Establishment of a Defect Analysis System for SiC Coating Layer in TRISO Fuel Particle

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1. Introduction

High-temperature gas-cooled reactors (HTGRs) employ tri-structural isotropic (TRISO) coated fuel particles to achieve reliable fission product retention under severe operating conditions. Each TRISO particle typically consists of a 300~500 μm uranium dioxide (UO_2) or uranium oxycarbide (UCO) kernel surrounded by four protective layers: a porous carbon buffer, an inner pyrolytic carbon (IPyC) layer, a silicon carbide (SiC) barrier, and an outer pyrolytic carbon (OPyC) layer. Thousands of such particles are embedded in a graphite matrix compact or pebble, providing structural stability, efficient heat transfer to the coolant, and defense-in-depth against radionuclide release.

The integrity of the SiC layer is particularly critical, as it serves as the primary barrier to metallic fission product transport. However, defects can occur during fabrication, irradiation, or chemical interactions with impurities, potentially compromising fuel performance. To assess coating soundness, coated particles are separated from the graphite matrix of compacts and subjected to a leach-burn-leach (LBL) procedure [1]. In the initial leach phase, exposed-kernel defects are detected by dissolution of uranium in nitric acid. The burn phase removes pyrocarbon and carbon pathways, enabling exposure of kernels shielded only by defective SiC. A final leach step dissolves uranium from these kernels, allowing enumeration of SiC-defective particles.

The LBL experimental system is currently being established and tested at the Korea Atomic Energy Research Institute (KAERI). This abstract presents the initial stage of developing a system designed to selectively dissolve nuclear fuel kernels from TRISO particles with defective SiC layers.

2. Methods

The leach-burn-leach (LBL) test for TRISO-coated fuel particles is composed of four sequential steps: (1) fuel compact deconsolidation, (2) pre-burn leaching, (3) burn-off of exposed carbon, and (4) post-burn leaching. Since TRISO particles are embedded in a graphite matrix, electrical deconsolidation is employed to separate them. Fuel compacts are immersed in 70% nitric acid, with a platinum wire serving as the anode and the solution as the cathode, applying 1–3 W of power to achieve decomposition, shown in Figure 1. As the compact deconsolidation, released TRISO particles and graphite residues settle at the bottom of the vessel, from which particles are isolated using filtration.

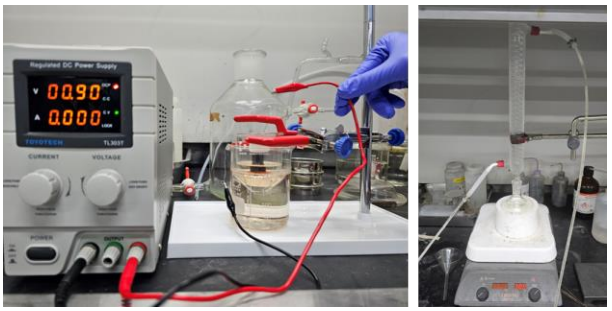

Fig. 1. Fuel compact deconsolidation and kernel dissolving apparatus

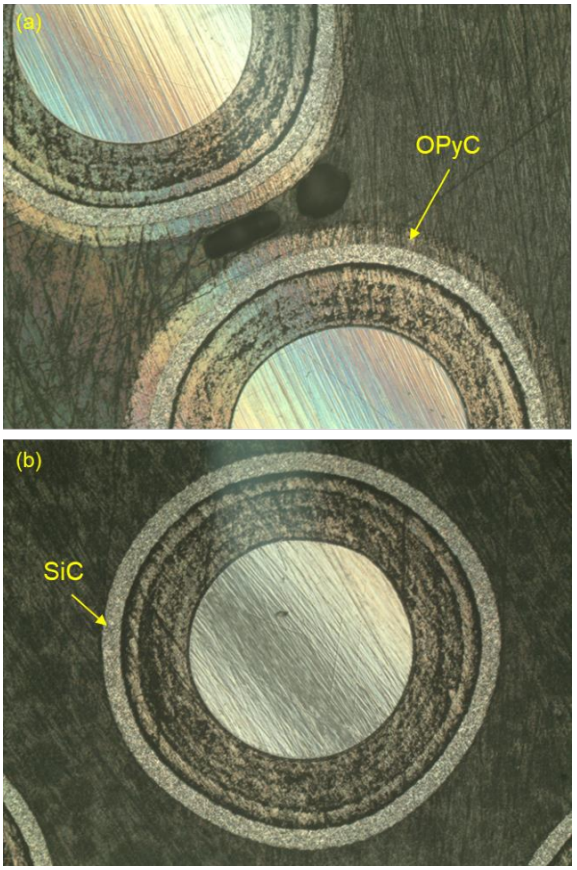

Fig. 2. Microstructure of (a) pre-burn TRISO particle, and (b) post-burn particle.

The recovered particles undergo a pre-burn leach to identify exposed-kernel defects. Specifically, particles are immersed for 48 hours in 100 mL of 60% nitric acid at 90 °C, while a 4 °C cooling fluid is circulated to suppress HNO_3 evaporation. The uranium concentration dissolved during this step is measured by inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma optical emission spectrometry ICP-OES, allowing determination of the exposed-kernel fraction.

Subsequently, pre-burned particles are subjected to a burn phase-either 10 minutes at 800 °C or 72 hours at 750 °C-to oxidize and remove carbon layers. A post-burn leach is then conducted under the same conditions as the pre-burn leach, and the uranium concentration is analyzed to quantify the defective SiC fraction.

3. Conclusions and future work

In this study, a preliminary LBL system comprising deconsolidation, leaching, and burning processes was established, and its verification and operating conditions were determined. Future work will focus on performing SiC layer defect inspection of TRISO particles using ICP-MS and ICP-OES.

Acknowledgments

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REFERENCES

[1] Hunn, John D., et al. "ORNL Analysis of Leach-Burn-Leach Round-Robin Test Samples.", Jun. 2023.