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Corrosion Resistance Evaluation of Zr-alloys Claddings in Commercialized PWR

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1. Introduction

The safety of nuclear fuel has always been a major issue in PWRs around the world. Thus, the fuel system is not damaged as a result of core operation. The cladding corrosion severely occurred during operation causes spalling wall thinning and the decreased ductility of cladding which are related with cladding damage. Therefore, it is very important to analyze fuel cladding corrosion resistance in reactor operating conditions.

As fuel burnup and cycle length are more increased for high burnup and energy economics, fuel vendors are required to develop more advanced Zr-based alloy with an enhanced corrosion resistance. For the reason above, HANA™ alloy for cladding material has been developed and it showed an excellent out of pile corrosion resistance in PWR simulating loop conditions [1]. And in-pile corrosion resistance of HANA™ claddings was examined at the first provisional inspection after ~185 FPD of irradiation in the Halden Reactor, and also shown superior to the other Zr-alloy [2]. In addition, other researches [3,4] showed a similar or better corrosion resistance when compared to the current Zr-based alloys in various corrosion conditions.

Pool Side Examinations (PSE) have been carried out to demonstrate the in-reactor performances including cladding corrosion of fuels with several Zr-alloy claddings operated during 2 and 3 cycles in Korea PWRs. In this study, the in-reactor cladding corrosion properties of several Zr-alloys were compared to HANA™ alloy cladding from the measured data.

Resultantly, oxide thickness of each alloy cladding is evaluated to assure the cladding corrosion resistance in commercial PWRs. The methods and equipment to measure oxide thickness in PSE were also described in detail.

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 Figure1.

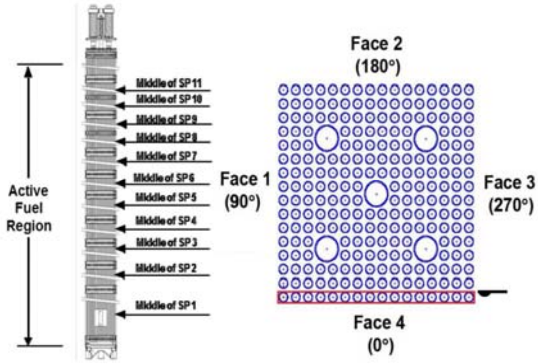

Fig. 1. The measurement of oxide thickness at axial position in fuel assembly

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, 10 mm higher, and 10mm lower than the selected location to secure the averaged value around approximately 1 inch height. Therefore, all the measured data from PSE in this study are averaged value around approximately 1 inch height distance. For the more accurate average calculation, the second step is performed to acquire the oxide thickness data for 4 faces angles of fuel rod. And then, the maximum oxide thickness data are averaged from position measurements of the fuel rod data [6]. The configuration of second step is shown in Figure 2.

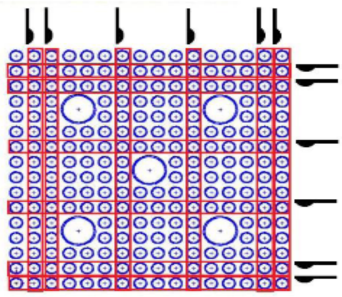

Fig. 2. Sectional drawing of oxide thickness measurement on the surface of fuel assembly by ECT apparatus

3. Comparison of oxide thickness for Zr-based alloys and Advanced alloy

The oxide thicknesses of fuel rod with Zr-alloys and HANA™ were measured using ECT apparatus after operated for each 2 and 3 cycles in the commercialized reactor. Table 1. shows the composition of the each alloy A and B, HANA^{TM}.

The HANA^{TM} and Alloy B were much better corrosion resistance when compared to the other Zr-alloys at high burnup condition. The measured oxide thicknesses of fuel rods with Zr-based alloys and HANA^{TM} are shown in Figure 3.

The oxide layer were accelerated for alloy A at high burnup (above 45,000MWd/MTU). However the similar oxide thickness results are showed each other under 35,000 MWd/MTU.

Table 1. Chemical composition of specimen

Element	Zr	Sn	Nb	Fe	Cu
Alloy A	Bal.	1.0	1.0	0.1	-
Alloy B	Bal.	-	1.0	0.04	-
HANA^{TM}	Bal.	-	1.1	-	0.07

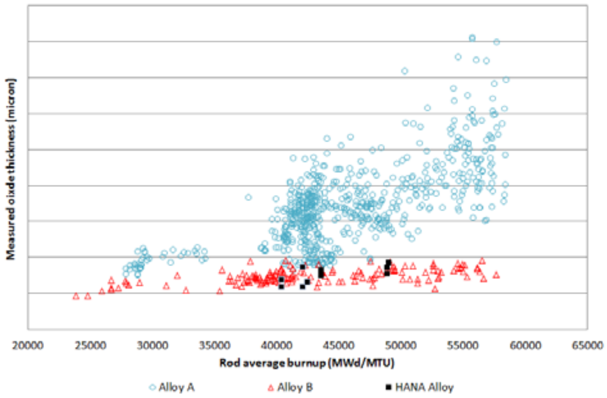

Fig. 3. Comparison of measured oxide thickness from PSE data

Figure 3 shows that the measured oxide thickness was varied during the normal operation because the heat flux and coolant temperature of the fuel rods were varied with a change in rod average burnup.

Generally, evaluation of corrosion resistance in-pile fuel rod, it is 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 of three alloys in Fig.3 satisfied the design criteria.

From the PSE observation of the oxide layer, as shown in Fig.3, the oxide thickness of HANA^{TM} claddings and Alloy B were about 50% thinner than that of Alloy A cladding at high burnup condition. In addition, the Alloy B and HANA^{TM} cladding appeared lower oxide thickness tendency than the other alloy cladding. The relatively lower oxide thickness of HANA^{TM} and Alloy B claddings than the Alloy A claddings are caused by the Nb content as an alloying element which is known as having a superior functionality to the corrosion resistance [3]. Therefore, the improved corrosion resistance of the advanced alloy, HANA was confirmed in commercialized nuclear power plant through PSE evaluation.

4. Conclusions

In this study, the corrosion characteristic of HANA^{TM} claddings are compared to the other Zr-based claddings in the commercialized PWRs. HANA^{TM} and Alloy B claddings showed a more improved corrosion resistance than the other Zr-based cladding mainly due to alloying composition with addition of Nb and reduction or elimination of Sn. And, these improved corrosion resistance are verified well within the oxide thickness criteria in PWR. Therefore, the result of this study demonstrated the comparable corrosion resistance of HANA alloy cladding similar to Alloy B which has well been known for corrosion resistance in all nuclear markets of the world.

REFERENCES

[1] Y.J. Park et.al., Proceedings of the Korean Nuclear Society Autumn Meeting, Yongpyong, Korea, Oct. 2004, p905
[2] Y.H. Jeong et.al., 2005 Water Reactor Fuel performance Meeting, Oct 3-7, Kyoto, Japan(2005)
[3] H.G. Kim et.al., Transactions of the Korean Nuclear Society Spring Meeting, May 25-26, Chuncheon, Korea(2006)
[4] J.Y. Park et.al., Transactions of the Korean Nuclear Society Autumn Meeting, October 27-28, Busan, Korea(2005)
[5] Young Ki Jang, “Irradiation Performance Update on Advanced Nuclear Fuel of PLUS7TM”, Proceedings of ASME 2011 Pressure Vessels & Piping Conference, 2011.
[6] O.H. Kwon et.al., Transactions of the Korean Nuclear Society Spring Meeting, May 30-*31*, Gwangju, Korea(2013)