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Microstructural and Mechanical Characterization Study of Cr Coated ATF Claddings After Simulated Integral LOCA Test

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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 Cr 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 cold spray 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 Cr coated ATF cladding sample for a clear understanding of their behavior under accident conditions. Ballooning behavior and microstructural changes of ATF cladding during the LOCA scenarios were studied systematically and mechanical test results are also presented.

2. Methods and Results

In this section some of the detailed process or techniques used to fabricate coating layer are described. The procedure of integral LOCA test and the highlight data will be shown with detailed explanation.

2.1 Coating Process

Coating layer were produced using commercially available pure Cr flake powder, 45±10 μm in size. Deposition was carried out onto Zr alloy tube sample using N process gas while maintaining a gas pressure of 2.94 MPa and temperature of 800°C. N gas which introduced to power feeder line Cr powder was pre-heated to 600°C before introducing into carrier gas. Other conditions of nozzle stand-off distance of 40 mm; deposition angle of 90°; and a nozzle traveling speed of 100 mm s^{-1} were used for coating process.

2.2 Integral LOCA Test

Figure 1 shows the schematic illustration of integral LOCA test apparatus used in this study. For integral LOCA tests, 400 mm long cladding sample was used and filled with 10 mm-long alumina pellets to simulate the heat capacity of the fuel. The pressure was injected through stainless tube at the top and the cladding specimen was supported at the top to minimize specimen bowing. 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. Heating rate was 28 ℃ /s from 300℃ to 1200℃. After oxidation at 1200℃ with hold time of 300s, the tube was cooled slowly and quenched at ≈800°C by bottom flooding.

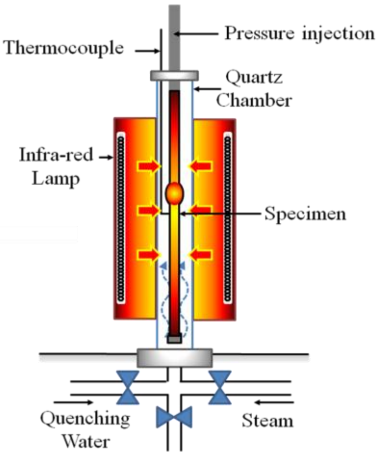

Fig. 1. Schematic illustration of the integral LOCA test facility.

2.3 Results

Fig.2 (a) and (b) show frontal view of the ballooned and burst region of the Cr coated ATF and existing Zr alloy tube samples, respectively. Internal pressure of 8 MPa during the test results in a plastic deformation of the alpha-phase of Zr matrix in both samples. Zr alloy tube sample, however, showed larger elongation and

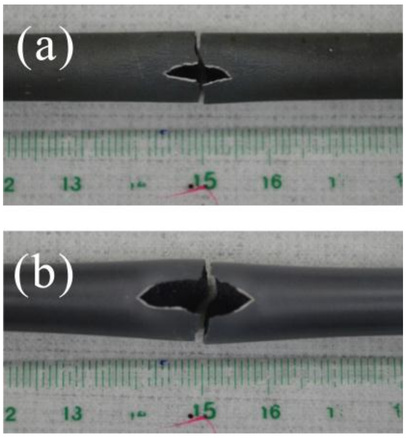

Fig. 2. Frontal view of burst opening of (a) Cr coated ATF and (b) existing Zr alloy tube samples after integral LOCA test.

rupture size in balloon region. This indicates that fuel dispersal through rupture opening may be more severe in existing Zr fuel cladding. Four-point-bend test was carried out and all samples showed failure near the burst midplane. This cross section fails indicates brittle mode fail. The sharp load drop more than 40% also indicates failure in a brittle mode(not shown here). Maximum load was slightly higher in Cr coated ATF tube sample(not shown here).

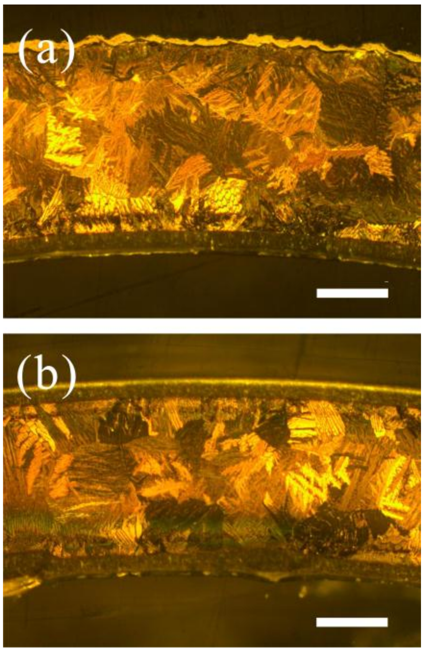

Fig. 3. Cross sectional micrographs 180° from the burst opening of (a) the Cr coated ATF and (b) Zr alloy tube samples after integral LOCA test. The bars indicate 200 μm in length.

Fig. 3 shows optical micrographic image of local cross section 180° from the burst opening. Although Cr coated ATF tube sample showed inner surface oxidation, oxide was not observed on outer surface. On the other hand, Zr alloy tube sample showed oxide layer on both inner and outer surface. Therefore, it can be concluded that Cr layer coated by cold spray technique is suitable for oxidation barrier of Zr-based alloy.

3. Conclusions

Cr coated cladding samples have been successfully fabricated by using existing Zr alloy fuel claddings. For comparative study, integral LOCA test was carried out using Cr coated ATF cladding and existing Zr alloy tube sample. Cr coated ATF cladding showed much smaller rupture opening and circumferential elongation compared to Zr alloy sample. Coated Cr layer prevented outer surface oxidation in spite of exposure for 300s at 1200°C in steam environment. In conclusion, it is considered that Cr coated ATF fuel cladding may enhance safety margin of nuclear fuels under accident condition in LWRs compared to existing Zr alloy cladding.

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