Analysis of Cracking Behavior of Gadolinia Disks in a Nuclear Fuel Pellet

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1. Introduction

A burnable absorber, used in nuclear reactors to control reactivity, is typically made of boron or gadolinium. Boric acid is commonly used in pressurized water reactors but can cause a positive moderator temperature coefficient (MTC) problem. To prevent the issue, solid-state burnable absorbers can be adopted. However, conventional mixed (Gd_2O_3-UO_2) or coated (IFBA) designs can lead to increased fuel temperatures and have limited effectiveness in high burnup application.

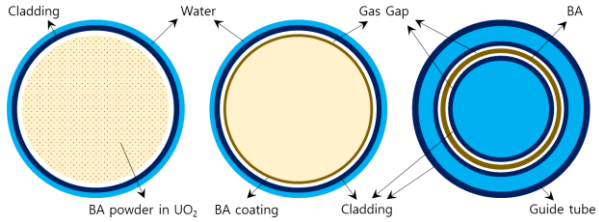

Fig. 1. Common fuel-burnable absorber design for commercial reactors

A new approach, the centrally-shielded burnable absorber (CSBA) concept [1], embeds lump gadolinia within fuel pellets. This concept delays the burn out of gadolinia, enabling use in high burnup reactors. To implement the novel design in nuclear reactors, safety validation is crucial.

In this study, we predicted the thermal-mechanical stability and stress-crack behavior of CSBA pellet using finite element method (FEM) and extended finite element method (xFEM). These predictions were compared with cracking test results.

2. Methods and Results

During reactor operation, the CSBA composite fuel experiences density changes due to thermal expansion, neutron irradiation-induced phase transformation, and sintering densification. To predict these behaviors, a thermo-mechanical properties database for the burnable absorber material was compiled. High-temperature behavior at the beginning of life (BOL) was analyzed using finite element analysis (FEA) with Abaqus software.

2.1 Burnable Absorber Thermal Property Model

Thermal properties of uranium dioxide and gadolinia, including thermal expansion, conductivity, and modulus, were collected and formulated for thermo-mechanical calculations [2].

2.3 Thermo-mechanical Analysis of CSBA Fuel Pellet

Finite element simulations predicted high-temperature behavior of CSBA fuel pellet. Thermo-mechanical calculations were conducted on fuel pellets composed of uranium dioxide and gadolinia, with simulations involving variations in absorber densities. Results indicated potential fuel cracking at the first rise of temperature as stress exceeded the fracture stress of UO_2.

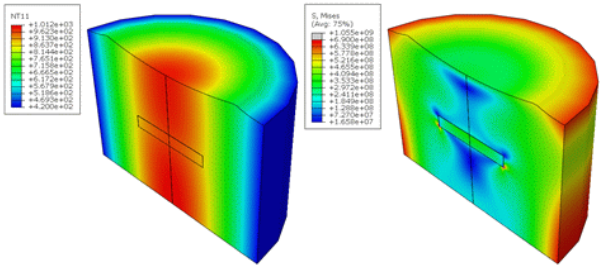

Fig. 2. CSBA fuel temperature and stress calculation results

2.4 Crack Test

To validate the crack formation behaviors predicted by the xFEM simulation, thermal shock tests on mockup pellets were conducted. CeO_2 was selected as a fuel surrogate, and CeO_2-Gd_2O_3 mockup CSBA pellets were fabricated. The results of these experiments were compared and evaluated with computational simulation results.

Fig. 3. Quenched CeO_2-Gd_2O_3 CSBA pellets

3. Conclusions

This study focused on designing materials and analyzing the high-temperature behavior of CSBA concept fuel pellets to advance long-cycle, high-burnup fuel technology. Finite element analysis results predicted the cracking at the first rise of temperature, and xFEM results revealed the detailed cracking behavior. Furthermore, thermal shock tests on mockup pellet were conducted and comparative analysis was followed. This work contributes to the enhanced fuel safety and accelerates the development of the innovative nuclear fuel.

REFERENCES

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