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Analysis of the Influence of Thread Parameter Deviation on The Sealing Performance of Drill Pipe Joint Under Axial Load

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Abstract: To explore the influence of the limit deviation of the thread parameters of the drill pipe joint on its sealing performance, based on the API NC38 drill pipe joint, the existence of the limit deviations of the three thread parameters of taper, side angle, and pitch is analyzed. Based on this, a total of 12 finite element models of drill pipe joints including various limit deviations and free combinations of internal and external thread limit deviations are established, and the sealing performance of different structures under the action of make-up torque and axial load is analyzed. The results show that the pitch limit deviation has the most obvious influence on the sealing performance of the drill pipe joint, and the yield failure of the contact surface is easy to occur. The existence of taper limit deviation makes the sealing performance of the drill pipe joint significantly reduced when subjected to tensile load. When the change of the limit deviation of the side angle of the internal and external thread teeth is opposite, the plastic deformation occurs locally in the drill pipe joint, which affects the sealing effect. Therefore, it is necessary to control further the tolerance range of the thread parameters of the drill pipe joint to reduce the risk of sealing failure of the drill pipe joint.

Keywords: Drill pipe joints; Taper limit deviation; Tooth side angle limit deviation; Pitch limit deviation; Sealing performance.

1. Introduction

With the increasing demand for oil and gas extraction, oil and gas drilling conditions have become increasingly harsh, and the service environment of drill pipe has become more and more complex, while the threads of the drill pipe joints are the weakest link in the connection of the drill pipe, and most of the failures of the drill pipe occur here[1]. Seal failure of drill pipe joints is very likely to induce high-pressure mud erosion from the shoulder surface, resulting in drilling accidents such as joint leakage and expansion of drill pipe joints, causing huge economic losses[2]. Therefore, it is important to study the sealing of drill pipe joints.

At present, to prevent the failure of drill pipe joints, scholars at home and abroad have carried out a lot of analysis and research on drill pipe joints. Sajad Mohammad Zamani systematically analyzed the various causes of failure of drill pipe joints[3]. Shi Jie Yu used a combination of experimental testing and finite element simulation to analyze in detail the causes of longitudinal crack failure in double-shouldered drill pipe joints[4]. A.R Shahani analyzed the stress concentration sites occurring in drill pipe joints[5], which for male clasps are located at the root of the threaded tooth close to the first tooth engaged in the shoulder of the table, and for female clasps at the root of the last tooth. Feng Chen analyzed the working load limit of drill pipe by the three-dimensional finite element method and proposed a new method to determine the torsional limit of threads under complex loads[6][7]. Jinhua Chen considered the effect of temperature on the joints of drill pipe[8], and finite element analysis of the joints of drill pipe was carried out by using the thermal coupling model and implicit-explicit transformation method. Many of these scholars have analyzed the mechanical properties of drill pipe joints from the structural design and under various complex loading conditions[9][10][11]. The study of the sealing performance of special joint threads is one of the hotspots for many scholars. Wang studied special threaded joints from the aspects of structural integrity and tightness and visually quantified the sealing performance of threaded joints[12]. Chen Wei studied the sealing performance of oil casing joints and analyzed the sealing mechanism of oil casing joints under composite load[13]. However, there are not many studies on the impact analysis of the impact of the processing of drill pipe joint thread parameters. Fan Yuan Hao discussed the causes of thread milling errors of drill pipe joints[14], and established a machining error model for the whole machining process of thread milling. Volodymyr Kopei studied the effect of pitch deviation on the fatigue life of drill tool joints[15]. Jinhua Cheng analyzed the effect of interference on the ultimate strength and failure mode of the drill pipe body and tool joint assembly[16].

The above studies mainly analyze the mechanical properties of drill pipe joints and the sealing performance of casing, but less analysis of the sealing performance of drill pipe joints. At the same time, most studies ignore the influence of thread parameter deviation on the mechanical properties of joints. However, during the processing of drill pipe joints, due to the different processing quality, it is inevitable that the thread parameters of the drill pipe joints will deviate. Therefore, this paper takes API NC38 joint thread as the research object considers the limit deviation of drill pipe joint thread parameters, and analyzes the influence of different thread parameter limit deviations on drill pipe joint sealing performance under axial load conditions. This has important reference significance for the design of thread parameter tolerances of drill pipe joints.

2. Sealing Mechanism of Drill Pipe Joints

The sealing function of a drill pipe joint relies primarily on the metal-to-metal surface elastic interference fit of the shoulder to achieve a seal. Numerous experts have studied the sealing performance of metal-to-metal, and this paper combines the results of previous studies and simultaneously adopts two indexes, the sealing index, and Mises stress, as the basis for judging the sealing performance of drill pipe joints.

a)Sealing index: To comprehensively consider the influence of contact pressure and contact length on the sealing effect of drill pipe joints, the sealing index is introduced as the basis for judging the sealing performance. During machining, the sealing surfaces are not smooth, so the roughness of the contact surfaces can result in a gap remaining after mating. According to the theory of fluid mechanics, the cross-sectional area of the gap between the sealing surfaces and the length of the leakage path determine the local resistance generated when the fluid passes through the gap is[17]:

$$\Delta F \propto \Delta l / S \quad (1)$$

The greater the contact stress on the contact surface, the smaller the cross-sectional area of the gap, and if the two are proportional, then there are:

$$\Delta F \propto p_t \Delta l \quad (2)$$

The leakage resistance is equivalent to the contact stress accumulated along the leakage path. When a gas or liquid passes through a gap, the resulting resistance is:

$$\Delta F \propto \int p_t dl \quad (3)$$

Therefore, the sealing capacity for a drill pipe joint can be obtained by integrating the contact pressure over the effective sealing length Les on the shoulder face, which is expressed by the sealing index W:

$$W = \int_{L_{es}} p_t dL \quad (4)$$

Comparing the critical sealing index of special threaded joints of oil pipes[18], the critical sealing index of drill pipe joints in the presence of threaded grease is considered to be:

$$W_{ac} = 1.843 \times \left(\frac{p_g}{p_a} \right)^{1.177} \quad (5)$$

Where: Δl is the leakage path length, S is the gap cross-sectional area, P_t is the contact pressure, P_g is the sealing pressure, and P_a is the atmospheric pressure.

Since the drill pipe is subjected to both drilling fluid and circumferential pressure during downhole operations, the sealing pressure should be greater than the pressure difference between the inside and outside of the drill pipe to achieve a sealing effect[19]. Here the critical sealing pressure is taken as the pressure difference between the inside and outside of the drill pipe as 0MPa, 10MPa, 20MPa[20]. The corresponding critical sealing index is calculated as 0mm·MPa,416.4 mm·MPa,941.5mm·MPa. To ensure the sealing of the drill pipe joints, it is necessary to allow $W \geq W_{ac}$.

b)Mises stress: When the maximum Mises stress on the sealing surface is too large, the contact surface is prone to plastic yield, which in turn leads to the bonding of the sealing contact surface. Therefore, to ensure the sealing reliability of the drill pipe joint, the Mises stress of the drill pipe joint should be less than the yield strength of the material[21].

Based on the above sealing mechanism, this paper comprehensively analyzes the influence of different thread parameter deviations on the sealing performance of drill pipe joints under the action of upper buckle torque and axial load.

3. Drill Pipe Joint Thread Limit Deviation Analysis

A. Taper limit deviation

The basic parameters of the NC38 drill pipe joint thread selected in this paper are: taper is 1:6; pitch is 6.35 and the flank angle is 30°[22]. Among them, the taper tolerances of the external thread and internal thread of the drill pipe joint are: in the range of full tooth high thread, and the average taper deviation is ${}^{+0.0025}_{0}$ mm/mm and ${}^{0}_{-0.0025}$ mm/mm , respectively. Figure 1 shows a schematic diagram of the limit deviation of the taper of the external thread. Here, the middle diameter of the thread measurement reference point is kept unchanged, and the taper deviation is calculated according to the taper formula (6) to obtain the middle diameter of the large end of the drill pipe joint thread, and then the limit taper of the inner and outer threads is calculated.

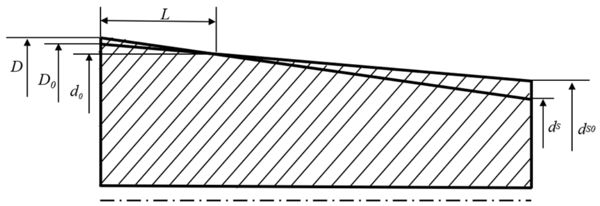


Figure 1. Schematic diagram of the limit tolerance of external thread taper

$$\begin{aligned} tpr &= \frac{D-d}{L} = \frac{D_0 + \Delta D - (d_0 + \Delta d)}{L} \\ &= \frac{D_0 - d_0}{L} + \frac{\Delta D - \Delta d}{L} = tpr_0 + \Delta tpr \end{aligned} \quad (6)$$

Where *tpr* is the thread taper; *L* is the distance from the measuring reference surface to the shoulder, d_0 is the ideal center diameter at the measuring reference surface, d is the actual center diameter at the measuring reference surface, D_0 is the ideal center diameter at the large end of the thread, *D* is the actual center diameter at the large end of the thread, D_{s0} is the ideal center diameter at the small end of the thread D_S is the actual center diameter at the small end of the thread.

This determines the parameters of the thread structure under the taper limit deviation as shown in Table 1. Among them, the taper of male and female buttons of drill pipe joints are indicated by taper I and II respectively.

Table 1. Thread structure parameters under taper limit deviation

Taper limit deviation combination	TaperI (mm/mm)	Taper II (mm/mm)
Combination I	1:5.91	1:6
Combination II	1:6	1:6.09
Combination III	1:5.91	1:6.09

B. Analysis of limit deviations in the lateral angle of teeth

The tolerance range of the lateral angle of teeth was selected in this article to be ±0.75°[22]. As shown in Figure 2 is a form of limiting deviation in the change of tooth side angle, the difference between the actual tooth side angle and the theoretical tooth side angle is the threaded tooth side angle deviation, expressed as $\Delta\theta$.

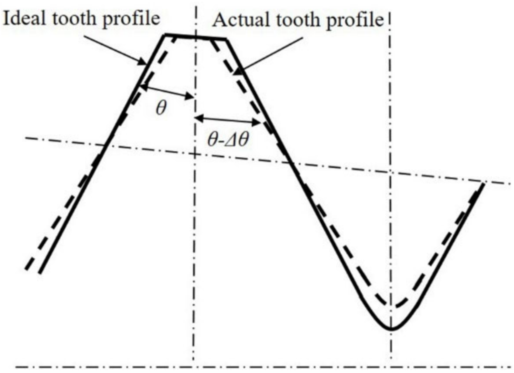


Figure 2. Schematic diagram of lateral tooth angle deviation

The deviation of the flank angle of threaded teeth includes the deviation of the left and right sides of the flank angle, which can be divided into the equivalent change and the unequal change deviation of the tooth flank angle on both sides. In this study, we analyze the equal variation of the lateral angle of the teeth on both sides of the internal and external threads, and the specific structural parameters are shown in Table 2. Among them, the lateral angles of the male buckle and the female buckle are indicated by the lateral angles I and II respectively.

Table 2. Limit deviation of tooth side angle thread structure parameters

Tooth lateral angle limit deviation combinations	tooth side angle I (°)	tooth side angle II (°)
Combination I	30.75	29.25
Combination II	29.25	30.75
Combination III	30.75	30.75
Combination IV	29.25	29.25

C. Pitch limit deviation analysis

The pitch tolerance is required to be within the range of full tooth high threads, and the cumulative pitch deviation should not exceed ±0.114mm[22]. Drill pipe joint thread pitch is greatly affected by the actual processing conditions, there will be a uniform change in the thread pitch deviation and a random change in the deviation of a certain or a few threaded teeth. A schematic diagram of the pitch deviation is shown in Figure 3.

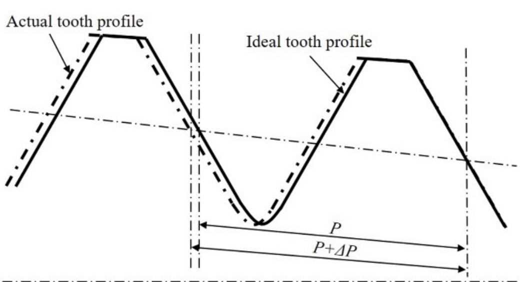


Figure 3. Schematic diagram of thread pitch deviation

Considering the feasibility of geometric modeling, this study analyzes the variation of pitch deviation such as the pitch of internal and external threads in the range of full-tooth high threads. Therefore, the cumulative pitch deviation is averaged to each threaded tooth, and all pitch deviations are $\Delta P=\pm 0.0081$mm. The specific parameters of the thread structure of the drill pipe joint are shown in Table 3. Among them, the pitch of the male buckle and female buckle of the drill pipe joint are indicated by the pitch I and II respectively.

Table 3. Thread structure parameters under pitch limit deviation

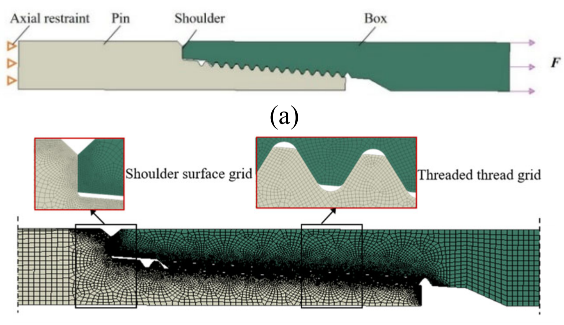
Pitch Limit Deviation Combination	pitch I (mm)	pitch II (mm)
Combination I	6.3581	6.3419
Combination II	6.3419	6.3581
Combination III	6.3581	6.3581
Combination IV	6.3419	6.3419

4. Finite Element Computational Modeling of Drill Pipe Joints

A. Drill pipe joint model simplification

In this study, the finite element calculation model uses NC38 drill pipe joints with an outer diameter of 127mm and an inner diameter of 61.9mm. According to the existence of the limit deviation of thread parameters analyzed earlier, the finite element models of drill pipe joints with different structures are established. Due to the small rise angle of the thread of the drill pipe joint, and the analysis of the machining limit deviation is large, to improve the calculation efficiency, the two-dimensional axisymmetric model is used for modeling and analysis. Taking into account the St. Venant effect, the length of the drill pipe joint taken for modeling is 2 times the distance from the small end of the thread to the vanishing point of the large end of the thread. Assume that the drill pipe joint is an isotropic, continuous homogeneous body. A boundary condition is a fixed boundary condition that is applied at one end of the buckle. When the external load is applied, an axial external load is applied at one end of the female buckle. The penalty function method is used to define the tangential contact boundary of the Coulomb friction form, and the normal contact is set to the "hard" contact. The finite element model of the drill pipe joint is shown in Figure 4(a).

The grid unit of the drill pipe joint is divided into the CAX4R 4-node bilinear axisymmetric quadrilateral unit, and the mesh refinement of threaded teeth and torque shoulder is carried out. The total number of drill pipe joint grid elements is 19393, of which 9526 mesh elements are male joints and 9867 mesh elements are female joints, and the grid elements are shown in Figure 4(b).



(a)

(b)

Figure 4. Drill pipe joint model

The material utilized for drill pipe joints is 37CrMnMo, possessing a modulus of elasticity measured at 2.06×105 MPa, a Poisson's ratio of 0.28, a yield strength reaching 931 MPa, and a tensile strength of 1035 MPa. Taking into account the influence of threaded grease containing zinc powder ranging from 40% to 60% by weight, the coefficient of friction in the finite element calculation was set at 0.08[23].

B. Finite element model validation

In the software, the two-dimensional axisymmetric model cannot directly apply the upper buckle torque, so the method of setting the interference amount on the shoulder surface is used to apply the equivalent upper buckle torque to the finite element model. According to the API upper buckle torque calculation formula (7), the upper buckle torque T=21.5kN·m is calculated, and further conversion can be obtained that the interference amount of the shoulder is 0.1mm. The Mises stress cloud of the drill pipe joint after the upper buckle is shown in Figure 5. The maximum Mises stress of the model is 578.78MPa, which is about 60% of the yield strength of the material, which is in line with engineering experience, which verifies the effectiveness of the model[24].

$$T = \frac{SA}{12}\left(\frac{P}{2\pi} + \frac{R_t f}{\cos\theta} + R_S f\right) \tag{7}$$

$$R_t = \frac{C + \left[C - \left(L_{PC} - 0.625\right) \times tpr \times 1/12\right]}{4} \tag{8}$$

$$R_S = \frac{OD + Q_C}{4} \tag{9}$$

Where: T represents the drilling column joint make-up torque, S denotes the API recommended make-up torque, A signifies the smaller value of the cross-sectional area at the root of the first engaging thread, P stands for the pitch, f is the friction coefficient of the contact surface of the effective engaging teeth between the male connector and the female connector, θ is the tooth half-angle, C represents the median diameter of the base surface, tpr is the taper, L_{PC} is the length of the male connector male threads, O_D is the outside diameter of the drilling column connector, Q_C denotes the diameter of the boring hole of the drilling column connector.

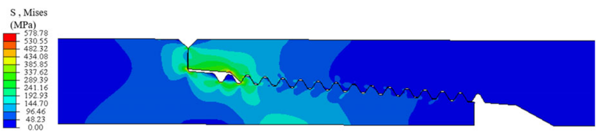


Figure 5. API NC38 make-up torque state Mises stress contour map

The finite element calculation results of the NC38 finite element model after the upper buckle in this paper are compared with the thread contact pressure of the NC38 drill pipe joint after buckling calculated by He Ti Cai using the theoretical model[25], and the comparison results obtained are shown in Figure 6. It can be observed that the variations in thread tooth contact stress calculated by the two methods follow the same trend, exhibiting a relatively high overall agreement. The maximum discrepancy between the two is 9.72%, which falls within an acceptable range and validates the accuracy of the finite element computational model.

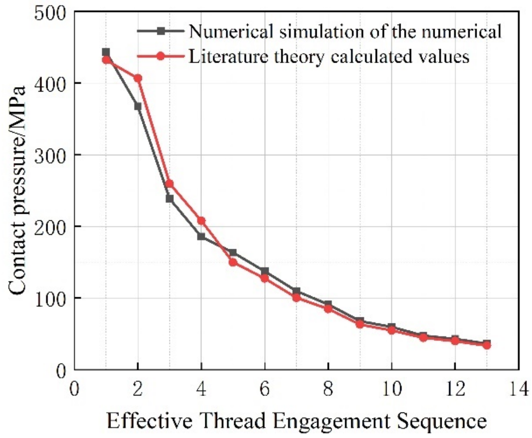


Figure 6. Contact Pressure Comparison

5. Simulation Results Analysis

A. The effect of thread parameter deviation in the upper buckle state

The Mises stress cloud of drill pipe joints with different taper limit deviations under the action of upper buckle torque is shown in Figure 7. It can be seen that the existence of taper deviation has little effect on the stress distribution law of the drill pipe joint, and the stress concentration part is still located in the first few threaded teeth near the shoulder.

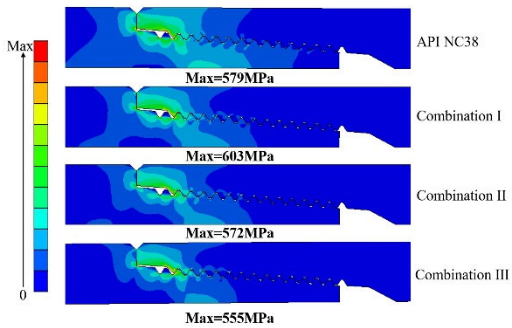


Figure 7. Mises stress cloud in the upper buckle state of taper deviation structure

The sealing index is obtained by extracting the contact pressure value on the shoulder path and integrating it along the actual contact path. The maximum Mises stress value of each drill pipe joint is extracted, and the statistical value is shown in Figure 8. It can be seen from the figure that the taper limit deviation has little effect on the maximum Mises stress of the drill pipe joint. The maximum Mises stress of the drill pipe joint increases from 579MPa in the ideal state to 603MPa in combination I, an increase of 4.1%, but all within 60% of the yield strength of the material, and the thread is only in a safe state under the action of the upper buckle torque.

At the same time, the sealing index of each structure is higher than the critical sealing index, which can achieve the sealing effect. However, the existence of taper limit deviation makes the sealing index of the drill pipe joint decrease compared with the ideal structure, which can be reduced by up to 36%, and the existence of taper limit deviation is not conducive to the sealing performance of the upper buckle state of the drill pipe joint.

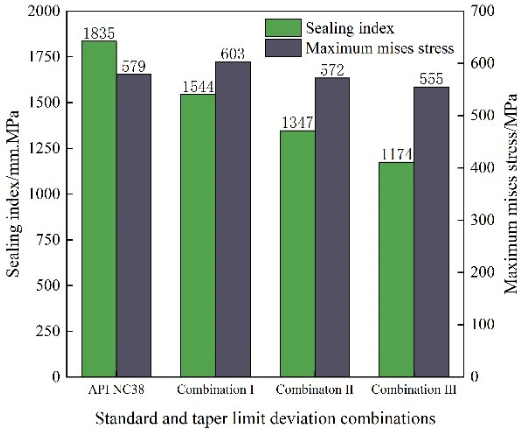


Figure 8. Sealing index and maximum Mises stress diagram of taper deviation structure

The Mises stress cloud of drill pipe joints under tooth flank angle deviation is shown in Figure 9. It can be seen that when the side angle error of the internal and external thread teeth changes opposite (combination I and II), the stress distribution of the drill pipe joint changes greatly, and the stress concentration part is regularly distributed in the upper or lower part of the threaded tooth. This is mainly due to the presence of tooth side angle deviation in the process of the upper buckle, resulting in local interference contact of threaded teeth, and then the phenomenon of stress concentration in the interference contact part of threaded teeth. The maximum Mises stress of the drill pipe joint reached 935MPa, which was 61.5% higher than the ideal state.

When the limit deviation of the side angle of the internal and external thread teeth is the same (combination III. and IV), the stress distribution law of the drill pipe joint is the same as that of the ideal structure because the meshing part of the internal and external thread teeth can be completely meshed due to the same side angle of the teeth. It can be seen that the existence of tooth flank angle deviation has a great influence on the stress distribution of drill pipe joints.

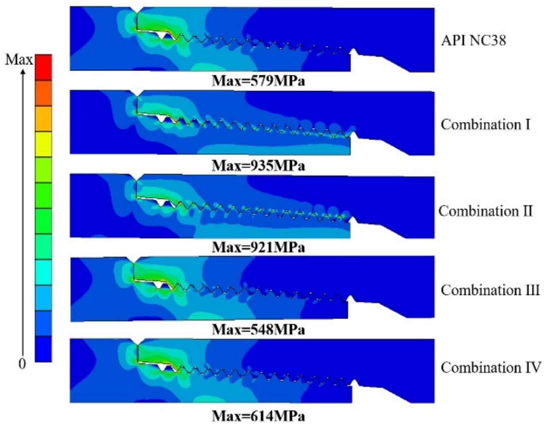


Figure 9. Mises stress cloud in the upper buckle state of tooth side angle deviation structure

It can be seen from Figure 10 that the limit deviation of the tooth flank angle has little effect on the sealing performance of the upper buckle state of the drill pipe joint. However, the existence of different tooth flank angle deviations of internal and external threads will cause the maximum Mises stress of the joint to approach or slightly exceed the yield strength of the material, and the drill pipe joint is prone to local plastic deformation, which reduces the sealing reliability of the joint.

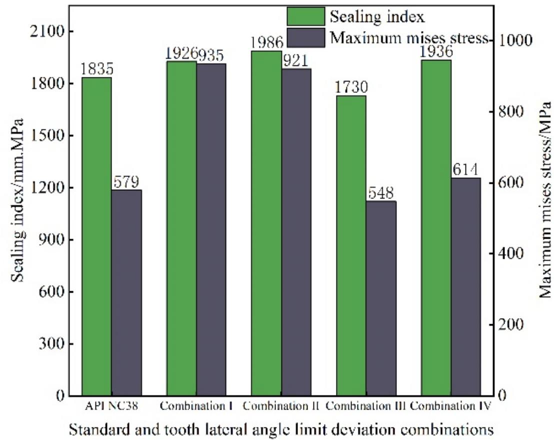


Figure 10. Sealing index and maximum Mises stress diagram of tooth side angle deviation structure

Figure 11 shows the Mises stress distribution cloud of drill pipe joints under different pitch deviations. It can be seen from the figure that when the thread parameters are combination I and combination III, the maximum Mises stress of the drill pipe joint increases significantly. The maximum Mises stress values were 931 MPa and 925 MPa, respectively, which were close to the yield strength of the material, which were 160.8% and 159.8% of the ideal state. This is because the increase in the deviation of the external thread pitch leads to a more pronounced stress concentration near the shoulder surface (combination I and III), while the increase in the internal thread pitch mainly affects the stress concentration of the last teeth of the thread (combination II).

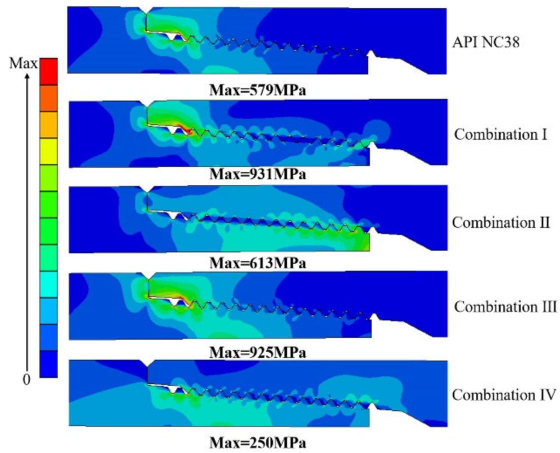


Figure 11. Mises stress cloud in the upper buckle state of pitch deviation structure

It can be seen from Figure 12 that the pitch deviation has a significant effect on the tightness of the upper buckle state of the drill pipe joint, and the increase of the external thread pitch will improve the sealing reliability of the joint, and the maximum sealing index is increased by 104.5% compared with the ideal state. However, at this time, the contact surface and threaded teeth have a large Mises stress, which is easy to cause damage to the sealing surface or threaded teeth when making up. The reduction of the external thread pitch will make the sealing index of the joint decrease, or even not have sealing (combination IV), and the risk of seal failure is high.

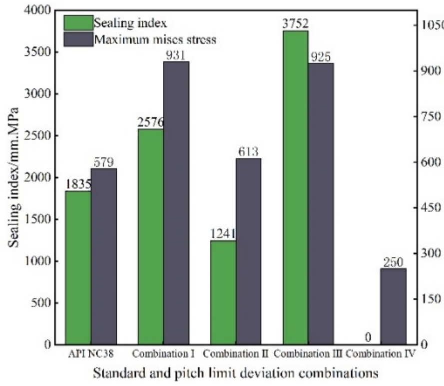


Figure 12. Sealing index and maximum Mises stress diagram of pitch deviation structure

B. Effect of thread parameter deviation under axial load

I). The effect of taper deviation

An axial tensile load is applied to the drill pipe joint based on the upper buckle torque, and the change in sealing index with tensile load is shown in Figure 13(a). Under the tensile load, the contact pressure of the shoulder surface of the sealing table gradually decreases, and the taper deviation makes the sealing performance of the drill pipe joint decrease rapidly with the increase of tensile load.

Among them, when the taper of the internal thread is reduced (combination II), the sealing index is lower than the critical sealing index with an internal and external pressure difference of 20MPa, which significantly reduces the sealing performance of the drill pipe joint. When the internal and external threads are at the same time limit taper deviation (combination III), the sealing index is always at a low value, and the sealing ability is quickly lost under tensile load.

It can be seen from Figure 13(b) that the maximum Mises stress of the three error structures gradually approaches the yield strength of the material during the increase of tensile load, which is higher than the value of the ideal structure. Especially in combination III., the maximum Mises stress value changed the most, and the maximum stress was 907MPa.

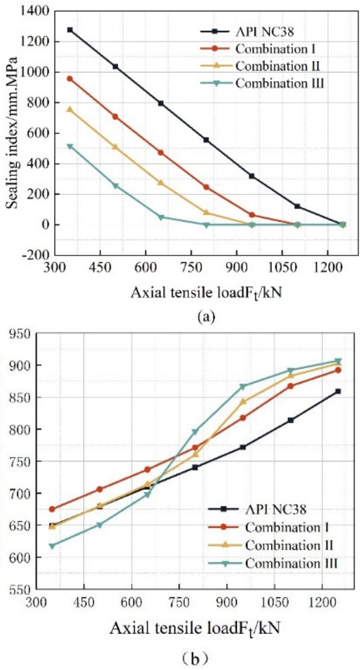


Figure 13. Sealing index and maximum Mises stress curve under tensile load

Change the direction of load application to apply axial compressive load to the drill pipe joint. As shown in Figure 14(a), with the continuous increase of axial compressive load, the sealing index of several structures increases almost linearly, and is much higher than the critical sealing index, and the sealing effect is good. Similar to the tensile load, when the inner and outer threads are taper limit deviations, the sealing performance of the drill pipe joint has the greatest impact, and the sealing index has always been at the lowest value compared to other structures.

It can be seen from Figure 14(b) that the structure containing the internal thread taper limit deviation (combination II. and III), when the axial compressive load is not higher than 950kN, the maximum Mises stress values are lower than the ideal structure, and the value changes are almost consistent. On the whole, the sealing performance of different taper limit deviation combination structures is greatly affected by the axial tensile load, and the sealing effect is not ideal, and the maximum Mises stress value changes greatly with the increase of tensile load, and the maximum increase is 46.7% (combination III).

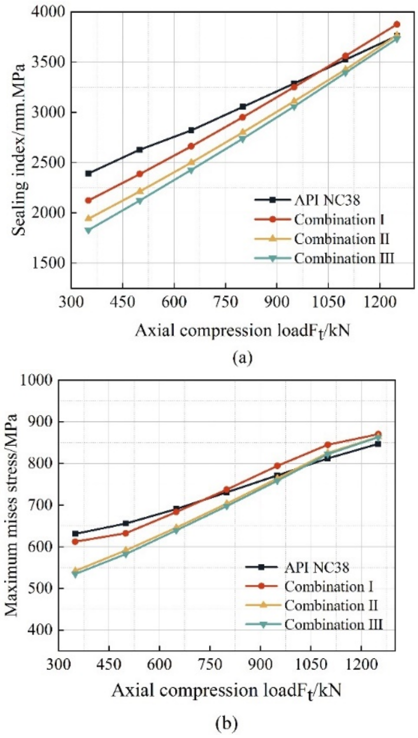
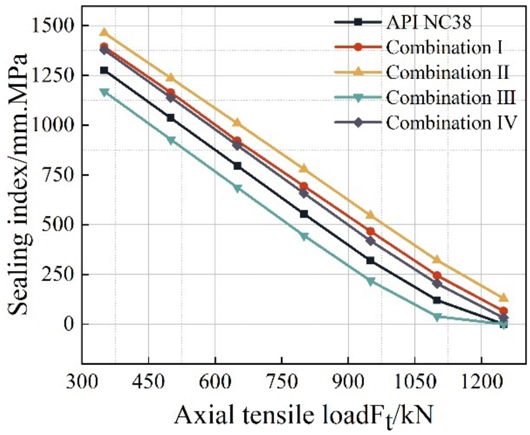


Figure 14. Sealing index and maximum Mises stress curve under compressive load

II). The effect of deviation of the tooth flank angle

It can be seen from Figure 15(a) that the changing trend of sealing index with the increase of axial tensile load of several tooth flank angle limit deviation combination structures is the same as that of ideal structures, and the overall value is not much different, and the maximum difference is 14.7% of the ideal state.

From the change trend of maximum Mises stress in Figure 15(b), it can be seen that the maximum Mises stress of the structures (combination I and II) with the opposite variation of the lateral angle deviation of the internal and external thread teeth has been located at a higher value with the increase of axial tensile load, which is much higher than the ideal structure and combination III and IV, of which the maximum value is 938.2MPa, which has exceeded the yield strength of the material. A certain amount of plastic deformation will occur in the part of the drill pipe joint, which will affect the sealing reliability. When the variation of the flank angle of the internal and external threaded teeth is consistent (combination III. and IV), the initial interference or gap of the contact surface of each threaded tooth is the same, and the value is much smaller than the size of the threaded tooth. Therefore, the variation trend of the maximum Mises stress value of the two is consistent with the ideal structure.



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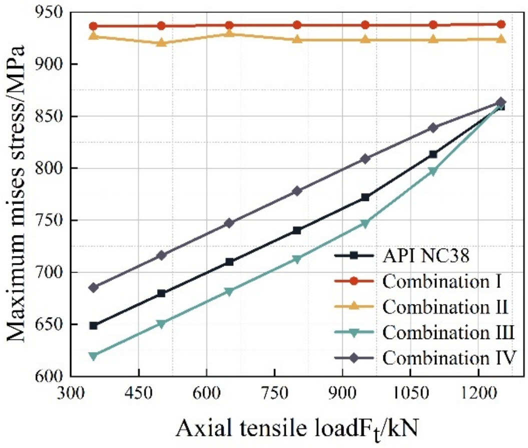
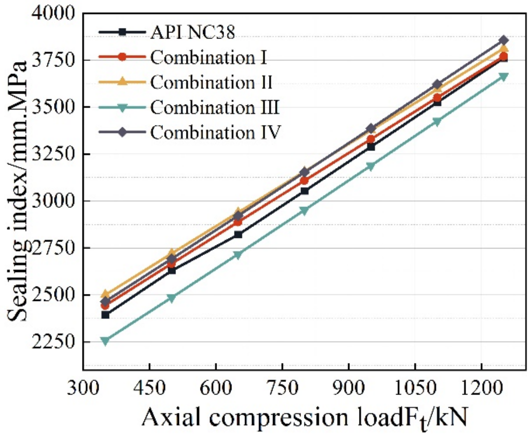


(b)

Figure 15. Sealing index and maximum Mises stress curve under tensile load

It can be seen from Figure 16(a) that the trend of the sealing index of the drill pipe joint is the same as that of the ideal structure, the change is almost linear, and the numerical difference is not large, which is similar to the change under axial tensile conditions. It can be seen from Figure 16(b) that, as in the tensile condition, the variation of the flank angle of the internal and external thread teeth is not the same (combination I and II), and the maximum Mises stress is at a higher value overall. For structures with the same change of tooth flank angle (combination III and IV), the maximum Mises stress change trend is the same as that of the ideal structure. Therefore, regardless of the axial load condition, the sealing index of drill pipe joints with different combinations of flank angle limit deviation is not much different from the ideal structure. However, when the limit deviation of the side angle of the inner and outer thread teeth changes the opposite, the Mises stress will be close to or slightly exceed the yield strength of the material, which is easy to causes damage to the contact surface and the unfavorable phenomenon of bonding.



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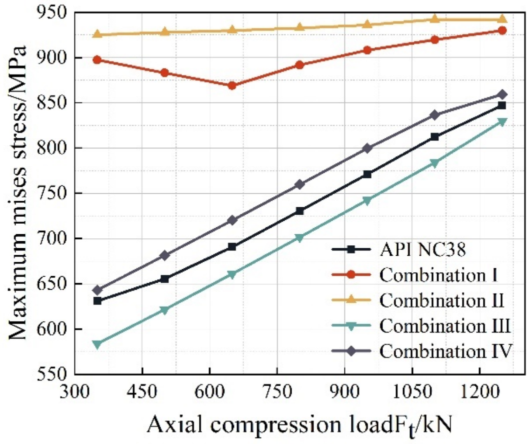


(b)

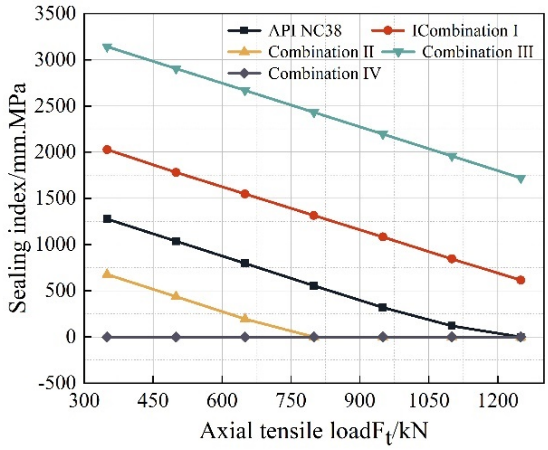
Figure 16. Sealing index and maximum Mises stress curve under compressive load

III). The effect of pitch deviation

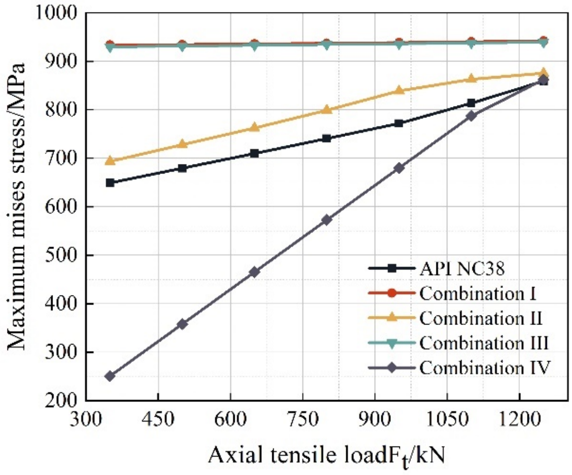
As shown in Figure 17(a), the presence of a pitch limit deviation in the drill pipe joint has a significant effect on the sealing performance of the joint. Among them, the sealing index is most affected by the change in the pitch of the external thread. When the external thread pitch is the limit pitch (combination I and III), the overall value of the sealing index is higher than the critical sealing index, the sealing performance is good and there is no leakage under different internal and external pressure differences. At the same time, the combination III seal reliability is the highest, and the highest sealing index is 146.1% of the ideal state.

When the external thread pitch is reduced (combination II and IV), the sealing index is significantly lower than the ideal structure, and the sealing performance is very poor. In particular, the sealing failure of the structure (combination IV) with reduced thread pitch of both internal and external threads has already occurred when the tensile load is 350 kN. This is the same influencing factor as in the upper buckle state, so it is necessary to improve the machining accuracy and try to control the pitch deviation in a lower range.

It can be seen from Figure 17(b) that the change in the pitch of the external thread also has a great influence on the maximum Mises stress of the drill pipe joint. When the pitch of the external thread increases (combination I and III), the maximum Mises stress is close to or slightly exceeds the yield strength of the material with the increase of tensile load, and local yield failure occurs. When the external thread pitch is reduced (combination II and IV), the maximum Mises stress of the drill pipe joint is not high, and the structure is in a safe state.



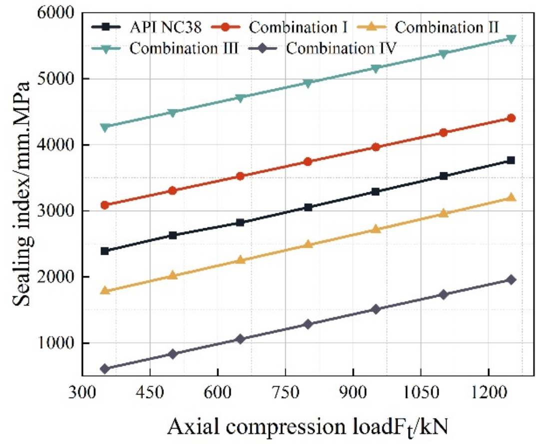
(a)



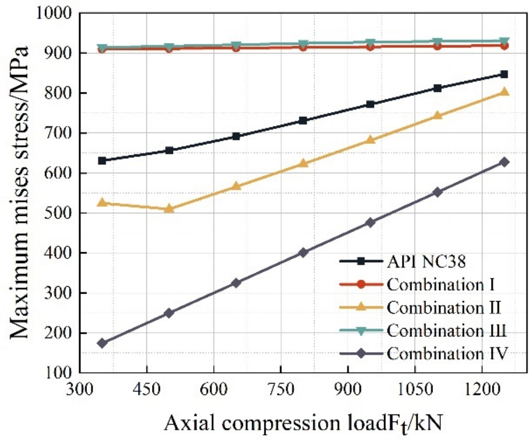
(b)

Figure 17. Sealing index and maximum Mises stress curve under tensile load

It can be seen from Figure 18 that when the drill pipe joint is subjected to axial compressive load, the change law of sealing index and maximum Mises stress is consistent with the axial tensile working condition, which is greatly affected by the change of external thread pitch. Among them, the sealing performance of combination IV is relatively poor, and when the axial compressive load is less than 500kN, it can only seal the working condition that the pressure difference between the inside and outside of the drill pipe is less than 10MPa. This is due to the change of the limit deviation of the external thread pitch, which will lead to a large interference or void in the contact surface of the first few teeth thread meshing near the shoulder surface of the buckle, which has a greater impact on the contact force of the shoulder surface when buckling. The change of internal thread pitch deviation makes the last few teeth away from the shoulder appear a large interference or gap, so the contact force at the shoulder surface has little effect, so it has little effect on the tightness of the drill pipe joint.



(a)



(b)

Figure 18. Sealing index and maximum Mises stress curve under compressive load

6. Conclusions

a) Taper limit deviation will make the sealing of drill pipe joints under the action of upward make-up torque and axial load decrease, especially the taper limit deviation of internal threads has a greater impact on the sealing of the drill pipe joints, and the sealing performance decreases significantly or even does not have the sealing effect.

b) The limit deviation of the tooth side angle has little effect on the sealing of drill pipe joints under the action of upward make-up torque and axial load, but when the limit deviation of the tooth side angle of internal and external threads varies inconsistently, the maximum Mises stress of the drill pipe joints is always at a high value close to or slightly exceeding the yield strength of the material, and plastic deformation is easy to occur in the local area.

c) The presence of pitch limit deviations significantly affects the sealing performance and stress distribution of drill pipe joints. Among them, the change of the outer thread pitch deviation has the greatest influence on the sealing performance of the joint. The sealing performance is significantly increased or decreased under the action of upward make-up torque and axial load, and the maximum Mises stress values of the joints slightly exceed the yield strength of the material, which is prone to unfavorable phenomena such as adhesion and damage of the sealing surface, thus leading to seal failure.

d) Among the limit deviations of several thread parameters, the pitch limit deviation has the greatest influence on the sealing performance of the drill pipe joints, followed by the taper limit deviation, and the tooth side angle limit deviation has the least influence. The existence of the taper limit deviation makes the joint safe only when the upper make-up torque is applied, but under the tensile load, the maximum Mises stress of the joint gradually approaches the yield strength of the material. The lateral angle limit deviation and pitch limit deviation lead to localized yield failure of the drill pipe joints in both the top-buckled state and under axial load, which affects the safety of the structure.

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