Development of ATF Pellet with High Thermal Conductivity and Fission Gas Retention Capability

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1. Introduction

Development goal of KAERI's Accident Tolerant Fuel (ATF) pellet is to reduce radioactivity release from fuel pellet to fuel outside, and to increase operational and safety margin during normal operation and accident conditions. At KAERI, microcell and microplate UO_2 pellets are being developed as ATF pellet.

Concept of microcell UO_2 pellet is that microcell-walls envelope UO_2 grains/granules in UO_2 pellet, and increase thermal conductivity and/or enhance retention capability of fission products (FPs) of UO_2 pellet [1-5]. The UO_2 grains or granules are enveloped by thin cell-walls. There are two types of microcell UO_2 pellets: metallic and ceramic. These pellets are classified according to the material from which their cell walls are composed. The metallic wall, which has high thermal conductivity, effectively enhance the thermal conductivity of the UO_2 pellet. The ceramic wall, which has chemical affinity to volatile FPs, acts as a chemical trap for FPs movement.

The metallic microcell UO_2 pellet which is a concept of high thermal conductive fuel is expected to enhance the performance and safety of current LWR fuels under normal operational conditions as well as during transients/accidents [6-7] through higher thermal conductivity and lower temperature of fuel pellet.

An enhanced thermal conductive UO_2 fuel pellet can reduce not only the FPs diffusivity and mobility but also the pellet thermal stress by lowering the fuel pellet temperature and temperature gradient. A reduction in the stored energy in low-temperature fuel pellets remarkably increases the fuel safety margin under accident conditions.

Lower temperature fuel pellet could significantly decrease the radial deformation of fuel under operational power transients due to the lower thermal expansion. In addition, because the ductility of metallic phase in the developed pellet is high compared to that of UO_2, a soft and ductile thin metal wall facilitates the faster creep deformation of the fuel pellets, thereby reducing the mechanical loading of the fuel cladding. These are expected to make the beneficial effects on the Pellet-to-Cladding Mechanical Interaction (PCMI) under operational power transients.

The metallic microplate UO_2 pellet which is another concept of high thermal conductive fuel can effectively enhance the thermal conductivity of the UO_2 pellet. A large number of metallic micro-sized thin plates were homogeneously dispersed in a UO_2 pellet, and arranged in the radial direction of the pellet. Heat transfer in the fuel pellet can be efficiently enhanced by the radially arranged metallic microplates. It is expected that we can provide various options for enhancing thermal conductivity of fuel pellets by using metallic microcell and microplate UO_2 pellets.

The ceramic wall in ceramic microcell UO_2 pellets is composed of the Si-based oxide phase with chemical affinity to volatile FPs (especially Cs), and acts as multiple traps to immobilize the volatile FPs [8]. The increased retention capability of the FPs will reduce the stress corrosion cracking at the inner surface of the cladding as well as the rod internal pressure. In addition, a soft ceramic-wall facilitates the fast creep deformation of the pellets, thereby reducing the mechanical stress of the cladding under operational transients.

2. Development of ATF pellet

The metallic microcell UO_2 pellet is fabricated by co-sintering of metal powder over-coated UO_2 granules through a conventional sintering process. The density of the sintered Mo metallic microcell UO_2 pellets is approximately 97.5 %T.D. [3]. Figure 1(a) shows a microstructure image of a 5 vol% Mo metallic microcell UO_2 pellet, in which the microcell concept was successfully implemented. The thickness of the metallic cell walls range from 4 μm to 6 μm, and the average diameter of the UO_2 cells is approximately 300-400 μm.

The metallic microplate UO_2 pellet is also being developed to effectively enhance thermal conductivity of the UO_2 pellet. The metallic microplate UO_2 pellet can be fabricated by sintering of UO_2 and metal-microplate powder mixture. Figure 1(b) shows a microstructure image of a 3 vol% Mo metallic microplate UO_2 pellet of 97 %T.D.

To fabricate the ceramic microcell UO_2 pellets, a conventional liquid phase sintering technique has been applied. A powder mixture of UO_2 and additives was pressed into green pellets, which were then sintered at

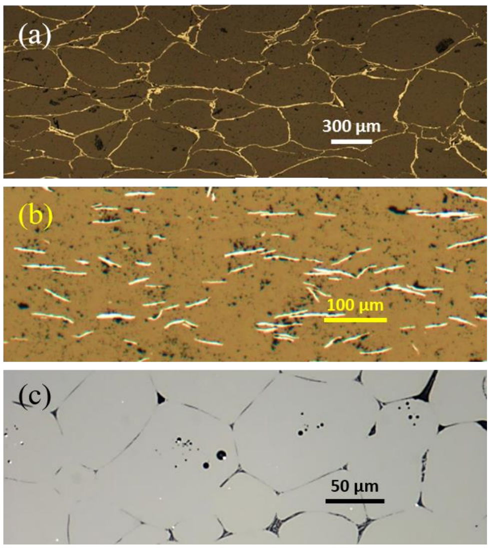

Fig. 1. Microstructure image of (a) Mo metallic microcell, (b) Mo metallic microplate (bright lines are the Mo metal phase), and (c) Si-Ti-O ceramic microcell UO_2 pellet (dark lines are Si-Ti-O ceramic phase).

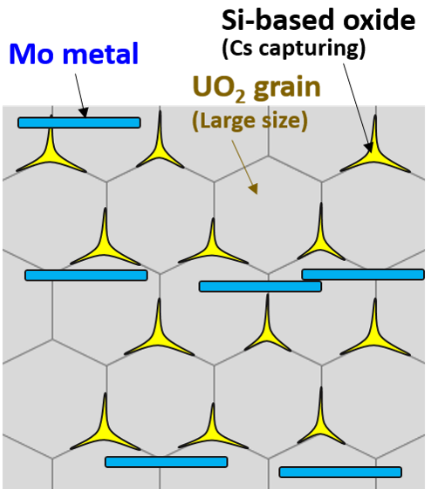

Fig. 2. Schematic of combined ATF concept of high thermal conductive fuel and fission gas retention capable fuel.

an elevated temperature which the additives for the wall materials formed a liquid phase, penetrating through grain boundaries and enveloped UO_2 grains to make the designed ceramic microcell. The sintered pellet density and averaged grain size were 98.2 %T.D. and ~80 μm, respectively (Figure 1(c)).

It has been experimentally verified that the microcell and microplate UO_2 pellet has very high thermal conductivity, compared to that of UO_2 pellet. The thermal conductivities of the 3 vol% Mo metallic microcell and 3 vol% Mo metallic microplate UO_2 pellets were increased by about 70~80 % at 1000 ℃, compared to that of a standard UO_2 pellet. Various out-of-pile testing of the fabricated microcell and microplate UO_2 pellets are conducting for a verification of the developed fuel performances. In addition, the basic in-reactor performance of the metallic microcell UO_2 pellet (5 vol% Cr metal) is verified through the irradiation testing in Halden Reactor in Norway.

The metallic microcell UO_2 fuel containing 5 vol% Cr metal exhibited a temperature that was remarkably lower than the reference UO_2 fuel, typically ~20% lower. This result confirmed that the metallic microcell UO_2 pellet had a beneficial effect on the fuel temperature. The online data of the fuel temperature were in good agreement with the predicted data based on a computational simulation [5].

During the irradiation test, a burnup of approximately 16,000 MWd/mtU was reached [4]. The temperature difference between the UO_2 reference pellet and 5 vol% Cr metallic microcell UO_2 pellet was consistently maintained up to the accumulated burnup. This is a direct evidence that the metallic microcell structures were preserved under an in-pile testing. We are planning to perform the post irradiation examinations of the irradiated sample.

In addition, KAERI is developing the combined fuel concept with high thermal conductivity and FP retention capability through a cooperation with KEPCO NF as well. The combined ATF concepts of high thermal conductive fuel (metallic microcell or metallic microplate pellet concept) and high FP retention capable fuel (ceramic microcell or PCI-remedy pellet concept) have been developed (Figure 2). The fabrication and out-of-pile testing of the combined ATF pellet are being conducted. The verification testing for mass production compatibility is in progress, and the irradiation testing is being planned and will be performed.

3. Summary

As an ATF pellet, the metallic microcell and the metallic microplate UO_2 pellets which are the high thermal conductive fuel, and the ceramic microcell UO_2 pellet which is the high FP retention capable fuel are being developed to enhance the accident tolerance of nuclear fuels under accident conditions as well as the fuel performance under normal operating conditions. The fuel concept design, a fabrication technology, mass production compatibility test, out-of-pile and in-reactor test of ATF pellets are being developed. In addition, a combined ATF concept is suggested and being developed as well.

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