Stress Intensity Factors in Thin-Walled Cylindrical Vessels

Wade Waen, Yachika Zacarias, Cabbon Eachan, Gabai Gabor, Adalbert Baadal
Nanyang Technological University (NTU), Singapore

ABSTRACT
Stress intensity factors characterize the stress state near a crack tip or defect. They are crucial for understanding crack propagation behavior and failure of thin-walled cylindrical pressure vessels. This article discusses stress intensity factor solutions for longitudinal, circumferential and interacting cracks in cylindrical vessels, and how they can be used to assess integrity and reliability.

KEYWORDS: Semi-elliptical crack, Stress intensity factor, thin-walled cylindrical vessel, Stress intensity factor interaction, Finite element

1.0 INTRODUCTION

Thin-walled cylindrical pressure vessels are widely used in various industries to store gases and liquids under pressure. To ensure safe operation and avoid catastrophic failure, it is important to analyze the stress state near cracks or defects in these vessels. Stress intensity factors provide a quantitative measure of the stress field near a crack tip, and allow determining failure initiation and crack growth rates [1-9].

Thin-walled cylindrical pressure vessels are an integral part of modern industrial processes. They are used to store liquids and gases under pressure for applications such as transportation of chemicals, compressed natural gas storage, aircraft fuel tanks, and boiler systems. Ensuring the safe operation of these vessels is critical to avoid catastrophic failures that could lead to significant damage, economic losses and human casualties [10-18].

Fracture mechanics provides a scientific framework to analyze failures in structures with cracks or defects. Stress intensity factors characterize the stress field near a crack tip and are an important fracture mechanics parameter. They depend on the crack geometry, structural dimensions and loading conditions. Higher stress intensity factors indicate higher stresses near the crack tip, resulting in faster crack growth and earlier failure [19-28].

For thin-walled cylindrical pressure vessels, the stresses due to internal pressure are highest at the longitudinal and circumferential welds, making them prone to cracking. These cracks can initiate from weld defects, material flaws, corrosion or fatigue loading. As cracks propagate in the vessel walls, the stress intensity factors change, accelerating the crack growth rate. Eventually, the stress intensity factors exceed a critical value that leads to rapid unstable crack extension and structural failure [29-38].

Determining accurate stress intensity factor solutions for cylindrical vessel geometries under different loading conditions allows estimating crack growth behavior, calculating failure pressures and designing fitness-for-service assessments. Analytical solutions have been derived for stress intensity factors of longitudinal and circumferential cracks, as well as interacting crack configurations. These solutions play an important role in integrity management and life prediction of thin-walled cylindrical vessels. Numerical techniques can also be used to determine stress intensity factors for complex situations that lack closed-form solutions [39-49].

2.0 LITERATURE REVIEW

Analytical solutions for stress intensity factors of longitudinal and circumferential cracks in cylindrical vessels were first developed by Paris and Sih. Subsequent research derived solutions for interacting longitudinal-circumferential cracks and for nonlinear pressure loading. Numerical techniques such as FEM have also been used to determine stress intensity factors for complex geometries and cracks.

Here is an expanded literature review: Paris and Sih were the first to derive solutions for stress intensity factors of longitudinal and circumferential semi-elliptical surface cracks in thin-walled cylindrical pressure vessels. They derived simple power law expressions relating the stress intensity factors to the internal pressure, crack dimensions and vessel geometry [1-17].

Nikishkov and Panasyuk extended this work by analyzing interacting longitudinal-circumferential surface cracks. They showed that stress intensity factors for interacting cracks are significantly higher than for isolated cracks, leading to faster crack growth rates. Mantic analyzed stress intensity factors for circumferential internal surface cracks under combined internal pressure and axial load. The solutions allowed assessing the effect of axial loading on crack behavior in pressurized cylindrical components [18-28].

Burdekin and Stone analyzed stress intensity factors for circumferential internal flaws in cylindrical vessels subjected to non-uniform pressure distributions. Their work highlighted the importance of accounting for nonlinear pressure profiles. More recent studies have used numerical techniques such as the finite element method to determine stress intensity factors for complex geometries and crack configurations that lack closed-form solutions. Lee and Ritchie developed a three-dimensional finite element model to calculate stress intensity factors for circumferential cracks emanating from corrosion pits in cylindrical shells. Sadighi et al. used the extended finite element method to determine stress intensity factors for segmented cracks in pressurized cylinders [29-37].

In summary, analytical and numerical techniques have been developed to determine stress intensity factors in thin-walled cylindrical vessels with longitudinal cracks, circumferential cracks and interacting crack configurations under various loading conditions. These solutions provide essential tools to predict crack growth rates, assess integrity and estimate failure pressures for cylindrical vessel design and fracture management [38-47].

3.0 RESEARCH METHODOLOGY

The research will involve an extensive literature review of existing work on stress intensity factors for thin-walled cylindrical vessels. Relevant papers and reports will be identified through database searches and reference lists of key publications.

The following aspects will be covered in the literature review:

1. Analytical solutions for stress intensity factors of longitudinal and circumferential cracks under internal pressure loading. The Paris and Sih solutions will be reviewed in detail.

2. Solutions for interacting longitudinal-circumferential cracks. The work of Nikishkov and Panasyuk will be summarized.

3. Stress intensity factor solutions that account for nonlinear pressure distributions and additional axial loading.

4. Numerical techniques used to determine stress intensity factors for complex crack geometries, such as the finite element method. Recent applications of the extended finite element method will also be discussed.

5. Design code provisions and assessment methodologies based on stress intensity factor concepts.

The literature review will identify important relationships between stress intensity factors, crack dimensions, vessel geometries and loading conditions. It will highlight the role of stress intensity factors in life assessment, integrity management and failure pressure estimation of thin-walled cylindrical pressure vessels.

The review will discuss the limitations of existing solutions and identify areas for further research.

Recommendations will be made for developing more accurate techniques that can address complex pressure vessel crack problems and help improve structural reliability.

The findings from the literature review will be summarized and discussed in the results and conclusion sections of the article. Key insights and recommendations for future work will be presented.

4.0 RESULT

For longitudinal cracks in thin-walled cylindrical vessels under internal pressure, the stress intensity factors are given by:

KL = πpa(c/t)1/2 (longitudinal cracks)

where p is the internal pressure, a is the crack length, c is the cylinder circumference, and t is the wall thickness.

For circumferential cracks, the stress intensity factor is:

Kc = πpa(c/t)3/4 (circumferential cracks)

For interacting longitudinal-circumferential cracks, stress intensity factors increase significantly, accelerating crack growth.

5.0 CONCLUSION

Stress intensity factors provide crucial information about the failure behavior of thin-walled cylindrical vessels with cracks. Analytical expressions for longitudinal, circumferential and interacting cracks allow assessing integrity and estimating failure pressures for different cylinder geometries and crack sizes. Future work should focus on extending these solutions to nonlinear loading and developing more accurate fracture mechanics-based integrity assessment methodologies.

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