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FATIGUE DESIGN SENSITIVITIES OF STATIONARY TYPE 2 HIGH-PRESSURE HYDROGEN VESSELS

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Abstract
Common manufacturing processes for type 2 high-pressure hydrogen storage vessels use a surrogate measure of the desired residual stress, *e.g.*, target strain on the external surface or target internal pressure. The critical value of these measures is chosen to impart residual stress sufficient to achieve a certain fatigue performance for the targeted operational pressure cycling and with given assumptions about the liner and overwrap geometry and materials. This paper uses computational simulation to study the sensitivities of fatigue performance to associated design specifications and assumptions.

1. Introduction

Type 2 high-pressure hydrogen vessels for storage at hydrogen refueling stations are designed assuming a predefined operational pressure cycle and targeted autofrettage conditions. However, the resulting finite life depends significantly on variables associated with the autofrettage process. Fatigue crack growth rates can vary widely for a given pressure range depending on the details of the residual strains imparted during the autofrettage process because of their influence on crack driving forces. Small changes in variables associated with the autofrettage process, *e.g.*, the hardening behavior of the liner steel, can result in large changes in the residual stress profile leading to possibly degraded fatigue life. In this paper, computational simulation was used to examine the sensitivity of design life to the autofrettage process and the impact on life if the targeted residual strain is not achieved during manufacturing.

2. Results

Finite element (FE) simulation of the autofrettage process for a typical type 2 tank geometry was used to approximate the residual stress field. An isotropic, elasto-plastic model was used to represent the SA-372 Grade J Class 70 liner steel and the hardening behavior was taken from tensile tests performed in both axial and circumferential directions conducted at Sandia. The carbon fiber overwrap material was included and assumed to remain elastic and in good structural integrity. The materials were assumed to be rate and temperature independent. The autofrettage process was simulated using a targeted hoop strain or a target overburden pressure, and kinematic boundary conditions were implemented so that internal pressure was the only cause of deformation, while maintaining global stability.

Crack growth simulation was performed using the fracture mechanics code FRANC3D [1]. FRANC3D is a pre- and post-processing code that modifies a FE input database to include the geometry and mesh of a crack, calls the FE solution engine, and post-processes the FE output database. The post-processing step computes the crack driving forces based on the FE solution, estimates the new crack geometry, and updates the FE mesh for the predicted crack growth. This process was used to establish the relationship between the crack geometry and corresponding driving forces. This relationship was subsequently used with crack growth rate data to estimate fatigue life.

The sensitivity analysis focused on the residual strain field by targeting typical choices for the functional form of the hardening model, as well as allowable variations in design-specified materials parameters, e.g., yield and ultimate strength. Other parameters explored include the liner thickness and the overwrap thickness, varying degrees of overwrap anisotropy, and the targeted hoop strain and targeted overburden pressure.

As an example, from the autofrettage FE simulation, a 90% reduction in overburden pressure led to a 61% reduction in residual compressive stress on the inside wall of the liner. Figure 1 shows the resulting predicted fatigue life versus initial flaw depth for various degrees of reduced autofrettage overburden ranging from 95% to 100% of the target. The curves for 99% and 100% of the target overburden are truncated because the integration algorithm was stopped when the design life was achieved (20 years / 100,000 cycles). Otherwise, the stopping criterion was the critical crack depth (25% of the liner thickness). From the figure, for an 0.5 mm initial flaw, missing the target overburden pressure by as little as 4% can comprise the design life by about 2 years. Further examples and outcomes of the sensitivity study will be presented.

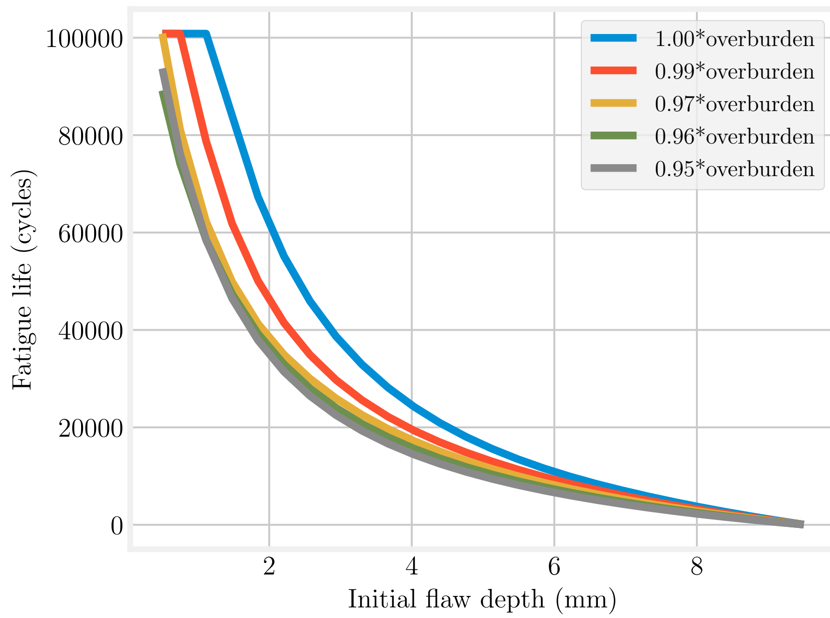

Figure1: Fatigue life (service years) versus initial flaw depth (mm) for reduced autofrettage residual stress.

3. Conclusions

This work used computational simulation to investigate the sensitivity of autofrettage residual stress to various design parameters and the implications for fatigue life. The fatigue life is sensitive to the magnitude of the residual stress, which in turn is sensitive to various parameters, e.g., material yield and ultimate strength.

4. References

1. [1] *FRANC3D Reference Manual, Version 8.0*. Fracture Analysis Consultants, Inc., United States, Dec 2021.

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