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Mechanical Behavior of Ballooned and Ruptured Zircaloy-4 Fuel Cladding in Loss-of-coolant Accident Conditions

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1. Introduction

A current loss-of-coolant accident (LOCA) criterion is based on the results obtained from non-pressurized claddings specimens under simulated LOCA condition. However, integrity of fuel cladding can be significantly affected by ballooning and rupture that caused by pressure difference between inner and outer cladding during LOCA. Ballooning may cause the fuel relocation or fuel dispersal due to its rupture opening during accidents. In addition, wall thickness of cladding can be reduced and local regions near the rupture open would become heavily oxidized and hydrided [1]. Therefore, integral test that can simulate whole process during LOCA should be carried out for comprehensive safety analysis. Although a number of researches have been conducted, most investigations of them were performed under unstrained condition.

In this study, burst behavior of zircaloy-4 claddings was investigated by integral LOCA test and their shortening behavior during ballooning and burst were also examined and recorded in real time. All the ruptured claddings were quenched under constrained condition.

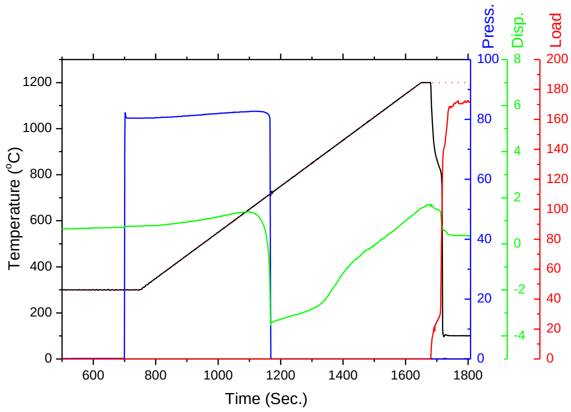
2. Methods and Results

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.

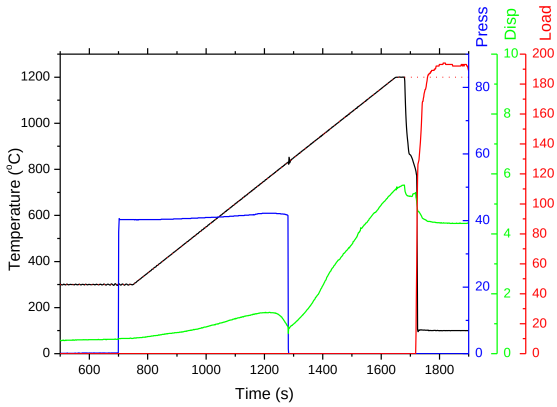
2.1 Integral LOCA Test

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, 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].

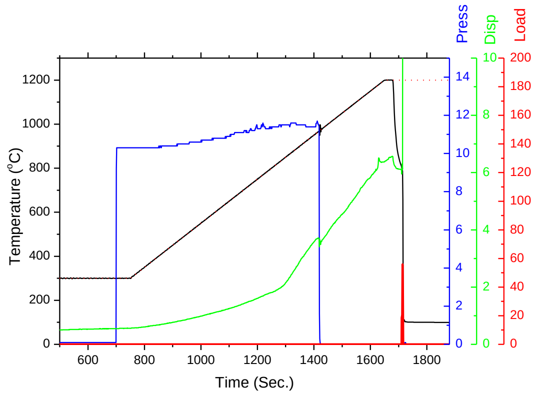
2.2 Shortening behavior



(a)



(b)



(c)

Fig. 1. Temperature, internal pressure, displacement, and applied load history of cladding specimens during intergral LOCA test;(a) internal pressure of 8MPa, (b) 4MPa, and (c) 1 MPa with heating rate of 1℃/s.

Fig. 1 shows the temperature, internal pressure, displacement, and applied load history of cladding specimens during integral LOCA test with different heating rate. Internal pressure of 8 MPa was applied to all the samples. All the tests exhibited a cladding shortening phenomenon. This behavior can be explained by “hot side straight” effect. Zircaloy cladding undergoes biaxial stress from internal gas pressure. When the cladding balloons uniformly, material flow axially to accommodate the ballooning and the cladding shortens [4]. Shortening of cladding becomes smaller as the internal pressure is decreased, as shown in Figs. 1(a)-(c).

2.3 Constraint effect during quenching

The load applied to cladding during quench phase with constrained condition was increased as the internal pressure was decreased. Total displacement of ruptured cladding was also increased similar to applied load. When the internal pressure was 1 MPa, fracture at mid height of ballooned region occurred during quenching at 800℃ The relation between the displacement and applied load is unclear. Therefore, further research should be undertaken. .

3. Conclusions

A comparison of the results of the integral LOCA test with various test conditions led to the following conclusions. Of the parameters that cause different load condition during quenching, the internal pressure and shortening of cladding were very important.

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