Irradiation Properties of HANA Claddings tested in Halden Research Reactor

Hyun-Gil Kim*, Byung-Kwan Choi, Jeong-Yong Park, Yong-Hwan Jeong
Nuclear Convergence Technology Division, 1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author:hgkim@kaeri.re.kr*

1. Introduction

In PWRs, Zr alloys have been used as fuel assembly components for fuel cladding tubes, spacer grids, as well as guide tubes since Zr alloys have a low neutron cross-section, good corrosion resistance, and mechanical strength in reactor operation condition. Recently, a variety of Zr-based alloys have been developed for application as a fuel assembly component [1-3], since the performance of Zircaloy-4 material is limited to continuously use as a fuel assembly components for high burn-up operation condition in reactor. At KAERI, many Zr alloys, which can be systematically controlled by the alloying element and heat treatment, were tested for various properties, particularly corrosion, tensile properties, creep, and high temperature oxidation. Therefore, the compositions of advanced Zr-based alloys named as HANA were designed as shown in Table 1.

Table.1: Chemical composition of advanced zirconium-based alloys for nuclear application

Alloy	Nb	Sn	Fe	Cr	Cu	Zr
HANA-3	1.5	0.4	0.1	-	0.1	Bal.
HANA-4	1.5	0.4	0.2	0.1	-	Bal.
HANA-5	0.4	0.8	0.35	0.15	0.1	Bal.
HANA-6	1.1	-	-	-	0.05	Bal.

It was reported that HANA claddings have a better performance such as corrosion, creep, and high temperature oxidation than Zircaloy-4 claddings [3]. Especially, the HANA claddings showed better corrosion resistance than Zircaloy-4 claddings from the in-pile test up to 60 GWD/MTU tested in Halden research reactor. To commercialize the new developed alloy the various irradiation properties were verified form the PIE (Post Irradiation Examination). So, this study was focused on the PIE of HANA claddings tested in Halden research reactor.

2. Methods and Results

In the Halden research reactor test, regular interim inspections are being conducted, covering visual inspection, oxide thickness and diameter measurements, and eddy current measurements to look for defects. Four test rods were discharged after three cycle irradiation and were subjected to PIE of hydrogen analysis, LOM (Light Optical Microscope), and ring tensile test. After three cycle irradiation the accumulated burn-up and fluence of HANA rods reached up to 34 GWD/MTU and 1.33 x 10^{21}n/cm^2 (E>1Mev), respectively.

2.1 Hydrogen analysis

Hydrogen content analyses were performed to investigate the hydrogen pick-up behavior of HANA claddings during the irradiation corrosion test. The samples were cut from the center region of rods and were treated in HNO_3 solution to remove any remaining fuel particles on the inner surface, and then ultrasonically cleaned and dried. The analysis was performed using an ELTRA-OH-90 equipment. Fig. 1 shows the analyzed hydrogen content as a function of oxide thickness. The hydrogen content of HANA claddings was ranged from 26 to 66 ppm. From these values, HPUF (Hydrogen Pick-Up Fraction) of HANA claddings could be compared to the commercial Zircaloy-4 data and it is known that hydrogen pick-up resistance of HANA alloys is better than Zircaloy-4 alloy.

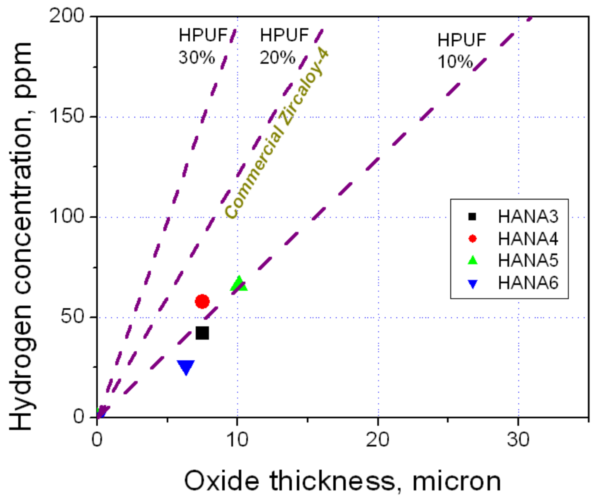

Fig. 1. Relationship between hydrogen concentration and oxide thickness of HANA claddings after three cycle irradiation

2.2 LOM examination

The purpose of LOM examination was to determine the oxide thickness and the presence of any defect. The samples were prepared to observe the cross-sectional direction. Fig. 2 shows the LOM observation of the oxide layer of the HANA claddings after tree cycle irradiation. The oxide layer seems to be continuous for the four orientations of 0, 90, 180, and 270°. And no defect was seen in the oxide layer for the four orientations. The oxide thickness of HANA claddings was measured in each image at three points and the average values were calculated and this result was shown in Fig.1.

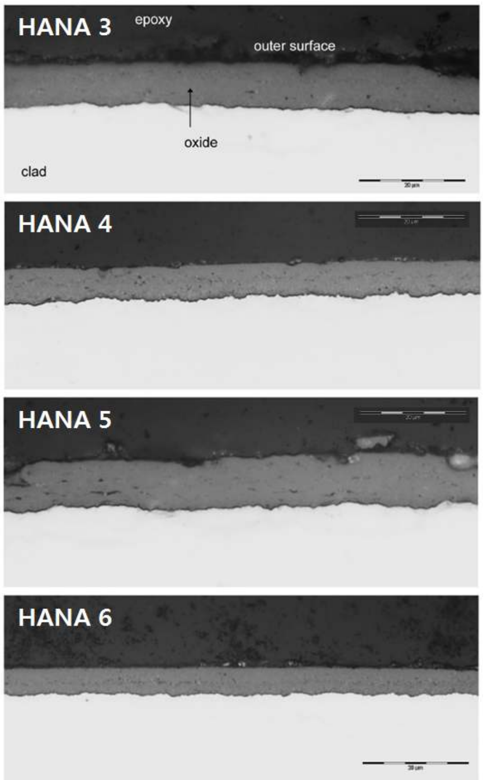

Fig. 2. LOM observation of the cross-sectional oxide layer of HANA claddings after three cycle irradiation

2.3 Ring tensile test

Tensile test at room temperature was done to obtain data on the mechanical properties such as the strength and ductility of cladding materials as function of irradiation fluence. Ring samples with a width of 2-3 mm were cut from the each fuel rod around the center of the axial direction. After cut the samples, the fuel is mechanically removed and treated in concentrated HNO_3 to remove remaining fuel particles and then the samples ultrasonically cleaned and dried. The testing was done on an Instron EZ50 tensile tester using a special tool designed for ring samples. The specimens were tested in the hoop direction at room temperature. The crosshead speed was 0.05 mm/min. The gauge length is not physically defined for ring samples, but a nominal gauge length equal to ca. 10% of the circumference is generally considered to be appropriate. The gauge length parameters for the specimens correspond to 3.0 mm. Fig. 3 shows the YS (Yield Strength), UTS (Ultimate Tensile Strength), and El (Elongation) values of HANA claddings after three cycle irradiation. When compared to the before irradiation results, YS and UTS was considerably increased, whereas, El was considerably decreased after three cycle irradiation. From the observation of fracture type, cup and corn mode was changed to the 35° shear mode in HANA-3 cladding by three cycle irradiation. The variation of those results was changed with the alloy compositions in the HANA claddings. The HANA-5 cladding showed higher variation of strength and ductility than other claddings.

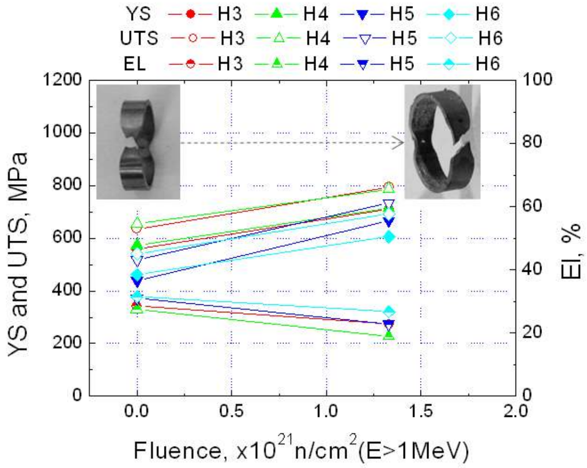

Fig. 3. Ring tensile test result of HANA claddings after three cycle irradiation

3. Conclusions

For the three cycle irradiation test rods of HANA claddings, the PIE examination was conducted. From the PIE results, it is known that the hydrogen pick-up resistance of HANA alloys is better than Zircaloy-4 alloy. The defect was not observed in the oxide layer for the four orientations of HANA claddings. The variation of tensile strength and elongation was affected by the alloy compositions in the HANA claddings.

REFERENCES

[1] R.J. Comstock, G. Schoenberger, G.P. Sabol, Influence of processing variables and alloy chemistry on the corrosion behaviour of ZIRLO nuclear fuel cladding zirconium in the nuclear industry, ASTM STP 1295 (1996) 710–725.
[2] J.P. Mardon, D. Charquet, J. Senevat, Influence of composition and fabrication process on out-of-pile an in-pile properties of M5 alloy zirconium in the nuclear industry, ASTM STP 1354 (2000) 505–524.
[3] Y.H. Jeong, S.Y. Park, M.H. Lee, B.K. Choi, J.H. Baek, J.Y. Park, J.H. Kim, H.G. Kim, Out-of-pile and in-pile performance of advanced zirconium alloys (HANA) for high burn-up fuel, J. Nucl. Sci. Technol. 43 (2006) 977–983.