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Behavior of Accident tolerant fuel cladding under simulated Loss-of-coolant Accident Condition

Dong Jun Park, Yang Il Jung, Jung Hwan Park, Byoung Kwon Choi, Young Ho Lee, Il Hyun Kim, Hyun Gil Kim
[a]*Nuclear Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon 34057, Korea*
**Corresponding author: pdj@kaeri.re.kr*

1. Introduction

Accident tolerant fuel (ATF) cladding has been widely studied by several research groups after Fukushima nuclear reactor accident [1-8]. Oxidation barrier layer coated Zr fuel cladding is one of the most promising candidate concepts owing to its easy process and lower cost for manufacturing and possibility of developing with short term study compared to other ATF concepts. We have successfully fabricated CrAl alloy coated ATF tube samples by using existing Zr fuel cladding for light water reactors (LWR). Coated layer on the surface of Zr tube sample was formed by arc ion plating (AIP) coating process. Main requirement of these ATF claddings may be high temperature oxidation resistance. Therefore, their oxidation kinetics and mechanisms have been studied at a wide range of temperatures and in various environments. However, just small plate or short tube samples were simply exposed to a high temperature steam environment [2,4,7,8].

In this study, integral loss-of-coolant accident (LOCA) tests simulating real conditions of fuel claddings during accident were conducted using ATF cladding samples for a clear understanding of their behavior under accident conditions. Ballooning and rupture behavior and of ATF cladding during the LOCA scenarios were studied systematically.

2. Methods and Results

In this section some of the experimental procedure and technical details of apparatus are described. Highlight data obtained from simulated LOCA test is also presented.

2.1 Integral LOCA Test

For the integral LOCA tests, 400 mm long tubular Zr alloy cladding samples were filled with 10 mm long alumina pellets to simulate the heat capacity of the fuel. The furnace was heated to a pre-test hold temperature of 300℃ within 240 s, where the steam flow and sample temperature were stabilized for 500 s. A heating rate of 5℃/s from 300℃ to 1200℃ was used. After exposure at 1200℃ for 300 s, the tube was cooled slowly to 800℃ and then quenched by flooding from the bottom of the chamber with water. The Specimen temperature was measured by type-R thermocouple located near the sample center and the quartz tube provides an enclosed volume for steam flow and water quench, both of which are introduced through the bottom. Further details of the test equipment and experimental procedures can be found in our previous paper [9].

2.2 Results

Fig.1 shows frontal view of the ballooned and burst region of the CrAl alloy coated ATF with different fabrication processes and existing Zr alloy tube samples, respectively. Internal pressure of 8 MPa and heating rate of 14˚C/s during the test results in a plastic deformation of the Zr matrix in the all samples. Zr alloy tube sample without coating layer, however, showed much larger circumferential elongation and rupture size in ballooned region. This indicates that fuel dispersal through rupture opening may be more severe in existing Zr fuel cladding when compared to the ATF cladding.

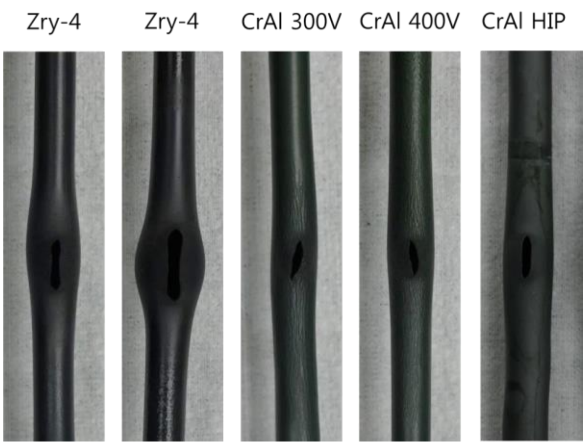
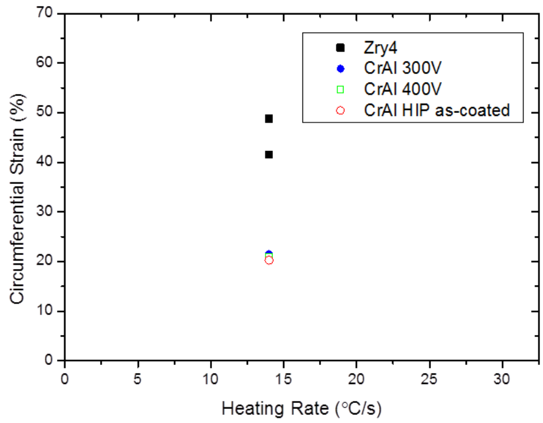


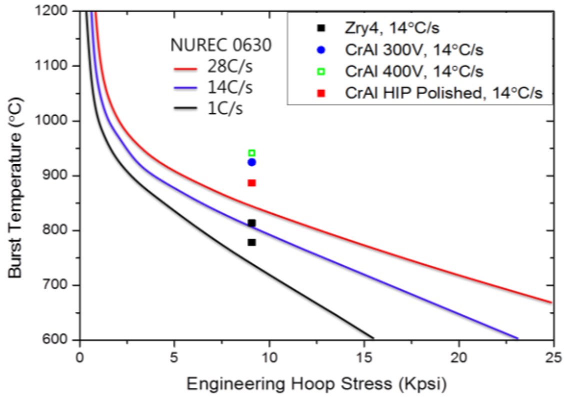
Fig. 1. Appearance of the candidate ATF claddings with various coating layer after integral LOCA test.

After the ballooning test, maximum circumferential strain is measured at the mid height of ballooned region and the results were shown in Fig. 2(a). The circumferential strain of the ATF cladding was less than 50% of that of the conventional Zr-based alloy cladding.

Fig. 2(b) shows the burst hoop stress versus burst temperature correlation for various cladding heating rates (1, 14, 28℃/s) presented in the NUREG-0630 document [4]. The results obtained in this study are superimposed on Fig. 2(b). When the fabrication conditions were optimized, the rupture temperature of the ATF cladding increased up to 130˚C compared to the conventional zirconium cladding.



(a)



(b)

Fig. 2. (a)Circumferential strain measured at the mid-height of ballooned cladding samples and (b) correlation of rupture temperature as a function of engineering hoop stress and ramp rate from NUREG0630. A result of ATF cladding samples is superimposed.

3. Conclusions

To improve the reliability and safety of existing Zr alloy fuel cladding under LWR accident conditions, a high temperature oxidation resistant layer was coated onto the surface of Zr alloy samples using various coating techniques. The rupture temperature of the coated tube was higher than that of the uncoated cladding. The circumferential strain and the size of the rupture opening at the ballooned area were smaller when the Zr tube was coated. All of the observed properties of the coated tube during LOCA scenarios are considered beneficial for the integrity and safety of the fuel cladding.

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