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Fabrication and Thermal Conductivity Characterization of UO_2 Nuclear Fuel with High-content Gd_2O_3

Ji Hwan Lee [a,b], Dong Seok Kim [a*], Dong-Joo Kim[a], Jae Ho Yang[a], Yeon song Jeong[a], Ji-Hae Yoon[a], Hyung jin Kim[a,c], Dong Wook Shin[b]
[a]*LWR Technology Research Division, Korea Atomic Energy Research Institute*
[b]*Division of Materials Science and Engineering, Hanyang University*
[c]*Nuclear & Quantum Engineering, KAIST*
Corresponding Author: dskim86@kaeri.re.kr

1. Introduction

In nuclear reactors, electricity is produced through nuclear fission reactions in nuclear fuel, and excess reactivity is high at the beginning of the fuel cycle, making reactivity control essential. Burnable absorbers (BAs) are used within the fuel pellets to effectively control this excess reactivity. Materials such as cadmium (Cd), boron (B), hafnium (Hf), and gadolinium (Gd) are commonly used as burnable absorbers, typically added into UO_2 fuel pellets [1].

Recently, the nuclear industry has focused on developing high-burnup, long-cycle nuclear fuels and advanced reactor concepts. Small modular reactors (SMRs) are gaining attention due to their advantages in flexible deployment and operation compared to conventional large-scale reactors. Additionally, soluble boron- free core designs, currently pursued by various countries, remove soluble boron from the coolant, simplifying reactor systems and improving maintainability. However, the absence of soluble boron makes reactivity control via control rods and burnable absorbers increasingly important. Thus, the development of SMRs and soluble boron-free core designs is closely aligned with advanced reactor designs and high-burnup fuel development trends.

Furthermore, efforts are underway to enhance reactor operation economics by increasing U-235 enrichment beyond the conventional limit to above 5%, thereby enabling extended fuel cycle operation. Higher enrichment levels necessitate increased burnable absorber content within fuel pellets to maintain safe and effective reactivity control.

Determining the fabrication process parameters is a critical step in fabricating mixed-composition sintered fuels containing burnable absorbers. Ceramic sintered bodies, such as UO_2 nuclear fuels, can exhibit significant microstructural changes, including pores and grain structures, depending on fabricating conditions. Therefore, systematic analysis of these processing parameters is essential to ensure the desired pore size and distribution, grain structure uniformity, minimization of microdefects, and homogeneous additive dispersion.

However, incorporating high amounts of burnable absorbers into fuel pellets introduces several technical issues [2]. Gadolinia (Gd_2O_3), commonly added to UO_2 fuel, adversely affects sintering behavior, leading to lower sintered densities and less uniform microstructures. Moreover, increased Gd_2O_3 content significantly reduces thermal conductivity, meltingpoint, and mechanical integrity of the UO_2 pellets, negatively affecting fuel performance [3].

Considering these issues, this study evaluated fabrication and thermal conductivity characteristics of UO_2 nuclear fuel pellets containing high content of Gd_2O_3. By providing experimental data not previously reported, this study aims to offer fundamental information useful for improving fabrication processes and enhancing the performance of high-content BA fuels, ultimately contributing to the development of next-generation reactors, including SMRs and soluble boron-free core designs.

2. Experimental & Results

This study analyzed the effects of various fabrication process conditions on the microstructure and thermal properties of UO_2 nuclear fuel containing high-content Gd_2O_3. Defect-free fuel pellets with a uniform distribution of burnable absorbers were fabricated using standard ceramic processing techniques to systematically evaluate their thermal properties.

Green pellets were prepared using three different powder processing methods: simple blend, sieve mix, and planetary mill. The fabricated pellets were sintered under a hydrogen atmosphere at approximately 1730°C for 4 hours. Pellet density was evaluated using Archimedes' principle by measuring dry weight, submerged weight, and saturated weight. Fig. 1 shows the variations in sintered density of pellets fabricated by planetary milling with increasing Gd_2O_3 content.

Optical microscopy (OM) analysis confirmed the absence of microdefects and uniform distribution of additives within the pellets.

Additionally, thermal conductivity was calculated based on measured thermal diffusivity, specific heat, and density. Thermal expansion behavior showed trends similar to pure UO_2 fuel, while heat capacity and thermal diffusivity varied significantly with the Gd_2O_3 content. These experimental results provide fundamental data useful for optimizing fabrication processes and improving fuel performance of high-content burnable absorber nuclear fuels.

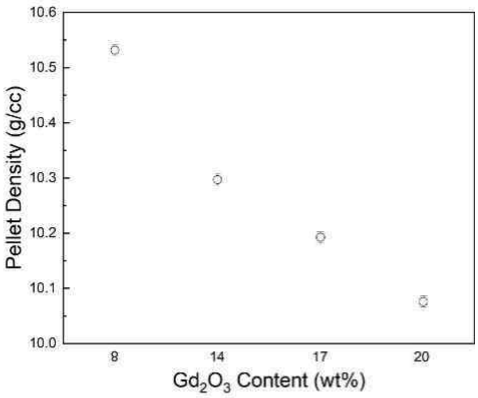

Fig. 1. Sintered density of UO_2 pellets with various Gd_2O_3 contents fabricated by planetary milling method.

4. Conclusions

In This study analyzed how fabrication process parameters influence the microstructure and thermal properties of nuclear fuels containing high-content burnable absorbers. Adjustments in processing parameters enabled uniform pore and grain distributions while minimizing microdefects, resulting in defect-free, high-density sintered pellets. Microstructural analysis confirmed a homogeneous distribution of the burnable absorber (Gd_2O_3) without detectable microdefects.

Thermal conductivity was calculated from measured thermal diffusivity and specific heat, revealing that increasing Gd_2O_3 content significantly impacted thermal diffusivity, demonstrating a direct relationship between additive content and thermal properties. Thermal expansion behavior exhibited trends similar to pure UO_2 fuel.

The results provide foundational data for evaluating the microstructural and thermal properties of UO_2 nuclear fuels containing 8–20 wt% Gd_2O_3, which can significantly contribute to future advanced reactor fuel development and performance enhancement.

ACKNOWLEDGEMENT

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