Stress-Based Criterion for the Creep Response of Spent Nuclear Fuel Rod

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1. Introduction

Among potential damage mechanisms postulated for spent fuel in dry storage, creep has been identified as the most likely mechanism [1]. In this report, we reviewed and analyzed the evaluating process of creep by stress-based criterion.

2. Creep Criteria

2.1 Strain-Based Criterion

1% creep strain criterion was extended from fuel design practice as a conservative limit, however test and simulation results, Fig. 1 and 2 showed that tertiary creep which could propagate to creep rupture did not occur, although creep strain exceeded 1%.

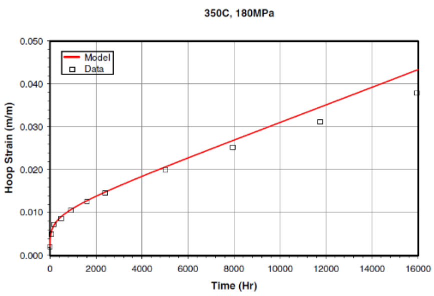

Fig. 1. FALCON analysis and test results.

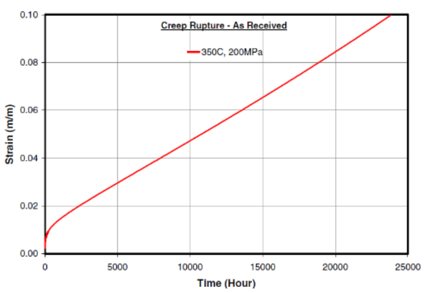

Fig. 2. FALCON analysis result.

2.2 Stress-Based Criterion

Strain alone is not an adequate measure for judging cladding integrity. Stress-based criterion is founded on the concept that, in order to creep failure to break out, the cladding effective stress must rise above the yield strength. The criterion consists of two basic elements: a stress and a Minor rule.

Relative damage in the cladding due to creep is defined by Minor rule,

$$D = \sum \Delta D_i = \sum \Delta t_i / t_{yi} \quad (1)$$

where D is the damage index, Δt_i is the i[th] time step size, and t_{yi} is the experimentally determined time to yield at the conditions prevailing at time t_i.

Under constant pressure creep tests, stress is continuously changing with time,

$$\sigma_{\theta\theta} = \sigma_{\theta 0} / e^{-2\dot{\varepsilon}_{si} t_i} \quad (2)$$

Eq. (2) can be rewritten as follows,

$$\sigma_y = \sigma_i / e^{-2\dot{\varepsilon}_{si} t_{yi}} \quad (3)$$

where, $\dot{\varepsilon}_{si}$ is the steady-state creep rate. Solving for t_{yi} from Eq. (3) yields,

$$t_{yi} = -\ln\left(\frac{\sigma_i}{\sigma_{yi}}\right) / 2\dot{\varepsilon}_{si} \quad (4)$$

and the damage index becomes,

$$D = \sum \Delta t_i / \{-\ln(\sigma_i/\sigma_{yi}) / 2\dot{\varepsilon}_{si}\} \quad (5)$$

Eq. (5) has been implemented in FALCON, as shown in Fig. 3.

A damage index value of unity implies 50% probability of yield.

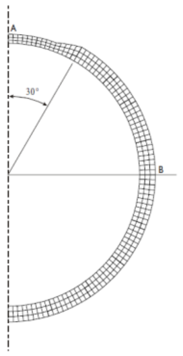

Fig. 3. FALCON R-θ grid for local effects creep analysis.

3. Results and Discussion

The fuel rod analysis case is given in Table 1. It assumes severer condition than dry storage condition. Three response parameters are calculated by R- θ analysis: stress, strain, and damage index. These are plotted in Fig. 4 and 5, and Table 2 shows a summary of the results. In Fig. 4 the peak strain exceeds 1%, however the damage index is less than 1 in Fig. 5. Therefore, cladding remains in elastic regime.

Table 1. Fuel rod analysis case

Peak Temp.(℃)		Pressure(MPa)
Initial Storage	During Drying	Initial Storage
400	440	19.1

Table 2. Summary of fuel rod analysis results

Stress Change (%)	Peak Strain (%)	Damage Index (%)
-16	9	43

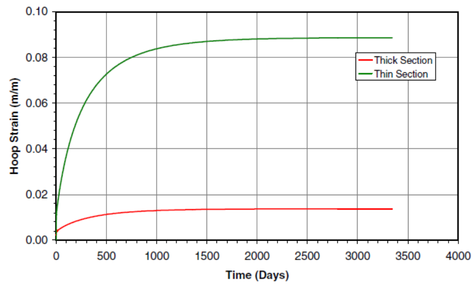

Fig. 4. FALCON analysis results – (a) Strain history.

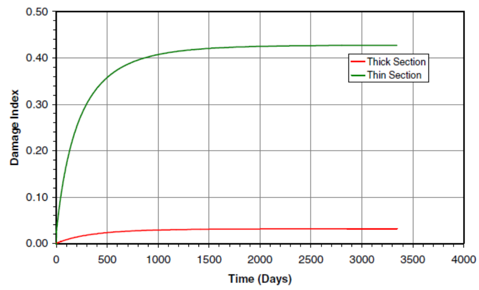

Fig. 5. FALCON analysis results – (b) Damage index history.

4. Conclusion

It is demonstrated that occurrence of creep rupture during dry storage is a remote possibility by FALCON analysis. Also, creep rupture of cladding should be evaluated by not only strain and but also stress.

5. Acknowledgement

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6. References

[1] Y. Rashid, R. Dunham, “Creep Modeling and Analysis Methodology for Spent Fuel in Dry Storage”, EPRI, Palo Alto, CA, (2001) 1003135.