Fabrication of Mn-Al doped UO_2 Annular Pellet with High Thermal Stability

Dong-Joo Kim, Young Woo Rhee, Jae Ho Yang, Jang Soo Oh, Jong Hun Kim, Ik-Hui Nam, Keon Sik Kim

LWR Fuel Technology Division, Korea Atomic Energy Research Institute,
1045 Daedeok-daero, Yuseong, Daejeon 305-353, Rep. of Korea
**Corresponding author: djkim@kaeri.re.kr*

1. Introduction

For a higher burnup and extended cycle, one of the innovative nuclear fuel concepts being developed has a new fuel geometry design that is of an annular sintered pellet, inner and outer cladding, and a dual cooling system which is cooled by both an internal and external coolant (dual cooled fuel) [1].

The advantages of dual cooled fuel are considerably lower surface heat flux and lower fuel temperature than those of solid fuel. While the lower heat flux gives a higher DNB (Departure from Nucleate Boiling) margin for the same power rate, the lower temperature reduces the stored energy of the fuel and cladding peak temperature. The dual cooled fuel has promising potential to increase both the reactor economy and safety.

In the development of a nuclear fuel pellet, the improvement of fuel performance to reduce the FGR (Fission Gas Release) and increase the resistance to the PCI (Pellet Cladding Interaction) is a technical challenge. As in the annular fuel pellet, the in-reactor performance of dual cooled fuel can be definitely enhanced by an improvement in PCI and FGR.

In the development of the dual cooled fuel concept, a ‘heat split’ behavior of the fuel is one of the issues that must be significantly considered. The heat split is a phenomenon with an unbalanced distribution of heat flux between inner and outer coolant-direction. In the densification of the annular pellet, inner gap of fuel will be changed narrower than outer gap of fuel. And then, the thermal resistance of inner gap will decrease lower than that of outer gap. Finally, the heat flux of inner coolant-direction will rise higher, and the temperature of inner coolant and cladding will increase [2].

Therefore, if an annular sintered pellet with a higher thermal stability can be fabricated, the dual cooled fuel performance in the reactor can be remarkably improved. That is to say, the annular pellet with a minimized dimensional change by densification needed.

In this study, an annular sintered pellet with a higher dimensional thermal stability was fabricated using the results that were developed by our previous work [3]. To verify the improved performance of the fabricated annular pellet, a resintering test [4-7] was performed. The diametric change between the sintered and resintered pellets was analyzed using a precise 3-dimensional measuring system.

2. Experimental and results

MnO and Al_2O_3 powders were mixed (Mn 950 ppm, Al 50 ppm) and ball-milled for 24 h in a jar containing zirconia balls and alcohol. The prepared MnO and Al_2O_3 powder mixture was added to ADU-UO_2 (Ammonium Diuranate) powder, and was mixed using a Turbula mixer for 0.5 h. The powder mixture was compacted using a double acting press, and sintered at 1730 ºC for 4 h in a flowing H_2 atmosphere (Figure 1). The sintered annular pellets were then resintered at 1700 ºC for 24 h in a flowing H_2 atmosphere.

The dimension, density and micro structure of the sintered and resintered pellets was precisely investigated using a precise 3-dimensional measuring system (VERTEX 230, MicroVu), a gas pycnometer (AccuPyc II 1340, Micrometritics) and an optical microscope, respectively.

Fig. 1. Sintered annular pellets.

3. Results

First of all, the pellet fabrication condition that was developed by our previous work can be directly applied to the annular pellet fabrication process.

In spite of the very low contents of additive, the Mn-Al doped annular pellet with very large sized grain (30~35 μm) could be obtained. Figure 2 shows the grain structures of UO_2 annular pellet and Mn-Al doped annular pellet. Also, the sintered density of Mn-Al doped annular pellet was slightly higher than that of UO_2 annular pellet. It can be said that the fuel performance of Mn-Al doped annular pellet is more superior to that of UO_2 annular pellet under the same fabrication condition.

After the resintering test, diametric and density changes of both annular pellets were precisely measured. The change of the Mn-Al doped annular pellet was lower than that of the UO_2 annular pellet. It can be said that the thermal stability of the developed annular pellet is enhanced.

The grain size of the developed annular pellet is much higher than that of the UO_2 annular pellet. Also, during the resintering step, the grain size of the developed pellet increased more. Therefore, the FGR can be reduced using the developed annular pellet.

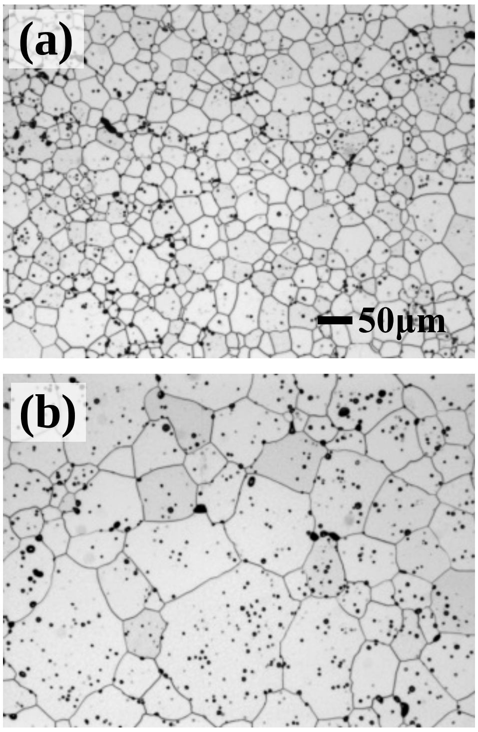

Fig. 2. Grain structures of annular pellets: (a) UO_2 and (b) $MnO\text{-}Al_2O_3$-doped UO_2

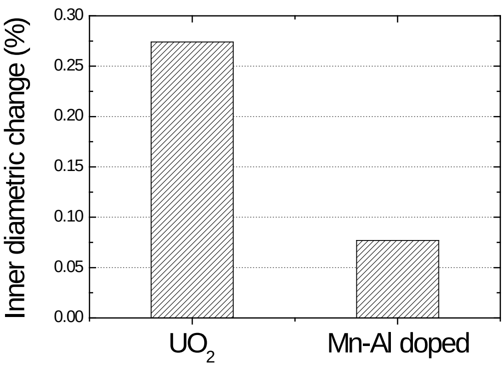

Fig. 3. Changes of inner diameter of annular pellets during resintering test

4. Summary

An annular pellet with a high thermal stability was fabricated, and then a resintering test for the sintered pellets was performed.

The developed annular pellet with a larger grain and a higher density could be obtained. It can be said that the fuel performance of Mn-Al doped annular pellet is more superior to that of UO_2 annular pellet.

During the resintering tests, the diametric and density change of the Mn-Al doped annular pellet was much lower than that of the UO_2 annular pellet. Therefore, it can be said that the thermal stability of the Mn-Al doped annular pellet is remarkably enhanced.

ACKNOWLEDGEMENT

The authors acknowledge that this work has been performed under the Nuclear Mid- and Long-term R&D Projects supported by the Ministry of Education, Science and Technology in Korea.

REFERENCES

[1] M.S. Kazimi, et al., High performance fuel design for next generation PWRs: final report, Massachusetts Institute of Technology, MIT-NFC-PR-082, 2006.

[2] K.W. Song, Y.S. Yang, T.H. Chun, J.G. Bang, Dual cooled nuclear fuel rod with higher thermal resistance to inner cooling water than to outer cooling water, KAERI and KHNP, Korea patent, Published No. 10-2011-0017156.

[3] K.W. Kang, J.H. Yang, J.H. Kim, Y.W. Rhee, D.J. Kim, K.S. Kim, K.W. Song, Effects of $MnO\text{-}Al_2O_3$ on the grain growth and high temperature deformation strain of UO_2 fuel pellets, Journal of Nuclear Science and Technology, Vol.47, 3, p.304, 2010.

[4] G. Maier, H. Assmann, W. Dörr, Resinter testing in relation to in-pile densification, Journal of Nuclear Materials, Vol.153, p.213, 1988.

[5] M.C. Paraschiv, A. Paraschiv, V.V. Grecu, On the nuclear oxide fuel densification, swelling and thermal re-sintering, Journal of Nuclear Materials, Vol.302, p.109, 2002.

[6] G.J. Small, Densification of uranium dioxide at low burn-up, Journal of Nuclear Materials, Vol.148, p.302, 1987.

[7] H. Assmann, H. Stehle, Thermal and in-reactor densification of UO_2: Mechanisms and experimental results, Nuclear Engineering and Design, Vol.48, p.49, 1978.