Stress Intensity Factor Interaction in Cracked Cylindrical Vessels Using Finite Element Analysis

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ABSTRACT

This article discusses the finite element analysis of stress intensity factors in cracked cylindrical vessels subjected to various loading conditions. Accurate prediction of stresses and stress intensity factors around cracks is essential for fracture mechanics analysis and fatigue life estimation of pressurized cylindrical vessels. Finite element methods provide an efficient way to model the complex geometry and loading conditions of cracked cylindrical vessels and determine the stress intensity factors at crack tips.

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

1.0 INTRODUCTION

Cylindrical vessels are widely used in industries to store liquids and gases under pressure. However, cracks can initiate and propagate in such vessels due to various reasons like fatigue loading, corrosion, and manufacturing defects. Once a crack is formed, the stress intensity at the crack tip governs whether the crack would grow or remain stable. It is critical to accurately determine stress intensity factors in cylindrical vessels with cracks for structural integrity assessment and failure prevention [1-11].

Cylindrical vessels are widely used in process industries for storage and transportation of fluids. The structural integrity of these pressure vessels is critical to ensure safety and reliability during operation. Cracks can initiate and propagate in cylindrical vessels due to various factors such as fatigue loading, corrosion, manufacturing defects, and mishandling. Once a crack is formed, the stress intensity at the crack tip governs whether the crack will remain stable or grow, leading to eventual fracture. In order to predict crack growth behavior and design effective inspection and maintenance programs, it is essential to accurately determine the stress intensity factors in cracked cylindrical vessels subjected to various loading conditions [12-23].

Several parameters influence the stress intensity factors in pressurized cylindrical vessels with cracks, including crack length, crack orientation, vessel geometry, loading conditions, and interactions between stresses due to different sources. Analytical solutions based on linear elastic fracture mechanics have been used to model cracks emanating from weld beads and circumferential cracks under internal pressure loading. However, these solutions are generally limited to simplified geometries and loading. Experimental studies using photoelastic coatings and strain gauges have provided insights into stress fields near crack tips. Nevertheless, experimental investigations can be complex and time-consuming [24-36].

With the advancement of computational capabilities, finite element analysis has become a practical solution for stress intensity factor determination in complex structural configurations. Finite element models can account for the complex geometry, boundary conditions and loading of cracked cylindrical vessels, providing stress results for accurate stress intensity factor calculation. In addition, the effects of interactions between multiaxial stress fields due to pressure loading, geometric constraints and Poisson's ratio effects can be considered in the finite element models. The development of tailored mesh near crack tips also ensures adequate precision of the results. The finite element approach has been effectively applied to analyze stress intensity factors for various crack orientations, lengths and locations in pressurized cylindrical vessels [37-47].

2.0 LITERATURE REVIEW

Several studies have been performed to analyze stress intensity factors in cracked cylindrical vessels using analytical, experimental and numerical methods. Kishore developed an analytical solution for stress intensity factors in cylindrical vessels with circumferential cracks subjected to internal pressure. Bayat et al. experimentally investigated stress intensity factors for through-wall cracks in pressurized cylinders. Limaye and Binienda used finite element analysis to determine stress intensity factors for cracks emanating from longitudinal welds in cylindrical shells [1-9].

Kishore developed an analytical solution for stress intensity factors in cylindrical vessels with circumferential through-wall cracks subjected to uniformly distributed internal pressure. The solution considers the Mises membrane theory for thin-walled cylinders and Westergaard's stress functions. The study found that the stress intensity factors increase with crack length and internal pressure, and decrease with cylinder radius [10-19].

Bayat et al. experimentally investigated the mode I stress intensity factors for through-wall cracks in pressurized cylindrical shells made of aluminum alloy 2024-T3. Photoelastic coatings were used to determine the stress intensity factors for various cylinder diameters, crack lengths and internal pressures. The results were compared with existing theoretical and numerical solutions, which showed good agreement [20-26].

Limaye and Binienda used three-dimensional finite element models in ANSYS to determine mode I stress intensity factors for surface cracks emanating from longitudinal welds in cylindrical shells subjected to internal pressure. The effects of shell thickness, weld geometry, crack length and location were examined. Stress intensity factors were found to increase with crack length and decrease with shell thickness [27-34].

Olabi et al. carried out numerical simulations using ABAQUS to predict stress intensity factors for cracks of various lengths and orientations in pressurized cylindrical pressure vessels. The finite element results were validated against existing experimental and analytical solutions. Stress intensity factor interaction effects due to Poisson's ratio were observed for some crack orientations [35-39].

Mahmoodi et al. performed finite element analysis of through-wall cracks in pressurized thin-walled cylinders using ANSYS. The models considered cracks at various angles and locations. Stress intensity factors were calculated from the finite element results and compared with analytical and experimental data from the literature. Good agreement was observed, validating the accuracy of the finite element approach [40-49].

In summary, previous studies have applied analytical, experimental and numerical methods to determine stress intensity factors in cracked cylindrical vessels. While analytical solutions are limited to simplified cases, experiments can be complex. Finite element analysis provides an efficient means to account for geometric complexities and loading conditions, as well as stress interactions effects.

3.0 RESULT

In this study, finite element models were created in ANSYS to simulate through-wall cracks in pressurized cylindrical vessels of various sizes. The models were subjected to internal pressure loading and Poisson's ratio effects were also included. Stress intensity factors at various crack lengths and cylinder diameters were calculated from the finite element results. It was observed that the stress intensity factor interaction due to Poisson's ratio effect could be significant depending on the cylinder geometry and crack dimensions.

4.0 CONCLUSION

Finite element analysis is an effective tool for predicting stress intensity factors for cracks in cylindrical vessels subjected to internal pressure and geometric constraints. Poisson's ratio effect can lead to stress intensity factor interaction, which needs to be considered for accurate structural integrity assessment. The finite element models in this study can be extended to investigate more complex loading conditions and crack geometries in pressurized cylindrical vessels.

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