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The influence of double pitting corrosion on casing collapsing strength based on different ellipsoid shape

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Abstract. Acidic environment always contributes on casing corrosion phenomenon, the local corrosion and pitting lead to stress concentration, which decreases the strength and is an important factor to cause damage to the casing. The influences of distance of two pitting, corrosion depth, section parameter on collapsing strength of casing are quantitatively analyzed under the condition of double pitting axial distribution and ring distribution. The results showed that the maximum Von Mises stress of casing first increases, and then goes down to a steady state as the distance of double pitting grows under the condition of double pitting axial distribution, while the stress goes down to a steady state as the distance of double pitting grows under the condition of double pitting ring distribution. It can provide the theoretical foundation for the casing design through analyzing and comparing the influence of double pitting on the collapsing strength of casing under different condition.

1. Introduction

Acidic environment usually leads to the casing corrosion phenomenon, and the corrosion damage form has two types: the uniform corrosion and local corrosion. The uniform corrosion which occurs along the whole casing wall generally causes less damage, while the local corrosion occurs on the certain areas of casing and the rest of the parts are in good condition. The common local corrosion is pitting corrosion(holes)[1-4]. Pitting corrosion reduces the thickness of the casing wall, and causes stress concentration which seriously reduces the strength of casing, bring serious potential danger to the production of oil and gas[5-8]. Therefore the analysis and study the influence of pitting corrosion defect on casing strength has a great significance on selecting materials and extending the service life of the gas well.

Aiming at the influence of pitting corrosion defect on the casing strength, the present study focused the casing collapsing strength of a single pitting defect[9-12]. Using the finite element software ANSYS with the actual casing size and the material parameters, we analyzed the influence of pitting hole spacing, hole section parameter and pitting depth on casing collapsing strength on two working conditions—— Double pitting holes distributed along the axial of casing wall and along the ring of casing wall, providing the theoretical basis for the safety assessment of pitting corrosion during the oil and gas production.

2. Failure criterion determination

Failure criterion is the basis of judging the failure, it depends on failure modes, and there are two criterion which are widely used:

1) Based on elastic failure criterion[13], casing failed when the equivalent stress of corrosion area (using Von Mises equivalent stress) reaches the yield strength of pipe material.

2) Based on plastic failure criterion[14], minimum stress of corrosion area reaches the tensile strength, casing failed.

Using the elastic failure criterion based on the security considerations, in the three dimensional principal stress space, the Von Mises condition[15] is expressed as in equation (1):

$$\sigma_v = \sqrt{\left\{\frac{1}{2}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2]\right\}} < [\sigma] \quad (1)$$

Where: σ_v is Von Mises equivalent stress , MPa; $[\sigma]$ is allowable stress, MPa.

3. The simplification of pitting corrosion defect

The common form of casing pitting holes can be simply divided into cylindrical spherical or ellipsoidal holes through reviewing literatures and investigation. But in the actual situation, the pitting holes are closer to the ellipsoid through a large number of pitting corrosion pit morphology observation. So we mainly consider the effects of ellipsoidal pitting on the mechanical behavior of casing. Depending on the pitting distribution location, the double pitting defects can be divided into two classes:

1) Pitting holes distribute along the axial, the adjacent pitting located on the same axis direction of casing wall, and circular projection overlap, as is shown in Figure 1. (a), the distance of two hole section center is h, written as the double hole axial spacing.

2) Pitting holes distribute along the ring, the adjacent pitting located on the same height of casing wall, the distribution of axial projection overlap, as is shown in Figure 1.(b), the distance of two hole section center isθ, written as the double hole ring spacing.

3）Pitting hole geometric description：Figure 2 is the three-dimensional topography of a ellipsoid pitting ,the pitting cross section is oval ,the half width is b, the half long is c, the maximum depth is a. Ellipsoid shape parameters is determined by the a,b,c three values. a depicts the depth of pitting, the d=c/b which is section coefficient controls the shape of the pitting section, t is wall thickness, t0 is the maximum pitting depth, t′=t0/t is relative corrosion depth.

(a) (b)

Figure 1. Casing pitting corrosion model:(a) Double pitting axial distribution, (b) Double pitting ring distribution.

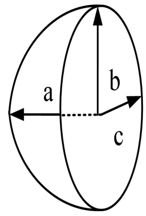


Figure 2. Ellipsoid pitting three-dimensional topography.

4. The establishment of the finite element model

In this paper, two pitting corrosion along the axial and ring distribution are chosen as examples respectively. Three dimensional finite element model of casing pitting corrosion is established using commercial available software ANSYS.

The casing is chosen in a super deep well section which is located in the Tarim Basin formation depth of 5000 m. The equivalent external extrusion pressure is about 70 MPa. Casing type is P110 with the pipe parameters shown in Table 1.

Table 1. Parameters of casing.

Pipe diameter(m)	Pipe thickness(m)	elasticity modulus (GPa)	Poisson's ratio	yield strength
0.1778	0.00919	2.06×1011	0.3	837MPa

5. The calculation results analysis

In order to study the differences between corrosion section, pitting depth and pitting space the influence law of distribution of casing collapsing strength, section coefficient d is selected as 0.5, 1, 2, 3, and relative pitting depth d is chosen as 10%, 20%, 30%, 40%, 50%, the specific calculation condition as shown in Table 2.

Table 2. Working condition of calculation table.

Working condition	Section coefficient	Relative pitting depth	Pitting space
Axial distribution	0.5、1、2、3	20%	2mm~50mm
	3	10%、20%、30%、40%、50%	2mm~50mm
Ring distribution	0.5、1、2、3	20%	2°~50°
	3	10%、20%、30%、40%、50%	2°~50°

A working condition with relative pitting depth t′=20%, pitting section coefficient $d=2$ is taken as an example. When the outer pressure is 50 MPa, the local stress cloud picture of casing pitting area is calculated. When two corrosion holes are along the axial distribution and the corrosion holes are intersected, the intersecting area between two holes is in high stress area, the maximum Von Mises stress zone is located in the intersection area of two holes, as pitting spacing increases, the high stress area gradually changed from the pitting hole edge to the pitting hole center. The maximum Von Mises stress is located in the pitting hole edge; When two corrosion holes are along the annular distribution, the intersecting area between two holes is in the low stress area and the center of two holes and a fraction of hole edges are in the high stress area. The maximum Von Mises stress lies in the edge of pitting hole. As the angle of pitting hole increases, the position of high stress area is unchanged.

5.1. The influence of pitting section on casing strength

When the relative pitting depth is fixed on 20%, the relationships between the maximum Von Mises stress of casing and pitting spacing under the different corrosion section coefficient are shown in Figure 3 an Figure 4. As shown in Figure 3, when double pitting holes is along the axial distribution, the relationship between the maximum Von Mises stress of casing and pitting space obey the Gaussian distribution. When the two hole is intersecting, the maximum stress increases with the increase of the axial spacing and reaches the maximum at the smallest intersection area. When the section coefficient is small, the Von Mises stress will exceed the casing yield strength and the casing is easy to be damaged by pitting corrosion. When the two holes are separated, the interaction of double pitting corrosion defect is weakened. When the spacing reaches the limit axial spacing, the maximum Von Mises stress changes very little. When the pitting section coefficient is 0.5, 1, 2, 3, the limit of the axial spacing is: 16 mm, 20 mm, 22 mm and 22 mm respectively. As is shown in Figure 4, when the double pitting holes are along the ring distribution, the maximum Von Mises stress of casing exponential decreases as the double pitting ring intersection angle increases. When the pitting section coefficients are 0.5, 1, 2 and 3, the limit toroidal angle are 18 °, 20 °, 22 ° and 22 ° respectively. When the pitting spacing is small and the double holes spacing is the same, the maximum Von Mises stress of double holes along the axial distribution is significantly larger than that of the double holes along the ring distribution. The double pitting holes along the axial distribution is more likely to damage the casing.

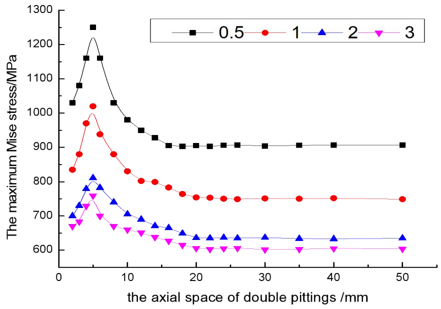


Figure 3. Variation curves of the maximum Von Mises stress with pitting space.

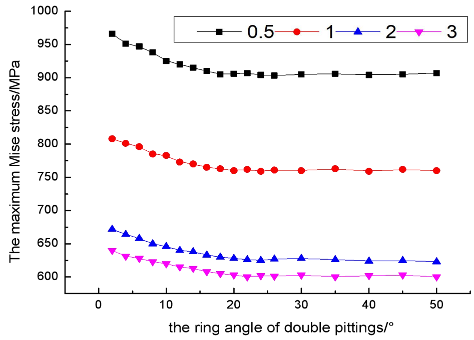
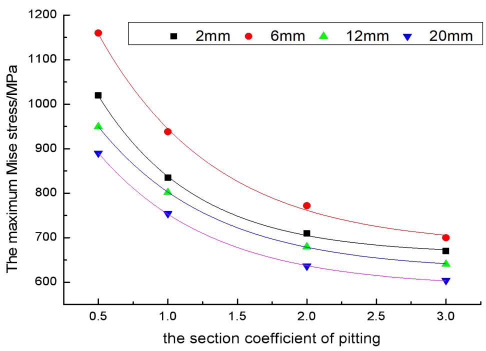


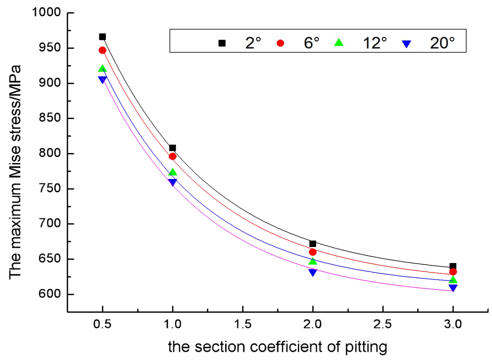
Figure 4. Variation curves of the maximum Von Mises stress with pitting angle.

The relationship between the maximum Von Mises stress of the defects and section coefficient is shown in Figure 5 when the double pitting axial spacing is 2 mm, 6 mm, 12 mm and 20 mm respectively and double pitting ring angle is 2°, 6°, 12°and 20° respectively. It shows that the maximum Von Mises stress decreases exponentially as the cross section coefficient increases. A case example is carried out when the axial spacing is 2mm and ring spacing angle is 2°.

When the cross section coefficient is 0.5, the Von Mises stress of casing exceeds the yield strength under the different pitting spacing, which leads to casing failure. Therefore in actual working condition, the small pitting defect causes a lot of damage to the casing. When the cross section coefficient d increases from 2.0 to 3.0, the maximum Von Mises stress of the pitting in axial distribution reduces to 5.6%, the maximum Von Mises stress of pitting in ring distribution reduced to 4.7%. There is less influence of pitting section on casing stress and pitting section coefficient is no longer the main factor which determines casing strength.



(a)



(b)

Figure 5. Variation curves of the maximum Von Mises stress with pitting section coefficient, (a)when double pitting axial distribution is different, (b) when double pitting ring distribution is different.

6. Conclusion

(1) The stress distribution of P110 casing when the double pitting is along axial distribution and ring distribution is studied by the finite element software ANSYS. The limit spacing of double hole axial pitting and double hole ring pitting are obtained. The limit spacing of double hole increases as the increase of the pitting section coefficient.

(2) Through the regression curve it can be obtained that the maximum Von Mises stress exponential decreases as the pitting section coefficient enlarges in the condition of double pitting along axial distribution and ring distribution. When the pitting section coefficient exceeds a certain value, the maximum Von Mises stress of casing does not decrease with the increase of the coefficient of cross section.

(3) Under the condition of the same pitting, double pitting holes along the axial distribution causes more damage than double pitting holes along the ring distribution while the pitting spacing is small.

Acknowledgments

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References

[1] Lu W Y. 2014. P110 casing corrosion cracking mechanism research. *Journal of Yangtze university (natural)* **11** pp. 78-80
[2] DNV. RP-F101 2010 Corroded Pipelines (Oslo:Det Norske Veritas)
[3] ASME B31G-2009 2009 Manual for determining the remaining strength of Corroded pipeline-Supplement to ASME B31 Code for Pressure Piping(New York: ASME B31 Committee)
[4] Dong S R, He D S and Zhang P 2005 Pairs of pitting corrosion of pipelines of elastic-plastic finite element analysis *Journal of design and research* **9** pp 20-22
[5] Wanees S A, Radwan A B, Alsharif M A and Haleem A E 2017 *Materials chemistry and physics* **190** pp. 79-95
[6] Xu Z Q, Yan X Z, Yang X J 2014 *Journal of mechanical design* **8** pp 75-78
[7] Ossai C I, Boswell B and Davies I 2016 *Engineering failure analysis* **60** pp 209-28
[8] Papavinasam S 2017 *Trends in oil and gas research and technologies* pp 663-88
[9] Deng K H, Lin Y H, Qiang H, Zeng D Z and Lin X X 2015 New high collapse model to calculate collapse strength for casing *Engineering failure analysis* **58** pp 295-306
[10] Liu S H, Zhang H L, Zhu X H and Tong H 2014 *Engineering failure analysis* **42** pp 240-51
[11] Huang X, Mihsein M, Kibble K and Hall R 2000 Collapse strength analysis of casing design using finite element method *Engineering failure analysis* **77** pp 359-67
[12] Kuriyama K,Tsukano Y, and Mimaki T 1992 Effect of wear and bending on casing collapse strength *SPE* **24597** pp 1-10
[13] Tian X and Zhang H 2017 Failure criterion of buried pipelines with dent and scratch defects *Engineering failure analysis* **80** pp 278-89
[14] Dolinski M and Rittel D 2015 Journal of mechanics and physics of solids 83 pp. 1-18
[15] Jaeger J C, Cook N G W, Zimmerman R W 2007 *Fundamental of rock mechanics* (Blackwell Publishing) Chapter 9 p 254