Results and Observations of the Integral Loss-of-coolant Accident Test with Surface Modified Claddings

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1. Introduction

For developing accident tolerant fuel (ATF) cladding, we have studied various concepts such as surface coating, oxide dispersion strengthening, and hybrid structure. Advanced materials have been also developed [1, 2]. At the present, surface modified Zr alloy fuel claddings have been successfully manufactured by three dimensional (3-D) laser coating and arc ion plating processes. In this study, integral loss-of-coolant accident (LOCA) test was carried for comprehensive understanding of phenomena such as ballooning, burst failures, and oxidation for the ATF cladding during a LOCA scenario.

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°C for 300 s, the tube was cooled slowly to 800℃ and then quenched by flooding from the bottom of the chamber with water. Further details of the test equipment and experimental procedures can be found in our previous paper [3].

Table I: Results for integral LOCA tests with candidate ATF claddings.

	Internal Pressure (MPa)	Burst Temp. (°C)
Zry-4	8.3	759
CrAl Ion	8.6	877
CrAl/ODS	8.5	902
CrAl PS	8.1	864
Cr Ion	8.3	966

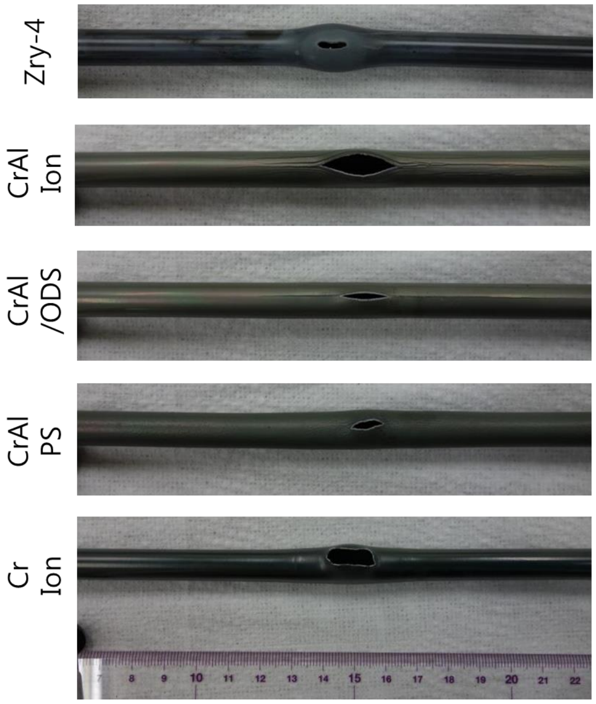

Fig. 1. Appearance of the candidate ATF claddings with various coating layer after integral LOCA test.

Burst behaviors such as initial internal pressure and burst temperature are shown in Table I. All the candidate ATF claddings with coating layers showed much higher burst temperature compared to the reference Zry-4 cladding sample. Fig. 2 shows the burst

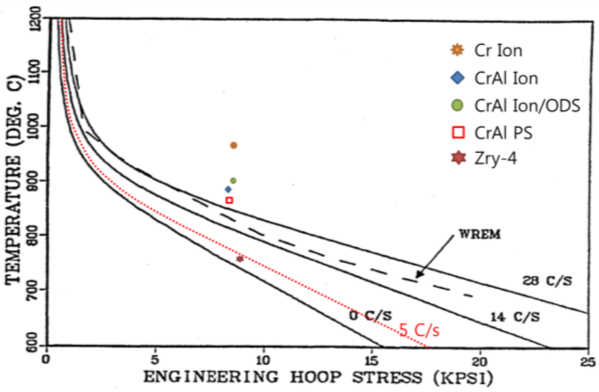

Fig. 2. Correlation of rupture temperature as a function of engineering hoop stress and ramp rate from NUREG0630. Results of ATF cladding samples is superimposed.

hoop stress versus burst temperature correlation for various cladding heating rates(1, 14, 28°C/s) presented in the NUREG-0630 document [4]. The results summarized in Table I are superimposed on Fig. 2.

2.2 Mechanical Test

Ballooned and oxidized tube samples were subjected to 4-point bend tests at room temperature to evaluate the mechanical properties. 400 mm long cladding samples were placed on two supporting pins 250 mm apart and two loading pins, 150 mm apart, applied force to the sample. The load displacement curves obtained from

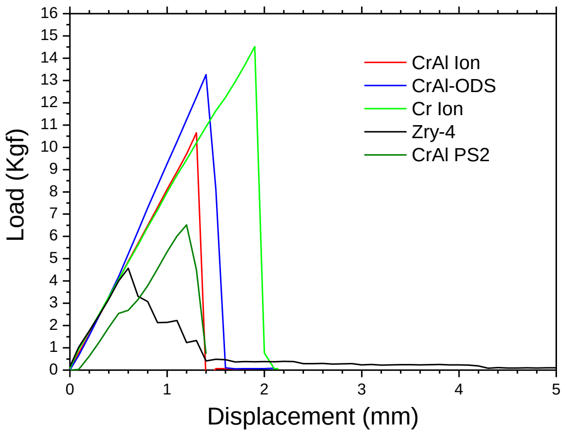

Fig. 3. Load-displacement curve during 4 point bend test for post-integral LOCA test samples.

4-point bend tests are shown in Fig. 3. In our tests, all samples showed failure near the center of the ruptured region regardless of the presence of a coating layer (not shown here). The maximum load for the coated tube sample was higher than that of the uncoated Zr sample. This may be due to the thicker average wall thickness and lack of external oxidation of the Cr-coated tube sample compared to the uncoated Zr sample. The thinnest wall thickness at the edge of the burst opening would result in the highest level of oxidation. Cracks can be initiated at this brittle burst tip and will propagate rapidly though the ballooned region. Therefore, the flexural strength of the ruptured tubes mainly depends on the thickness of the load bearing Zr metal at the opposite side to the rupture opening.

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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