Residual strength of a casing with corrosion semi-ellipsoid defect in high-sulfur gas wells

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Abstract. There are few studies on the residual strength of semi-ellipsoid defect casing considering the bending moment load in high sulfur gas well. In this paper, a numerical model of a casing with corrosion defects exposed to bending moment is proposed. The effect of the defect positions along the circumference on the residual strength of the casing with bending moment is investigated. Parametric studies highlight that defect size have significant effect on the residual strength of the casing, and the circumferential defect and the axial defect can change the critical internal pressure and the critical axial load. This finding has a significant guidance for residual intensity evaluation of a casing with defect.

Keywords: Corrosion semi-ellipsoid defect; Casing; Equivalent stress; Residual strength; Numerical simulation.

1. Introduction

Casing pipe and production string is an important equipment for oil and gas exploitation [1]. However, failure of the pipe will result in oil and gas leakage, blowout, et al. Is should be noted that corrosion is a major cause of the string failure during oil and gas development. Moreover, pitting corrosion and contiguous corrosion with irregular shapes and sizes are the common corrosion types [2], and continuous casing pressure is common in high temperature and high pressure oil and gas wells [3]. Some studies pay attention to the on casing corrosion mechanism and surrounding rock mechanics [4-6]. In addition, casing pipe load-carrying capacity faces enormous challenges due to corrosion and constant stress. Furthermore, to ensure the applicability and integrity of the string, it is necessary to investigate the residual strength of the casing pipe with corrosion defects [7-9].

Currently, the research based on numerical simulation on residual strength of defective casing pipe with bending moment is rare [10-12]. The nonlinear finite element method is usually used to evaluate the equivalent stress distribution of defective casing [13].

This paper is devoted to study the residual strength of volumetric defects of a casing under bending moment in high-sulfur gas wells. The method in this paper provides the reference for high sulfur gas well integrity management and assessment of residual strength of corroded defective casing.

2. Model establishment

The finite element model for a P110 casing pipe, the 7 inch (outside diameter 177.8 mm, wall thickness 12.65 mm), was chosen to perform numerical simulation, three-dimensional (3D) model of casing pipes with different defects were established respectively, and the ultimate bearing capacities for axial force and internal pressure were evaluated under the action of complex loads. The physical parameters of the P110 casing pipe are shown in Table 1.

In this paper, the ellipsoid defect shape is regularized into three common shapes of sphere. [14]. To analyze the influence of different shapes defects on the residual strength of the pipe. Due to the fact that the depth of the defect usually has a great influence on the bearing capacity of the pipe [15].

The ellipsoid defect is simplified as the short axis radius R_s (the depth) and the long axis radius R_l, and the short to long axis ratio of 1:2 is confirmed for the semi-ellipsoid pit in Fig. 1. For the convenience of statistics and analysis, the feature sizes of the defect were dimensionless processing, the dimensionless defect depth coefficient *t=C/e*. The physical dimensions for the corrosion defect model are shown in Table 2.

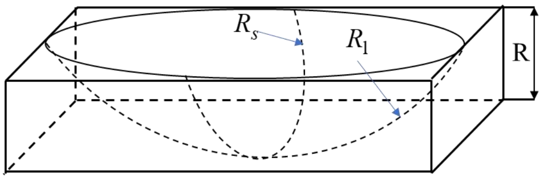


Fig. 1 Semi-ellipsoid defect geometric model.

Table 1. P110 casing pipe physical parameters.

Density (kg/m^3)	Elastic modulus (GPa)	Poisson 's ratio	Yield strength (MPa)	Outer diameter, D(mm)	Wall thickness , e(mm)	Tube length, L(mm)	Dog leg
7800	206	0.3	758-965	177.8	12.65	889	6°/30m

Table 2. Defect depth parameters.

Semi-ellipsoid minor axis radius, R_s	Dimensionless depth factor, t
1.265	0.1
2.530	0.2
3.795	0.3
5.060	0.4
6.325	0.5
7.590	0.6

2.1 Mesh and boundary conditions

Considering the actual working conditions of the casing pipe, the mechanical model of the pipe was presented in Fig. 2, the casing bears the axial load *T*, the internal pressure load imposed on the inner surface P_i, and the external pressure load exerted on the outer surface applies P_0. Due to the curvature of the wellbore, additional bending moments are applied to the casing pipe. Therefore, the influence of the bending moment on the residual strength of the casing pipe was considered when calculating the bearing capacity, the incremental method is used to gradually increase the load value until the failure condition requirements are met.

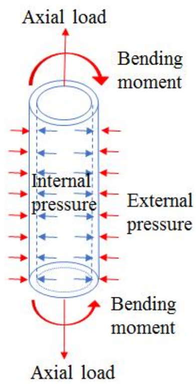


Fig. 2 Casing pipe mechanical model.

3. Results and discussion

3.1 Compound load effects

The multi-factor loads are considered for high-sulfur well, and the load parameters are listed in Table 3. Then, the dimensionless depth coefficient is $t=0.3$, the radius R for hemispherical defects is depth, and the ratio of the short axis radius to the long axis radius Rs: R_l =1:2 shown in Fig. 1.

As shown in Fig. 3 for the casing pipe with hemispherical defects, the critical internal pressure decreases under the same axial load when the bending moment is applied in the high critical internal pressure region. However, it should be noted that the critical internal pressure can be increased by applying external pressure. But the external pressure has a greater influence on the critical internal pressure under the same axial load. Moreover, in the low critical internal pressure region, applying bending moment or external pressure under the same internal pressure load will reduce its critical axial load.

Table 3. Different combined loads.

working condition	compound load
one	Axial force +Internal pressure
two	Axial force +Internal pressure +Bending moment
three	Axial force +Internal pressure +External pressure
four	Axial force +Internal pressure +Bending moment+ External pressure

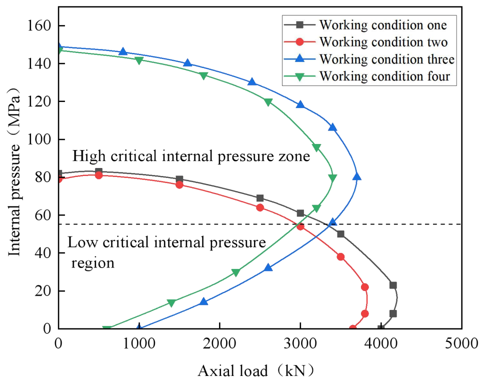


Fig. 3 The influences of composite load on residual strength of a semi-ellipsoid casing pipe.

3.2 Semi-ellipsoid defect effects

When the casing pipe with defect is subjected to the ultimate load under the combined stress of axial force, internal pressure, bending moment and external pressure, the influence of three kinds of defects on the stress and strength of the pipe is investigated. The stress distributions of the pipe wall with rectangular volume defects are depicted in Fig. 4. It can be seen from the longitudinal section that the high stress range is wider than for hemispherical defects because the defects are elongated in the axial direction.

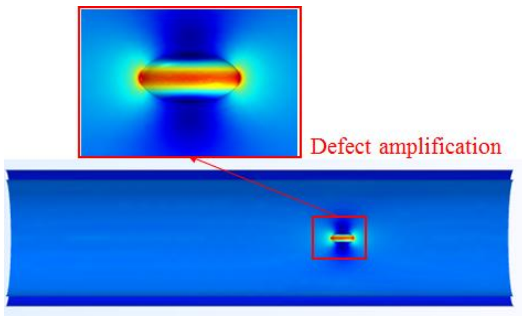


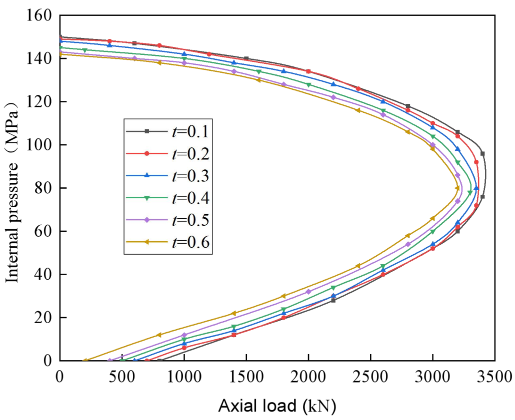
Fig. 4 Von Mises stress contours for semi-ellipsoid defect.

Table 4. Semi-ellipsoid defect minor to major axis ratio.

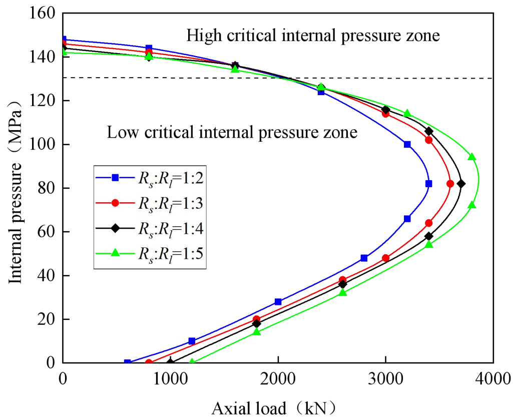
$R_s : R_l$	5:1, 4:1, 3:1, 2:1, 1:2, 1:3, 1:4, 1:5

For semi-ellipsoid defect, Rs and R_l are minor axis and major axis, respectively, listed in table 4. The ultimate load envelopes are drawn in Fig. 5 for semi-ellipsoidal depth, circumferential and axial defect. For depth defect in Fig. 5(a), the results for semi-ellipsoid defect are the same as hemispherical defects. The residual strength of the pipe string decreases with the increase of the depth coefficient.

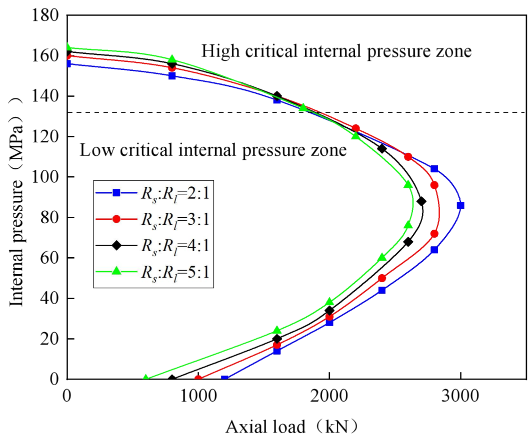
For the axial defect shown in Fig. 5(b), it is revealed that the critical internal pressure at the same axial load increases with the increase of Rs: R_l when load capacity is in the high critical internal pressure region. But the critical axial load at the same internal pressure decreases with the increase of Rs: R_l when load capacity is in the low critical internal pressure region. The reason is due to the fact that the large Rs: R_l leads to the more loss of casing volume and influence the high critical internal pressure region, however, the large Rs: R_l leads to the reduction of curvature and influence the low critical internal pressure region. Moreover, the result in Fig. 5(c) under both the high and low critical internal pressure region is the same as those in Fig. 5(b). It also can be concluded that the axial and hoop defect have a great effect on both the critical internal pressure and the axial load.



(a) Depth coefficient



(b) Axial defect



(c) Hoop defect

Fig. 5 Influence of semi-ellipsoid defect size parameters on remaining strength of casing pipe.

4. Conclusions

This paper mainly established the casing model with the difference defect sizes considered bending moment load. The influence of size on the stress distribution and residual strength of the casing under different composite loads were investigated. For the combined load, the bending moment load reduces the residual strength of the casing. However, the bearing capacity of the internal pressure is improved due to the existence of external pressure. the bending moment has great influence on the critical internal pressure and critical axial load. In addition, the von Mises equivalent stress is mainly concentrated in the bottom of the defect and the arc surface along the bottom for semi-ellipsoid defects. For the residual strength, it can be concluded that the semi-ellipsoid defect has the greatest influence on the residual strength of the casing under the compound load. For defect size parameters, the axial and hoop defects have a great influence on both the critical internal pressure and the axial load for the casing with semi-ellipsoid defect.

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