A Review of the Probabilistic Model for Chloride-Induced Stress Corrosion Cracking

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1. Introduction

It is important to study how to manage spent nuclear fuel (SNF) dry cask storage in S. Korea, because the dry cask has been chosen as the interim storage instead of the wet pool. One type of degradation is Chloride-Induced Stress Corrosion Cracking (CISCC), leading to release the radioisotope from the canister.

The Electric Power Research Institute (EPRI) and the U.S. NRC have undertaken research on the CISCC mechanism [1]. In addition, Sandia National Laboratories (SNL) has extensively researched the effect of CISCC on the management of dry storage canisters, suggesting a probabilistic model for CISCC [2].

The aim of this study is to review probabilistic CISCC model and to analyze the model more specifically.

2. Probabilistic CISCC Model

SNL suggests the probabilistic model to predict the potential impact, including timing and location, of stress corrosion cracking (SCC). The model consists with three periods; incubation before pit initiation, pit growth, and crack growth.

2.1 Incubation before pit initiation

The canister surface temperature and realistic environmental conditions are important factors in the incubation period. The canister surface temperature can vary with the decay heat of the spent fuel and the location and environment of the storage sites. Due to the canister surface temperature, the relative humidity (RH) could vary, and it affects to the deliquescence of the brine on the canister (Fig.1).

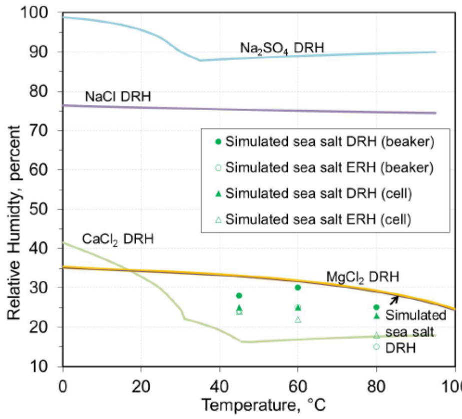

Fig. 1. Summary of Simulated Sea Salt Deliquescence [1].

To analyze the environmental conditions, dusts were collected from the dry storage canisters at Hope Creek and Diablo Canyon in the US. It was identified that the dusts at Hope Creek were composed of Fe, Si, Ca, K, and S, because Hope Creek is located near the territory and river. On the contrary, Diablo Canyon is located near the Pacific Ocean. Therefore, Cl was additionally observed at that site. SEM/EDS, XRF, ICP-OES, and IC were used for the analysis of the dusts at the SNL [2].

2.2 Pit growth

The maximum pit size model and pit-to-crack transition model were introduced to describe the pit and crack. Z.Y. Chen et al. [3] proposed an analytic expression to calculate the bounding conditions of pitting under atmospheric conditions. The expression could predict the maximum pit size based on the maximum cathode current. The expression can be written as:

$$\ln I_{c,max} = \frac{4\pi k W_L \Delta E_{max}}{I_{c,max}} + \ln\left[\frac{\pi e r_a^2 \int_{E_{corr}}^{E_{rp}} (i_c - i_p)\, dE}{\Delta E_{max}}\right] \quad (1)$$

Where $I_{c,max}$ is the maximum cathodic current, k is the conductivity of the electrolyte, W_L is the electrolyte layer thickness, ΔE_{max} is the difference between E_{rp} and E_{corr}, r_a is the radius of the pit, E_{rp} is the potential to the pit, E_{corr} is the potential from the cathode edge, and i_c and i_p are the cathodic and passive current density, respectively.

Y. Kondo [4] suggested the corrosion pit growth rate to predict the pit-to-crack transition using the concept of the stress intensity factor range (ΔK). The proposed expression can be written as:

$$\frac{dc}{dN} = \left(\frac{1}{3}\right) C_p{}^3 f^{-1} \alpha^2 \pi^2 Q^{-2} (2.24\sigma_a)^4 \Delta K^{-4} \quad (2)$$

Where c is the radius of the crack, C_p is the coefficient, f is the frequencies, α is the aspect ratio (= a/c), Q is the shape factor, and σ_a is the stress amplitude.

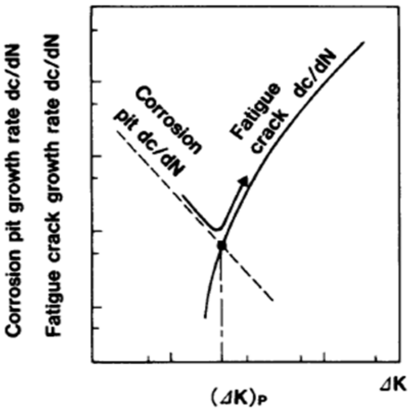

Fig. 2. Effect of the stress amplitude on the critical pit condition [4].

2.3 Crack growth

Mock-up canister tests have been studied to measure the effect of the weld residual stress (WRS) [5]. The residual stress at the heat-affected zone (HAZ) is an important factor for SCC. A variety of methods is available to measure residual stress.

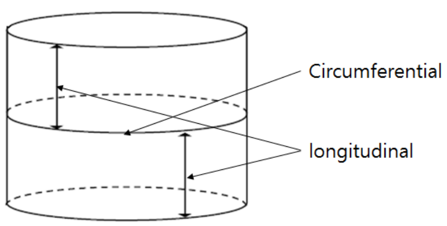

Fig. 3. The location of the welds on the mock-up canister.

According to the welded regions in Fig.3, the residual hoop and axial stress were measured. Because the residual stress causes the rate of cracking to quicken, the values of residual stress must be known.

3. Conclusion

The probabilistic CISCC model proposed by SNL was analyzed more detailed in this review paper. CISCC is one of the issues in the degradation of the dry storage. CISCC has been widely studied by the EPRI, U.S. NRC, and SNL.

The government of S. Korea decided to use the dry cask as an interim storage method instead of the wet pool. However, there is not enough information about the degradation of the dry storage in S. Korea. This review paper would be useful for the management of the dry storage.

REFERENCES

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