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Hot Cell Examination of Irradiation Hardening in Spacer Grid

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1. Introduction

Although zirconium alloys have been used in the nuclear material, better mechanical properties of the Zirconium alloy are required enough to keep the integrity in high burn-up. There have been many investigations into the zirconium alloy of cladding tube in the point of corrosion resistance and PCI (Pellet Cladding Interaction) [1]. However, the other researches about the spacer grid are relatively insufficient even though the regions are damaged in high burn up. In this study, spacer grid samples detached from fuel assembly during intermediate burn-up (21GWd/tU, 44GWd/tU) were analyzed to observe the mechanical property change and fracture behavior of the spacer grid.

2. Experimental procedure

The detached samples were obtained from the Ulchin-2 Power Plant after $1^{st}/2^{nd}$ irradiation. One was the sample detached from the Fuel Assembly at the burn-up of 21GWd/tU. And the other two were detached after 44GWd/tU. The specimens were moved to the IMEF (Irradiated Material Examination Facility) in KAERI and cut in several small regions. Each region was mounted properly with brass material.

To show the hydrogen concentration dependent on the heat effect during welding process, two specimens were selected. One was in the welding heat-affected region. The other was relatively far away position from the welding heat-affected region. The hydrogen concentration analysis was examined by LECO RH-404.

Optical Microscope (Reichert-Jung, Telatom-2) and Scanning Electron Microscope (Philips, XL-30) were used to observe the fracture surface and hydride. The fracture zone and welding zone were examined in the spacer gird.

3. Results & Discussion

3.1 Micro-Hardness

The micro-hardness of the spring region of the spacer grid was examined with depending on the burn-up. The spring region did not receive the heat effect from welding process on the micro-hardness. The micro-hardness gradually increases not only in the spring region but in the welding region shown in Fig.1 as burn up increases. And the welding heat - affected region shows higher micro-hardness than that of the spring region.

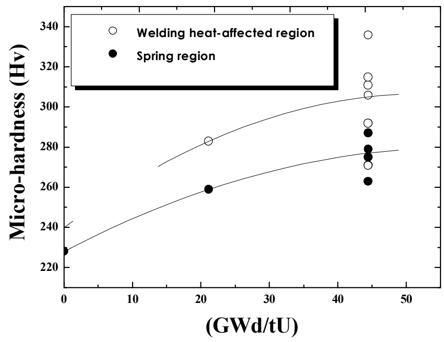

Figure 1. The micro-hardness of the spring region of and welding heat-affected region of spacer grid with depending on the burn-up

3.2 Hydrogen concentration & Hydride

The Hydrogen average concentration of the welding heat-affected region and spring region which had been not affected by welding heat had 435 μg/g and 358 μg/g at 44GWd/tU, respectively.

The welding heat-affected region was able to be divided into two zones. The welding zone was melt and solidified by welding process directly. The other zone was affected by welding heat through welding zone. Here were different results in hydride. The welding zone in Fig.2 took relatively less sufficient hydride than the zone adjacent to the welding zone. And the hydride closer to the heat-affected zone shows random orientation. The fracture was not occurred at the welding zone. Therefore, the crack appeared to initiate close to the welding zone even though the welding zone connected thinly seems to be weak.

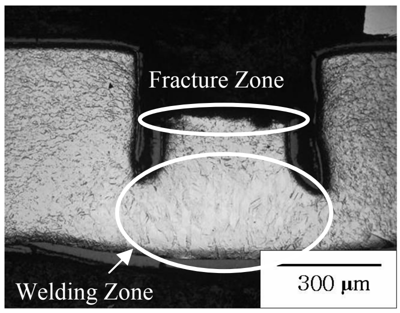

Figure 2. The OM image of welding heat-affected region in detail to observe the hydride in the welding zone.

3.3 Fracture surface Image

When the spacer grid was exposed at the burn-up of

21GWd/tU, the fracture surface image was different from the one after 44GWd/tU as shown in Fig.3. The fracture image seemed to be a fracture with the strain deformation in Fig.3(a). However, the Fig.3(b) seemed to be a brittle fracture. Therefore, the fracture of the spacer grid seemed to propagate as a brittle fracture with being exposed in irradiation longer.

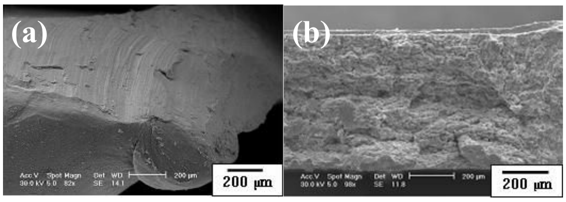

Figure 3. The fracture surface of spacer grid.: (a) 21GWd/tU burn-up, (b) 44GWd/tU burn-up

There were previous works about the effects on the mechanical property of zirconium alloy. Some reports referred to the hydrogen behavior which results in the degradation of the mechanical property [2]. Other reports refer to the welding effect. The SPPs precipitation in welding region had been resulted by the annealing during welding process. The SPPs embedded in Zirconium alloy acts as a preferred path for hydrogen uptake [3]. So the degradation of the mechanical property is due to the combined effect of hydride and irradiation [4]. In this result, the welding heat also affected the combined effects of hydride and irradiation and played an effective role resulting in the micro-hardness variation and fracture behavior.

4. Conclusions

In this study, the micro-hardness of the welding heat-affected region and the spring region increased. The micro-hardness of welding heat-affected region was higher than that of the spring region. And the hydrogen concentration was higher in the welding heat-affected region than in the spring region with no effect of welding heat.

The welding heat-affected region was divided into two zones that consist of the welding zone and the zone close to the welding zone. In detail, the hydride was less distributed in welding zone than in the zone close to the welding zone.

The fracture surface seems to initiate not the welding zone which has thin connection but the zone which was affected less by welding heat relatively.

The fracture with strain deformation behavior was changed to the brittle fracture as the burn-up increased.

Acknowledgements

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