Thermal Expansion of UO_2 with Solid Solution Impurity

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1. Introduction

A new fuel cycle, called the Direct Use of spent PWR fuel In CANDU reactors (DUPIC), has received renewed interest recently as a PWR to CANDU synergistic fuel recycling option[1]. Taking advantage of the Korean nuclear reactor strategy of having both light water reactors (PWR) and heavy water reactors (CANDU) for electricity generation, the DUPIC concept as a alternative nuclear fuel cycle has been suggested. The spent PWR fuel can be burned again in CANDU reactors by a direct refabrication of CANDU-compatible DUPIC fuel which is fabricated by only mechanical and thermal processes without the separation of any sensitive nuclear materials, even fission products.

The main characteristic of the DUPIC fuel is its initial content of fission products as impurities. The thermal properties of the DUPIC fuel are expected to be different from the CANDU fuel because of the fission products. The thermal properties of this fuel material should be known to assess the behavior of the fuel elements at a high temperature in the reactors. Thermal expansion of nuclear fuel is one of the most important properties because it affects the gap conductance and the interaction with the cladding. It also causes a density variation with the temperature, which is used for the calculation of other properties such as the thermal conductivity.

In this study the thermal expansions of UO_2 and a simulated fuel with fission products forming solid solutions are measured using a dilatometer in the temperature range of 298 to 1900 K to confirm the effects of solid solutions on the thermal expansion of a simulated fuel. And the density variations with the temperature are calculated from the experimental data of the thermal expansion.

2.Experimental

UO_2 fuel pellets and simulated fuel pellets with an equivalent burnup of 30 and 60 GWd/tU were used in this study. The fission product composition of the irradiated fuel was determined by its initial enrichment and irradiation history. In this study the fission products which only form solid solutions were added into the UO_2 in order to confirm the effects of solid solutions on the thermal expansion of simulated fuel. Complete descriptions of the fabrication methods and characterization results have been provided in a previous publication[2]. The densities of the UO_2 and simulated fuel were calculated to be 10.43 $g \cdot cm^{-3}$ (95.2 % of TD) and 10.35 $g \cdot cm^{-3}$ (95.6 % of TD), respectively. The average grain sizes of the UO_2 and simulated fuel are measured to be 12.5 and 13.0 m, respectively.

The thermal expansions of the UO_2 and simulated fuel pellets were measured in the axial direction with a linear variable differential transformer (LVDT) transducer in the temperature range of 298 to 1900 K by a push-rod-type dilatometer (DIL 402 C, Netzsch).

3.ResultsandDiscussion

As expected, it is observed that the linear thermal expansions of all the specimens increased progressively with the temperature. For the simulated fuel, it is slightly higher than that of the UO_2, and the difference between this fuel and the UO_2 increased

progressively with the temperature. However, the difference between the simulated fuel and the reference simulated fuel can hardly be observed. Simulated fuel of a 60 GWd/tU burnup incorporates the fission products which form solid solutions, while the reference simulated fuel has the fission products which form metallic and oxide precipitates as well as solid solutions. However, they have a similar total amount of additives. The effects of solid solutions on the thermal expansion were similar to that of the metallic and oxide precipitates in the simulated fuel. The thermal expansions obtained in this study are fitted by the following equations:

For the simulated fuel with solid solution fission products,

$$dL/L_0\ (\%) = -0.2849 + 8.683\times10^{-4}T + 1.409\times10^{-7}T^2 + 6.131\times10^{-12}\,T^3 \pm 0.0028. \quad (1)$$

For the UO_2,

$$L/L_0\ (\%) = -0.2885 + 9.334\times10^{-4}T + 1.769\times10^{-8}T^2 + 3.803\times10^{-11}\,T^3 \pm 0.0077. \quad (2)$$

The relative density ($\rho(T)/\rho(298)\times100$) variations of all the specimens decreased progressively with the temperature as expected. For UO_2, as the temperature increased to 1800 K, the relative density decreased to 95.1 % of the initial density at 298 K.

For the simulated fuel, the relative density is lower than that of UO_2. At a low temperature to 600 K, the difference of the relative densities of the simulated fuel and the UO_2 is small and increased with temperature. As the temperature increased to 1800 K, the relative density of the simulated fuels decreased to 94.7 % of the initial densities at 298 K. The relative density variations calculated with the temperature are fitted by the following equations:

For simulated fuel with solid solution fission products,

$$\rho(T)/\rho(298)\times100,\ \% = 100.86 - 0.0026T + 3.945\times10^{-7}T^2 + 3.316\times10^{-12}T^3 \pm 0.0083. \quad (3)$$

For UO_2 fuel,

$$\rho(T)/\rho(298)\times100,\ \% = 100.96 - 0.0032T + 4.332\times10^{-7}T^2 + 2.606\times10^{-10}T^3 \pm 0.0175. \quad (4)$$

In the above equations, the last terms represent the standard deviations.

4.Conclusions

The thermal expansion of the simulated fuel with the fission products which form solid solution is higher than that of UO_2. The relative density of the simulated fuel is lower than that of UO_2. The effects of a solid solution on the thermal expansion were similar to that of the metallic and oxide precipitates in the simulated fuel. The measured and calculated data in this study will be useful for the performance evaluation of in-reactor DUPIC fuel behavior.

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Referernce

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