EVALUATING THE SENSITIVITIES OF AISCC SUSCEPIBILITY IN STAINLESS-STEEL NUCLEAR WASTE STORAGE CANISTERS FOR DEVELOPMENT OF A LIFETIME PREDICTION MODEL

Sarah Blust[1]*, James Burns[1], Robert Kelly[1], Rebecca Schaller[2] and Robert Tyron[3]

[1]University of Virginia, Charlottesville, VA, USA, [2]Sandia National Laboratory, Albuquerque, NM, USA
[3]Vextec Corporation, Brentwood, TN, USA
** Presenting Author email: smb4ayb@virginia.edu*

Abstract

Spent nuclear fuel (SNF) is currently stored across the US in passively cooled stainless steel dry storage canisters (DSC). Due to the design of the DSC, aerosols from the outside environment are able to deposit on the stainless-steel canisters. Over time the deposited aerosols will deliquesce on canisters to form concentrated salt brines resulting in localized corrosion, which when coupled with the high residual stress around welds can lead to stress corrosion cracking (SCC). The scope of the work presented is to investigate the boundaries of SCC to varying sensitivities such as environmental factors, microstructure variability, and material composition. These sensitivities will allow for recommendations to be made for canister monitoring and which variables are of the greatest concern for SCC of the DSCs. The data generated will be used in probabilistic FM predictions of AISCC growth for lifetime management of DSC. These predictions will inform a framework to quantify and manage a risk-based ranking of storage sites.

1. Introduction

Spent nuclear fuel is stored in passively cooled stainless steel canisters encompassed by concrete casks. The canisters are made from either 304L or 316L austenitic stainless steel and are cold rolled, then welded into cylinders creating the final canister shape. Air from the surrounding environment is circulated through the cask, exposing the stainless-steel canisters to the surrounding atmospheric conditions. The inlet air for cooling contains aerosolized precipitates which vary in contaminants from storage locations, as DSCs are stored in various regions throughout the U.S. The main contaminant canisters will be in contact with is sea water. Sea water contains aggressive ions, specifically varying types of chloride salts, which can form concentrated salt deposits on the canisters. While canisters are currently at temperatures too high for salt deposits to deliquesce, the canister temperatures will eventually decrease to a level optimal for salt deliquescence. This will create a corrosive aqueous layer on the canisters which can lead to pitting, and with sufficient residual stress the transition from pitting to atmospheric-induced stress corrosion cracking (AISCC) will occur. SNF canisters are designed to confine radioactive material and a through wall crack in the canister could potentially release radioactive material. Understanding the impacts of varying parameters which could lead to increased AISCC susceptibility is the focus of this work and will help to inform monitoring procedures and the recertification process for DSCs.

2. Results

There are two main components which are needed for crack growth prediction in the LEFM model. The first being a driving force that is generated using a K-solution, which accounts for the geometry of the crack/component, stress applied, and the initial flaw geometry. The second is relevant crack growth kinetics for the material and environment of interest. To enable LEFM based predictions the growth kinetics should be in the form of a da/dt vs. K relationship; such data can be generated by testing performed in a laboratory setting. The lack of rigorously generated da/dt vs. K relationships for the canister materials in relevant environments is a major knowledge gap that has resulted in sub-optimum approaches to life management of storage casks.

In this effort, da/dt vs. K testing was performed using rising K tests at a dK/dt of 0.33 MPa√m/hr. SENT samples were machined with a notch by EDM wire and fatigued out 250 microns at a ΔK of 7 for annealed materials and ΔK of 9.6 for cold-worked materials with a R of 0.2 to create a sharpened crack. Crack extension was monitored using direct current potential drop method (dcPD) to allow for real time tracking of crack growth. Once K-rise testing is completed samples are cleaned, heat-tinted, and fractured in fatigue. Fracture surfaces are imaged using SEM and measured to confirm dcPD accuracy.

The work presented focuses on the generation of crack growth kinetics for multiple material systems and environments. The data will be used to (1) find the boundaries for canister lifetime predictions, (2) understand the sensitivity of these predictions to relevant variables (e.g. residual stress level, material, temperature, chloride composition, etc.), and (3) demonstrate a framework of how these growth kinetics can be coupled with a LEFM life prediction model to inform risk assessments of nuclear waste canisters. This project will look at the individual contributions of temperature, Cl^- concentration, $MgCl_2$ vs. NaCl, addition of other environmental constituents, and atmospheric testing on the crack growth kinetics. Currently temperature dependence and full immersion vs. atmospheric are the focus of testing being performed. Results of temperature dependence on 304L cold-worked are shown below in Figure 1. Temperature is seen to play a prominent role in crack growth rate in this material system, with increasing temperature increasing stress corrosion cracking susceptibility.

For lifetime prediction modeling a K-solution is derived from canister geometry, initial flaw geometry, and residual stress, all which can be changed to accommodate for variations in canister design and location. The coupling of a K-solution with generated da/dt vs. K relationships will allow for the extrapolation of crack growth rates for a given crack tip driving force. The process of K-solution calculation and extrapolation of the related crack growth rate is repeated as the crack continues to grow. Figure 2 shows a demonstration of a lifetime prediction generated by the LEFM model. This demonstration uses the da/dt vs. K relationship data from Figure 1. As previously stated, the goal of this work is to understand the sensitivities of the prediction to individual parameters, whether environmental or material related. A clear dependence on temperature is seen for lifetime predictions of the canisters.

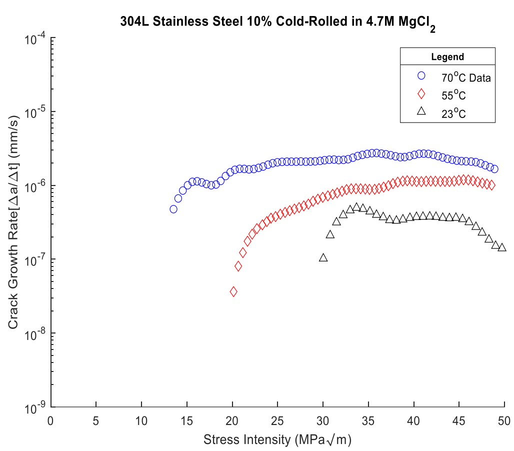

Figure 1: Temperature dependence of Da/dt vs. K of 304L Cold-Rolled Stainless Steel in 4.7M $MgCl_2$

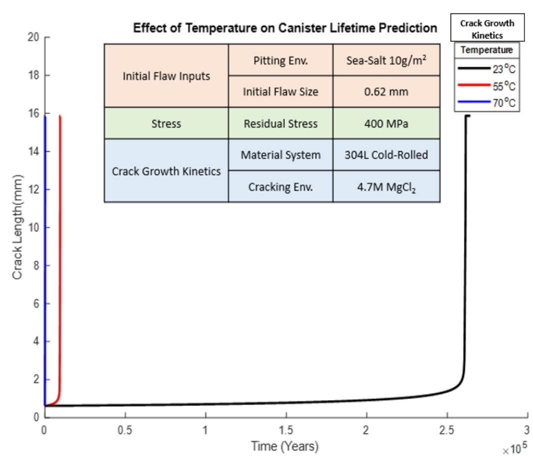

Figure 2: LEFM Model demonstration using da/dt vs. K relationships seen in Figure 1.

3. Conclusions

Investigation into the sensitivity of DSCs AISCC susceptibility will allow for recommendations to be made for canister monitoring. Data generated will be used in probabilistic FM predictions of AISCC growth for lifetime management of DSC. These predictions will inform a framework to quantify and manage a risk-based ranking of storage sites.

4. Acknowledgements

The financial support of the Department of Energy through their Office of Nuclear Energy University Program (NEUP) for this work through a contract with UVA, Vextec Corp. and SNL is gratefully acknowledged.