Fabrication Process of CSBA-loaded UO_2 Fuel for Enhanced Reactivity Control

Ji Hwan Lee [a], Dong Seok Kim [a]*, Dong-Joo Kim[a], Jae Ho Yang[a], Heung-Soo Lee[a], Ji-Hae Yoon[a], Dong Wook Shin[b]
[a]*LWR Technology Research Division, Korea Atomic Energy Research Institute*
[b]*Division of Materials Science and Engineering, Hanyang University*
Corresponding Author: dskim86@kaeri.re.kr

1. Introduction

In nuclear power plants, electricity is generated through nuclear fission reactions of nuclear fuels, and since the initial reaction of the nuclear fuel is excessive, burnable absorber(BA) rods are required to control it. They are designed to be depleted before the fuel reaches the end of cycle, which helps to maintain a consistent reactor power output. The burnable absorbers are typically made of UO_2 fuels with neutron absorbing materials such as cadmium (Cd), boron (B), hafnium (Hf), and gadolinium (Gd) [1].

Recently, many of efforts have given in nuclear industry to increase economic efficiency of reactor operation, to achieve long-fuel cycle length by enriching U^{235} higher than 5%. Accordingly, the more enrichment requires the more burnable absorbers in fuel pellets, enabling reactivity control in a safety margin.

There are several issues in increasing the amount of burnable absorbers in fuel pellet. In an example, Gd utilized as a burnable absorber element in oxide form Gd_2O_3, due to the deleterious effect of Gd_2O_3 on UO_2 sintering behavior, a strictly controlled manufacturing process is required to obtain homogeneous and high density pellets. Regarding fuel performances, thermo-physical properties of UO_2 fuel pellet such as fuel melting temperature, thermal conductivity and mechanical strength are largely decreased by the addition of Gd [2].

To address the issue, a Centrally-Shielded Burnable Absorber (CSBA) fuel design has been developed, which incorporates burnable absorber material at the center of the fuel. The CSBA design can contribute to improving the safety and efficiency of nuclear power plants by controlling the neutron population within the core and reducing the burn-up rate of the fuel [3-5].

In this work, a unique design of burnable absorber fuel pellet, CSBA-loaded UO_2 pellet was fabricated by placing Gd_2O_3 disks at the center of UO_2 Fuel. The effects on the microstructures of variable parameters for fabrication process was investigated, and the integrity of the CSBA-loaded UO_2 fuel was characterized.

2. Experimental & Results

The CSBA-loaded fuel was designed as two cylindrical Gd_2O_3 CSBA pellets were placed along the centerline of the UO_2 fuel pellet such that the distance between them was twice the distance between each and the axial pellet boundary[5], as shown in Fig. 1.

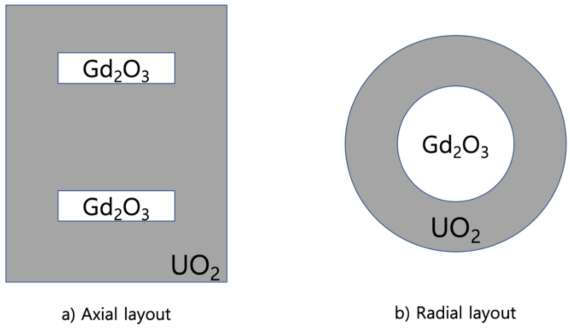

Fig. 1. Schematics of CSBA-loaded UO_2 fuel pellet design, a) Axial layout and b) Radial layout

The CSBA-loaded UO_2 fuel pellets were fabricated as follows. for the Gd_2O_3 disk, Gd_2O_3 powder was weighed for achieve designated dimension, and then pressed with varying pressure to prepare the Gd_2O_3 disk-shaped specimen with controlled density. The disks were positioned at the center of UO_2 powder, loading alternately in a mold die. After the loading, the UO_2-Gd_2O_3 powder composite was pressed into a green pellet, the width and height of the specimen was about 10 mm and 12 mm, respectively.

The green pellet was sintered in a hydrogen atmosphere at approximately 1730°C for 4 hours. After sintering, the width and height of the pellet decreased by approximately 20%. The density of the sintered pellet was measured using the Archimedes method by measuring the dry weight, underwater weight and apparent weight. The sintered pellets were exhibited a density of approximately 97%.

In order to specify the configuration of sintered pellet inside, the sample was cut in half vertically and also horizontally. As shown in Fig 2, it was confirmed that the Gd_2O_3 disks were well positioned and aligned at the center of the fuel pellet.

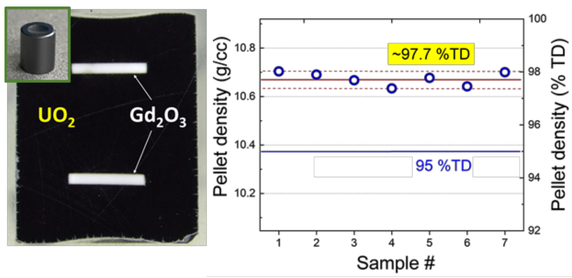

Fig. 2. Cross-section of CSBA-loaded UO_2 fuel pellet (left) and the densities of the pellets (right)

The cross-sections were observed using an optical microscope, the observations confirmed that there were no defects in the UO_2 matrix and Gd_2O_3 disks in a certain range of forming pressure, in other case, cracks were found to be formed around the CSBA disks through the UO_2 matrix. As a result, the variables of process parameters and integrity of the CSBA-loaded UO_2 fuel were characterized.

4. Conclusions

In this paper, CSBA-loaded UO_2 fuel pellets were fabricated and investigated the microstructural integrities with process parameters. CSBA disks were found to be successfully placed in fuel matrix as designed, and the pellet integrity was sound in a certain process condition. The experimental results could suggest the possibility of increasing the enrichment of fuels for longer cycles with burnup extension while maintaining safety margins and economic feasibility.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) (No. RS-2022-00144431).

REFERENCES

[1] J. A. Evans, D. D. Keiser Jr, M. D. DeHart, K. D. Weaber, Nucl. Eng. Des., 391, (2022)
[2] J. H. Yang, D.-J. Kim, D. S. Kim, H. S. Lee, J.-H. Yoon, H. J. Ryu, H. J. Kim, Transactions of the Korean Nuclear Society Autumn Meeting Changwon, Korea, Oct. 20-21, 2022
[3] X. H. Nguyen, C. Kim, Y. Kim, Nucl. Eng. Tech., 51 (2019) 369.
[4] A. Rahman, X. H. Nguyen, Y. Kim, Transactions of the Korean Nuclear Society Autumn Meeting Gyeongju, Korea, October 25-27, 2017
[5] S. Yoon, Y. Kim, Transactions of the Korean Nuclear Society Spring Meeting Jeju, Korea, May 19-20, 2022