Mechanical Strength and Thermal Shock Resistance of LAS-Doped UO_2 Pellets for Accident Tolerant Fuel

Chaerin Kim[a], Sung-Woo Ha[a], Yeon-Soo Na[a], Min-Jae Ju[a], Kwang-Young Lim[a]
[a] *Department of Nuclear Fuel Technology, KEPCO Nuclear Fuel, 242, Daedeok-daero 989, Daejeon 34057, Korea*
**Corresponding author : kylim@knfc.co.kr*

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1. Introduction

Accident Tolerant Fuel (ATF) is developed to enhance the safety and performance of nuclear reactors under severe accident conditions. As part of a near-term ATF development program, KEPCO Nuclear Fuel is developing the ESPER^{TM} (Enhanced Safety Performance with Efficiency and Reliability) fuel, consisting of a Cr-coated cladding and LAS-doped UO_2 pellets. The LAS-doped UO_2 pellet (hereafter, the LAS pellet) is include 0.1 wt% additives (La_2O_3, Al_2O_3, SiO_2). The LAS pellet exhibits a threefold increase in grain size compared to standard UO_2 pellet, which improves high-temperature plasticity and reduces fission gas release (FGR) [1,2].

However, since UO_2 is a brittle ceramic, cracking and fracture occur due to thermal gradients under reactor operating conditions. These structural defects can potentially offset the FGR mitigation benefits of the LAS pellets. Therefore, evaluating their thermal shock resistance and mechanical strength is needed. Accordingly, this study investigates the strength and thermal shock behavior of LAS and standard UO_2 pellets to characterize their fracture behavior.

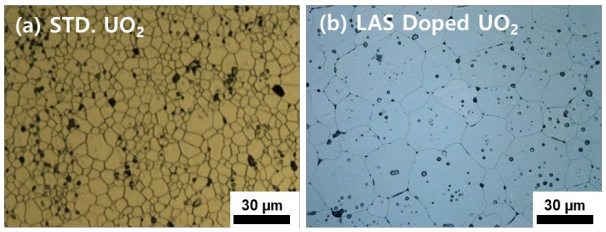


Fig. 1. Optimal microscopy images of (a) STD UO_2 and (b) LAS Doped UO_2

2. Experimental Procedure

LAS and standard (STD) UO_2 pellets were fabricated by sintering at 1700°C for 4 h under a hydrogen atmosphere, achieving a relative density of 95% for both pellet types. To evaluate the fracture behavior and flexural strength of the LAS and STD UO_2 pellets, tests were performed.

Thermal shock tests were performed in a furnace under an Ar atmosphere (200 ml/min) with a temperature gradient (ΔT) of 800°C. The 800°C was selected based on the temperature difference between the centerline and surface of the UO_2 pellet under normal operating conditions. Accordingly, this thermal shock test was designed to simulate the pellet cracking behavior induced by the thermal gradient. The specimens were heated to the target temperature at a heating rate of 5°C/min and held for a soaking time of 20 min. Thermal shock was then induced by water quenching the specimens to room temperature. Post-quench internal crack behavior was observed using a scanning electron microscope (SEM, JEM-6500, JEOL, Japan).

For flexural strength evaluation, bar-shaped specimens were ground to a size of 2 mm × 1.5 mm × 25 mm in accordance with ASTM standards. Four-point bending tests were performed at room temperature using a universal testing machine (Kappa 50 SS, Zwick/Roell, Germany) at a crosshead speed of 0.5 mm/min.

3. Results

Fractographic analysis after thermal shock testing revealed that standard UO_2 exhibited mixed transgranular and intergranular fracture, whereas LAS pellets showed predominantly transgranular fracture. Since crack propagation typically follows the minimum-energy path, this mixed mode in standard UO_2 implies comparable fracture energies for both paths.

Four-point bending tests evaluating flexural strength showed that LAS pellets possess higher flexural strength than standard UO_2. The flexural strengths of the LAS and STD UO_2 pellets are approximately 120 and 85 MPa, respectively. This strengthening is attributed to the grain coarsening induced by LAS addition, which lengthens the relative proportion of crack path along grain boundaries, and raises the total fracture energy. As described by the Hasselman equation (1), this increased strength directly improves thermal shock resistance. Consequently, LAS pellets demonstrated enhanced thermal shock resistance compared to the standard UO_2 pellets, which is expected to sustain the FGR reduction benefits provided by their large-grain structure.

$$(1)\quad R_s = \frac{\lambda \cdot \sigma_F}{\alpha \cdot E}$$

R_S is the thermal shock resistance
λ is the thermal conductivity
σ_F is the flexural strength
α is the coefficient of thermal expansion

E is the modulus of elasticity

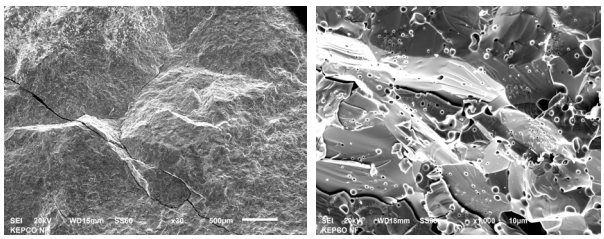


Fig. 2. SEM image of the fracture surface of the LAS pellet thermal shock test specimen

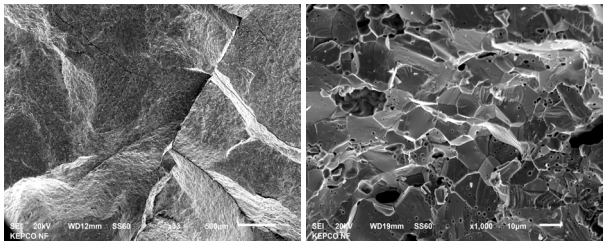


Fig. 3. SEM image of the fracture surface of the STD UO_2 pellet thermal shock test specimen

The flexural strength above 1,000°C will be tested.

4. Conclusion

Developed as accident tolerant fuel (ATF) designed to maintain fuel integrity and enhance safety margins under severe accident conditions, LAS pellets were evaluated for their flexural strength and thermal shock behavior.

The results demonstrated that LAS pellets exhibited more bending strength than STD UO_2, along with predominantly transgranular fracture attributed to an increased crack path length. As a result, LAS pellets exhibited higher thermal shock resistance than STD UO_2, which is expected to sustain their FGR reduction capabilities with the LAS pellets' larger grain size.

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