is processed as: the contact surface of the valve stem and the valve body are overlapped to remove the gap, but the valve stem and the valve body are still two independent entities, which is convenient for subsequent dynamic seal simulation. Use the valve body to fill the gap size to ensure that the size of the sealing groove remains unchanged. In the model (Figure 6), the long rod on the left side of the seal is the valve stem, and the right part is the valve body sealing groove.

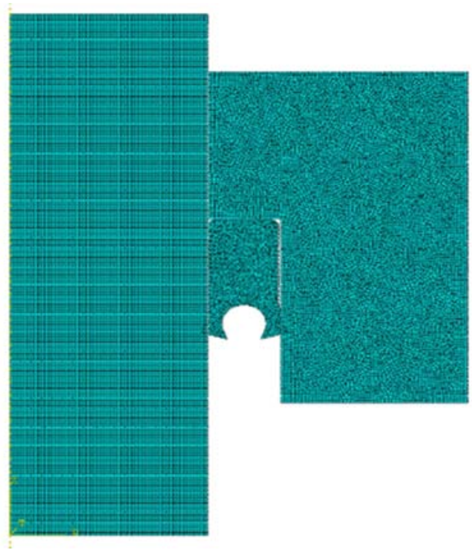


Figure 6. *Model grid.*

The grid of pan-plugging uses hybridization units. Since the friction coefficients of the three research materials are very close, the friction coefficient between the seal and the valve stem is unified to 0.19. In the analysis step, the geometrically nonlinear switch is turned on, the pressure loading surface is the part where the lip is in contact with the pressure, and the pressure is simplified as a uniform pressure perpendicular to the contact surface.

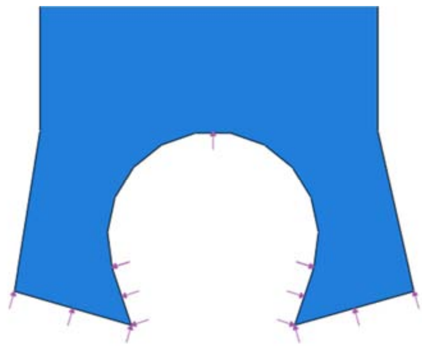


Figure 7. *Lip pressure loading method.*

In the model, the elastic modulus of the valve stem E=21600MPa, the Poisson's ratio μ=0.28, the elastic modulus of the valve body E=21000MPa, and the Poisson's ratio μ=0.3. The stress and strain data obtained from the tensile test are substituted into Abaqus. The material data is first fitted to determine its constitutive model, then the constitutive model is selected, and finally the material stress and strain data is substituted for simulation.

3.2. Simulation Result Analysis

The effective sealing part of the pan-plug seal is the lip, so the focus of this article is on the lip. Mises stress is the resultant stress in the equivalent sense. Generally speaking, where the Mises stress is larger and more concentrated, the object is more prone to damage. This part is often the place where the model deforms the most.

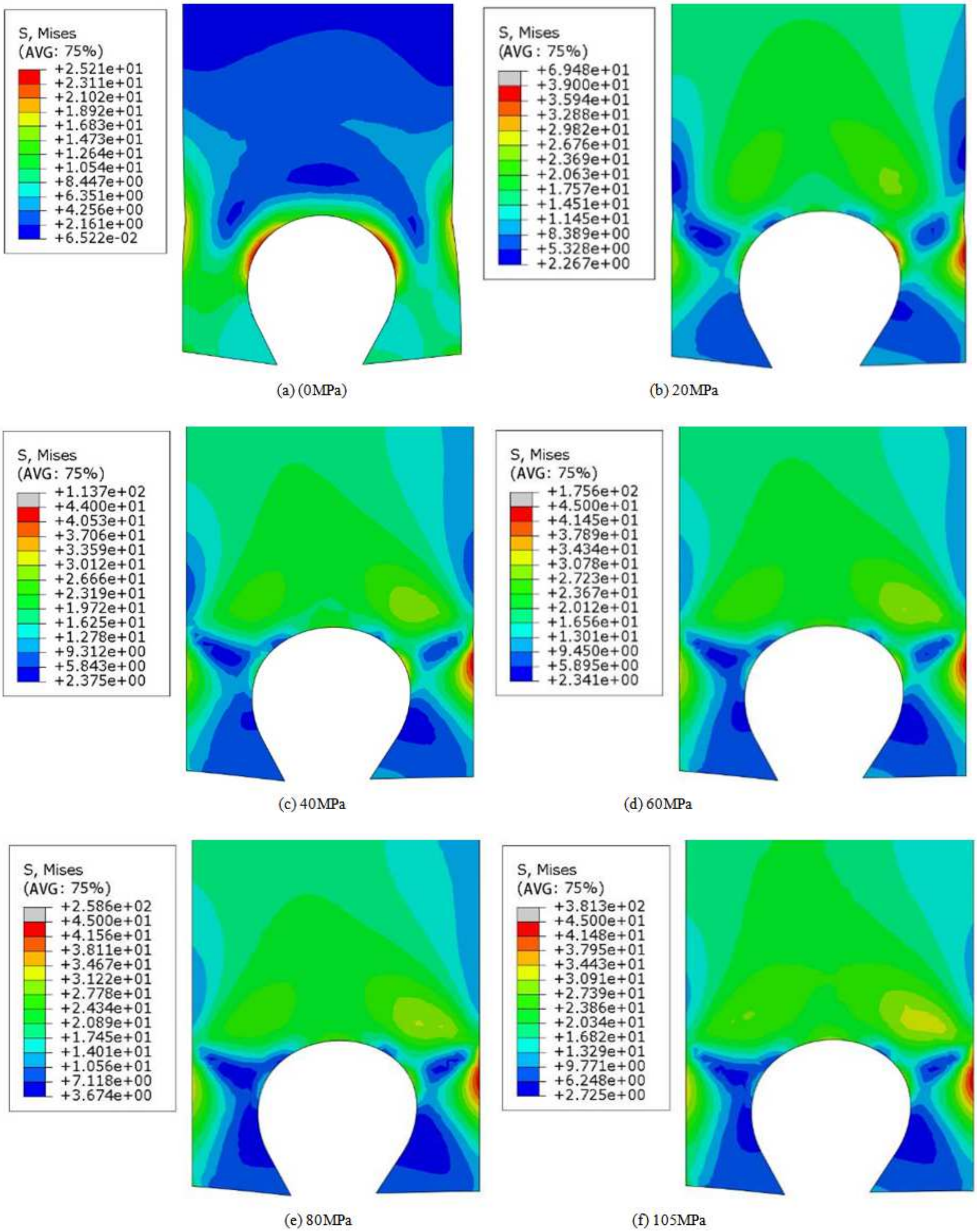


Figure 8. *Mises stress cloud diagram of 10% carbon fiber PTFE at 20°C.*

Figure 8 is the Mises stress cloud diagram of a pan plug made of 10C-PTFE at 20°C. It can be seen from Figure 9 that the maximum Misses stress of the three pan-plug seals all appeared at the outer lip (the red box in the figure). Make a path at the most likely damage position outside the outer lip, as shown in Figure 10, then output the Mises value on the path, and select the maximum Mises stress value under each pressure to form Figure 10.

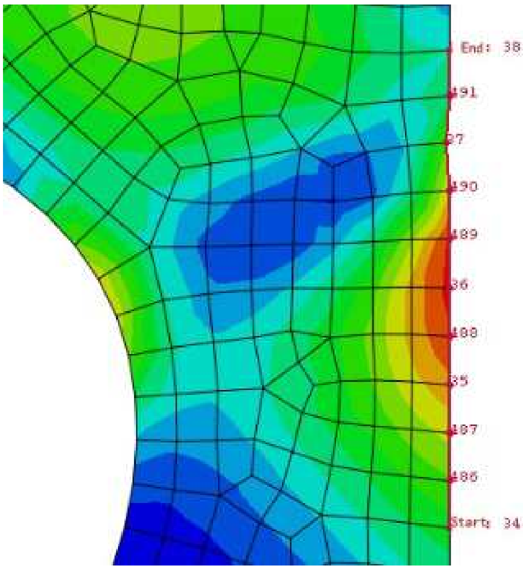
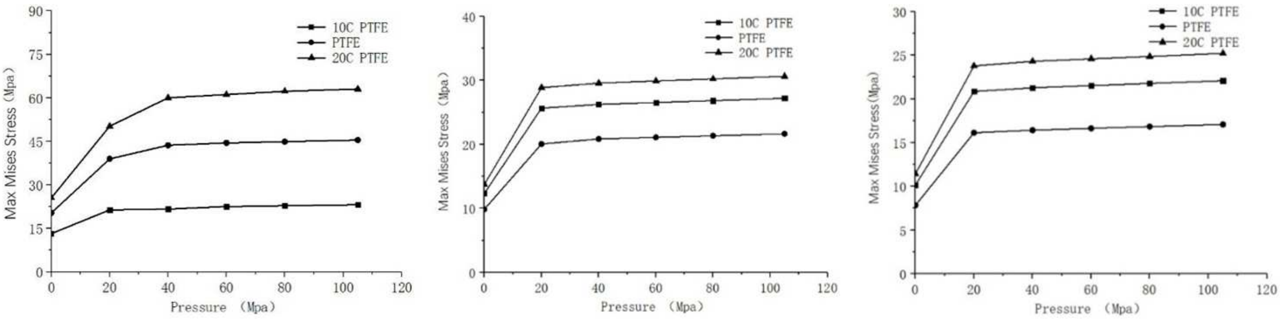


Figure 9. *Outer lip research path.*



(a) 20°C (b) 60°C (c) 90°C

Figure 10. *The maximum Mises stress curve at each temperature of the outer lip.*

It can be seen from Figure 10:

(1) The curves of the three materials are similar. When the maximum Mises stress of the outer lip of the three materials increases to a certain amount, an inflection point will appear. The maximum Mises stress increases with the pressure difference before the inflection point. After the inflection point, the Mises stress increases with the pressure difference. The increment is small.

(2) As the temperature increases, the maximum Mises stress of the seals made of various materials decreases monotonically.

(3) The higher the carbon fiber content, the greater the maximum Mises stress value.

The compression deformation of the seal is divided into two stages:

(1) Deformation from compression to complete compression.

(2) Complete compression stage. Through uniaxial tensile and compression tests on the seal material, it can be known that the tensile strength of the PTFE and its two carbon fiber modified materials studied in this paper are between 23-28 MPa at 20°C, and with the temperature increasing, the tensile strength is slightly decreased, but the compressive strength of the three materials is very large (see the uniaxial compression test for details). Therefore, when analyzing the equivalent pressure, we should pay attention to the stretching area, which is the negative equivalent pressure value area.

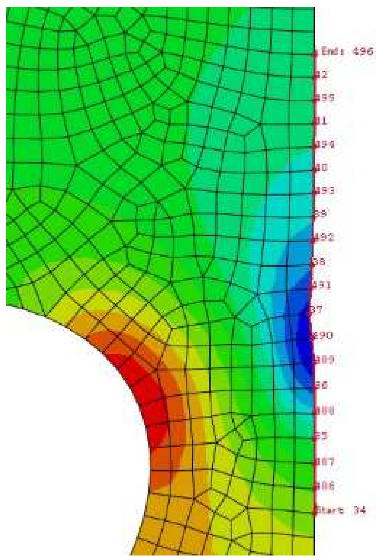


Figure 11. *Equivalent pressure research path.*

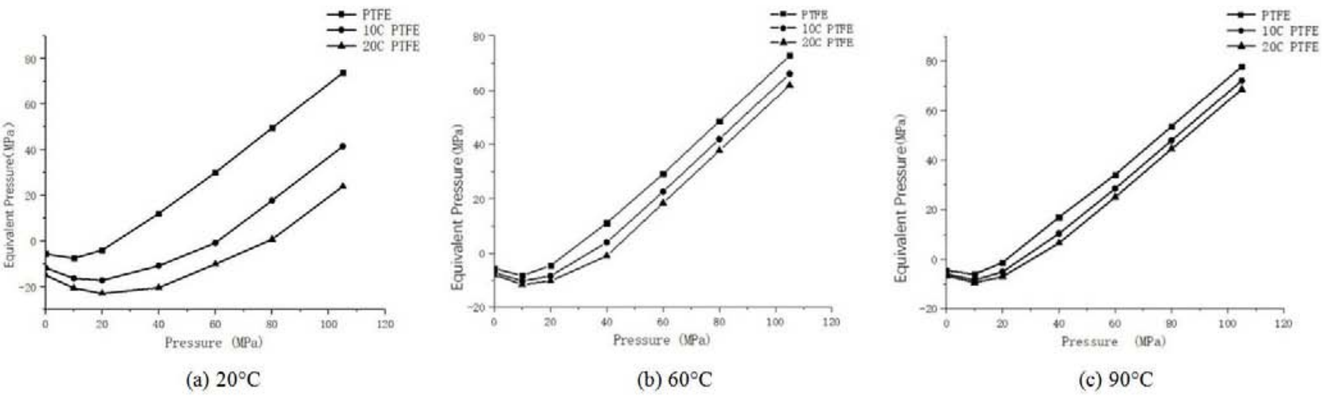


Figure 12. Curve of equivalent stress of outer lip at various temperatures.

From Figure 12, it can be concluded that the pressure difference at which the seals of each material are most likely to be damaged by tension, as the temperature increases, the seals of the three materials are less likely to be damaged by tension. At 20°C, the seal made of 20% carbon fiber modified PTFE material is the most affected by stretching, and the tensile strength of this material at this temperature is the smallest among the three materials; the less carbon fiber, the degree of stretching smaller.

3.3. Analysis of Sealing Performance of Pan Plug Seal

There are two main indicators that affect the sealing. The first is the contact stress. The contact stress of the sealing part is greater than the applied pressure. The second is to have a contact length sufficient to meet the contact stress requirements. The cross-section of the pan-plug seal studied in this paper was not symmetrical, and the inner and outer lip should be paid attention to when studying the sealing performance analysis.

After analyzing the statics of the model, the contact stresses of the inner lip and outer lip are extracted respectively (only the part exceeding 105MPa is shown), as shown in Figure 13 and Figure 14. As the temperature rises, the contact stresses of the inner and outer lips of the pan plug seals of the three materials decrease, and the stress of the PTFE material drops significantly; the inner and outer lips of the three materials have a certain sealing length, and the contact stress is greater than the external pressure of 105MPa, which can be used in static sealing. Meet the sealing requirements.

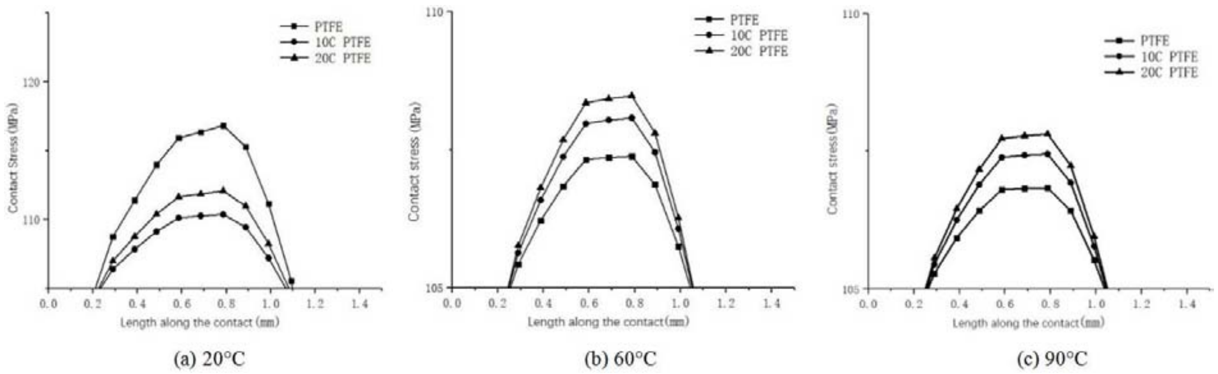


Figure 13. Contact stress curve of inner lip.

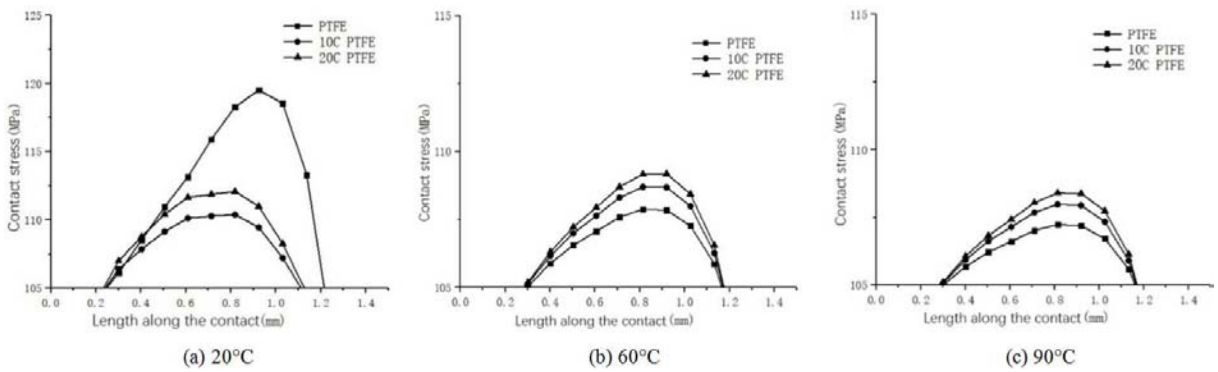
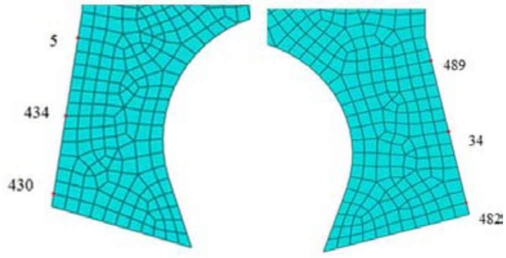


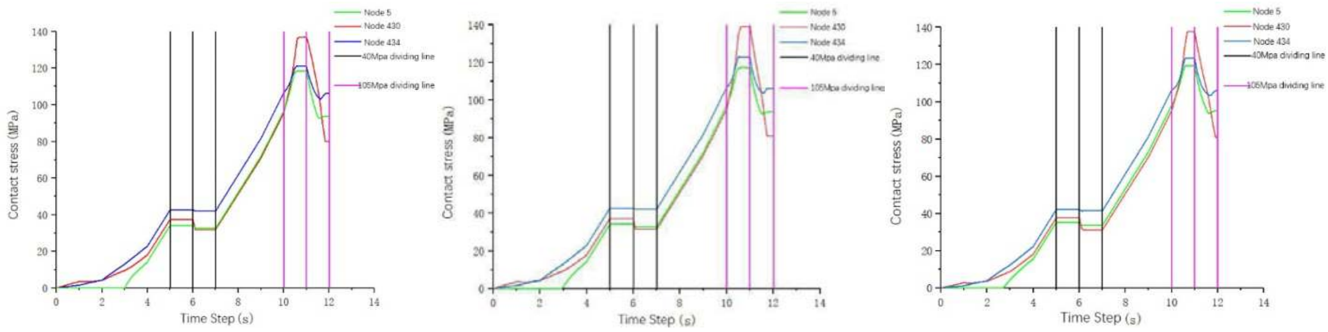
Figure 14. Contact stress curve of outer lip.

When the plate valve is switched on and off, the valve stem and the pan plug seal produce axial relative displacement, which requires the designed sealing ring not only to meet the static sealing, but also to meet the reciprocating sealing. When the pan plug seal is in a dynamic sealing state, the seal will be affected by the movement of the valve stem, which will affect the sealing performance of the pan plug seal, and severely cause the seal to leak. Take three nodes on the inner and outer lips of the finite element model seal to output the contact stress and find out the change distribution law.

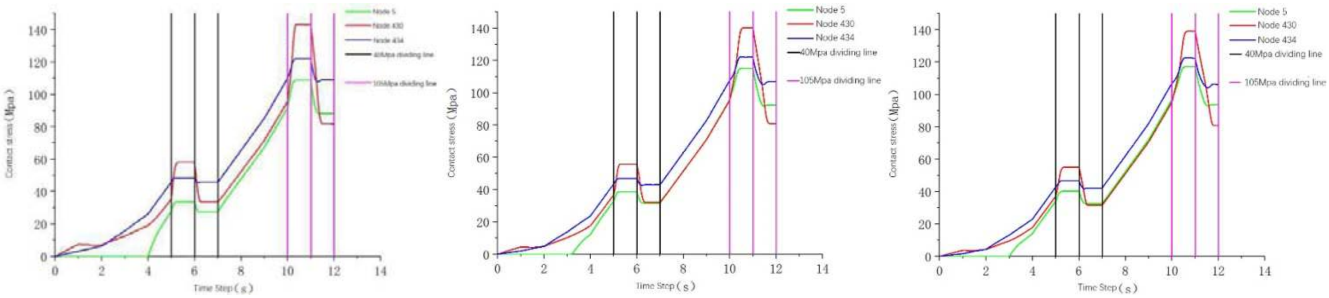


(a) Inner lip (b) Outer lip

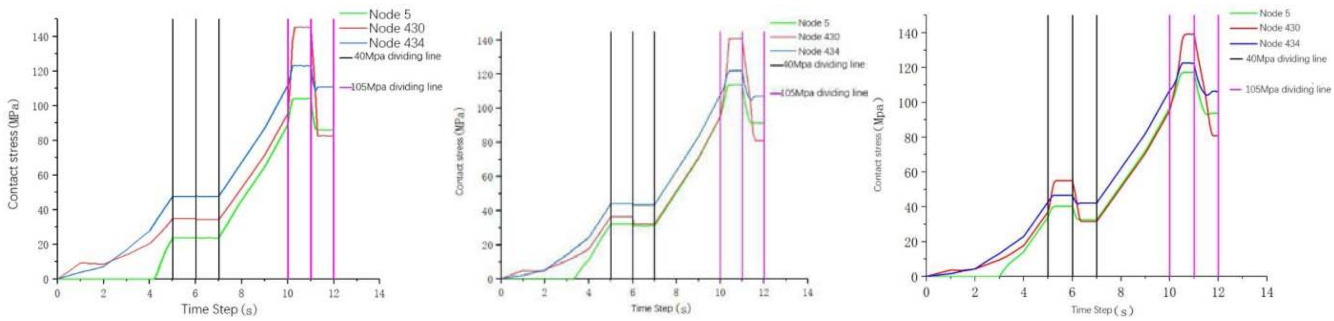
Figure 15. *Inner and outer lip nodes.*



(a) PTFE pan-plug seal (20°C, 60°C, 90°C)



(b) 10C-PTFE pan-plug seal (20°C, 60°C, 90°C)

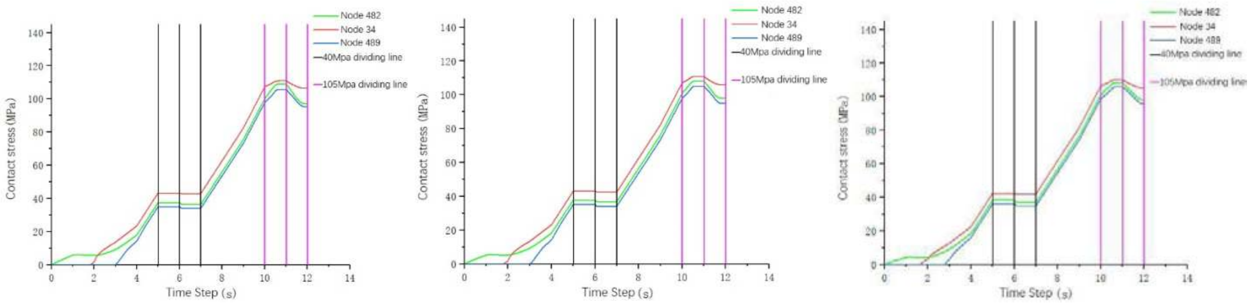


(c) 20C-PTFE pan-plug seal (20°C, 60°C, 90°C)

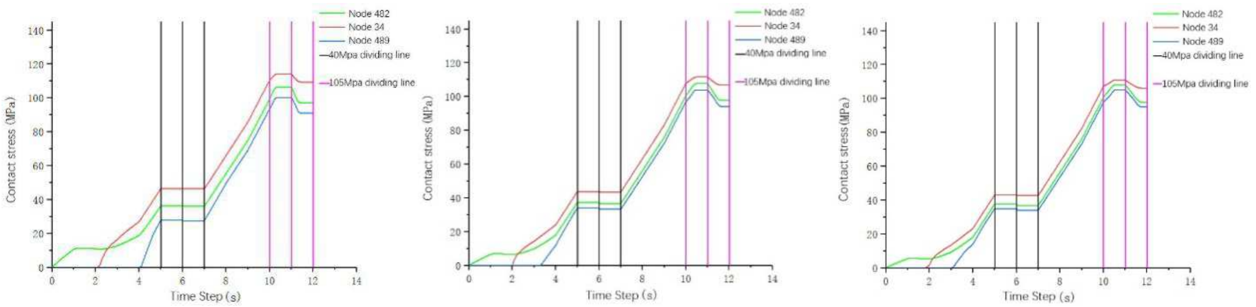
Figure 16. *Contact stress curve diagram of inner lip three-point dynamic seal.*

Figure 16 is the output curve of the contact stress history of the three nodes of the inner lip during dynamic sealing. In the finite element analysis, the valve stem moves up and down at 40MPa and 105MPa respectively, that is, the valve stem first moves up in a time step of 5 to 6 seconds, and moves down to the initial position within a time step of 6 to 7 seconds. The external pressure is 40MPa. In a time step of 10 to 11 seconds, the valve stem first performs an upward stroke, and a downward stroke in a time step of 11 to 12 seconds to return to the initial position, the external pressure is 105 MPa, and the remaining time steps are in a static sealing state. It can be seen from Figure 16 that at the same temperature, the stresses of the three nodes of the inner lip have roughly the same change over time. The node stress value will gradually increase during the upstroke and reach the maximum value in the stroke. During the upstroke, it is beneficial to seal the external pressure. The node stress value will first decrease from the maximum value at the end of the upstroke during the downstroke stage. In the 105MPa downstroke, the stress values of No. 5 and No. 434 nodes decreased to the minimum and then increased slightly. In the 105MPa up and down stroke, the stress value of No. 430 node changes the most, followed by No. 434, and finally No. 5, that is, the node closer to the end of the inner lip, the greater the impact of valve stem movement.

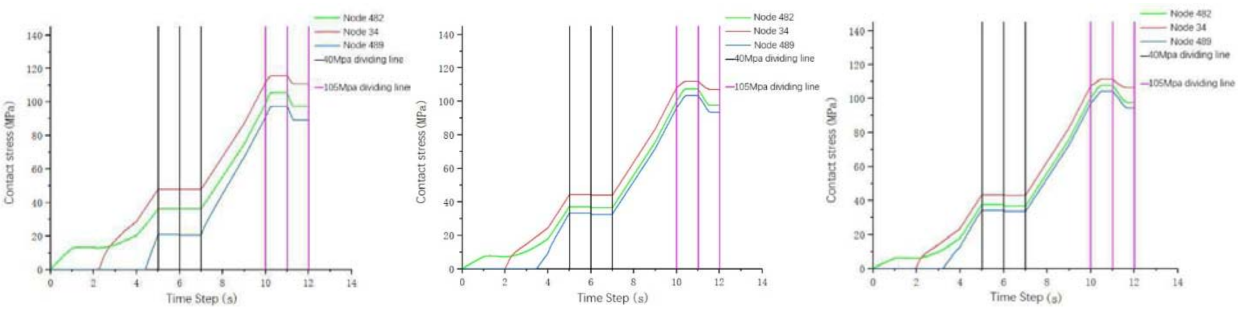
Figure 17 is the history output curve of the contact stress of the three nodes of the outer lip during the dynamic seal. The contact stress of the three nodes remains unchanged after entering the 40MPa upstroke, and the stress value remains unchanged after entering the 40MPa downstroke. In the upper stroke of 105 MPa, the contact stress value of the three points of the outer lip will gradually increase, and then reach the maximum value. At 105 MPa, the stroke stress value gradually decreases and remains almost unchanged. The stress values of the three nodes of the outer lip vary much more moderately than those of the three nodes of the inner lip. There is no stress rebound phenomenon in the stress values of the three nodes of the outer lip during the 105MPa down stroke.



(a) PTFE pan-plug seal (20°C, 60°C, 90°C)



(b) 10C-PTFE pan-plug seal (20°C, 60°C, 90°C)



(c) 20C-PTFE pan-plug seal (20°C, 60°C, 90°C)

Figure 17. *Contact stress curve diagram of outer lip three-point dynamic seal.*

4. Conclusion

(1) Through tensile and compression tests, the changes in tensile strength and elongation at break of the three materials with temperature and carbon fiber content are determined. No signs of damage can be observed for the three materials except for the flattening of the specimen under 120MPa pressure.

(2) When the maximum Mises stress of the outer lip of the three materials increases to a certain amount, an inflection point will appear. The maximum Mises stress before the inflection point increases with the pressure difference, and the Mises stress increase gradually decreases after the inflection point. The higher the carbon fiber content, the material, The greater the maximum Mises stress value of the lip.

(3) Point out the pressure difference at which the seals of each material are most likely to be damaged by tension. As the temperature increases, the seals of the three materials are less likely to be damaged by tension. The less carbon fiber, the less the degree of tension.

(4) When the valve stem moves up and down, the stress value of the inner lip changes more than the stress value of the outer lip. The upstroke is beneficial to the realization of the seal. The part near the end of the inner lip is more affected by the movement of the valve stem.

5. Prospect

By studying the sealing performance of modified polytetrafluoroethylene under high temperature and high pressure, it provides a theoretical study for the development of seals under 140Mpa. Follow-up can continue to study on the carbon fiber content of PTFE, and at the same time continuously increase the temperature and pressure of the experimental group to prepare for the development of 140Mpa seals.

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