Experimental Observation of Densification Behavior of UO_2 Annular Pellet

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1. Introduction

Recently, in the nuclear industry, one of the major issues is the improvement of a fuel economy. And many efforts have been made to develop a nuclear fuel for a high burnup and extended cycle. In the development of a high performance fuel, in-reactor fuel behavior (fission gas release, pellet-clad interaction, stress corrosion cracking, cladding corrosion, etc.) must be seriously reconsidered. Also, fuel fabrication (high enriched UO_2 powder handling, fuel rod and assembly manufacturing, fabricated fuel rod and assembly storage and transport, etc.) and an enrichment process (5 w/o criticality limit, etc.) must be discussed [1].

A modification and an improvement of the nuclear fuel system will be also required. The typical fuel geometry of a PWR (Pressurized Water Reactor) is composed of a cylindrical pellet with a tubular cladding. And the outer surface of the cladding is cooled with water. However, to allow a substantial increase in the power density, an additional cooling is needed. One of the best ways is the application of the new fuel geometry that is of annular shape and has both internal and external cooling [2]. From this point of view, the double cooled fuel is being developed by KAERI (Korea Atomic Energy Research Institute), and as a part of the project, the development of a fabrication process of a UO_2 annular pellet is now in progress.

The dimensional behavior of UO_2 fuel is an important parameter in an irradiation performance. Various investigations (resintering test, model calculation, in-pile dimensional change measuring, etc.) had been performed [3-5]. In designing a double cooled fuel, the importance of the dimensional behavior of a fuel pellet is higher, because the gap distance between a pellet and cladding can considerably affect on the in-reactor fuel performance (gap conductance). And the dimensional behavior of an inner/outer gap is different with a cylindrical pellet, when the pellet shrinks (densification), the inner gap distance decreases and the outer gap increases. When the pellet expand (gas/solid swelling, thermal expansion), the opposite phenomena happen. In reactor condition, the shrinkage and expansion of pellet is simultaneously occurred.

In this study, to experimentally observe the densification behavior of an annular pellet, resintering test of a UO_2 annular pellet with various sintered densities was performed. The relationship between the dimensional change rate (outer diameter, inner diameter, length, thickness) and density change of an annular pellet was investigated by using the measured data.

2. Experimental and Results

UO_2 sintered pellets with various densities were prepared as follows. ADU-UO_2 powder (Ammonium Diuranate) was granulated with a pressure of 40 MPa and a 20 mesh sieve. Granulated powder was mixed with lubricant powder (Zn stearate, 0.3 wt%). Powder mixture was compacted with a compaction pressure of 300 MPa, and sintered in the various sintering conditions (temperature and time). All the sintering processes were conducted in a flowing dry hydrogen atmosphere.

The density of the sintered pellet was determined by using an immersion method, and the dimension of the sample was measured by using a micrometer (outer diameter and length) and a bore gauge (inner diameter).

Resintering test of UO_2 sintered pellets with various densities was carried out at 1700 ºC for 24h in a flowing H_2 atmosphere. It is a typical resintering test condition of UO_2 nuclear fuel for PWR. And the density and dimensions of the resintered sample were also measured. The sintering condition, the sintered/resintered density and dimensional change rate of each sample were shown in Table 1.

Table 1. The sintering condition, the sintered/resintered density and dimensional change rate of each sample

	Sample 1	Sample 2	Sample 3	Sample 4
Sintering condition	1450 ºC 15 min	1500 ºC 15 min	1700 ºC 15 min	1730 ºC 4h
Sintered density (%T.D.)	91.879	92.710	95.428	97.114
Resintered density (%T.D.)	97.438	97.328	97.132	97.203
OD change rate (%)	–1.875	–1.651	–0.641	–0.142
ID change rate (%)	–1.845	–1.647	–0.513	–0.016
Thickness change rate (%)	–1.944	–1.660	–0.923	–0.421

Green pellets with a density of ~50 %T.D. (Theoretical Density) were sintered in various sintering conditions, and sintered pellets with various densities were obtained. Especially, the density of sample 3 (~95.5 %T.D.) corresponds with the conventional pellet density of PWR.

In the resintering test, every sample reached a density of ~97.3 %T.D. And the measured dimensions of the resintered sample were compared with that of sintered sample.

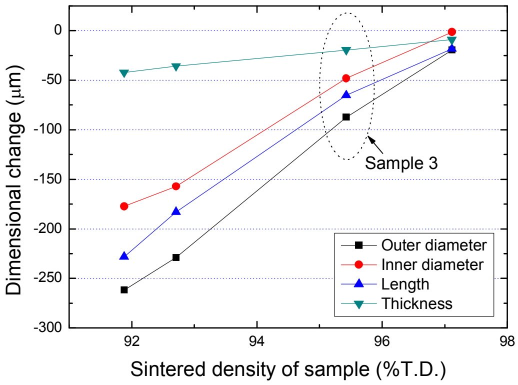

Figure 1. Dimensional change of UO_2 annular pellet in the resintering test (initial outer diameter 13.8 mm, inner diameter 9.5 mm, length 10.14 mm, thickness 2.15 mm: averaged value).

Figure 1 shows the dimensional change of the UO_2 annular pellet for the resintering test. The relationship between the magnitude of a dimensional change and an initial sintered density of the annular pellet is shown. Every dimension (outer diameter, inner diameter, length and thickness) decreased with an increasing density of a sample. And the magnitude of a dimensional change was proportional to that of the density change.

The magnitude of a dimensional change is important, because it can be used to predict the dimensional behavior of a gap for a double cooled fuel. For example, dimensional decrement of sample 3 is

- outer diameter (OD): ~87 μm
- inner diameter (ID): ~48 μm
- length: ~65 μm
- thickness: ~20 μm

From the result of sample 3, if the initial inner gap of the double cooled fuel is designed above 50~60 μm (in the only case of the initial dimension of sample 3: OD 13.86 mm, ID 9.55 mm), it is expected that there will be no gap contact caused by a densification of the annular pellet.

And it is shown that the thickness of the annular pellet decreases with a proceeding densification. It can be said that a decrement of the thickness is for a larger initial dimension of the outer diameter rather than for a slightly higher dimensional change rate.

To precisely obtain the magnitude of a dimensional change, an additional experiment will be required. However, it is expected that these results can be used to predict the tendency of the densification behavior of an annular pellet.

3. Conclusion

Experimental observation of the densification behavior of a UO_2 annular pellet was carried out by a measurement of the dimensional and density change. In the resintering test, the densification behavior of the sample with various sintered densities was compared.

Every dimension (outer diameter, inner diameter, length and thickness) decreased with an increasing density (decreasing volume) of the annular pellet. The magnitude of the dimensional change was proportional to that of the density change.

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