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In-reactor Performances of HANA Claddings in Halden

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1. Introduction

KAERI have been developing an advanced cladding (i.e. HANA, High-performance Alloy for Nuclear Application) for the high burn-up fuel so as to enhance safety margin and to reduce manufacturing cost. The HANA claddings had showed the superior performances in the out-of-pile tests, including corrosion, creep, tensile, burst, microstructure, and physical properties, to the commercial reference claddings. The LOCA, RIA, PCI, wear, and fatigue properties of the HANA claddings were also exhibited comparable when compared with those of the reference claddings [1,2,3]. Since 2004, the HANA claddings are testing in Halden research reactor to evaluate their in-reactor performances. In this study, the status and results of the irradiation test of the HANA claddings were summarized briefly.

2. Overviews

Two test rigs (IFA-673 and IFA-674) were utilized for the evaluation of the HANA cladding's in-reactor performances in Halden in Norway. This test is similar to the Joint Program IFA-638 test series [4], with two parts to the experiment: one using fuelled cladding sections and the other using unfuelled coupons. The positioning of the coupons is in holders both above the test fuel rods and also along the center of the rig. The addition of these unfuelled cladding sectors could allow the effects of heat flux on corrosion behavior to be assessed. The two rigs have been irradiated in the HBWR since February 2004 (i.e. a total of 4 reactor cycles) during exposure to water chemistry, fluence and thermal hydraulic conditions similar to those of the commercial PWRs. The corrosion behaviour of the test materials (in the form of fuelled tube claddings and/or coupons) is assessed by means of once-a-year interim inspections.

Irradiation commenced in February 2004. The test will be irradiated for at least three calendar years reaching a burn up of ca. 35 MWd/kgU. The first interim inspection was performed in November 2004, after 185 days at power. And the second interim inspection was performed in November 2005, after a total of 379 days at power.

3. Irradiation Conditions

During the 2005 irradiation, the test conditions of IFA-673 and IFA-674 rigs were the almost same as those of 2004 irradiation. The summary of the 2005 irradiation conditions in Halden are followed;

Heat rate:
The average linear heat rate for the two clusters has been in the range 30 - 35 kW/m during most of the irradiation so far in all the rods, but the upper cluster rods has had somewhat higher power (ca. 10-15%) during both irradiation cycles.
Neutron flux and fluence:
The fast neutron flux levels ($\geq$ 1 MeV) within the fuel rod region ranges from 2.9 to 3.7 x 10^{13} n/cm^2/s. Calculated fast neutron fluence levels at the fuelled section were 0.9 to1.1 × 10^{21} n/cm^2.
Coolant temperature:
The coolant temperature measured at the inlet of the test rig was 291^{o}C with about 25^{o}C rise in temperature through the channel.
Coolant pressure and flow rate:
The coolant flow rate and pressure have been kept approximately at 1.6 -1.7 m/s and from 166 to 167 bar, respectively, for the main part of the irradiation. The thermal hydraulic conditions along the axial length of the fuel rods have been calculated from the start-up.
Water chemistry: It is measured the concentrations of lithium (2 ppm) and boron (700 ppm) from the coolant analysis and calculated the pH_{300} (~7.1) in IFA-673 and IFA-674. The hydrogen content has been maintained at about 2 ppm, and no oxygen has been measured in the coolant.

4. Results

Corrosion:
Oxide thickness measurements were made, after brushing each fuel rod, at 120^o orientations, resulting in a total of 3 axial traces (0^o, 120^o and 240^o). Maximum, minimum and averaged oxide thickness data for three axial lengths of each fuel rod (top, middle and bottom 1/3 of the rod length) are analyzed for IFA-673 and IFA-674, respectively. Oxide thicknesses, averaged over all three orientations, for each segment are calculated for all the

rods. It is seen that in general, the HANA claddings show better corrosion behavior than the reference claddings [Figure 1]. The measured oxide thicknesses on the fuel rods are in the range from 30 to 80% depending on alloy and axial position (i.e. heat flux) when compared with the reference claddings.

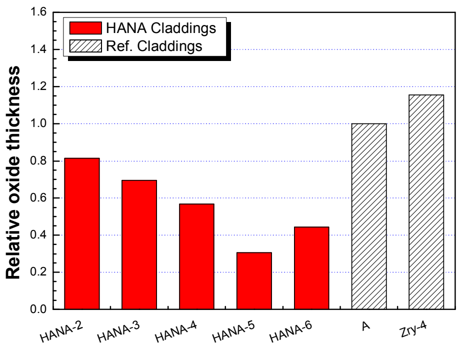

Figure 1 Corrosion properties of HANA claddings after the 379-day-irradiation in Halden

Creep: Rod diameter measurements were made, after brushing each fuel rod, at two orientations, resulting in a total of 2 axial traces (0^o, and 90^o) for each fuel rod. Maximum, minimum and averaged diameter data for three axial lengths of each fuel rod from the first interim inspection are summarized for IFA-673 and IFA-674 respectively. Diameter change has been corrected for the addition due to corrosion, as measured during the interim inspection. The measured creep-down ranges from less than 50 to 65 % depending on alloy and axial position (i.e. neutron flux and heat flux) when compared with the reference claddings. HANA claddings showed better creep resistance than the reference claddings, as shown in Figure 2.

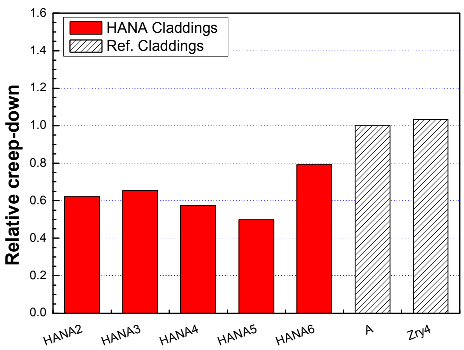

Figure 2 Creep properties of HANA claddings after the 379-day-irradiation in Halden

5. Summary

The second interim inspection of the HANA claddings was carried out in November 2005 after 379 FPD of irradiation in the Halden Reactor. The HANA claddings showed better corrosion and creep properties than the reference claddings, based on the results of the oxide thickness and rod diameter measurements. Irradiation of the HANA claddings is continued with the reactor start-up in January 2006.

ACKNOWLEDGEMENT

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