Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

In-Reactor Densification of Dual Cooled Annular Fuel Pellet during Irradiation Test at HANARO

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1. Introduction

Recently, an internally and externally cooled annular fuel, namely, a dual cooled annular fuel has been considered as a promising solution for an extended power uprate of a PWR fuel assembly. A dual cooled annular fuel shows a lot of advantages from the point of a fuel safety and its economy due to its unique configurational merit such as an increased heat transfer area and a thin pellet thickness [1]. These advantages result in a considerably low pellet centerline temperature.

Because of this considerably low pellet temperature, in-reactor behavior of an annular pellet, such as densification and swelling may be significantly different from that of the conventional PWR solid pellet. Since the pellet temperature of an annular fuel rod is lower than that of a PWR solid fuel rod by several hundred degrees, the in-reactor densification and swelling of a dual cooled annular fuel pellet might be considered as athermal phenomena due to a low pellet temperature.

In order to investigate the in-reactor behavior of the annular UO_2 pellet, HANARO irradiation test was planned and conducted for annular pellets with 5 different types. Post irradiation test is being carried out in the KAERI's PIE facility. In this study, we are going to report the preliminary results of PIE test on the in-reactor densification behavior of a dual cooled annular fuel pellet.

2. Annular Pellet Preparation

Annular fuel pellets were prepared by the Integrated Dry Route (IDR) UO_2 powder. The powder was pre-compacted under 10 MPa by using a cold isostatic press. Pre-compacted lump of UO_2 powder was crushed and granulated with 20 mesh sieves. The granules were mixed with a 0.3 wt% of zinc stearate in a tumbling mixer for 30 min. The compaction was conducted in a double acting press by using an annular shape mold. Different amounts of the granules were charged to the pressing mold and then the green densities were varied from about 50 %TD to about 56%TD.

In order to achieve annular fuel pellets with the same dimensions and various sintered densities, we control the green density and the sintering temperatures. The compacts were sintered at the temperature ranges of 1450 °C and 1730 °C for 1.5-4 h in H_2 atmosphere. The heating and cooling is at a rate of 5 K/min. Sintered density was measured by the water immersion method. Centerless grinding was conducted to control the outer diameter. The inner and outer diameters of the sintered pellets were measured carefully by using a 3-dimensional measuring system (VERTEX 230, MicroVu). The detailed specification of the annular pellet was shown in Table 1.

Table 1. Specification of the fabricated annular pellet.

	Sintered density (%TD)	Height (mm)	Outer diameter (mm)	Inner diameter (mm)
Type A	89.7±0.24	8.540 ±0.009	14.627 ±0.002	10.286 ±0.008
Type B	92.4±0.11	8.635 ±0.007	14.625 ±0.002	10.289 ±0.007
Type C	96.0±0.31	8.752 ±0.012	14.625 ±0.002	10.290 ±0.004
Type D	97.9±0.13	8.709 ±0.009	14.620 ±0.001	10.285 ±0.010
Type E	98.0±0.05	8.699 ±0.003	14.685 ±0.003	10.271 ±0.002

3. HANARO Irradiation Test and PIE test

Irradiation test was conducted at the OR-4 hole in HANARO by using a non-instrumented test rig. The test rig contained two test capsules at upper and lower region. Each test capsule was composed of 3 test fuel rods with a triangular lattice. The claddings of the fuel rods were made of SUS316L. Six annular pellets were inserted into each test fuel rod.

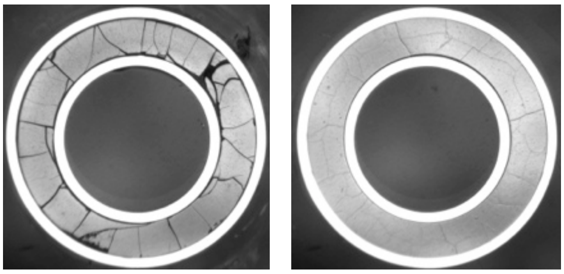
The in-reactor densification of annular pellet was investigated as a function of its initial sintered density by using annular pellets with four different sintered densities of 89.7, 92.4, 96.0, 98.0%TD.

Maximum local burnup was estimated around 10.9 MdW/kgU. The pellet temperature of the test rods was calculated by DUO- THERM[2]. The maximum pellet temperature was about 700 °C at BOL.

After a non-destructive test such as gamma-scanning, test rods were cut and polished for the microstructural investigation and the density measurement at KAERI's PIE facility.

Figure 1(a) and 1(b) show the macroscopic cross-sections of a dual cooled annular fuel rods with initial sintered densities of 90 %TD and 98 %TD, respectively. Many radial cracks and circumferential cracks were shown in both cross-sections.

It seems that the crack width of an annular pellet with lower sintered density is broader than that of an annular pellet with high sintered density. Also, it appears that there are much more void space or gaps between cladding and pellet in the annular fuel rod with low sintered density pellet. It might be attributed to the



(a) (b)

Fig. 1. Macroscopic cross-section of the annular fuel pellets with initial sintered densities of (a) 90 %TD and (b) 98% TD.

difference in the amount of in-reactor densification. Density measurement results were shown in Fig. 2. It shows that more than 8 %TD of densification occurred in the annular pellet with 90 %TD of initial sintered density. It seems that much more densification occurred than the expected values based on MATPRO relations of in-reactor densification at low pellet temperature.

This enhanced densification might be attributed to the high fission rate during HANARO irradiation. M.D. Freshley et al.[3] noted that densification increased with fission rate, fuel temperature, and burnup. However, he could not evaluate the possible effect of fission rate and fuel temperature on densification independently, because fission rate and fuel temperature are interdependent in his experiment. This study might be the first report on the effect of high fission rate on densification of UO_2 pellet irradiated at low temperature.

A slight swelling occurred in the annular pellets with high initial sintered densities. Yang et al.[4] reported that the swelling rate of the annular pellet is corresponded to the one observed for solid fuel pellets irradiated at low temperature.

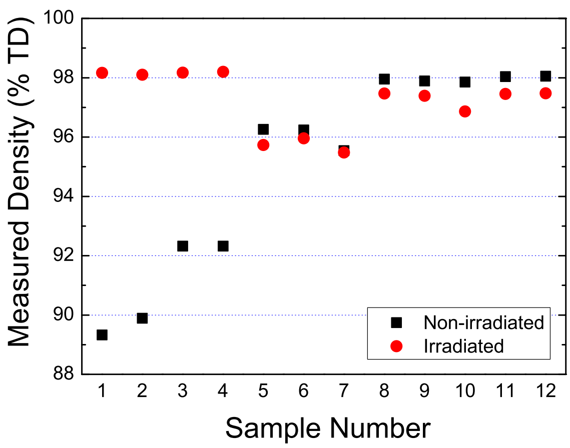


Fig. 2. Measured densities of annular pellets before and after irradiation.

4. Conclusion

Irradiation test of dual cooled annular UO_2 pellet was conducted at the OR-4 hole in HANARO by using a non-instrumented test rig. The preliminary results of PIE test on the in-reactor densification behavior showed that the irradiated pellets densified much more than expected values based on MATPRO relations of in-reactor densification at low temperature in the annular pellet with low initial sintered density. It might be attributed to the higher fission rate during HANARO irradiation.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (2013000720).

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