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The Analysis on Wall Effect After Expansion and Expandable With Threaded Performance of Single Wellbore Diameter Expandable Casing

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Abstract

Single wellbore diameter expandable casing technology is an important development direction of the expandable casing technology. The development and maturity of this technology will cause a revolution in drilling technology. Elastic-plastic finite element analysis of frictional contact is used to analyze the effect of geometrical deviation before expansion on casing thickness after expansion; the expansion casing thread connections expandability is analyzed, the connection status of the expanded general casing thread is simulated, then based on the study above, one kind of thread which is suitable for the single wellbore diameter expandable Casing connection is designed. The results for this paper provide the basis for the standardization of the expansion casing's machining precision and the selection of connecting thread, which promote the development of single wellbore diameter expandable casing.

Key words: Single wellbore diameter expandable casing; Drilling technology; Analysis of frictional contact; Threaded performance; Non-uniform wall thickness

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INTRODUCTION

Expandable casing has its unique advantages and great potentials in Oil and Gas Production and now it has been successfully applied in areas such as drilling and completion. Data shows that one important development direction of expandable casing is to change the current structure of the tapered wellbore by allowing using the same type of bits in the whole drilling procedure, which can realize monohole drilling[1]. This will cause a technical revolution in drilling industry. However, comparing with the current expandable casing, the new technology puts forward higher requirements on expansion tools, construction technology, casing materials, casing machining accuracy, connection thread sealing and other related technologies[2]. In this paper, we conducted an exploratory study on thickness unevenness of expandable casing before expansion and expansibility of connection screw thread through numerical simulation. By doing this, we've learned the effects of thickness unevenness on tube thickness after molded and the appropriate screw thread tooth form for monohole expandable casing. This will provide a reference for the standardization of monohole expandable casing machining accuracy and the choice of connection screw threads so that promotes the development of monohole expandable casing[3].

1. MATHEMATICAL AND PHYSICAL MODEL

1.1 Mathematical Model

Essentially, the expansion and forming of expandable casing is a large displacement, finite strain elastoplastic issue. In this process, the unit shape, strain and stress status of each analysis step can results in great impact on the next one so that stress and strain be redefined after each step and constitutive equations, balance equations and virtual work equation should be represented by these new parameter before next analysis.

1.1.1 Kinematic Relations and Stress-Strain

Use X and x to respectively represent the position vectors of particle X in the deformation body[4], then the local deformation of X can be described with deformation gradient tensor F:

$$F = \frac{\partial x}{\partial X}. \tag{1}$$

According to Lee's multiplicative elastoplastic multiplicative decomposition theory, F can be resolved into deformation gradient tensor F^e and plastic deformation gradient tensor F^p.

$$F = F^e F^p. \tag{2}$$

According to Polar decomposition theorem of affine quantity, F^e can be resolved as[5]

$$F^e = R^e U^e. \tag{3}$$

R^e, Rigid rotation tensor; U^e, Right elongated elastic, stand for tensor pure elastic deformation.

Define elastic logarithmic strain tensor E^e and the conjugate stress tensor of its work as

$$E^e = \ln(U^e),\ T = \det(U^e) R^{e^T} \sigma R^e. \tag{4}$$

σ, Cauchy stress tensor on the formation of reality; $(A)^T$ and $\det(A)$ stand for transposition and third stress invariants of second-order tensor A.

1.1.2 Constitutive Relations

The stress response of the normal metallic materials under finite deformation could be described as super elastic constitutive Equation (5).

$$T = 2\mu E^e + \lambda tr\,(E^e) I. \tag{5}$$

μ, shear elasticity; λ, lame constant; I, second-order tensor; tr, trace.

According to the definition of the inter-configurated plastic velocity gradient tensor L^p, gradient of the plastic deformation could be described as

$$\dot{F}^p = L^p F^p. \tag{6}$$

When anisotropy of the material caused by plasticity induction is not serious, approximately counted $L^p \approx D^p$, L^p is symmetric part of the inter-configurated plastic velocity gradient tensor D^p. Similar to mises yield surface on formation of reality, define inter-configurated yield function as

$$f(\overline{\sigma}, s) = \overline{\sigma} - s \le 0, \tag{7}$$

$$\overline{\sigma} = \sqrt{\frac{3}{2} T' : T'}. \tag{8}$$

$\overline{\sigma}$, inter-configurated equivalent stress; s, yield strength; $T' = T' - \frac{1}{3} tr(T) I$, deviatoric tensor of T. Based on principle of maximum plastic dissipation and Kuhn-Tucker condition of optimization problems, plastic flow theorem and loading formula could be defined as

$$D^p = \frac{3}{2} \frac{\dot{\varepsilon}^p}{\overline{\sigma}} T', \tag{9}$$

$$\dot{\varepsilon}^p = 0 \quad \dot{\varepsilon}^p \ge 0. \tag{10}$$

$\dot{\varepsilon}^p = \sqrt{\frac{2}{3} D^p : D^p}$, equivalent plastic strain rate.

Thus, the evolution equation and plastic consistency condition of s could be described by

$$\dot{s} = H(\varepsilon^p) \dot{\varepsilon}^p \quad \dot{f} = 0. \tag{11}$$

H, sclerosing modulus; $\varepsilon^p = \int_0^t \dot{\varepsilon}^p \, dt$, equivalent plastic strain.

1.1.3 Continuum Equation and Its Linearization

In the incremental solution procedure, specify C_t, which is the configuration for the beginning of increment t as the informative configuration[6].

$$\int_V P_t(\tau) : (\delta u \otimes \nabla) dV - \int_{\Omega F} f_t \bullet \delta u dA + \frac{1}{\eta} \int_{\Omega_c} g \bullet \delta u dA_c = 0. \tag{12}$$

δu, arbitraty virtual displacement vector, and on any displacement on the surface $\delta u = 0$; ∇, gradient operator of Ω_t; Ω_F, V, surface area and volume of configuration C_t; f_t, surface force vector at moment τ on the unit surface of the configuration C_t. $P_t(\tau)$, the actively first Piola-Kirchhoff stress tensor; Ω_c, possible contact surface; g, contact surface between each other; The inverse of the penalty factor η could be physically considered as normal and tangential stiffness of the spring between contact surface[7].

$$\sigma(\tau) = (\det F_t(\tau))^{-1} P_t(\tau) F_t^T(\tau). \tag{13}$$

Because the nonlinearity of geometry and materials, Formula (12) should be discretized, then nonlinear equations about node displace increment could be obtained, and the equations can be solved by Newton-Rephson algorithm. Assume that K times approximate solution has already be obtained, in order to ameliorate the solution[8], we expand Formula (12) using Taylor algorithm and just retain linear items. Then, linear equations of balance equations could be obtained.

$$\int_v dP_t(\tau) : (\delta u \otimes \nabla) dV = \overline{R}(\tau) - \int_V P_t^{(k)}(\tau)_1 : (\delta u \otimes \nabla) dV. \tag{14}$$

$\overline{R}(\tau)$, virtual work of exogenic force. We integrate constitutional equation on time t after obtaining displace increment $k+1$ times approximate solution $\delta u^{(k+1)}$ by Formula (14) and test whether the accuracy of balance equations are in a given range or not. It will be going on iterating until satisfying the accuracy, then going to the next increment step.

1.2 Physical Model

1.2.1 Physical Parameters

Casing material uses the Ideal elastoplastic linear hardening model[9], Elastic Modulus is 2.1×10^5 MPa, Poisson's ratio is 0.3, Yield stress σ_s is 379 Mpa, tensile strength σ_b is 480 MPa, Stress-strain curve is approximated through yield strength and ultimate strength of the casing and the curve is showed in Figure 1.

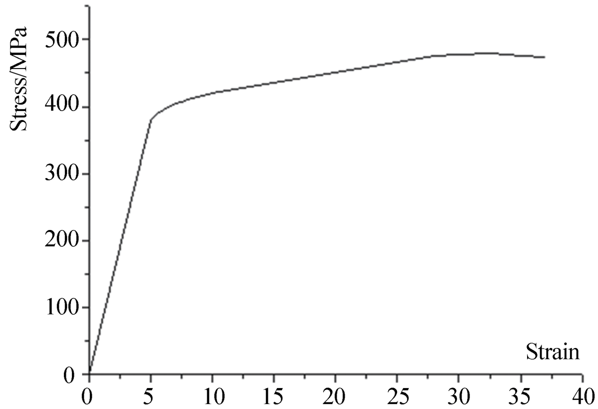


Figure 1
Stress-Strain Curve

1.2.2 Boundary Conditions

Symmetric boundary conditions are $\dot{u}_\theta = 0$, $\partial \dot{u}_r / \partial\theta = \partial \dot{u}_z / \partial\theta = 0$. In this paper, if not particularly indicated, outer diameter ϕ = 195 mm, thickness t = 8.97 mm before expansion and the outer diameter is 245 mm after expansion. Set expanding cone taper angle 12° and friction coefficient of 0.15.

The expansion procedure of expandable casing is a highly nonlinear state mutually coupled by numerous factors such as contact nonlinearity, material nonlinearity and geometric nonlinearity[10]. If three-dimensional solid modeling approach is used to solve this problem, it will involve large amount of calculation so that the efficiency is very low. In addition, the mesh density is limited by computer performance. Therefore, Effect of thread lead angle is ignored in the calculation. Consider the threaded casing as axially symmetrical structure, the three-dimensional model of the expansion process is then simplified into a two-dimensional axisymmetric model. The mode is showed in Figure 2.

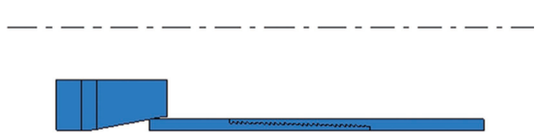


Figure 2
The Geometry Model

2. THREADED EXPANSION CHARACTERISTICS ANALYSIS

Research and practice have confirmed that regular casing threads will lose its structure and sealing integrity after expansion and sometimes the joint structure can be damaged. Directly connected thread is a widely used in expandable casing[11-12]. It is laminated by medal and has the same inside and outside diameter. Based on this type of thread, we analyzed the effect of different thread types on the connections and sealing characteristics.

2.1 Parallel Screw Thread

Screw thread parameter: Pitch is 5.08 mm, thread section is Isosceles triangle. The model is shown in Figure 3.

Figure 3
Direct Connection Type Parallel Screw Thread

As shown in Figure 4, detachment occurred at the contacting parts of threads end thus on this site the thread sealing integrity can't be guaranteed. The meshing point has also changed from totally engaged into partially contacted which makes it difficult ensure the strength of thread connection. Thus, the parallel screw thread does not apply to the expansion of expandable casing.

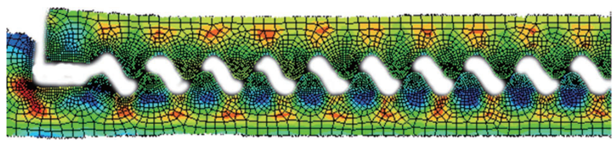


Figure 4
Direct Expansion of Even Type Cylindrical Thread

2.2 Trapezoid Screw Thread

Change the thread form into an equilateral trapezoid with of 60° base angle and taper is 1:16. Result of the numerical analysis is shown in Figure 5.

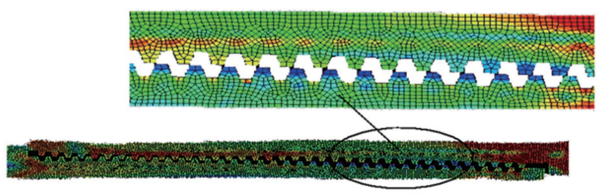


Figure 5
Trapezoidal Thread Expansion

Figure 5 shows that the inner wall contact point has completely separated, the male connector warped towards inner wall. Detachment occurred at the bottom where only a small section is still connected. Coupling performance has failed which makes it difficult to ensure the strength of the threaded connection. The detachment at the inner wall threaded engagement has formed a tunnel for high-pressure liquid leakage. This can no longer ensure sealability during expansion and seriously affect the normal construction. This shows that trapezoid screw thread is not suitable for expandable casing.

2.3 Buttress Thread

Bearing surface is 0° , guided angle is 45°, thread pitch is 5.08 and taper is 1:16. The result is shown in Figure 6.

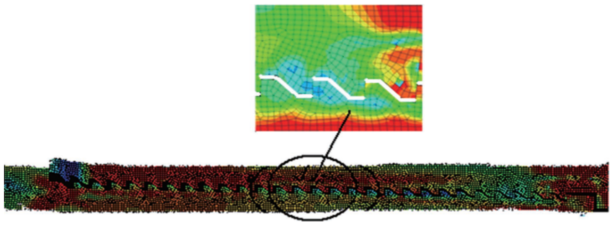


Figure 6
Expansion of Buttress Thread

Figure 6 shows that the connecting performance of buttress thread is significantly better than the previous two. Screw threads are basically well engaged together and thread connection strength can be guaranteed. However, there are still some gaps in threaded connection, so it is still not secure enough for complicated downhole problems. Further improvement and optimization are still needed.

3. THE DESIGN OF A NEW DIRECTLY CONNECTED EXPANDABLE CASING SCREW THREAD

Inspired by the study above, we've found that the expandable casing connection strength and sealability after expansion are closely related to the thread bearing surface angle. The smaller the angle the better the connection strength and sealability. But taking machining into consideration, the angel can be too small. Besides, small angel may cause a cusp, so preliminary design of the bearing surface angle is -5°~-10°. In order to prevent the inner wall warping, we set a 15° bevel at the contact surface. The screw thread design is shown in Figure 7 and numerical simulation result is shown in Figure 8.

Figure 7
Design of Expansion Pipe Thread Model

End warpage of the new thread has been significantly improved, thread connection depth is increased and connection length and strength has also improved significantly.

Thread engagement of the new design remains the same after expansion while the buttress thread has a small detachment which has proved that the new thread has a better connection performance. Besides, the connection strength and sealing performance also increased. As shown in Figure 9.

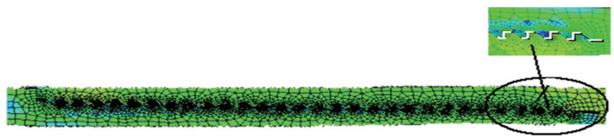
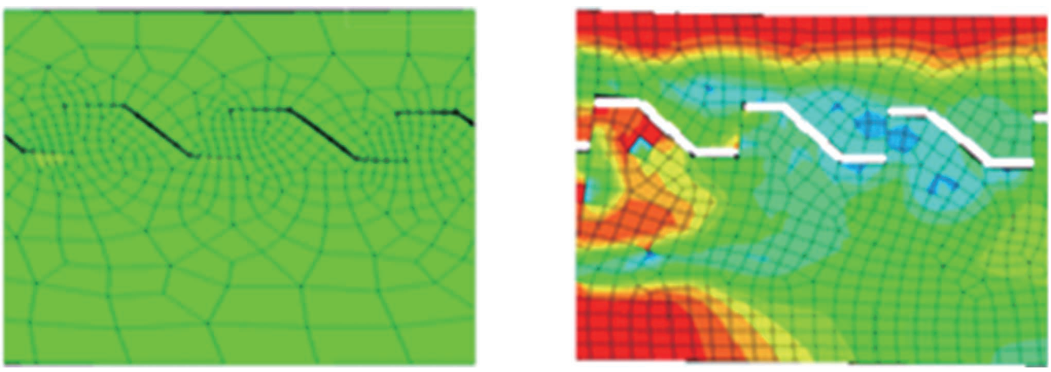


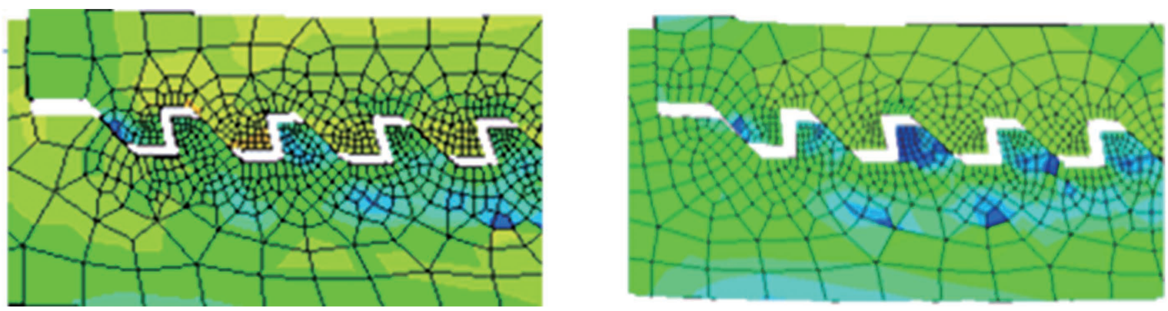
Figure 8
Design of Expansion Pipe Thread



(a) New Expansion Pipe Thread

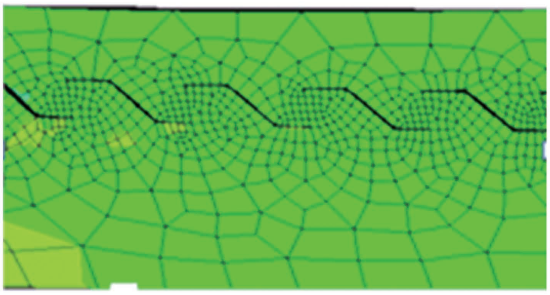
(b) Buttress Thread

Figure 9
Compared Thread Buttress Thread With Design

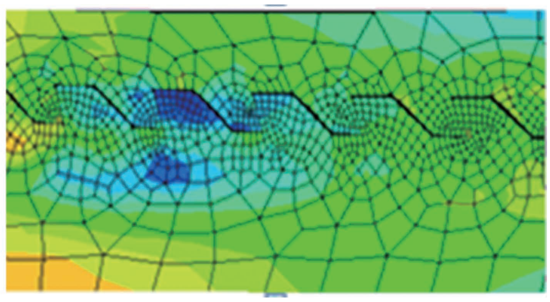


(a) Bottom Thread With Angle Value -5°

(b) Bottom Thread With Angle Value -10°



(c) Top Thread With Angle Value -5°



(d) Top Thread With Angle Value -10°

Figure 10
Comparison of Different Bearing Surface Angle

Figure 10 indicates that there is no significant difference of connecting performance between the bearing surface angle value is -5° and -10°. When the angle value is 10°, screw thread stress distribution is relatively better, but not obvious. Given that the bigger the angle is, the more difficult it is to machine, we choose -5° as the bearing angle value of expandable casing screw thread after taking these two factors into consideration.

CONCLUSION

(a) Monohole expandable casing can completely change the existing wellbore structure, and achieve a technical revolution of drilling industry.

(b) We analyzed the effect of geometric unevenness on monohole expandable casing thickness unevenness after expansion through Frictional contact Finite Element Method and the result shows that when eccentricity degree before expansion is less than 0.3 mm, it changes very little after expansion.

(c) Effects of multiple screw threads on expandable casing connection performances are analyzed and thread tooth type appropriate for monohole expandable casing expansion is designed based on this study. This new design will provide a reference for the development of monohole expandable casing technology.

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