Swelling Rate and Diameter Change of Annular Pellet Irradiated in HANARO

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1. Introduction

In-reactor behavior of annular UO_2 fuel may differ from conventional solid UO_2 fuel because it is expected to operate at low temperature, and because the geometrical shape of the two kinds of fuel rods is not identical. Since the temperature of an annular fuel rod is lower than solid fuel by several hundred degrees [1], densification and swelling generally known as athermal phenomena could be affected by low temperature. In contrast with the solid fuel having only one gap, annular fuel has both inner and outer radial gaps which can accommodate the change in pellet volume. When pellet densification occurs at the beginning of life (BOL), outer gap would obviously increase due to the decreased outer pellet diameter. On the other hand, it is unclear whether inner gap would either increase or decrease. KAERI performed out-of-pile re-sintering test for annual fuel pellets with four densities [2]. Test result shows that both the outer and inner diameter of the annular fuel pellet decreased as a result of re-sintering. This implies that, while the pellet densification would lead to the outer gap increase, it would reduce the inner gap at the early stage of irradiation. Therefore, in order to investigate the in-reactor behavior of the annular UO_2 pellet, the irradiation test was carried out in the HANARO [3,4] and post irradiation test was carried out in KAERI's PIE facility.

2. Swelling Rate and Diameter Change of Annular UO_2 Pellet

2.1 Determination of swelling rate

As mentioned above, one of the dual cooled annular fuel characteristics is the lower temperature than solid fuel. Thus it was expected that the swelling rate of annular pellet is lower than that of the solid pellet. Densification is the dominant process during the early period of irradiation and it results in an increase of fuel density. But, the annular pellet had a high initial density of 98%TD and irradiated up to 10,900 MWD/MTU, thus densification effect was excluded for the determination of swelling rate.

The swelling rate of the annular pellet was determined by density measurement tests of irradiated pellets which were carried out in the hot cell according to the ASTM B311-93 test method. Table 1 shows the measured densities and the calculated swelling rates of the irradiated annular pellets. The swelling rates of the annular pellets were presented with those of the solid pellets irradiated at low temperature in Fig. 1 [5]. In Fig. 1, it is shown that the swelling rates of the solid UO_2 pellets are in the range of 0.25 to 0.6 vol.% per 10 MWd/KgU and the swelling rates of the annular UO_2 fuels are also in the same range with the solid pellets. The average swelling rate of annular pellet was determined to be 0.451 ± 0.1 vol.% per 10 MWD/KgU. Therefore, it is verified that the dual cooled annular fuel has lower swelling rate than the commercial solid fuel.

Table 1. Density and swelling rate of irradiated annular pellets

Specimen No.	As fabricated density (%TD)	Post irradiation density (%TD)	Calculated swelling rate
R2-SP2	98.086	97.457	0.591
R2-SP3	98.053	97.476	0.588
R2-SP4-1	97.995	97.409	0.598
R2-SP4-2	97.995	97.422	0.585
R8-SP2	97.953	97.470	0.493
R8-SP3	97.889	97.391	0.509
R8-SP4-1	97.645	97.333	0.320
R8-SP4-2	97.645	97.391	0.260
R14-SP4-1	97.885	97.398	0.498
R14-SP4-2	97.885	97.466	0.428
R14-SP6-1	97.728	97.235	0.504

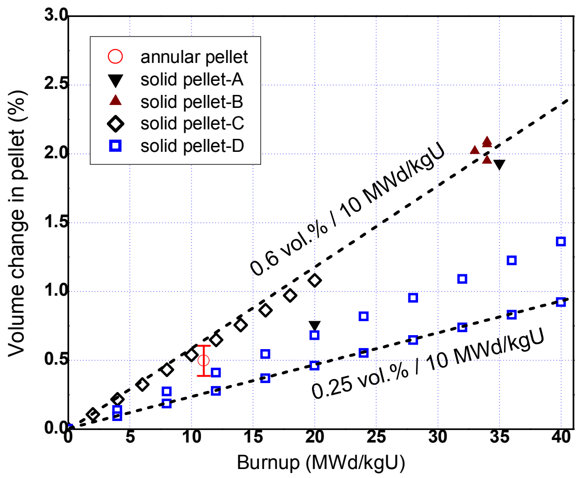

Fig. 1. Swelling rates of annular pellet and solid fuel irradiated at low temperature.

2.2 Diameter change of irradiated annular pellet

Dual cooled fuel has both inner and outer gap. The change of the gap size affects to the heat split. The inner and outer diameter of the annular pellet were determined using SEM and any 3-point circle radius determination method (Eqs. 1&2 and Fig. 2). The measurements were carried out two times each specimen.

$$x^2 + y^2 + Ax + By + C = 0 \quad (1)$$

$$r = \frac{\sqrt{A^2 + B^2 - 4C}}{2} \quad (2)$$

Table 2 shows the changes of the inner and outer diameter of the annular pellet. The changes of inner diameter were in the range of -6 ㎛ to 41 ㎛ and those of outer diameter in the range of -20 ㎛ to 34 ㎛. But considering the measuring and specimen manufacturing errors, it was not clear whether the diameter increased or decreased.

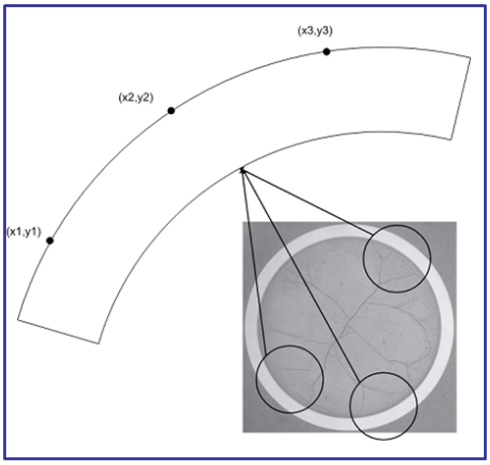

Fig. 2. Measuring points for 3-point circle radius determination.

Table 2. Changes of the inner and the outer diameter

Specimen No.	Position	As-fabricated Diameter (㎜)	Post-irradiation Diameter (㎜)		Diameter change
R02	Inner Dia.	10.264	10.305	10.297	0.033~0.041
	Outer Dia.	14.688	14.668	14.722	-0.020~0.034
R08	Inner Dia.	10.284	10.294	10.278	-0.006~0.010
	Outer Dia.	14.618	14.646	14.606	-0.012~0.028
R10	Inner Dia.	10.276	10.332		0.056
	Outer Dia.	14.626	14.635		0.009

3. Conclusions

To investigate the in-reactor behavior of an annular UO_2 fuel rod, an irradiation test was carried out in HANARO. The annular UO_2 pellets were irradiated up to 10,900 MWD/MTU. PIE was performed for the irradiated annular fuel rods at KAERI's PIE facility.

Swelling rate derived from density measurement of the annular fuel pellets with 98.0%TD was 0.451± 0.1 vol.% per 10 MWd/kgU, corresponding to the one observed for solid fuel pellets irradiated at low temperature. This implies that, when fuel pellet is irradiated at low temperature, swelling rate of the fuel pellet is in the same range whether it has a solid or annular shape. The diametral changes of annular pellets were measured. But it was not clear whether the diameter increased or decreased

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