

Residual Strength Analysis of Oil and Gas Pipelines with Different Corrosion Depths

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ABSTRACT

In this study, a finite element model has been created to evaluate the residual strength of oil and gas pipelines under varying degrees of corrosion. In pipelines affected by corrosion, the highest stress typically concentrates in the damaged area due to the detachment of material caused by corrosion, which weakens the pipeline's structural integrity. The maximum stress varies with different levels of defect depth; as the defect becomes more severe, the peak stress in the pipeline increases. If the defect depth remains below 6 mm, the pipeline's strength is sufficient to meet operational requirements and prevent failure.

KEYWORDS

Finite element model, Oil and gas pipelines, Residual strength.

Nomenclature	
d	inner diameter (mm)
D	outer diameter (mm)
Dd	depth of the defect (mm)
L	length (m)
P	pressure (MPa)
W	width (mm)
Greek symbols	
σ	stress
ν	Poisson's ratio
Subscript	
t	tensile strength
VME	Von Mises equivalent
y	yield strength

1. INTRODUCTION

Pipelines, as the main mode of oil and gas transport, are important for ensuring energy security. Due to the complexity of the working environment of the pipeline, it is inevitable that the pipeline with long service time will be corroded. Corroded pipeline will appear local material shedding, reduce the pressure-bearing capacity of the pipeline, and in serious cases, it will also cause oil and gas leakage, resulting in huge economic losses and the occurrence of some unsafe accidents. Therefore, it is of great significance to evaluate the remaining strength of oil and gas pipelines containing corrosion defects.

The earliest formula used to calculate the pipeline failure stress is by the United States Battelle Institute based on fracture mechanics and the results of blasting experiments to obtain the semi-theoretical and semi-empirical formula NG-18[1]. Due to the results of the calculations being too conservative, Kiefner in the formula on the basis of a revision of the formula. On this basis, the American Society of Mechanical Engineers (ASME) established the pipeline corrosion assessment code ASME B31G-1984, which has been the earliest and most widely used corrosion pipeline assessment code[2]. In 1990 and 1991, ASME was revised to introduce two new codes based on this evaluation code-ASME B31G-1991[3] and Modified ASME B31G[4]. Later scholars tried to introduce ultimate tensile strength into the assessment specification and proposed, for example, Shell-92[5], API-579[6], DNV-RP-F101[7], PCORR[8], and other assessment specifications.

In this paper, a pipeline containing localized corrosion defects is constructed, and the effect of different corrosion depths on the residual strength of the pipeline under internal pressure is analyzed using finite elements.

2. METHODOLOGY

2.1. Finite element model

In this paper, ANSYS is used to perform finite element analysis of the residual strength of a section of pipeline containing corrosion defects. The length of the pipe (L) is 3m, the outer diameter of the pipe (D) is 1219mm and the inner diameter of the pipe (d) is 1180mm. The length of the defect (L_d) at the corrosion site is 100 mm, the width of the defect (W_d) is 90 mm, and the depth of the defect (D_d) is the parameter we are going to analyze, which varies from 4 to 12 mm. The operating internal pressure (P) of the pipe is 10 MPa. The yield strength (σ_y) of the pipe material is 460 MPa, the tensile strength (σ_t) is 535 MPa, and the Poisson's ratio (ν) is 0.3. The grid of the numerical model is shown in Fig.1.



Fig. 1. Mesh of the model.

2.2. Determination of limit loads

Since the steel used in pipelines is usually a high toughness material and normally destroys in the form of plastic flow, the ultimate load should be determined according to the fourth strength theory. The strength conditions obtained by the fourth strength are as follows:

$$\sigma_{VME} = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2]} \leq [\sigma] \quad (1)$$

where σ_{VME} is the Von Mises equivalent stress and $[\sigma]$ is the permissible stress.

The permissible stress can be written as:

$$[\sigma] = \frac{\sigma_y + \sigma_t}{2} \quad (2)$$

3. RESULTS AND DISCUSSION

In this paper, finite element analysis was carried out for pipes with different corrosion depths. As shown in Fig. 2, the maximum stresses tend to occur in the defective parts of the pipelines with different corrosion depths. This is due to the fact that the defective parts of the pipeline cause some of the pipeline material to fall off due to corrosion, and the strength of the pipeline decreases.

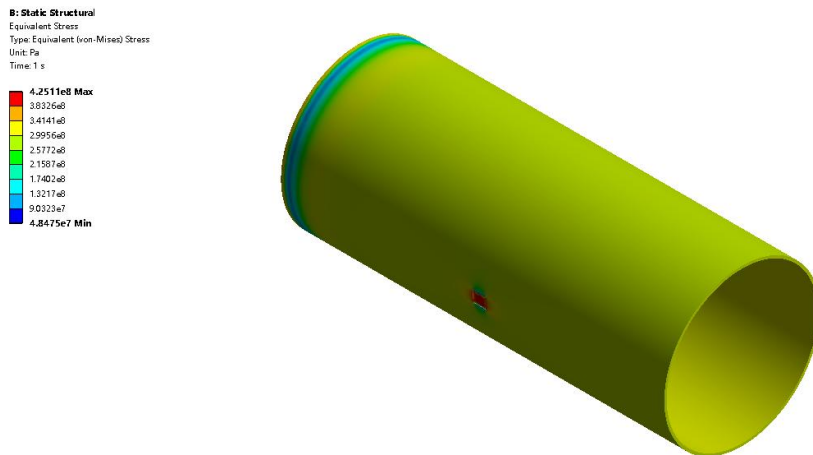


Fig. 2. Pipe stress distribution at P=4MPa.

Fig. 3 represents the maximum stresses applied to the pipe at different corrosion depths, and it can be seen that the maximum stresses applied to the pipe increase as the corrosion depth increases. This is because the deeper the corrosion depth, the lower the strength of the pipe in the defective region. In addition, the permissible stress of the pipe is 492.5 MPa obtained according to Eq. 2. The results show that the pipe can meet the strength requirement without failure when the corrosion depth is less than 6 mm.

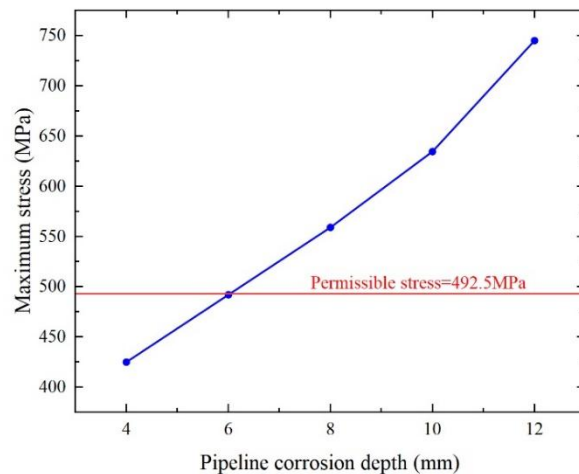


Fig. 3. Maximum stress at different defect depths.

4. CONCLUSIONS

In this paper, a finite element model is developed to analyze the residual strength of oil and gas pipelines at different corrosion depths. For corroded pipelines, the maximum stress tends to occur in the defective areas because corrosion causes the material in the defective areas to be detached and reduces the strength of the pipeline. The maximum stresses are different for pipelines with different defect depths. The deeper the defect depth, the higher the maximum stress on the pipeline. When the defect depth is less than 6 mm, the strength requirements of the pipe can be met to ensure that it will not fail.

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