Development status of improved UO_2 fuel in KEPCO Nuclear Fuel

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1. Introduction

Since the 1960s, additives have been investigated as improved performance aids for the production of UO_2 fuel. The main objectives of improved UO_2 using dopants as additives include the reduction of fission gas release (FGR) and reduced susceptibility to pellet-cladding interaction (PCI) failure. The addition of appropriate additives at ppm concentrations in UO_2 contributes to the promotion of grain growth, reduced FGR, higher density, and viscoplasticity. Large-grain UO_2 exhibits several advantages compared to standard UO_2, such as increased diffusion path to grain boundaries for FGR and the prevention of a high burn-up structure. By the addition of an additive, the amorphous phase in the located grain boundary reduces FGR via the formation of compounds from the chemical reaction between the fission product and additive composition. In addition, the dislocation movement and grain boundary sliding by the addition of the additive lead to high creep rate and low yield strength for the UO_2 fuel.

Recently, main nuclear fuel companies have announced a loading plan in the commercial reactor of accident transient fuel (ATF). Especially, Framatome and Westinghouse have reported a plan to use UO_2 with an additive for the ATF pellet until 2026 due to safety benefits, including lower FGR during accidental transients, increased margin to PCI, and improved resistance against post-failure secondary degradation. Currently, KEPCO Nuclear Fuel (KEPCO NF) is developing additives for improved UO_2 and performing several out-pile tests.

In this study, the effect of the properties of the developed additive composition on the thermal, mechanical, and chemical properties of UO_2 was investigated. In addition, the commercial manufacturability and nuclear design were evaluated.

2. Methods and Results

2.1 Fabrication

Commercially available DC-UO_2 and the additives (A-S-L or M-C-S) were used as the starting powders. The mixture of the raw materials was DC-UO_2 and 500–1500 ppm various additives. The mixture was sieved (60 mesh) and sintered under reduction conditions by using a commercial manufacturing furnace.

2.2 Evaluation

The relative densities of the UO_2 specimens were greater than 95% TD for all samples. The morphology and grain size of the etched microstructure were examined by scanning electron microscopy and optical microscopy. Figure 1 shows the average grain size of the A-S-L or M-C-S-doped UO_2 specimen: The average grain size increased up to 35 μm; this value is greater than the grain size of standard UO_2. Results obtained for the density and grain size revealed that the developed additive composition can serve as a sintering aid. By the addition of additives, large grains are expected to reduce FGR. In addition, the chemical composition of grain boundaries was analyzed by energy-dispersive X-ray spectroscopy. The precipitation of A-S-L or M-C-S additive compounds in ternary system at the UO_2 grain boundary was homogeneously located.

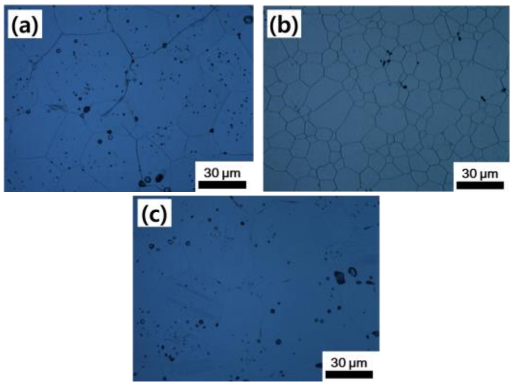

Fig. 1. Typical microstructure of sintered UO_2: (a) A-S-L-doped UO_2, (b) M-C-S-doped UO_2, and (c) std. UO_2.

For steady creep strain measurements, a high-temperature compressive creep test was performed at 1450°C/1500°C for 20 h under 20–45 MPa. Figure 2 shows the typical steady creep strain. The creep strain of UO_2 with additives was increased by greater than three times that of std. UO_2. The creep strain can be controlled by the additive composition and content. The creep strain of UO_2 increased with the compressive pressure and temperature. The A-S-L or M-C-S additive exhibited a glassy phase at the UO_2 grain boundary, and the microstructure caused not only diffusion creep but also boundary slip. Hence, UO_2 with the A-S-L or M-C-S additive is expected to considerably decrease the possibility of cladding PCI failure via the minimization of the applied pressure to cladding through flexible deformation under transient conditions.

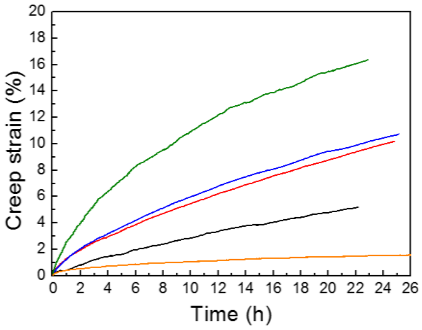

Fig. 2. Typical steady creep strain of sintered UO_2 with various additives at 1450°C and 40 MPa.

Thermal properties of UO2 pellet sintered with the additives were measured from room temperature to 1200°C. With respect to the corrosion performance of UO_2 in PWR water chemistry under environmental conditions, a washout test was performed by using a loop-type autoclave washout equipment. The thermal properties and corrosion performance of UO_2 with the A-S-L or M-C-S additive were almost the same as those of standard UO_2, exhibiting the advantage of minimizing modeling code changes.

Nuclear design was performed using KARMA and ASTRA. The developed additive-doped UO_2 exhibited a cycle length reduction of the maximum 3 days compared to that of a PLUS7-type fuel, but it can be easily solved by increasing the sintering density by less than 0.5%.

In the commercial manufacturability evaluation of developed additive-doped UO_2, the out-pile test result of commercial and laboratory-scale processes was not significantly different.

3. Conclusions

KEPCO NF developed the additive composition for UO_2 and performed out-pile tests. The creep strain and grain size were significantly improved in comparison to conventional UO_2, and the thermal and chemical properties did not change. The improved as-developed UO_2 will reduce the fission product release, significantly reduce the cladding contact pressure, and improve the fuel safety performance.

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