EFFECT OF SEALING CLEARANCE ON SEALING PERFORMANCE OF A PACKING ELEMENT

[1]GANG HU, [2]LIMING DAI, [3]GUORONG WANG

[1,3]School of Mechatronic Engineering, Southwest Petroleum University, Chengdu 610500, China
[1,2]Industrial Systems Engineering, University of Regina, ReginaS4S 0A2, Canada

Abstract - This research aims to experimentally and numerically determine the optimal sealing clearance for a rubber packing element system used in a staged fracturing pipe string. A 3-D finite element model of the system with an asymmetric structure is established. Based on the experimental results, the constitutive relation for the rubber used in the system is quantitatively constructed with the parameters of the relation determined in the experiments of the research. The optimal sealing clearance is obtained on the basis of the finite element model established, such that the optimal sealing of the system can be reached with no negative effects applied on the rubber material. The results of the research provide guidance for designing packing element systems and to be used in fracturing and oil production.

Keywords - Compression packer; Packing element; Sealing clearance; Finite element simulation.

I. INTRODUCTION

Compression packer in the staged fracturing pipe string is a core component for achieving multi-stage fracturing technique[1]. During fracturing, damages occurred in packing element including shoulder extrusion, shoulder detachment, and shoulder crack, which triggers packer sealing failure. The major cause of sealing failure is that the unreasonable structural design cannot meet the requirement of practical working conditions [2]. Therefore, it is necessary to select appropriate methods for improving sealing reliability and safety.

In recent years, investigations concerning the sealing performance of packing element in compression packer have attracted a great deal of attention from numerous scholars. By using the integral Lagrange method, J. Fan et al. [3] constructed the calculation column of incremental nonlinear finite element mixing methodology of rubber-like materials with large displacement and strain, based on the principle of potential energy. Focusing on the stick-slip friction contact problem between the packing element and casing. S. Jia et al. [4] developed a numerical method to resolve the packing element fraction contact problem by adopting the penalty function in combination with the incremental analysis process of rubber's large deformation. K. Wu et al. [5] studied the relationship among the axial compression load, the maximum contact pressure and compression distance of packing element. V.L. Polonsky and A.P. Tyurin[6] discussed several structural design for improving sealing reliability of packing element by combining the working conditions of packing element in compression-set packer, resulting in a new structural scheme aiming at the packer applied in casing. At present, most research achievements are based on axisymmetric simulation models. In this paper, the hyperelastic constitutive model of rubberhas been optimized via experiments, and the packing-element system with 3D asymmetric structures was modeled. However, since the oil production practice and technology continue to develop, asymmetrical structures, including triangle grooves, neck bushes, and extrusion prevention parts, are being incorporated into packing element of packer.The effect of sealing clearance onsealing performance of packing element has been evaluated via the finite element method.

II. HYPERELASTIC CONSTITUTIVE RELATION OF RUBBER

Packing element of compression packer is made up by hydrogenated butadiene-acrylonitrile rubber. Without considering the time-dependent characteristics of rubber, the rubber can be regarded as a isotropic and incompressible complete hyperelastic material [7]. Based on the phenomenological theory of continuous medium, Yeoh constitutive model is as follow:

$$W = C_{10}(I_1 - 3) + C_{20}(I_1 - 3)^2 + C_{30}(I_1 - 3)^3 \quad (1)$$

where C_{10}, C_{20}, and C_{30} are the parameters of the constitutive model.

By referring to ISO 37:2011 and 7743:2011 [8,9], uniaxial tension and compression laboratory tests of the rubber material were carried out by a CMT6104 microcomputer-controlled electronic universal testing machine.According to the least squares method, the constitutive parameters were fitted, thus obtaining the parameters of Yeoh constitutive model are: .

III. NUMERICAL SIMULATION

3.1.Finite element model

Based on the working principle of compressionpacker, the sealing mechanism with 3D asymmetric structures has been constructed. The 7'' casing model is established inside the 3D model of packing-element system. Then imported the finite element software and completed relevant settings,

resulting in the accomplished finite element model as displayed in Fig 1. The external back band, internal back band, check ring, and inner bushing are set as steel 45, and the elastic modulus, Poisson ratio, and density are set as 209,000 MPa, 0.269, and 7890 kg/m3, respectively. The central pipe material is set as 40CrNiMoA, and the elastic modulus, Poisson ratio, and density are 209,000 MPa, 0.295, and 7870 kg/m3, respectively. The casing pipe is P110, and the elastic modulus, Poisson ratio, and density are 206,000 MPa, 0.269, and 7870 kg/m3, respectively. The cone is made of 42CrMo. Its elastic modulus, Poisson ratio, and density are 212,000 MPa, 0.280, and 7850 kg/m3, respectively. The rubber constitutive model is set according to the parameters described in Chapter 2. The friction coefficients are set as follows: the metal-metal friction coefficient is 0.1, the rubber-metal friction coefficient is 0.3, and the rubber-rubber coefficient is 0.4. At the same time, the quasi-static analysis method is adopted in order to save simulation time.

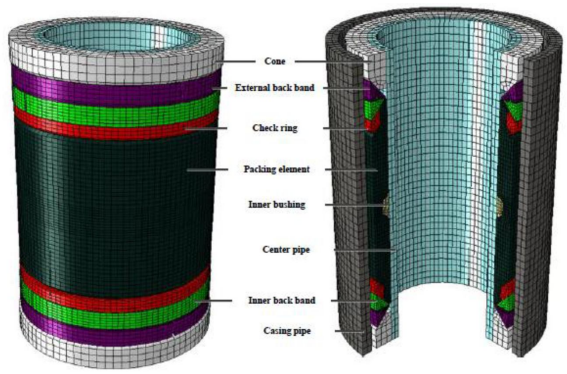


Fig 1. Finite element model of the packing-element system of the Y443 packer.

3.2. Simulation parameters

When the packer dimension and casing external diameter are fixed, the sealing clearance mainly depends on the casing pipe wall thickness. That is the chief cause to investigate the influence of sealing clearance on the packing-element sealing performance, i.e., the influence of casing wall thickness. The finite element model of the packing-element with a height of 110 mmis utilized. Since the packer is used in 7'' casing, casing pipes with five different wall thicknesses are assessed according to ISO 11960:2014 [10]. Detailed working condition parameters are listed in Table 1.

Casing wall thickness (mm)	Sealing clearance (mm)	Setting pressure (MPa)
11.51	4.39	20、25、30、35、40
10.36	5.54	20、25、30、35、40
9.19	6.71	20、25、30、35、40
8.05	7.85	20、25、30、35、40
6.91	8.99	20、25、30、35、40

Table 1. Working condition parameters of the influence evaluation of sealing clearance on the sealing performance.

IV. RESULTS AND DISCUSSION

4.1.Sealing performance coefficient K

Under different setting pressure, the contact stress contours of packing-elements set with various sealing clearances have similar distribution. In this paper, only take the packing-element contact stress contour with setting pressure of 40 MPa as example to discuss, which is displayed in Fig 2. It suggests that the contact stress of packing element is relatively large near the compressed end, and the inner wall contact stress is larger than that of the outer wall. The maximum contact stress occurs at the contact area between the check ring on compressed end and the packing element. It indicates that with an increase of sealing clearance, the effective contact length of the packing-element reduces, and a severe twist phenomenon occurs when the clearance comes to 7.85 mm and 8.99 mm, which should be avoided in practice. In the field, the sealing clearance of packing element is recommended to be lower than 7 mm. Hence, these two conditions mentioned above will not be discussed further in following research.

Sealing performance coefficient K is equal to the product of the effective contact stress among packing element, casing tube and central tube, as well as their effective contact length.According to Fig 3, the effective contact stress increases with increasing setting pressure. Under a given setting pressure, the effective contact stress increases with an increase of sealing clearance. The effective contact length has small fluctuations. Under a given setting pressure, the effective contact length decreases with rising setting clearance. To compare the sealing performance, the sealing performance coefficient K can be obtained with the processing approach mentioned above, as displayed in Fig 4. From the results, it reveals that under a constant sealing clearance, the sealing performance coefficient K increases with rising sealing pressure, and under a constant setting pressure, the sealing performance coefficient K also increases with rising sealing clearance.

Hence, when packing element is set in 7'' casing pipe with wall thickness mentioned above, the sealing performance improves as the sealing clearance increases.

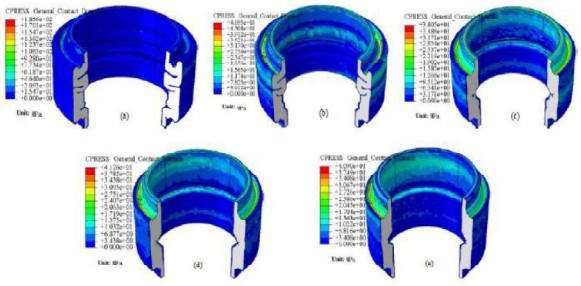


Fig 2. Contact stress contours of different sealing clearance (setting pressure of 40 MPa) (a) sealing clearance: 8.99 mm; (b) sealing clearance: 7.85 mm; (c) sealing clearance: 6.71 mm; (d) sealing clearance: 5.54 mm; (e) sealing clearance: 4.39 mm.

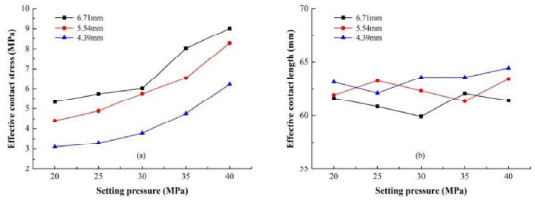


Fig 3. Effective contact stress and effective contact length of packing element with different sealing clearance (a) effective contact stress; (b) effective contact length.

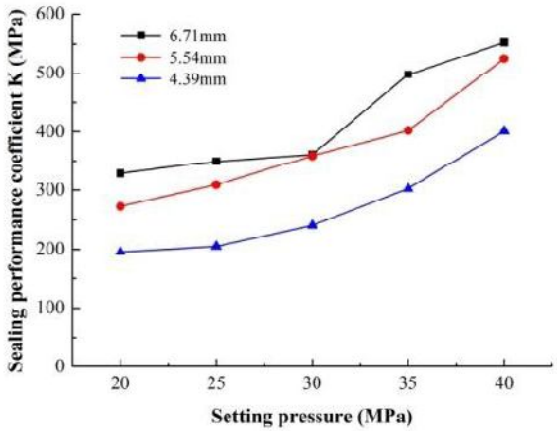


Fig 4. Sealing performance coefficient K.

4.2. Mises stress

The stress state of the packing element itself is an important reference index for evaluating whether or not the packing element is damaged.The Mises stress distribution of packing element has the same regularity under different working conditions, this paper, thus, only discusses Mises contours with different sealing clearances under the setting pressure of 40 MPa, as displayed in Fig 5. Given a certain setting pressure, when the packer sets in the packing element with the above three sealing clearances, the compression degree increases with rising sealing clearance, and the shoulder extrusion also becomes severe. At the same time, the overall stress distribution tends to be more uniform, demonstrating a distribution pattern that the Mises stress near the compressed end is higher than far away from it. To investigate the influence of sealing clearance on the packing element safety performance, the maximum Mises stress varying with setting pressure under different sealing clearances has been plotted in Fig 6. When the packer is applied in casing with the above three sealing clearances, the sealing clearance has a limited influence on the maximum Mises stress when the setting pressure is kept within 35 MPa. While the setting pressure reaches 40 MPa, the maximum Mises stress decreases with increasing sealing clearance, which is attributed to the fact that under a relatively strong setting pressure, a narrow sealing clearance would lead to nonuniform deformation of packing element.

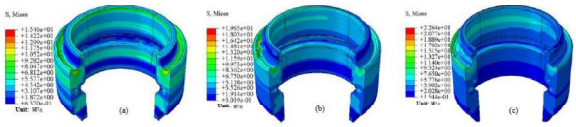


Fig 5. Mises contours of packing element with different sealing clearance (a) sealing clearance: 6.71 mm; (b) sealing clearance: 5.54 mm; (c) sealing clearance: 4.39 mm.

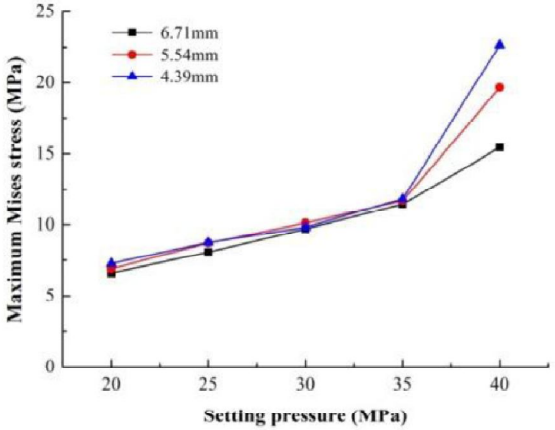


Fig 6. Maximum Mises stress of packing element with different sealing clearance.

4.3. Shoulder extrusion

Shoulder extrusion describes the difference between the highest point of the outer part of extruded elastomer (called “shoulder”) and the lowest point of the compressed spacer ring after pressure set.Fig 7 displays how the shoulder extrusion of packing element changes with the setting pressure, which implies that the shoulder extrusion value reaches a peak when the sealing clearance is 6.71 mm. The curves of the other two sealing clearances are close to each other. The reason is that fact that an increase of sealing clearance causes larger space for the shoulder extrusion after compression. It could be concluded that the packerapplied in casing pipe with sealing clearances of 5.54 mm and 4.39 mm is safer than that with 6.71 mm sealing clearance.

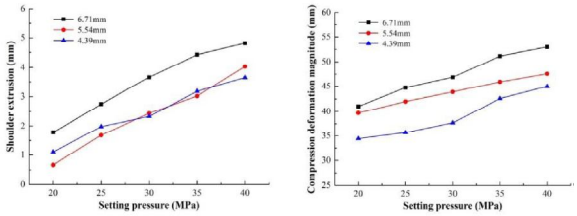


Fig 7. Shoulder extrusion under different sealing clearance. Fig 8. Packing-element compression deformation magnitude curves under different sealing clearances

4.4. Compression deformation magnitude

The compression deformation magnitude of packing element varying with setting pressure has been illustrated in Fig 8. It implies that the compression deformation magnitude increases with an increase of setting pressure. Under a given setting pressure, the larger sealing clearance packing-element has, the

greater compression deformation would be created. For a setting pressure of less than 30 MPa, the compression deformations of packer set in casing pipes with sealing clearances of 5.54 mm and 6.71 mm are similar. When the setting pressure exceeds 30 MPa, the compression deformation magnitudes of packing-element set in casing pipes with sealing clearances of 4.39 mm and 5.54 mm are close to each other. Hence, the packing element has a larger compression space when the sealing clearance is set as 4.39 mm and 5.54 mm.

CONCLUSIONS

The effect of sealing clearance on the sealing performance of packing element is studies in the present research. The results of the research reveal that twist of the packing element system may easily occur and lead to failure when the sealing clearance is either 7.85 mm or 8.99 mm. Under a given setting pressure, packers in the casing with sealing clearance of less than 7 mm, the sealing performance of packing element improves when the sealing clearance increases. Meanwhile, the maximum Mises stress reduces accordingly, while the shoulder extrusion becomes more severe. Therefore, sealing clearance of 5.54 mm is recommended parameter in optimal design of packing elements.

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