Predicting Amount of Radial Hydrides in Spent Fuel During Dry Storage

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1. Introduction

When spent fuels are placed in dry storage, hydrides from corrosion are dissolved and reprecipitated radially. Such radial hydrides can have a severe effect on mechanical properties of spent fuel at drop accident during transportation. In this report, we reviewed and analyzed the process of the predicting amount of radial hydrides [1].

2. Hydride Precipitation Model

2.1 Radial Hydride Fraction

A hysteresis effect between the hydride dissolution solvus and the precipitation solvus is observed in Fig. 1 [2].

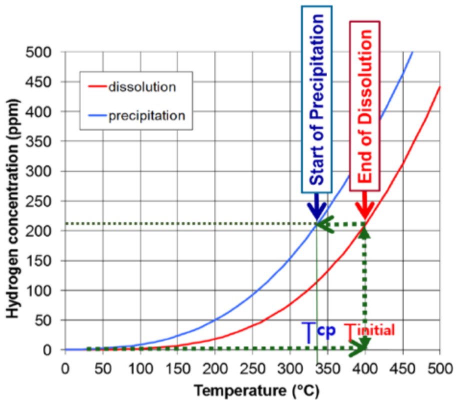

Fig. 1. Dissolution and precipitation curves of hydrides.

A red curve is stress-free hydride dissolution solvus during heating, namely,

$$C_{eq} = C_1 e^{-C_2/RT} \tag{1}$$

A blue curve is stress-free hydrogen precipitation solvus during cooling, namely,

$$C_p = C_3 e^{-C_4/RT} \tag{2}$$

Constants are given by:

T: Absolute temperature

R = 1.986 cal/mole·K

C_1 = 6.6E4 ppm
C_2 = 7.69E3 cal/mol
C_3 = 3.1E4 ppm
C_4 = 6.038E3 cal/mol

When the hydrogen atoms in the matrix are cooled under constant stress σ, some portion of them are reprecipitated radially. The following mathematical expression is derived for the radial hydride fraction [3].

$$F_\sigma(T^{\text{initial}}, T^0, \sigma) =$$
$$\left[1 + \left(\frac{1-F_0}{F_0}\right)\exp\left\{-\frac{579.7\delta_\varepsilon}{T^{\text{initial}}}(\sigma - \sigma_r)\right\}\right]^{-1} \tag{3}$$

Where F_σ is the volume fraction of radial hydrides relative to the hydrogen concentration in solid solution in the Zirconium alloy. The model parameters are follows:

F_0: Initial value of F_σ
δ_ε: "Misfit" strain, due to hydride formation (m/m)
T^{initial}: Initial temperature (K)
T^0: Observation temperature (K)

σ: Applied stress (MPa)

σ_r: Internal stress due to hydrides volume expansion (MPa)

2.2 Evolution of Radial Hydrides over Time

Eq. (3) does not provide information for intermediate observation temperatures. To apply to continuous cooling, a general expression for the radial hydrides concentration at any intermediate temperature T under any temperature and stress history is given below,

$$C_R(T) - C_R(T^{cp}) = - \int_{T^{cp}}^{T} \frac{d}{dT} \{F_\sigma(T^{cp}, T, \sigma) C_p(T)\} dT \qquad (4)$$

$$C_R(T) - C_R(T^{cp}) = - \int_{T^{cp}}^{T} \{F_\sigma(T^{cp}, T, \sigma) \frac{dC_p(T)}{dT} + C_p(T) \frac{d}{d\sigma} F_\sigma(T^{cp}, T, \sigma) \frac{d\sigma}{dT}\} dT \qquad (5)$$

If the eq. (5) is carried out under constant stress, over the temperature T^{cp} to the temperature T, the second term in the integrand drops out, and the model results can be compared to experimental data [4] usually generated under constant stress.

3. Results and Discussion

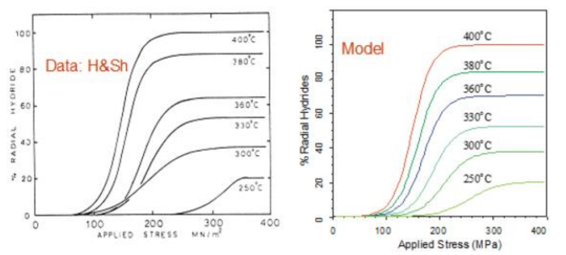

Fig. 2. Model and experimental results of radial hydrides.

The model has been validated by experimental data [4] in Fig. 2, left curves are radial hydrides fraction data from Hardie and Shanahan and right curves are model results simulated by FORTRAN.

4. Conclusion

Only a small fraction of the hydrides reprecipitated radially in dry storage. As depicted in Fig. 3, less than 15 ppm of radial hydrides is expected after 40 years of dry storage. These model results will be used in integrity evaluation process to predict the mechanical properties of spent fuel rods.

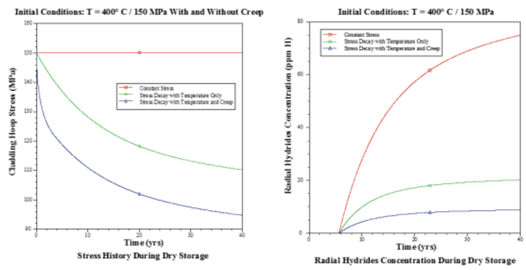

Fig. 3. Evolution of radial hydrides under stress histories.

ACKNOWLEDGEMENT

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