Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 24-25, 2024

Preliminary Fracture Assessment of Spent Nuclear Cladding according to Crack Distribution

Sangil Choi*, Sangsoon Cho, Seunghwan Yu
Transportation and Storage R&D Section, Korea Atomic Energy Research Institute,
Daejeon 34057, Republic of Korea
**Corresponding author: sichoi89@kaeri.re.kr*

***Keywords :** Fracture toughness, Spent Nuclear Fuel, Cladding, Stress intensity, Crack, Probability

1. Introduction

Due to the early end of life of Kori Unit 1 in 2017, the safety analysis of transport and storage of spent nuclear fuel has become a major issue. According to the "2nd Basic Plan for High-Level Radioactive Waste Management", each type of construction period for storage had predicted. For the intermediate storage facility, it would take a total of 20 years after securing and selecting the site and then 17 years would be taken for permanent site. The conventional research trend on spent fuel was safety analysis based on mechanical perspective with hydride. To improve fuel cladding analysis, precise and accurate mechanical safety evaluation is required, based on material properties. Failure probability of fracture behavior was calculated using the critical stress intensity factor (KIC) and crack depth distribution. We confirmed that stress intensity did not reach 17MPa$\sqrt{m}$ even crack depth nearly equal to cladding thickness at accident drop condition (170G)

2. Methods and Results

Failure behavior can be categorized into two types: rupture and fracture. Representative examples of these two types of failure mechanisms are shown in the figure 1. Rupture is a result of strains exceeding the ductility limit. Fracture is a result of excessive stress on an existing crack in the material.

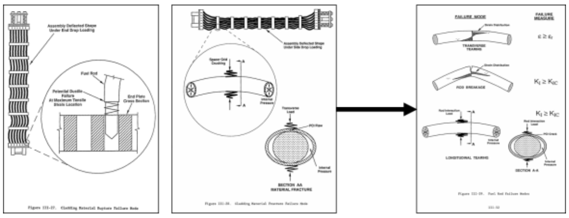

Fig. 1. Representative examples of rupture and fracture [1]

2.1 Schematic of research idea

Failure probability can be calculated using the critical stress intensity factor and crack distribution. Therefore, we aimed to establish the crack distribution using the KIC and failure rate values. And then try to find failure rate and safety analysis

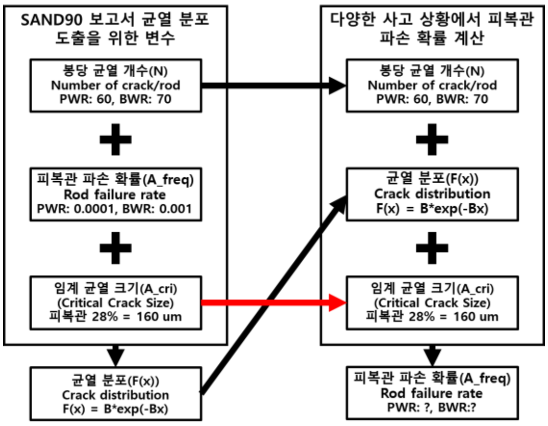

Fig. 2. Approach method to assess the failure behavior

2.2 Crack size distribution

As described in Ref. of SAND90-2406[1], cladding rupture behavior can be probabilistically assessed based on the mechanical properties and stress(or strain). However, in fracture mechanics, not only mechanical properties(critical stress intensity factor(K_{IC})) but also distribution of cracks size is crucial factor to determine failure behavior. The probability distribution of rupture and fracture properties was calculated using Python code, directly utilizing the information from the SAND90 report[1].

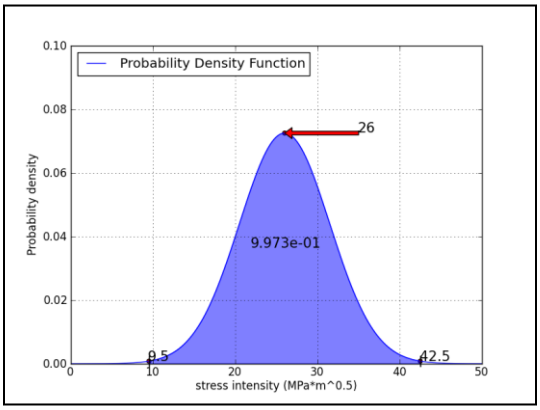

Fig. 3. The failure probability distribution by critical stress intensity factor

The probability distribution is represented using a Gaussian distribution. 95% rupture occurs at 10% positive strain under uniaxial bending[1]. The average fracture toughness was be 26.0 MPa$\sqrt{m}$ with a standard deviation of 5.5 MPa$\sqrt{m}$[1].

The crack probability distribution is represented using an exponential distribution. With a governing equation, a specific point must be determined to obtain a unique solution. Critical crack size definition was suggested that cladding failure occurs with a probability of 0.5(17MPa$\sqrt{m}$)[1].

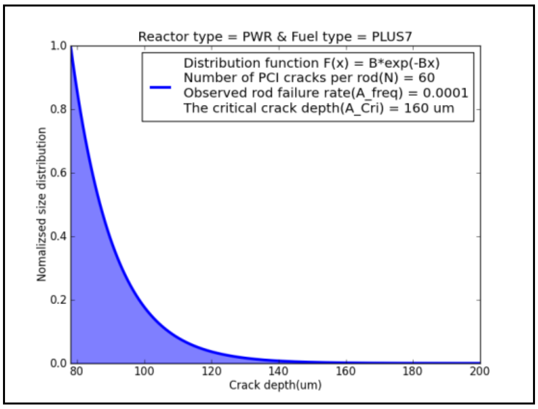

Fig. 4. The crack distribution by depth

2.3 Failure assessment at accident condition

In order to calculate the probability of failure, the stress intensity factor according to the crack depth under a given stress condition should be calculated. Because according to the crack depth, stress intensity could be compared with critical stress intensity. If stress intensity value greater than the critical stress intensity is obtained, the accident probability can be calculated according to the probabilistic distribution of the crack depth. ANSYS Simulation was adopted to analyze external cracks, and both circumferential and axial directions were considered. The depth of the initial crack was 150, 300, and 450 um.

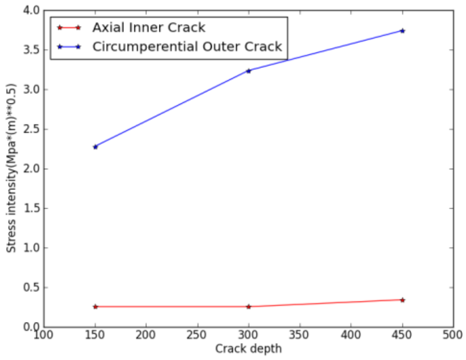

Fig. 5. The stress intensity by crack depth at 170G

In the drop accident, even though the crack depth reached a cladding thickness at a load of up to 170G, it did not reach the limit of critical stress intensity coefficient of 17MPa$\sqrt{m}$.

3. Conclusions

Failure probability of fracture behavior was calculated using the critical stress intensity factor (KIC) and crack depth distribution. We confirmed that stress intensity did not reach 17MPa$\sqrt{m}$ even crack depth nearly equal to cladding thickness at 170G. This paper considered the initial crack depth and the bending stress of the cladding due to the impact acceleration. In future, we will applied the crack length and pinch load due to grid compression as well as the bending stress.

Acknowledgements

This work was supported by the Institute for Korea Spent Nuclear Fuel (iKSNF) and National Research Foundation of Korea(NRF) grant funded by the Korea government (Ministry of Science and ICT, MSIT) (No. 2021M2E1A1085229)

REFERENCES

[1] T. L. Sanders, K. D. Seager, Y. R. Rashid, “SAND90-2406: A Method for Determining the Spent-Fuel Contribution to Transport Cask Containment Requirements”, Sandia National Laboratories, 1992

[2] NUREG-2224, Dry Storage and Transportation of High Burnup Spent Nuclear Fuel Final Report, 2015

[3] NUREG/CR-7198, Mechanical Fatigue Testing of High-Burnup Fuel for Transportation Applications, 2016