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The Cause of Failure of the REP Na-1 Fuel Rod in a Simulated RIA Accident

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1. Introduction

The REP-Na1 test was a simulated reactivity initiated accident (RIA) test where the fuel rod failed at an unexpected low enthalpy with cladding fragmentation. In contrast, all the other REP-Na tests showed no failures of the fuel rods or their failures at higher enthalpy under the same simulated RIA conditions [1]. Many efforts have been made towards understanding the cause of an early failure of the REP-Na test fuel rod at so low enthalpy. However, a controversy still exists as to the validity of the REP Na-1 test. Considering that the REP-Na1 test rod has experienced a thermal cycle with preheating to 380 ^oC and holding there for 14h, there is a view that this thermal cycle is the cause of the redistribution of hydrides resulting in the early and dramatic failure of the REP-Na1 test fuel rod. Although it has been agreed that the cladding is maintained under stresses during preheating to 380 ^oC, there has been a disagreement on the magnitude of applied stresses and their effect on the cladding integrity.

The aim of this study is to resolve this controversy and understand the early failure of the REP-NA1 fuel rod at low enthalpy during a simulated RIA test. To this end, a model experiment was conducted with a Zr-2.5Nb tube to simulate this thermal cycle effect on precipitation of radial hydrides and the formation of a crack by delayed hydride cracking.

2. Experimental Methods

The cantilever beam (CB) specimens taken from a Zr-2.5Nb tube, 38 mm long x 3.2 mm wide x 4.3 mm thick were used with a dull notch with 0.5 mm deep and a root radius of 0.05 mm. The CB specimens charged with 60 to 80 ppm H were subjected to a thermal cycle involving heating to the peak temperature of either 310 or 380 ^oC, holding there for 50 h and then cooling to 250 ^oC. The stress applied to the CB specimens corresponding to 18.4 MPa√m was applied at either the beginning or the end of the hold time at the peak temperature, and after cooling to 250 ^oC, respectively.

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3. Results and Discussion

When the stress of 18 MPa√m was applied at the peak temperature of 380 ^oC, many radial hydrides were precipitated across the section as shown in Fig. 2a, but little reorientation of the radial hydrides, however, occurred except at the notch region at a lower peak temperature of 310 ^oC (Fig. 2b). Upon application of the same stress after cooling to 250 ^oC from 380 ^oC, however, little radial hydrides were also observed except at the tip of the notch as shown in Fig. 3. These results demonstrate that dislocations introduced by the applied stresses at a peak temperature provide the sites for precipitation of radial hydrides.

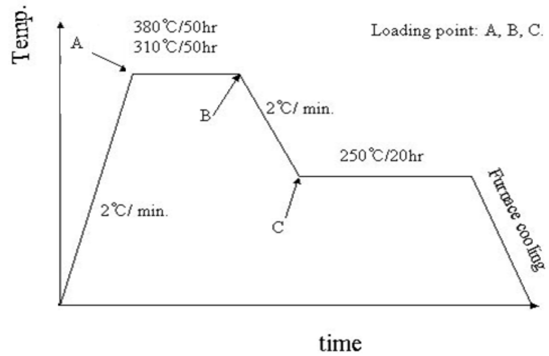

Fig. 1. Thermal cycle given to the Zr-2.5Nb cantilever beam specimens where the loading time changed from the peak temperature (point A) through the onset of cooling from the peak temperature (point B) to the test temperature (point C).

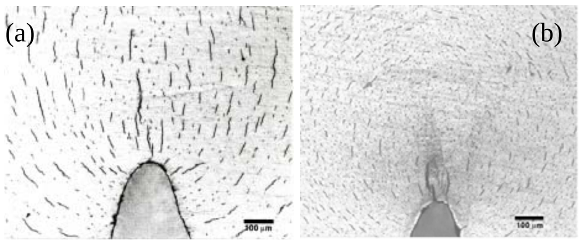

Fig. 1. Distribution of reoriented hydrides in the radial direction when the Zr-2.5Nb tube was given a thermal cycle with the peak temperature changing from (a) 380^{o}C to (b) 310^{o}C.

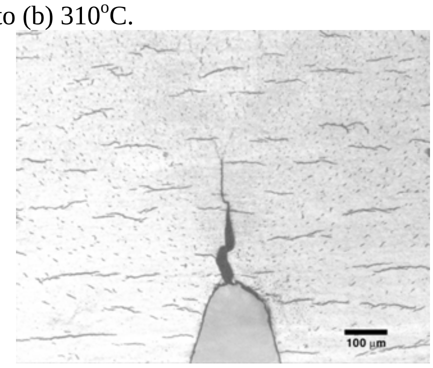

Fig. 3. Precipitation of little reoriented hydrides except the crack tip of the Zr-2.5Nb CB specimen upon loading after cooling to 250^{o}C.

Many radial hydrides and the radial cracks at the ID side of the NEP-Na1 fuel rod, not in all the other fuel rods indicate that the NEP-Na1 fuel rod experiences plastic deformation before the pulse test. It should be noted that the ID side of the fuel rod experiences higher plastic deformation than the OD side under the stresses caused by fuel expansion. Accordingly, higher strain energy by applied stresses causes hydrides to preferentially precipitate at the ID side on cooling from 380 ^{o}C to 280 ^{o}C. This is the cause of the appearance of many radial hydrides in the ID side of the NEP-Na1 fuel rod. In the presence of the radial hydride precipitated at the ID side of the fuel rod, heating to 301 ^{o}C and the rod power of 150 W/cm would induce large tensile stresses in the transverse direction, causing cracking of the precipitated hydrides and consequently sharp cracks. On cooling to RT, these cracks would grow by DHC, as demonstrated in the NEP-Na10 test where a long axial crack grew by 108 mm at around $2.9x10^{-9}$ m/s during its storage in a spent fuel storage pool after the simulated RIA test. These DHC cracks and many small radial hydrides would be the possible cause of cladding fragmentation during the pulse test.

3. Conclusions

It is demonstrated that the plastic deformation arising during a thermal cycle facilitates precipitation of the radial hydrides primarily at the ID side of the fuel rod, causing the early failure of the fuel rod in a simulated RIA accident. Thus, it seems that the REP Na-1 test cannot simulate the typical condition of the RIA.

ACKNOWLEDGMENTS

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REFERENCES

[1] R.L. Yang, Proc. 2004 International Meeting on LWR Fuel Performance, ANS, Orlando, Fl., pp. 56-575, 2004.