Analysis of the Performance Improvement Effect of Combined Packing for Oil and Gas Well Packer

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Abstract. Packer is a commonly used downhole tool for oil and gas wells. In order to understand the working performance of combined packing, a finite element analysis is performed on the double expansion-compression-expansion combined seal packers to find the effect of combined seal. Taking packers sealed in casing with a diameter of 114.3mm and a wall thickness of 12.7mm as an example, finite element models are established for double expansion and expansion-compression combined seal packers respectively. By applying packer-setting pressure to the finite element models and processing the strain-stress data resulting from finite element analyses, the distribution rules of packing stress and contact pressure between the packing and the inner casing wall for different combined seal packers are obtained. The working performance of the single expansion seal packer and the double expansion and expansion-compression combined seal packers is compared and analyzed. According to the results of finite element analyses, both double expansion combined seal and expansion-compression combined packings can be in effective contact with the casing under a packer-setting pressure of 15MPa, and the contact pressure between the combined seal packing and the inner casing wall is larger than that of a single seal packing. The combined seal packer therefore can actually improve the sealing and packoff effect of the packer. The expansion-compression combined seal has the highest pressure bearing capacity, which is 50% higher than that of the single expansion packer. The lower packing of the double expansion combined packer and the expansion packing of the expansion-compression combined seal packers should be appropriately strengthened and thickened to improve the packing performance of the combined seal packer. The results of contrastive analysis reveal the improvement effect of the sealing and packoff performance of the combined seal packers, which can be used as a reference for the improved design of such packer.

1. Introduction
Packer, one of the commonly used downhole tools for oil and gas wells, is used to pack off the annular space between tubing and the casing or between casing and open hole [1]. The packing made of rubber or other non-metallic materials is the most important part of packer for the function of sealing and packoff. The packer packing can be divided into two types: compression packing that compresses and seals based on axial pressure and expansion packing that expands and seals based on radial pressure [2]. In order to improve the packoff and sealing performance of packer, the compression packing and the
expansion packing are combined to form a combined seal packer [3]. The packings of the combined packer needs optimized design in terms of structure and to be used within the limited pressure range [4], packing damage and packer sealing failure will otherwise be easily caused [5]. The packer packing is a kind of nonlinear material and thus makes its analytical analysis difficult. Currently, numerical analysis methods such as finite element analysis is usually used to analyze its related mechanical properties [6]. Through the finite element analysis, the packing structure can be optimized [7] and the sealing performance of the structure-improved packer packing can be understood [8]. In literature [9], a hyperelastic constitutive model is used to fit experimental data, recognizing a constitutive model that can accurately describe the stress-strain relationship of packing and obtaining the distribution of axial contact pressure. Literature [10], by taking component contact into consideration, develops a finite element computational mechanical model for compression and expansion packers and analyzes the distribution law of contact pressure. In literature [11], the impact of the working length, thickness and shoulder shape of packing and the arrangement of steel cord on the stress and deformation of expansion packing is analyzed by using the finite element analysis software. In literature [12], the contact pressure and the packing volume are optimized based on finite element analysis, the structure of the packer packing is therefore optimized in design.

Finite element analyses are performed on the packing stress and contact pressure between the packing and casing for double expansion, compression-expansion combined seal packers to observe the effect of combined seals and provide a reference for improved design of the combined seal packer.

2. Finite Element Analysis of Double Expansion Combined Seal Packer

Taking packer sealed in casing with a diameter of 114.3mm and a wall thickness of 12.7mm as an example, the longitudinal cross section of the model of a double expansion combined seal packer formed by two expansion sealing elements is shown in Figure 1, and the geometric and mechanical parameters of the packing are presented in Table 1. The finite element meshing of the model is shown in Figure 2. The Mises stress of the double expansion packer as shown in Figure 3 is obtained by applying 15MPa expansion pressure. The stress of the mandrel is far larger than that of the packing, and the parts where the packings at both ends contact with the mandrel have the maximum stress which is about 270.4MPa. Therefore, the mandrel of the packer should be made of medium carbon alloy steel with high strength and subject to proper heat treatment to ensure its strength and ductility.

![Figure 1. Sectional View of the Analysis Model of Double Expansion Combined Packing.](image1)

![Figure 2. Sectional View of the Finite Element Meshing of Double Expansion Combined Packing.](image2)

| Part     | Inner diameter/mm | Outer diameter/mm | Height/mm | Elastic modulus/MPa | Poisson's ratio | Material constants |
|----------|-------------------|-------------------|-----------|---------------------|----------------|-------------------|
| Casing   | 88.90             | 114.30            | /         | 2.1×10^5           | 0.28           | /                 |
| Mandrel  | 16.78             | 27.68             | /         | 2.1×10^5           | 0.28           | /                 |
| Packing  | 45                | 62.33             | 300       | 13.8               | 0.49           | C10=1.53,C01=0.77 |
Figures 3 to 5 illustrate Mises stress of packing under the expansion pressure of 15MPa. Through comparison of Figure 4 and Figure 5, the working stress of packing 2 below the packer is larger than that of packing 1 in the upper part, and the stress of the middle part between two packings close to the end is the maximum, while the stress of the middle part between two packings is smaller and even.

Figures 6 and 7 illustrate the contact pressure nephogram of two packings and inner casing wall. It can be seen that the maximum contact pressure between packing 1 and casing under the expansion pressure of 15 MPa amounts to 10 MPa, while the maximum one between packing 2 and casing amounts to 14MPa; also, both seal packings can be in effective contact with the casing, therefore, the contact pressure between the double expansion combined seal packing and the inner casing wall is larger than that of a single seal packing. The double expansion combined seal therefore can actually improve the sealing and packoff effect of the packer.

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**Figure 3.** Stress Nephogram of Packing and Casing.

**Figure 4.** Stress Nephogram of Packing 1.

**Figure 5.** Stress Nephogram of Packing 2.

**Figure 6.** Contact Pressure Nephogram of Packing 1 and Inner Casing Wall.
3. Finite Element Analysis of Expansion-Compression Combined Seal Packer

Table 2 shows the geometric and mechanical parameters of an expansion-compression combined seal packer. As shown in Figure 8, finite element meshes are divided for expansion-compression combined seal packer. The stress nephogram of expansion packing and compression packing is obtained, as shown in Figures 9-12, through exerting the expansion packer-setting pressure of 15MPa on expansion packing and axial packer-setting pressure of 15MPa on compression packing. It can be seen that the working stress of expansion packing is larger than that of compression packing, the stress of the middle part between expansion packing close to the head end and tail end is higher, with the maximum one amounting to around 15MPa, and the working stress of middle packing is even, about 10MPa. However, the stress of the extruded part in the center of compression packing is the highest, about 9MPa, while the stress at edge is lower; the contact pressure between the compression packing and casing amounts to 6.6MPa, while the maximum contact pressure between the expansion packing and casing is about 15MPa, which is larger than the overall contact pressure between the single seal packing and casing. Therefore, the sealing effect of expansion-compression combined packing is better than that of the single packing.

Table 2. Data of Components of Expansion-Compression Combined Seal Packer.

| Part                  | Inner diameter /mm | Outer diameter /mm | Height /mm | Elastic modulus/MPa | Poisson's ratio | Material constants |
|-----------------------|--------------------|--------------------|------------|--------------------|----------------|------------------|
| Casing                | 88.90              | 114.30             | /          | $2.1 \times 10^5$  | 0.28           | /                |
| Mandrel               | 16.78              | 27.68              | /          | $2.1 \times 10^5$  | 0.28           | /                |
| Expansion packing     | 45                 | 62.33              | 300        | 13.8               | 0.49           | $C_{10}=1.53, C_{01}=0.77$ |
| Compression packing   | 40                 | 68                 | 100        | 13.8               | 0.49           | $C_{10}=1.53, C_{01}=0.77$ |

Figure 7. Contact Pressure Nephogram of Packing 2 and Inner Casing Wall.

Figure 8. Sectional View of the Meshing of the Expansion-Compression Combined Seal Packer.
4. Comparative Analysis on Performance of Combined Seal Packer

The performance of single seal packer and different combined seal packers can be listed in Table 3 through the finite element analysis. It can be seen that the packer-setting pressure of combined seal packer is lower than that of single seal packer, but the pressure bearing capacity of combined seal packer is higher than that of single seal packer. The expansion-compression combined seal has the highest pressure bearing capacity, which is 50% higher than that of the single expansion packer.
Table 3. Comparison of Data on Performance of Different Combined Seal Packers.

| Technical parameters         | Single expansion packer | Double expansion combined packer | Expansion-compression combined packer |
|-----------------------------|-------------------------|----------------------------------|----------------------------------------|
| Packer-setting pressure/MPa | 20                      | 15                               | 15                                     |
| Outer diameter of packing/mm| 62.33                   | 62.33                            | D_1 = 62.33, D_2 = 68                  |
| Inner diameter of casing/mm | 82.5                    | 82.5                             | 82.5                                   |
| Seal pressure difference /MPa| 20                      | 25                               | 30                                     |
| Unsealing                   | Off                     | Good                             | Good                                   |

5. Conclusion

The finite element analysis software can be used to analyze the performance of double expansion combined seal packer and compression-expansion combined packing, it can be seen that:

(1) Under the design packer-setting pressure of 15MPa, the contact pressure between the double expansion combined seal, expansion-compression combined seal packing and the inner casing wall is larger than that of single seal packing. The combined seal packer therefore can actually improve the sealing and packoff effect of the packer. The expansion-compression combined seal has the highest pressure bearing capacity, which is 50% higher than that of the single expansion packer.

(2) For double expansion combined packer, the working stress of packing below the packer is larger than that of packing in the upper part, therefore, the lower expansion packing should be strengthened and thickened properly in design; for expansion-compression combined seal packer, the working stress of expansion packing is about 50% larger than that of compression packing, therefore, expansion packing should be strengthened and thickened for such combined packers.

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