Corrosion Resistance Evaluation of HANA Claddings in Commercial PWR

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1. Introduction

One of the fuel cladding materials, zirconium alloys have been used for several decades, since these alloys have revealed a good corrosion resistance and mechanical properties in reactor operating conditions. However, as fuel burnups of commercial PWR increase with longer operating cycle lengths, fuel vendors are required to develop more advanced Zr-based alloy with an enhanced corrosion resistance. For the reason above, Korea Atomic Energy Research Institute (KAERI) in collaboration with KEPCO Nuclear Fuel (KNF) developed newly-advanced alloy which are named HANA (High-performance Alloy for Nuclear Application) for high burnup PWR nuclear fuel, showed an excellent out-pile corrosion resistance in PWR simulating loop conditions [1]. And in-pile corrosion resistance of HANA claddings, which was examined at the first provisional inspection after ~185 FPD of irradiation in the Halden Reactor, and also shown superior to the other references alloy [2]. Also, other researches [3,4] showed a much better corrosion resistance when compared to the other Zr-based alloy in various corrosion conditions.

In this study, the LTA program for newly-developed fuel assembly (HIPER) with the HANA claddings was implemented to justify the performance for 3 cycles of operation schedule in Hanul nuclear power plant. During the LTA program, after two cycles of irradiation, Pool Side Examination (PSE) was carried out for the performance confirmation. The objective of this study is to compare corrosion properties of reference alloy with HANA claddings loaded in Hanul nuclear power plant. For the examination procedures, the oxide thickness measurements method and equipment of PSE are described in detail as follow in measurement methods chapter. Finally, based on the above-mentioned measurements method, the summarized oxide thickness data obtained from PSE are evaluated for the corrosion resistance in commercial nuclear power plant and some discussion for the corrosion resistance are described.

2. Measurement Methods

PSE is performed at the spent fuel pool during the overhaul period and should usually be completed within the very limited time frame because of the tight overhaul schedule. Therefore, it is essential to have skillful engineers and automated measurement tools to complete the work within the given time. The oxide thickness is measured with ECT (Eddy Current Test) in PSE. The oxide thickness measurements are processed in two steps. At first step, oxide thickness is measured for all the most outer rods on the face with the highest burnup distribution among four faces of the fuel assembly over 11 axial positions to acquire axial distribution of cladding oxide thickness [5]. The configuration of first step is shown in Fig. 1.

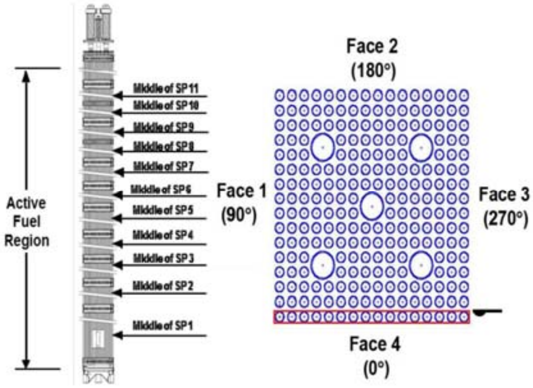

Fig. 1. The measurement of oxide thickness at axial position in fuel assembly

After determining the axial elevation which shows the peak oxide thickness, as the second step, all targeted rods are measured at that elevation to obtain the maximum oxide thickness. In the second step, the ECT prove inserts from outer specific face of fuel assembly into the space between the fuel rods at the axial elevation selected in the first step. Therefore, all the measured data from PSE in this study averaged value around short height distance. For the more accurate average calculation, the second step is performed once again to acquire the oxide thickness data for in the 90^o angle of fuel rod. And then, the maximum oxide thickness data are averaged from two position measurements of the fuel rod data. The configuration of second step is shown in Fig. 2.

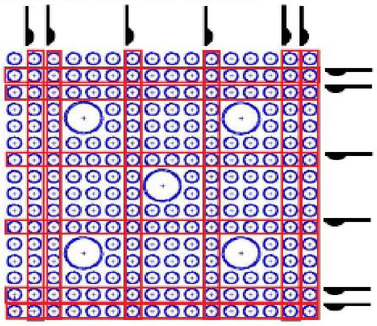

Fig. 2. Sectional drawing of oxide thickness measurement on the surface of fuel assembly by ECT equipment

3. Results and Discussion

3.1 Comparison results

The locations of the LTAs during two cycles of irradiation in Hanul reactor are shown in Fig. 3. Each four LTAs which consist of HANA alloy and reference alloy were irradiated in the symmetrical locations which were near the core shroud for the first cycle and at the center of the core for the second cycle. Therefore, average burnup of all LTAs is shown similar results about 38,700 MWD/MTU.

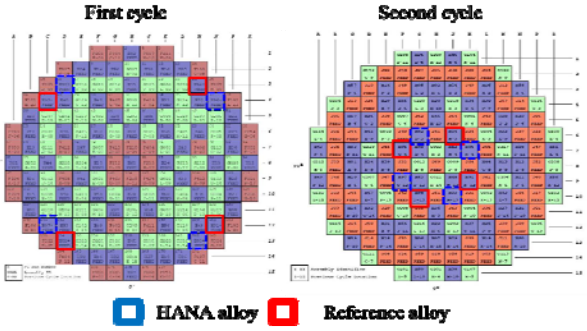

Fig. 3. LTAs loading pattern during 2 cycles

The oxide thicknesses of fuel rod with reference alloy and HANA which are applied to cladding in HIPER were measured for LTAs using ECT equipment after second cycle in the Hanul reactor. The measured oxide thicknesses of reference alloy and HANA alloy are shown in Fig. 4.

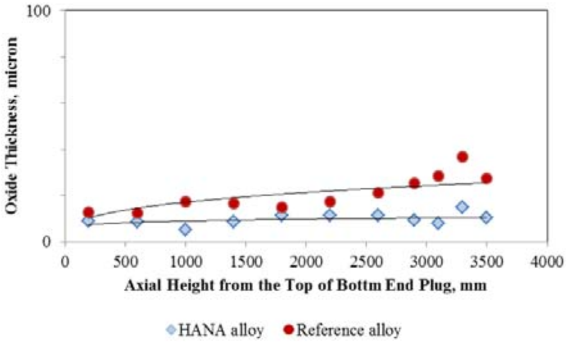

Fig. 4. Typical axial profiles of cladding oxide thickness after two cycle of irradiation in the Hanul reactor

The measured oxide thickness was varied with the axial position of the fuel rod because the heat flux and coolant temperature of the fuel rods were varied with a change in the elevated position of the fuel rod from the top of bottom end plug. As shown in above Fig. 4, the maximum oxide thicknesses were found at about 3300mm from top of bottom end plug in fuel rod.

For the evaluation of corrosion in the irradiated fuel rod, it is generally accepted that PWR fuel rods retain their mechanical integrity during normal operation up to a corrosion layer thickness of 100μm with sufficient safety margin against failure. According to the generally accepted criteria, all the summarized data in Fig. 4 are able to be met within the criteria.

3.2 Discussion for corrosion resistance of reference alloy and HANA alloy

From the PSE observation of the oxide thickness, as shown in Fig.4, the oxide thickness of HANA claddings was approximately 30% thinner than reference alloy claddings. In addition, according to the results from the second step in Fig. 2, the HANA claddings appeared lower oxide thickness tendency than reference alloy claddings. It could be thought that the corrosion resistance was affected by the Nb and Sn content as an alloying element. High-Nb causes local break down of oxide and lead to the well-known sensitivity of these alloys to accelerated corrosion in oxidizing environments [6]. Reducing the Sn contents in the alloys has been a standard technique for improving corrosion resistance [7]. Consequently, the low Sn content and small Nb content in HANA alloy thought to affect the corrosion resistance in commercial nuclear power plant.

4. Conclusions

In the past, corrosion resistance of HANA claddings was successfully conducted in test reactor. In this study, the corrosion characteristic of HANA claddings which are applied to HIPER is examined in the commercial nuclear power plant. HANA claddings in the HIPER showed a more improved corrosion resistance than reference alloy claddings and are evaluated well with meeting the oxide thickness criteria. In the foreseeable future, PSE after three cycles of irradiation is scheduled to perform again comparison of the oxide thickness for reference alloy and HANA claddings. For the corrosion mechanism and characteristic investigation with more PSE and experiments are recommended.

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