

# Application and Analysis of Fracture Simulation of the Slip of the Permanent Packer

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**Abstract**—The slip is the core component of the permanent packer, and its performance affects the anchor reliability of the packer directly. The slip of the permanent packer is used to anchor the casing and lock the packer. The slip structure is especially important for the sealing performance of the packer. The research methods of laboratory tests and numerical simulation are combined to improve the overall performance of the permanent packer. First of all, the scheme of the laboratory tests is designed, the anchor load range of the permanent packer slip is obtained, and the reliability of the anchor is verified. Taken the setting load of laboratory tests for as the simulation boundary conditions, the values of the first, the second, the third critical fracture stress of the permanent type packer slip are obtained by numerical simulation software LS-DYNA, meanwhile the trends of expansion of cracks and fracture morphology are well known. Comprehensive analysis of laboratory tests and numerical simulation results show that: packer setting anchor effect is good under the condition of 30MPa setting load, and slip fracture morphology in laboratory tests is consistent with the results of numerical simulation. The accuracy of the numerical simulation analysis provides scientific basis for slip structure design of the permanent packer.

**Keywords**—permanent packer; slip; fracture; simulation analysis

## I. INTRODUCTION

Permanent packer is mainly used in oil and gas well fracturing, well completion, acidification, test, and so on. Packer slip is one of the important components, it plays an important role to anchor the casing, support packer and lock glue tube. Foreign permanent packer type mainly includes: Baker Hughes SAB-3, Schlumberger QLH, Halliburton Perma-series, Smith ES, Weatherford UltraPak TH, etc. The research progress of permanent packer in China is fast, and the temperature and pressure tolerance index basically meets the demand of domestic conventional oil and gas wells. However, in high temperature and high pressure deep oil and gas well, there are still many problems be solved. Permanent packer slip structure design and analysis has a great influence on bearing capacity, thus it is necessary to carry out packer slip fracture numerical simulation analysis to provide theoretical guidance for the slip structure optimization to reduce the casing damage, field construction.

## II. THE STRUCTURE OF PERMANENT PACKER

The permanent packer structure is mainly composed of upper connector, sealing section, working tube, central pipe, upper slip, rubber, lower slip, lock ring, outer tube and lower joint, as shown in figure 1.

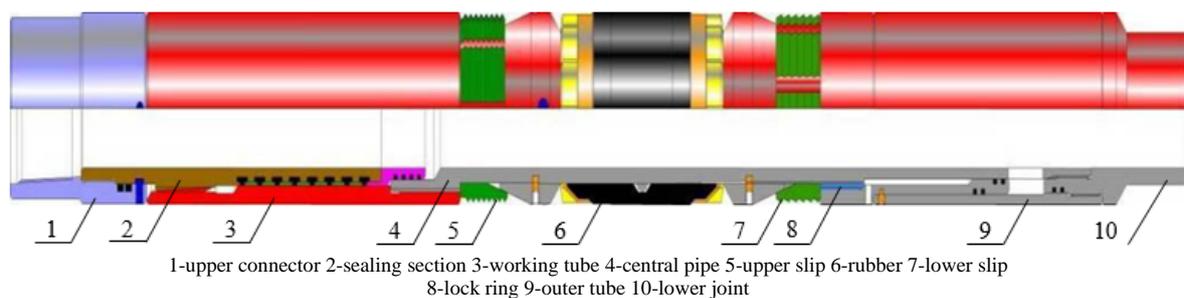


FIGURE I. THE STRUCTURE OF PERMANENT PACKER

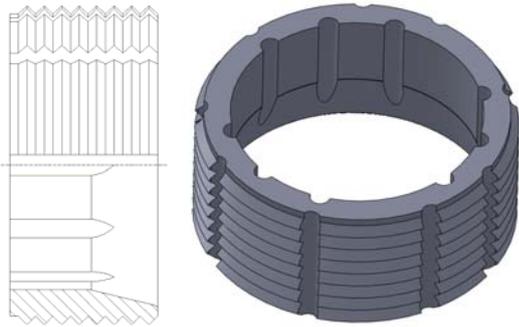
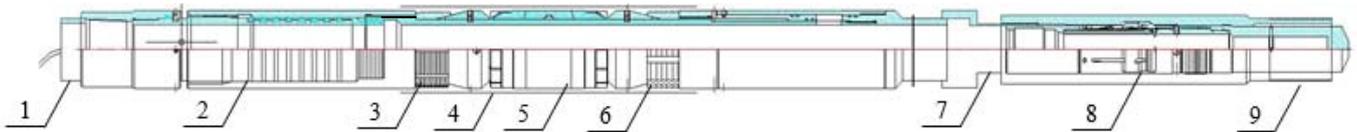


FIGURE II. UPPER SLIP MODEL OF PERMANENT PACKER

III. LABORATORY TEST OF PERMANENT PACKER SLIP

A. Laboratory Test

1) *Setting Test*: The permanent packer is assembled as shown in figure 1, and then is slowly put into the casing nipple along the horizontal direction. The plug lock, the working barrel, and the buckle joint are connected with the lower joint at the bottom of the permanent packer, and then can be connected with the sealing section and the pressure inlet, as shown in figure 3.



1-pressure inlet 2-seal section 3-upper slip 4-casing 5-rubber 6-lower slip 7-buckle joint 8- plug lock 9-plug working barrel

FIGURE III. STRING STRUCTURE OF SETTING TEST

The high pressure pump is used in setting test, firstly, when the inlet pressure is up to 1MPa, the pressure in the string is stable. Then the pressure is increased to 15MPa, the pressure has no significant change for 5 minutes. After that the pressure is increased to 20MPa, the pressure immediately drops to 17MPa, and then it raised slowly, kept at 19.9MPa for 5 minutes. After that the pressure is increased to 25MPa, the pressure keeps at 24.8MPa for 5 minutes. After that pressure is

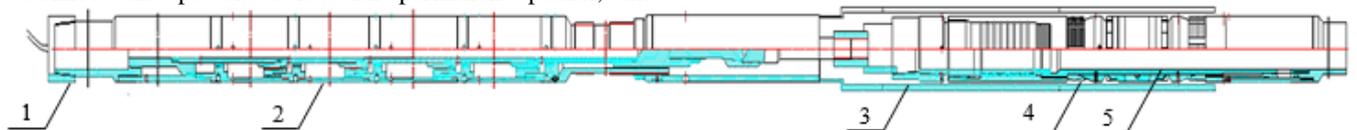
increased to 30MPa, the pressure immediately drops to 25MPa, and then it raised slowly, kept at 29.8MPa for 5 minutes. By observing the pressure change and sound of packer in the process of setting, it is judged that the two groups of packer slips are broken and the packer have been set and sealed. The pressure is released and increased to 30MPa twice, and it has no significant decrease for 5 minutes. Test data are shown in table 1.

TABLE I. DATA OF SETTING TEST

Name	Inlet pressure (MPa)	Pressure change after five minutes of steady pressure (MPa)	Note
Setting test	10	0	The fracture pressure of upper slip and lower slip respectively is 20MPa, 30MPa
	15	0	
	20	0.1	
	25	0.2	
	30	0.2	
	30	0.1	
	30	0.2	

2) *Anchoring Test*. The power tool is clamped on the platform pliers and connected with the short joint of the casing. The power tool pull rod is connected with the seal section through the variable buckle joint, as shown in figure 4. Connect the power tools with permanent packer, the

pressure in the string is increased to 5MPa, 10MPa, 12MPa respectively and kept for 5 minutes, and there is no relative displacement between permanent packer and sleeve. Anchoring force is shown in table 2.



1-pressure inlet 2-power tool 3-casing 4-upper slip 5-permanent packer

FIGURE IV. STRING STRUCTURE OF ANCHOR TEST

TABLE II. DATA OF ANCHORING TEST

Name	Pressure (MPa)	Standup pressure time (min)	Anchoring force (kN)
Anchoring test	5	5	14.5
	10	5	29.0
	12	5	34.8

B. Results Analysis

In setting test, the cone of permanent packer is flexible, the fracture pressure of the upper slip and the lower slip of pressure 20MPa and 30MPa respectively. In the process of the pressure stabilization, there is no obvious pressure drop in the string, and the slip is ruptured into three parts, as shown in figure 5. The broken parts for the fracture are justly at design part, and test results meet the design requirements. In the anchoring test, the maximum force of the power tool is 12MPa (equivalent tension is 34.8kN). There is no relative displacement between permanent packer and sleeve, and the anchoring force meets the requirements of field test.

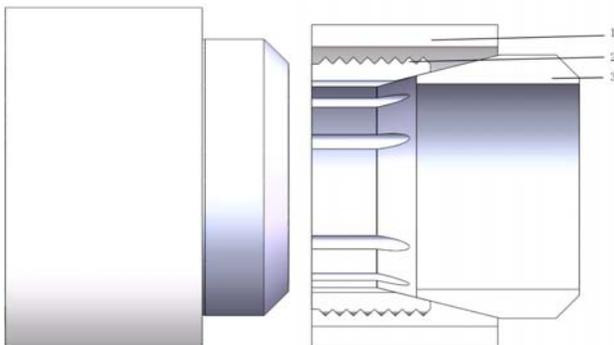


(a)upper slip (b)lower slip  
FIGURE V. RESULTS OF FRACTURE TEST OF SLIP ON PERMANENT PACKER

III. SIMULATION ANALYSIS OF SLIP FRACTURE ON PERMANENT PACKER

A. Upper Slip Simplified Analysis Model

According to the working principle of slip on permanent packer, there is less effect of center pipe, lock ring and the piston on the fracture process of slip. Therefore, these parts are ignored in the calculation model, and a simplified calculation model is shown in figure 6.



1-Casing 2-Upper slip 3-Cone  
FIGURE VI. GEOMETRIC MODEL OF UPPER SLIP

B. Finite Mesh Grid

The finite element calculation model of permanent slip is analyzed, and the contacts include the cone and slip, slip and sleeves. The contact belongs to automatic surface to surface contact unit. The grid shape of the cone and the casing is hexahedral, and the grid size is 4 mm. Because the slip structure is relatively complex, the grid shape of the slip is tetrahedral, and the grid size is 2 mm, as shown in figure 7.



FIGURE VII. GRID MODEL OF NUMERICAL SIMULATION

C. Boundary Conditions and Parameter Settings

According to the working conditions of permanent packer slip, the boundary conditions of its calculation model are dealt with:

- (1) Fixed constraint on the bottom surface of the slip, and axial load was applied to the upper surface of the cone.
- (2) Fixed constraint on the casing, because it is under the condition of cementing.
- (3) Time step of iteration is 0.05s.

In a material subroutine, the failure unit is defined by the keyword \*MAT\_ADD\_EROSION. After the operation of material subroutine, according to the destruction criteria, LS DYNA3D will judge whether the unit fails, if the unit is failure, then it will be deleted from the model. When a node is failure, the node is deleted in the finite element model.

TABLE III. FAILURE CONTROL PARAMETERS OF THE SLIP UNIT

Material parameters	Value	Material parameters	Value
density	7.9g/cm <sup>3</sup>	modulus of elasticity	2.1×10 <sup>5</sup> MPa
Poisson's ratio	0.27	excl	123
yield limit	605MPa	epssh	123
tensile strength	450MPa	sigth	123
failure strain	0.06	failtm	123

D. Analysis of Simulation Results

Permanent slip is an axisymmetric structure, and its slot angle is 120°, and the both sides of it are designed with different slots to supplement inadequate fracture. Axial load

on the interface of permanent slip is applied, stress and deformation occur when the units are under the pressure, and the pressure will transferred to slip teeth, and the slip is set on the inner of the casing.

When the upper cone is imposed by a load of 17MPa on the permanent slip, the maximum equivalent stress on the permanent slips unit reaches 451MPa, which exceeds the tensile strength of 450MPa, and then the slip will fracture, as shown in figure 8. After initial fracture, due to the slip anchoring unfinished, permanent slip equivalent stress instantly dropped to 437MPa, axial displacement under the action of external loading shows the volatility increase, until reaching the secondary breakdown limit stress value, as shown

in figure 9.

When the permanent slip is broken, it is squeezed under the external load of the upper cone so that the external slip teeth are embedded into the slot of the inner wall of the casing. At this time, the main effect of permanent slip fracture is bending stress. When the slip unit internal stress reaches 594MPa, which is more than 450MPa tensile strength, slip secondary breakdown occurs, the second slot rupture, due to the effect of anchoring of the casing wall, slip stress continues to increase, at this time in a very short period of time, stress is up to 592MPa again, break the third slot, and full anchoring effect has been achieved, as shown in figure 10.

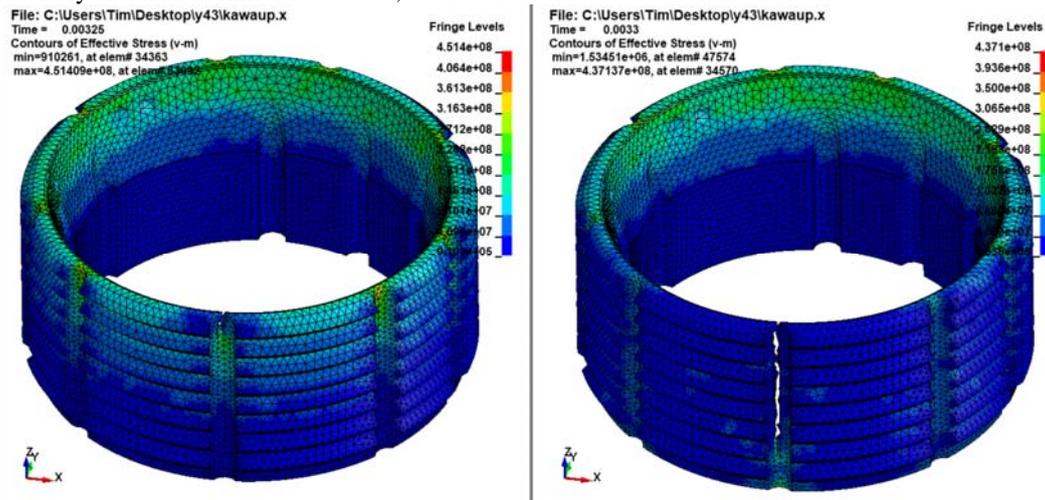


FIGURE VIII. EQUIVALENT STRESS OF UPPER SLIP(PRESSURE LOAD IS 17MPA)

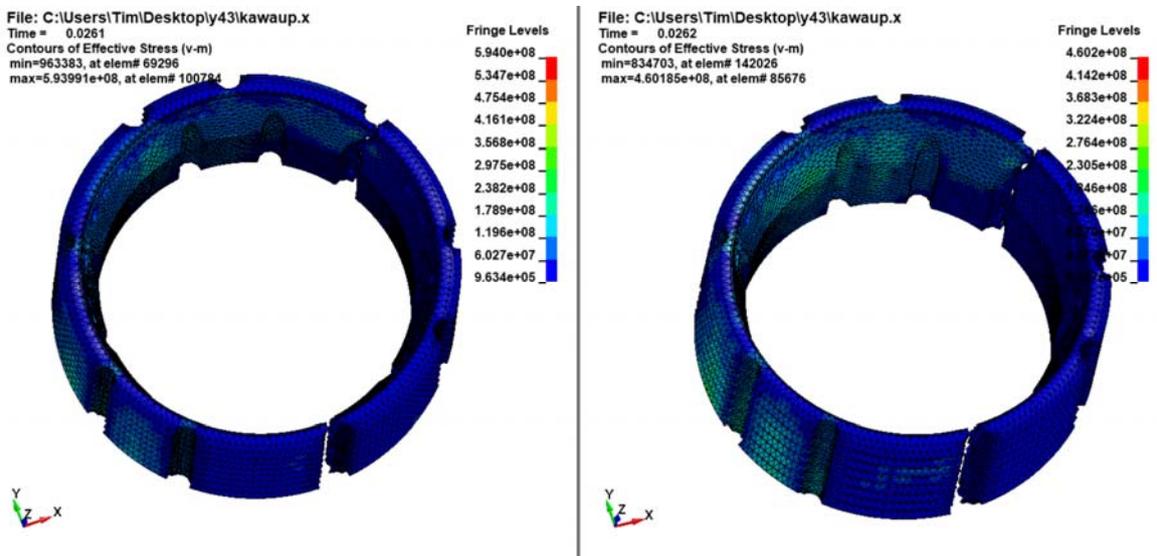


FIGURE IX. EQUIVALENT STRESS OF UPPER SLIP(PRESSURE LOAD IS 19.5MPA)

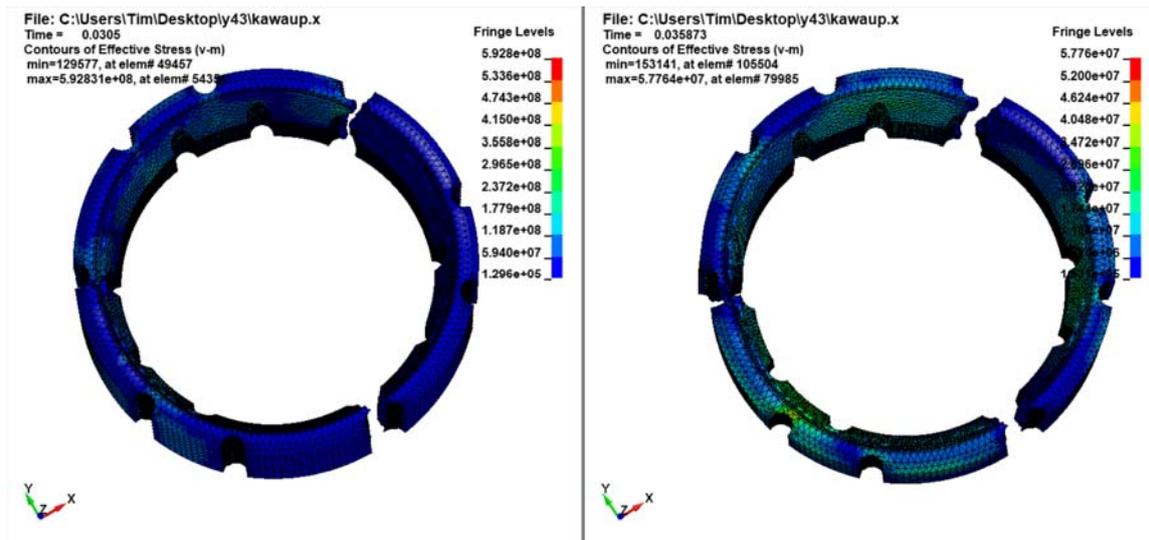


FIGURE X. EQUIVALENT STRESS OF UPPER SLIP(PRESSURE LOAD IS 23MPA)

After the slip of the permanent packer is completely broken, the stress on the slip still keeps high value. The teeth of slip have been sufficiently pressed into the casing wall, and that plays a role of permanently fixed. The numerical simulation method can simulate the process of fracture, anchor, setting conditions about the slip of core component on completion string.

#### IV. CONCLUSIONS

(1) LS-DYNA was used to conduct finite element analysis on the fracture process of slip on permanent packer, and the critical point of slip on permanent packer was obtained, and the crack morphology of slip was simulated.

(2) By means of laboratory test, the fracture test of permanent packer slip with different parameters was carried out, and the scope of the cracks on permanent packer slip has been obtained through the test.

(3) The numerical simulation and laboratory test results of the comprehensive analysis shows that numerical simulation of slip fault coincided basically with the anchoring process and laboratory test results, the numerical simulation method can be used in similar slip fracture analysis, which makes up for the test under different external force in the process of operating frequency and detect discontinuous shortcomings, through experiment and numerical calculation mutual authentication can achieve permanent type slip anchor the comprehensive study of the process can be achieved, the simulation results have good engineering significance.

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