Evaluation of properties of candidate burnable absorber for soluble boron free in the i-SMR

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1. Introduction

Currently, the Korea is developing an innovative small modular reactor(hereafter referred to as i-SMR) that selects as its top tear requirement(TTR) as such the soluble boron-free, load-follow operation and the 24 months cycle operation [1]. Due to the application of boron-free operation, flexible operation and 24 months cycle operation of the i-SMR, the core has become more severe than that of commercial nuclear power plant. And the high initial excess reactivity control means of the i-SMR core must be adjusted only with control rods and burnable absorber. However, since the role of control rods is limited due to the prevention of excessive insertion, the development of innovative burnable absorber with high thermal neutron absorption cross-section and appropriate self-shielding effect is essential to control the initial excess reactivity in i-SMR. The KEPCO NF is carrying out the government project "Development of burnable absorber rod for i-SMR application" to develop an innovative burnable absorber for i-SMR, and is developing the Highly Intensive Gadolinia Burnable Absorber(hereafter referred to as HIGA) and a high content Gd_2O_3-UO_2 pellet as candidate materials. In particular, the HIGA absorber is an developing absorber to control the initial high excess reactivity for boron-free operation, and contains a high gadolinium oxide of 20 mol.% or more in metal oxide such as Al_2O_3 or ZrO_2 to restrict hydration. Therefore, in this study, HIGA absorber was fabricated among the candidates for i-SMR. Also, we carried out the out of pile test using the fabricated HIGA absorber.

2. Specimen fabrication

Based on the results of preliminary nuclear design , the Gd_2O_3 content was selected in the range of 20 mol.% to 30 mol.% depending on the matrix oxide, as summarized in Table 1.

The fabrication of the HIGA pellets were carried out following the typical ceramic fabrication process of mixing → forming → sintering.

In the mixing stage, 1 wt.% binder and ethanol were added to ensure a homogeneous mixture, And then a ball milling was performed for 16 hours. After ball milling, the mixture was dried in an oven for 24 hours.

Table 1. the chemical composition and sintering condition for HIGA absorbers

No.	Base oxide	Gd_2O_3	Sintering condition
1	Al_2O_3	20 mol.%	1,600 ℃, air
2	TiO_2	20 mol.%	1,400 ℃, air
3	ZrO_2	30 mol.%	1,700 ℃, Ar

The homogenized mixed powder was charged into a forming mold in a controlled amount and compacted into a green pellets by uniaxial pressing under a load of approximately 500–1,000 kgf/cm².

The fabricated green pellets were subsequently sintered under the conditions listed in Table 1. Fig. 1 shows the fabricated HIGA absorbers.

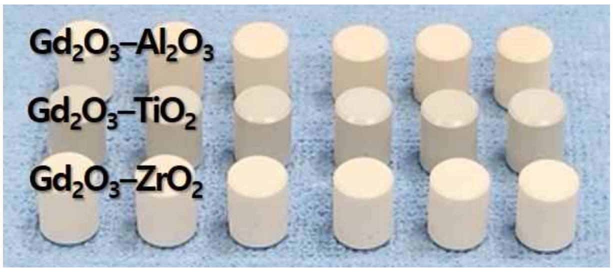

Fig. 1 Fabrication of HIGA absorbers

3. Out of Pile test and Results

3.1 Thermal properties

Fig. 2 shows the thermal expansion and diffusivity of each composition. The Gd-Al composition exhibited the lowest thermal expansion strain, which was over 20% lower than that of commercial UO_2 pellets and about 10% lower than that of commercial Gd_2O_3-UO_2 pellets. Also, as shown in Figure 3, the Gd-Al composition also exhibited the highest thermal diffusivity, demonstrating its superior thermal properties among the three HIGA absorbers. These results suggest that HIGA absorbers can ensure higher thermal integrity under in-reactor conditions compared with conventional fuel rods.

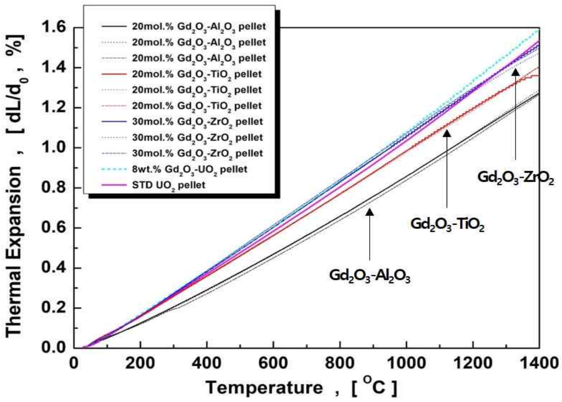

Fig. 2 Thermal expansion of HIGA absorbers

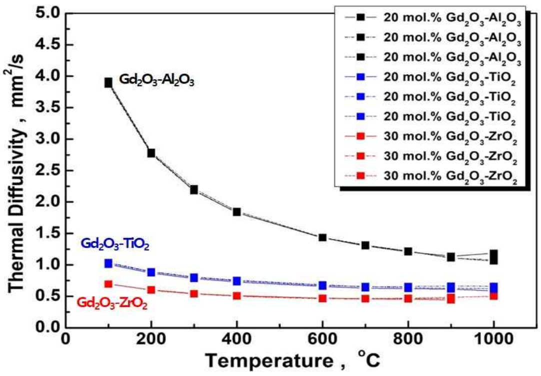

Fig. 3 Thermal diffusivity of HIGA absorbers

3.2 Hydration test

Figure 4 shows the results of a corrosion test performed on the HIGA absorbers at 350 °C and 15.9 MPa for 15 days. As shown in Fig. 4, all of the HIGA absorbers exhibited excellent corrosion resistance. This resistance is considered to result from limiting the Gd_2O_3 content to below 40 mol.% within corrosion-resistant oxide matrices such as Al_2O_3 or ZrO_2, which suppress the hydration behavior of rare-earth oxides as reported in previous studies. Further investigations, including XPS analysis, are planned to examine the surface hydration behavior of the HIGA absorbers.

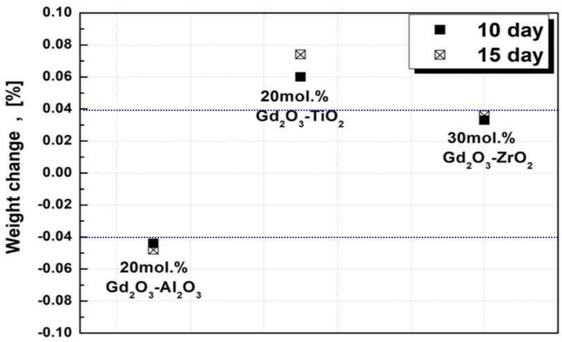

Fig. 4 The results of hydration test for HIGA absorbers

3.3 Irradiation test

The candidate materials for burnable absorber rods developed in this project are scheduled to undergo an irradiation test at the HANARO research reactor starting on October 13, 2025, for one cycle. The HANARO test rig, shown in Figure 5, consists of two clusters, each designed to hold four test rods. Approximately six burnable absorbers will be loaded into each test rod. After achieving 200 EFPD (based on HANARO reactor operation), post-irradiation examinations, including density, dimensional change, gas analysis, and thermal diffusivity, will be conducted at the IMEF hot cell facility.

Fig. 5 Rig and rod for irradiation test in HANARO reactor

4. Conclusions

In this work, to analysis the material properties of candidate burnable absorber for i-SMR, we fabricated three type of HIGA burnable absorber.

As the results of out of pile test using fabricated HIGA absorbers, the Gd-Al composition also exhibited the highest thermal diffusivity and low thermal expansion, demonstrating its superior thermal properties among the three HIGA absorbers. Also, all of the HIGA absorbers exhibited excellent corrosion resistance.

In the future study, we are scheduled to undergo an irradiation test at the HANARO research reactor starting on October 13, 2025, for one cycle due to the analysis of irradiation behavior for candidate burnable absorber. After achieving 200 EFPD (based on HANARO reactor operation), post-irradiation examinations, including density, dimensional change, gas analysis, and thermal diffusivity, will be conducted at the IMEF hot cell facility.

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