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# Double Shoulder Thread Mechanics Study and Life Analysis of Drilling Tools

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**Abstract:** Under the trend of the continuous in-depth development of global oil and gas exploration and development, the torque in deep drilling is excessively high, and drill string failure accidents occur frequently. The threaded connection part of the drill string is the main weak link of the drill string, and improving its torsional resistance performance is the main way to reduce the risk of drill string fracture and failure. Based on the mechanical analysis of the torque load of the double-shoulder drill string thread in this paper, a double-shoulder drill string thread model was established. By comparing it with the stress collected from experiments, the rationality of the simulation model was verified. The sensitivity analysis of the torsional resistance performance of the double-shoulder joint thread under torque load was studied, and its torsional resistance performance is better than that of the API thread. The sensitivity analysis of the fatigue life of the double-shoulder joint thread under torque load was carried out, and its torsional resistance performance is significantly improved compared with that of the API thread. The research results show that the torsional resistance performance of the double-shoulder joint is increased by 20.8% compared with that of the API joint, and the fatigue life is increased by 147%.

**Keywords:** Drill string thread; Double shoulder; Mechanical analysis; Fatigue life.

## 1. Introduction

Under the trend of the continuous in-depth development of global oil and gas exploration and development, deep well and ultra-deep well operations have become increasingly common. As the core component of drilling operations, the performance of the drill string directly affects the progress and benefits of the operations. However, the problem of drill string failure has always been a difficult issue to solve, plaguing major oil fields[1-2]. The fracture diagram of the drill string is shown in Fig.1 According to incomplete statistics, drill string failure accidents occur frequently in oil fields across the country every year, reaching hundreds of cases[3]. In the oil fields in western China, the cost of a single drilling operation can reach tens of millions or even hundreds of millions of yuan. Once the wellbore is scrapped due to drill string failure, the resulting economic losses are astronomical[4-5].

**Figure 1.** Failure diagram for drilling tool joints

According to statistical analysis, the threaded connection part of the drill string is the main weak link of the drill string, and most failure events originate from this part[6]. Excessive torque load is the main factor leading to the failure of the joint thread. With the increase in the operation depth, the double-shoulder drill string thread has been widely used in the industry because it can effectively improve the torsional strength of the thread and balance the load distribution[7]. However, it cannot be ignored that there are still many shortcomings in the current research on the double-shoulder drill string thread[8]. On the one hand, the mechanical analysis is difficult to accurately simulate the complex and changeable load conditions downhole. For example, the combined effects of extreme loads such as bending moment, torque, erosion, friction and vibration are often simplified or ignored. On the other hand, the accuracy of the life calculation method is not good enough, and it cannot provide a reliable reference for the service life in actual operations[9-10].

In this paper, through the analysis of the mechanical analysis of the double-shoulder drill string thread under actual working conditions, the mechanical performance under torque load is deeply explored. At the same time, combined with the failure cases in actual production, the root causes of the failure are analyzed, aiming to lay a solid theoretical foundation for the optimized design and reasonable use of the double-shoulder drill string thread.

## 2. Finite Element Analysis of Drilling Tool Threads

### 2.1. Equation for threaded connection of drilling tools

The drilling tool threaded connection is preloaded by suitable upper buckle torque to ensure the sealing performance of the joint threads, enhance the resistance of the joint to the tensile load effect, and prevent the threads from unbuckling under the tensile load, so determining the suitable upper buckle torque is one of the keys to the design of the drilling tool joints. The torque balance equation (1) obtained from the deformation coordination formula shows that when the drilling tool male buckle is subjected to torque, the external torque $T$ is equal to the sum of the frictional torque $T_T$ on the thread engaging surface and the frictional torque $T_P$ on the contact surface of the table shoulder, and the sum of axial force $F_T$ on the thread engaging surface is also equal to the combined force $F_P$ applied on the table shoulder[11]. Fig.2 shows the mechanical characteristics of a variable tooth height double shoulder drilling tool thread under torque loading.

$$F_P = F_T, \quad T = T_T + T_P \tag{1}$$

$$\sum_{i=1}^{n} F_i = F_T = F_P \tag{2}$$

$$\sum_{i=1}^{n} T_i = T_T \tag{3}$$

Where $n$—The total number of thread engagement turns; $i$—Number of threaded turns; $F_P$—Axial forces on the shoulder surface; $T_T$—Torque generated by the shoulder.

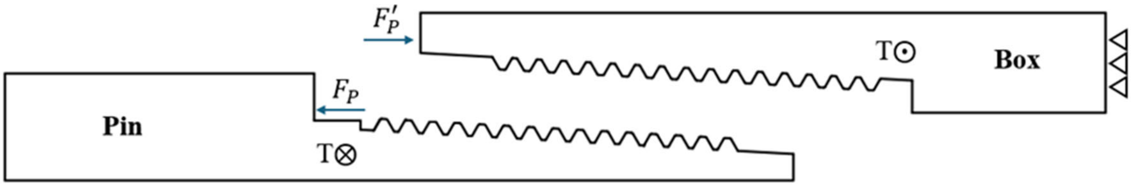



**Figure 1.** Analysis of torque forces on double shoulder drilling tool joints

The figure indicates that the plane is facing inward, indicates that the plane is facing outward, and is a fixed boundary condition.

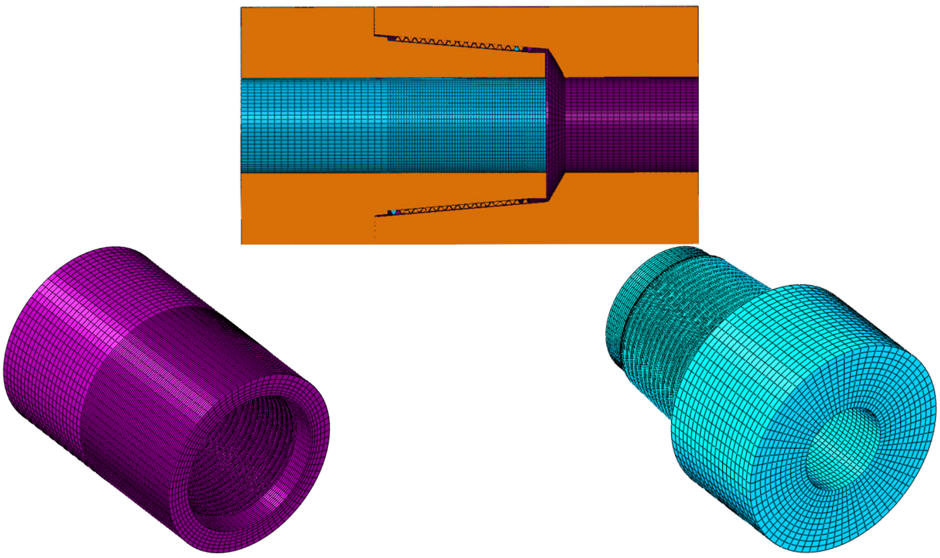
It can be seen that the shoulder bears part of the torque for the thread, and the double shoulder structure can increase the contact area of the shoulder, improve the friction torque $T_P$ and axial force $F_P$ on the shoulder surface, and reduce the friction torque $T_T$ and axial force $F_T$ between the thread engaging surfaces.

## 2.2. Three-dimensional finite element modeling of drilling tool threads

In order to better simulate the contact of the threads of the joint of the drilling tool, the 3D model of the external threads of the pipe body and the internal threads of the coupling is established with the help of 3D drawing software. After the modeling of the external and internal threads is completed, the fit is set in the 3D drawing software for assembly, and the assembly is imported into the finite element software for meshing.

(1) API threads

Taking the 7-inch API drilling tool joint thread as an object, NC50 thread specification is used as the connection thread of the tool, and the tooth type is selected as V-0.038R. 3D drawing tools are used to construct a 3D model of the conventional buckle, which is then imported into the finite element simulation software for mesh delineation. In order to ensure the accuracy of calculation, hexahedral mesh is selected as the mesh type, and the cell type is set as C3D8R. In the thread contact area and its periphery, high-density fine mesh division is implemented; while in the part far away from the thread contact, sparse mesh division is used to improve the calculation efficiency, in which the number of cells for external thread division is 114894, and the number of nodes is 149180, and that of the internal thread is 123,496, 160 nodes and 123496. 123496, the number of nodes is 160933, as shown in Fig.3.



(a) external thread (b) female thread

**Figure 3.** API thread 3D mesh model

(2) Double shoulder joint threads

The double shoulder structure adds a sub-shoulder on the basis of the conventional API thread, which increases the contact area of the shoulder surface and the friction torque of the shoulder surface, thus reducing the load on the threaded part and making the load distribution uniform at the beginning and end of the thread. The three-dimensional model is shown in Figure 34. The mesh division is consistent with the above, in which the number of cells for external thread division is 116154 and the number of nodes is 150650, while the number of cells for internal thread is 121156 and the number of nodes is 158515, as shown in Fig.4.

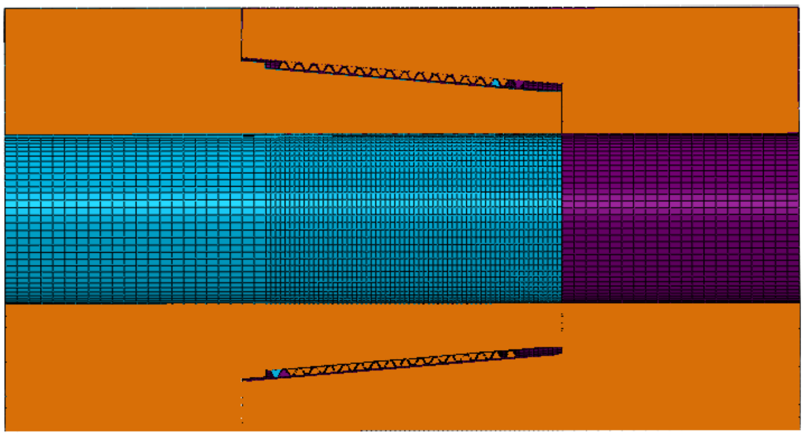


**Figure 4.** Three-dimensional mesh model of a double-shouldered structure

### 2.3. Simulation Model Accuracy Verification

In order to verify the accuracy of the finite element calculation results, this paper refers to the literature[12] experimental testing of Ø139.7mm × 7.72mm long round threaded casing fitting, experiments were used in this casing fitting with different compression loads, in different number of upper buckles and under different tensile loads to carry out research experiments, for the theoretical analysis of casing fittings threads and numerical analysis to provide experimental results of the support of the data. Under the experimental conditions of axial tension of 1200.96kN, the data of stress change on the outer surface of the casing were collected, and the stresses of 10 data points on the outer surface of the casing were taken in the simulation results and compared with the collected data of the corresponding points on the outer surface of the experimental casing, as shown in Fig.5.

As can be seen from Fig.5, the calculation results obtained by the two methods show a basic consistent trend, with a maximum error of 8.72%. It proves the accuracy of the finite element simulation model of the drilling tool threads constructed. The model can be used to gain a deeper understanding of the stress distribution of the threaded casing joint of the drill pipe and provide an important theoretical basis for optimizing the design of the main parameters of its threads.

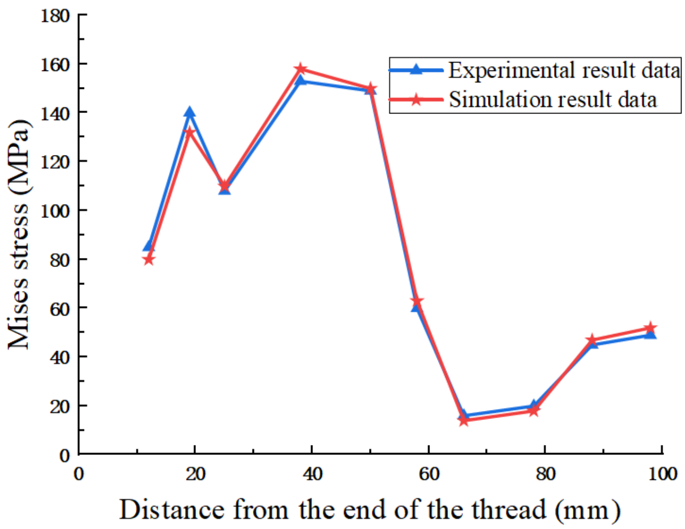



**Figure 5.** Comparison of experimental and simulation results

## 3. Analysis of Thread Torque Carrying Performance of Double Shoulder Joints

The stress characteristics of the two couplings under torsional loading are simulated and analyzed based on the three-dimensional finite element method to obtain the stress distribution pattern and then evaluate their torsional strength. The boundary conditions are fixed at one end of the joint threads, and the other end is applied with torsional load at the coupling point, which is loaded slowly by using a smooth loading method. The torsional performance of the two structures is compared by calculating the stresses under torsional loading. The results of the API thread calculations are as follows:

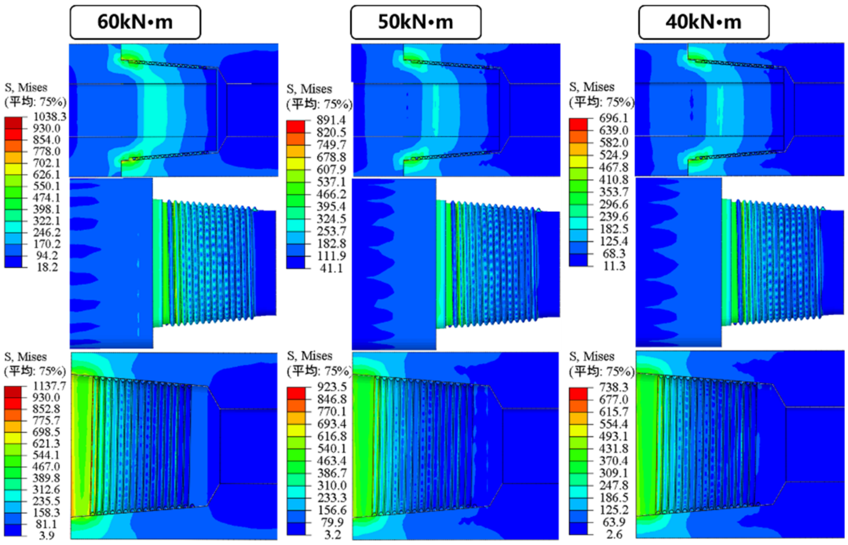


**Figure 6.** Torque Load - API Threaded Joints Thread Stress Clouds

Fig.6 shows the stress cloud diagram of API threads under torsional loads of 40kN·m, 50kN·m and 60kN·m. As the torque decreases, the thread stress decreases, and the stress exceeds the yield limit (930MPa) under the 60kN·m torque. It can be seen from the cloud diagram that the maximum stress of API joint threads under torsional load is concentrated in the first turn of threads on the shoulder side of the main platform, and the friction moment generated on the shoulder side of the main platform resists part of the torque load, and the first turn of the threaded teeth is significantly larger than the rest of the threaded teeth, and the friction moment generated on the threaded surfaces resists the rest of the torque load, so that the distribution of the stress on threads shows that the maximum stress of the first turn of the threads is decreasing in turn afterward. The stress distribution is extremely uneven, which can easily cause the stress concentration in the first turn of the thread, resulting in fatigue damage.

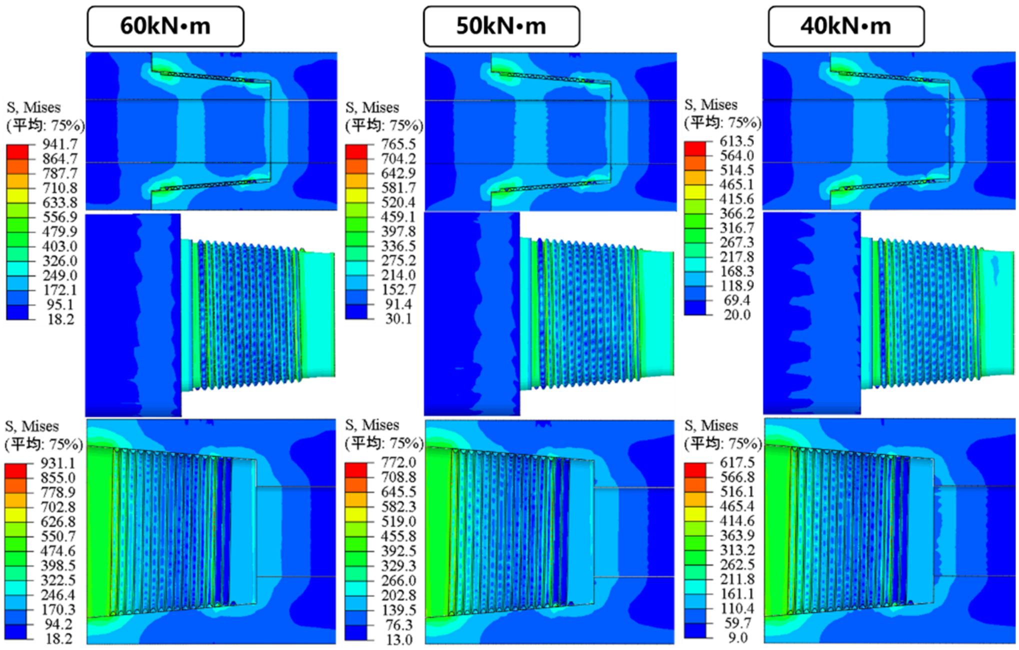


**Figure 7.** Torque Load-Double Shoulder Threaded Joints Thread Stress Clouds

Fig.7 shows the stress cloud diagram of double shoulder threads under torsional loads of 40kN·m, 50kN·m and 60kN·m. As the torque decreases, the thread stress decreases, and the stress exceeds the yield limit (930MPa) under the 60kN·m torque. Under the action of torsional load, the stress part of the thread of the double shoulder joint is at the main shoulder and the secondary shoulder, at this time, the main shoulder surface and the secondary shoulder surface are in contact with the friction moment to share part of the load, and the main stress part of the thread is located in a circle of the thread close to the main and the secondary shoulders, and the distribution of the thread stress shows that the maximum stress at the head and the tail is decreasing towards the middle in order of the distribution. The double shoulder structure resists the torsional load through the friction moment generated between the main shoulder surface, the secondary shoulder surface and the thread engaging surface. Compared with API joint threads, the double shoulder structure can reduce the load of the threaded part, reduce the load bearing pressure of the first loop of threads, and increase the load bearing of the last loop of threads, so as to make the distribution of the stress more uniform and to improve the performance of torsional resistance of the threads.

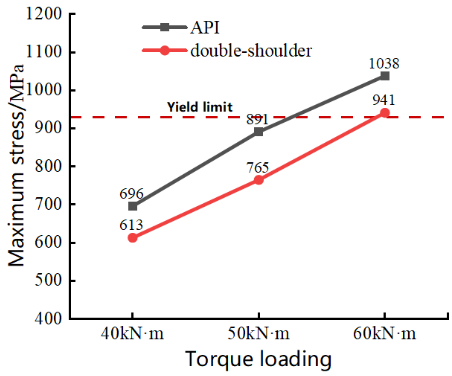



**Figure 8.** Comparison of torsional properties of male threads

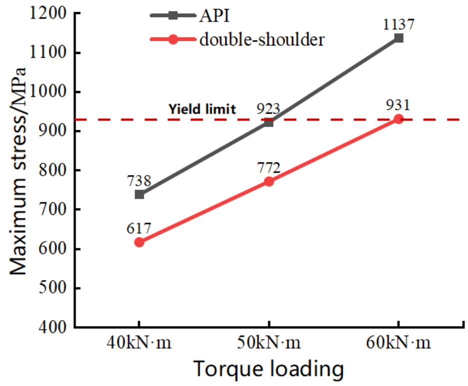



**Figure 9.** Comparison of torsional properties of female threads

From Fig.8 and Fig.9 shows the torque corresponding to the maximum stress value of the female and male threads, it can be seen that: the maximum stress value of the two structures and the magnitude of the torque load is basically a linear change in the relationship between the maximum stress value and the magnitude of the torque load, in the same torque load, the double shoulder structure of the peak stress is lower than that of the API structure, and as the torque increases, the torsional performance of the double shoulder structure improves even more. According to the maximum stress as the strength evaluation criterion, the comparison of the results shows that the torsional performance of the double-shouldered structure is about 20.8% higher than that of the API structure under 60kN·m torque.

# 4. Thread Fatigue Life Analysis of Double Shoulder Joints

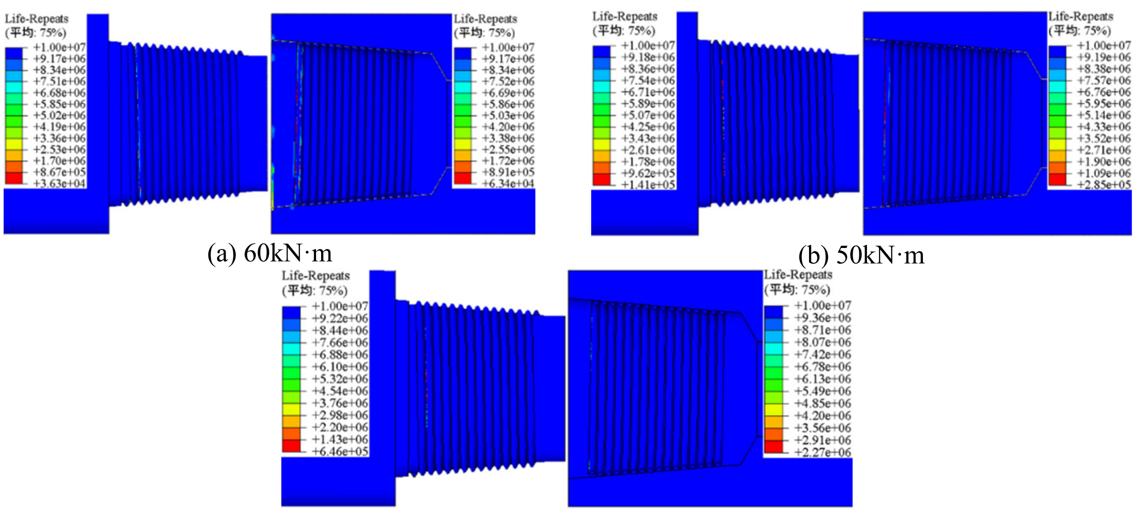
## 4.1. Fatigue damage and fatigue life of drilling tool joints

Fatigue damage and fatigue life are key concepts in assessing the performance of materials and structures under cyclic loading. Fatigue damage refers to the phenomenon of progressive damage accumulation until rupture that occurs when a material is subjected to alternating stresses below its static load limit strength, or even below its yield strength, for a long period of time. It is significantly different from static load damage, characterized by low stress, suddenness and sensitivity to material microscopic defects. According to the number of cycles and stress level, fatigue damage is divided into high-cycle fatigue and low-cycle fatigue, the former cycle number is greater than 104 times less than 107 times, elastic strain dominated; the latter cycle number is around 104 times, plastic deformation plays a major role[13].

Fatigue life, on the other hand, is the number of cycles or time that a material or structure undergoes from the beginning of cyclic loading until fatigue damage occurs. There are various models for calculating fatigue life, such as the two-stage model that divides it into crack formation and expansion stages; the three-stage model that further subdivides the small crack stage; and the multi-stage model that refines the small cracks by microscopic, physical, and structural levels. Accurate understanding of the fatigue damage mechanism and fatigue life calculation method is crucial for predicting the reliability and service life of double-shouldered drilling tool threads under complex downhole cyclic loading conditions[14].

## 4.2. Calculation of drilling tool thread fatigue life

This paper mainly analyzes the research drilling tool joint threads under high torque load, based on the finite element life analysis software, simulation and analysis under torque load, to get the life of drilling tool threads and evaluate its fatigue life. The calculation results are as follows:




(a) 60kN·m

(b) 50kN·m

(c) 40kN·m

**Figure 10.** API Fatigue Life Cloud at Thread Torque

Fig.10 shows the cloud diagram of the number of fatigue cycles under 40kN·m, 50kN·m, and 60kN·m torsional loads for API. Although the maximum stress of the female buckle is greater than the maximum stress of the male buckle, the three results are all male buckle fatigue life is less than the fatigue life of the female buckle, indicating that the high stress level of the male buckle has a wider range, resulting in a lower number of fatigue cycles of the male buckle, and they all appeared in the first ring of the male buckle, which is in line with the engineering of the first ring of the male buckle is prone to the occurrence of fatigue fracture phenomenon.

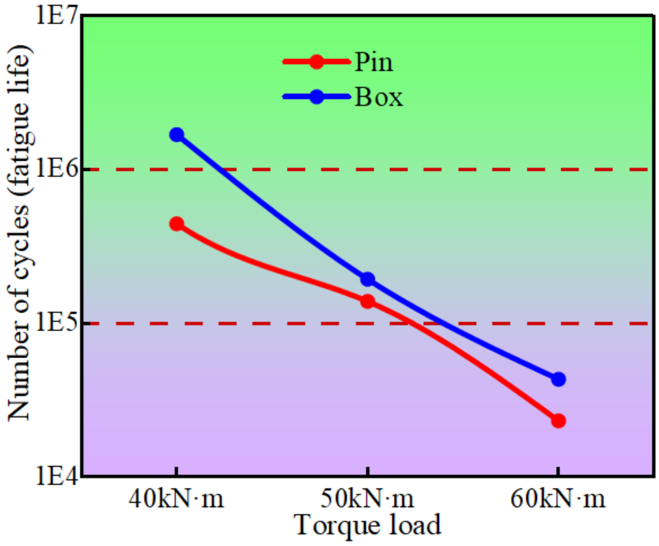
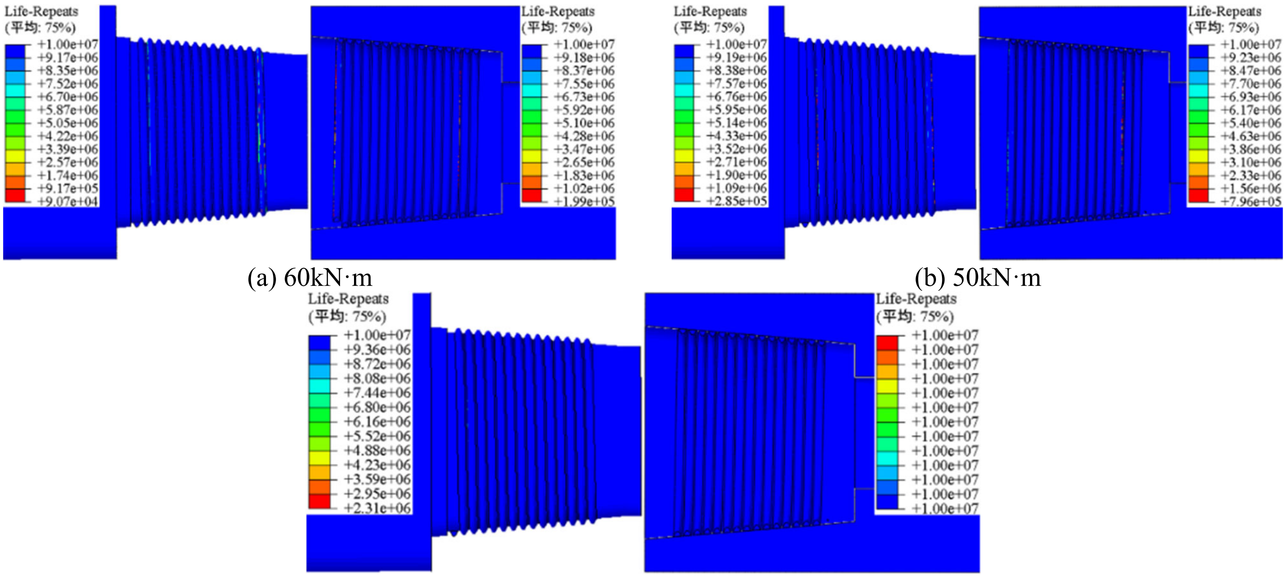



**Figure 11.** Fatigue Life Curves at API Thread Torque

Fig.11 shows the fatigue life of API joints versus torque load. As the torque increases, the number of fatigue cycles of male and female buckles of API structure decreases, and under the torque of 60kN·m, the number of fatigue cycles decreases to the order of 104. The number of fatigue cycles of the male buckle are smaller than the female buckle, indicating that the male buckle is more prone to fatigue failure, need to improve the fatigue performance of API joints.




(a) 60kN·m (b) 50kN·m

(c) 40kN·m

**Figure 12.** Fatigue life cloud under double shoulder thread torque

Fig.12 shows the cloud diagram of the number of fatigue cycles of double shoulder structure threads under 40kN·m, 50kN·m and 60kN·m torsional loads. Although the maximum stress of the female buckle is greater than the maximum stress of the male buckle, the three results are all male buckle fatigue life is less than the fatigue life of the female buckle, indicating that the high stress level of the male buckle has a wider range, resulting in a lower number of fatigue cycles of the male buckle, and they all appeared in the first ring of the male buckle, which is in line with the phenomenon of fatigue fracture that is prone to occur in the first ring of the male buckle in the engineering position.

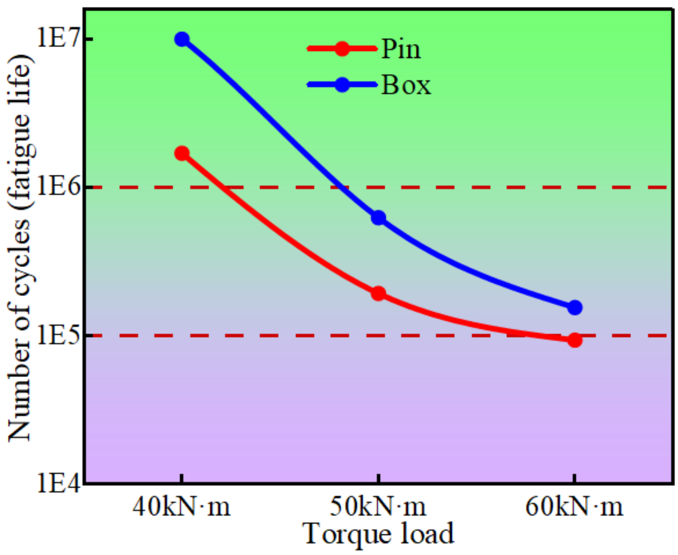


**Figure 13.** Fatigue life curve under double shoulder thread torque

Fig.13 shows the fatigue life of double shoulder joints in relation to the torque load curve. With the increase of torque, double shoulder joint male buckle female buckle fatigue cycle number decreases from high week fatigue 106 magnitude down to 104. male buckle fatigue cycle number are smaller than the female buckle, indicating that the male buckle is more prone to fatigue failure, but the overall number of fatigue cycles is less than the API structure, has a better fatigue resistance.

## 5. Conclusions

In this paper, for deep and ultra-deep oil and gas drilling, the problem of excessive torque and frequent failure of the drill column, the thread structure of double shoulder drilling tool with better anti-torsion performance is mechanically analyzed and life calculation, and the following conclusions are obtained:

(1) Analyze the mechanical analysis of joint thread torque load, establish a finite element model for calculating the thread strength of the three-dimensional structure of double-shoulder thread, and compare the calculated outer wall node stress with that obtained from the experimental results, which verifies the reasonableness of the simulation model.

(2) Comparative analysis of API and double-shoulder structure through torque load calculation, API stress is mainly concentrated in the main shoulder side, and then decreases sequentially, while the stress of double-shoulder structure becomes the distribution state of threads with two large ends and a small middle, and the thread stress is more balanced, and the torsional performance of the double-shoulder structure is improved by 20.8% compared with that of API threads.

(3) Through the fatigue life calculation, API and double-shoulder structure are compared and analyzed, the fatigue failure location of API structure is mainly located in the first turn of the thread, while the fatigue failure location of double-shoulder structure is at the two ends of the thread, and the double-shoulder structure shows a better fatigue resistance, and the fatigue life is improved by about 147% compared with API thread.

## Acknowledgement

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