Fatigue Life Characterization of Simulated Fuel Cladding to Hydride Contents for Normal Transportation Integrity

Kang-Hee Lee*, Heung-Seok Kang, Jae-Yong Kim, Yong-Sik Yang, and Donghak Kook
Korea Atomic Energy Research Institute, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Republic of Korea
*leekh@kaeri.re.kr

1. Introduction

After the interim or long-term dry storage, the spent nuclear fuel should be transported into the central storage site for further extended storage or final disposal, through a certain type and designated route of normal transportation. Degraded spent fuel was known to be brittle from seasoned hydride in in-reactor burnup and storage environment [1, 2], whose integrity was significantly vulnerable against impacts and repeated loads such as transportation or external impact accidents. Fig. 1 showed influential parameters to affect spent fuel fatigue failure. Herein, spent fuel fatigue life characterization was carried out using a rotary bending test machine and non-irradiated cladding tube section with controlled hydride contents. Overall test setup and some insights from test results will be discussed.

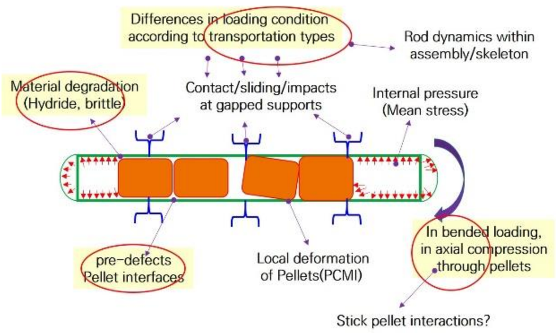


Fig. 1. Influential factors to spent fuel fatigue failure.

2. Experiment

Non-irradiated Zircaloy-4 cladding tube section with 120 mm length was charged 200 ppm and 400 ppm hydrogen and heated to promote a gas penetration into a metal surface for 24 hours in the 410℃ furnace. Table 1 summarized test matrix, test parameters and those test ranges for whole test program of simulated fuel cladding tube fatigue life characterization [3].

Table 1. Test matrix for simulated fuel cladding fatigue test

Moment loading	Excitation Frequency	Hydrogen Contents	Pellet gap effect
2.5~10* Nm by 2.5 Nm Step	25 Hz (1500 rpm), 50 Hz (3000 rpm)	Fresh, 200 ppm, 400 ppm, 600 ppm	No pellet, 30 μm (OD8.917), 50 μm (OD8.877)

The rotary bending fatigue test machine (YAMAMOTO, model GIGA QUAD YRB200, Fig. 2) and straight tube section without grooved cut-out were used for the whole test program. The pure moment loading was applied to rotating tube specimen with certain amount of end mass. Excitation frequencies used were 25 Hz and 50 Hz which is selected for stable operation of the test machine. Rotation rpm and weight of end mass were calibrated for reliability of the test quality program.

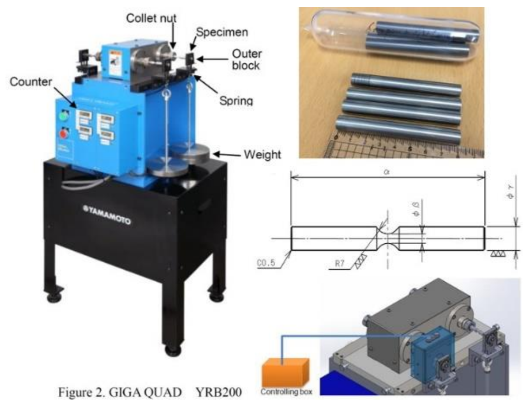
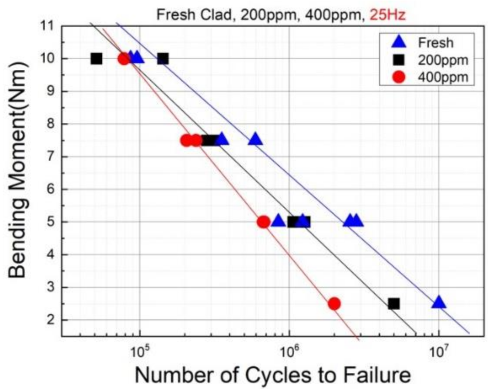


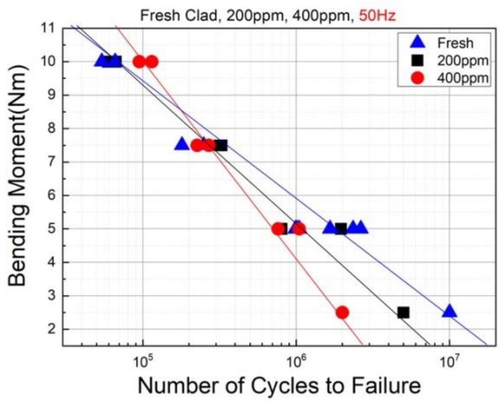
Fig. 2. Rotary bending test machine and non-standard tube specimen to be tested.

3. Test Results

Fig. 3 showed the result comparison of measured fatigue life (cycle to failure) of simulated fuel cladding tube according to the hydride contents up to 400 ppm, for two different frequencies of moment excitation. The slight lines over the dots in the Fig. 3 helped rough grouping and the identification of the trend; fatigue life became smaller as the hydride contents increase, in particular, for high cycle region above 5.0E5 cycles. There were also somewhat slightly different failure behaviors to the excitation frequency corresponding to the speed of rotation. Results also showed large scatter even in the same moment and excitation frequency, especially in fresh cladding. Fig. 4 showed typical photos of the broken section of failed specimen, which now doesn't show meaningful interpretation, thus the SEM (Scanning Electron Microscopy) will be needed for further investigation. If the more test data would be added up to this diagram, we could map the fatigue life of spent nuclear fuel in a quantitative way for normal transportation integrity.



(a) 25 Hz (1500 rpm)



(b) 50 Hz (3000 rpm)

Fig. 3. Typical fatigue test results of simulated fuel cladding according to the hydride contents.

4. Conclusion

Spent fuel fatigue life characterization was carried out using a rotary bending test machine and non-irradiated cladding tube section with controlled hydride contents. Overall test setup and some insights from test results were discussed. The results showed that the hydride contents affected to reduce fatigue life of simulated fuel cladding in somewhat different way to the different frequency of excitation. Further investigation on the broken section of failed specimen and the additional test operation for higher hydride contents were needed to get a solid finding and verify the test results in the near future.

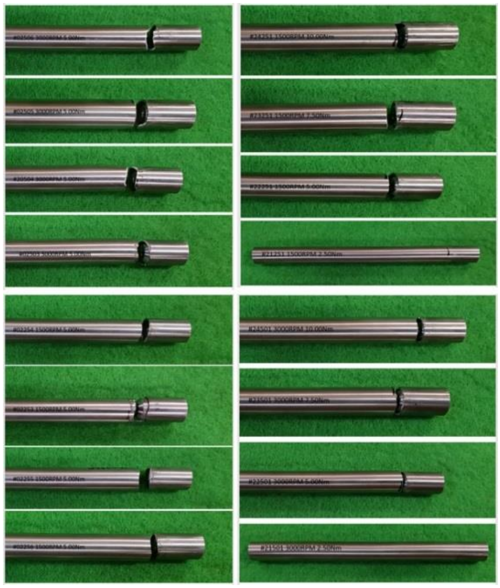


Fig. 4. Typical broken sections of the failed specimen.

ACKNOWLEDGEMENT

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) granted financial resource from the Ministry of Trade, Industry and Energy, Republic of Korea (No. 20141710201 66A).

REFERENCES

[1] U.S. NRC, 2014, “Mechanical fatigue Testing of high-burnup fuel for transportation applications”, NUREG/CR-7198. ORNL/TM-2014/214.

[2] Dong-Hak Kook et al, 2012, Review of spent fuel integrity evaluation for dry storage, Nuclear Engineering and Technology, Vol. 45, No. 1, 2013.

[3] Kang-Hee Lee, et al, 2018, Spent Fuel Structural Integrity Evaluation Test Plan to Repeated Bending and Impact Loading: Test Matrix, KAERI/TR-7222/2018.