Development of Enhanced Thermal Conductive UO_2 Pellet as Accident Tolerant Fuel

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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. The collective volume of the thin cell walls ranges from 1 vol% to 5 vol%. There are two types of microcell UO_2 pellets: metallic and ceramic. Such 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 is expected to enhance the performance and safety of current LWR fuels under normal operational conditions as well as during transients/accidents [6-7].

An enhanced thermal conductive UO_2 fuel pellet can reduce not only the FPs diffusivity/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 significantly increases the fuel safety margin under accident conditions.

An improvement in FPs retention capability leads to a reduction of the inner surface cladding corrosion caused by FPs as well as of the internal pressure of a fuel rod.

Because the ductility of metallic phase in the developed pellet is very high compared to that of UO_2, a soft/ductile thin wall facilitates the fast creep deformation of the fuel pellets, thereby reducing the mechanical loading of the fuel cladding under operational transients. These benefits are expected to preserve the robustness of fuel rods under accident conditions as well as normal operational conditions.

A mesh-like, rigid cell-wall structure is also expected to prevent the massive fragmentation of pellets during accidents, thereby reducing the release of retained radiotoxic FPs into the environment.

The metallic microplate UO_2 pellet can effectively enhance the thermal conductivity of the UO_2 pellet. A large number of metallic micro-sized 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.

2. Enhanced Thermal Conductive UO_2 Pellet Development

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 main benefit of the metallic microcell UO_2 pellets is their enhanced thermal conductivity. A continuously connected metallic cell-wall can effectively increase the thermal conductivity of UO_2

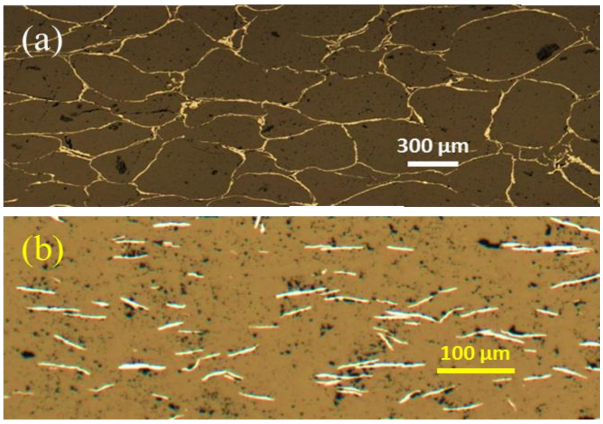

Fig. 1. Microstructure image of (a) 5 vol% Mo metallic microcell UO_2 pellet and (b) 3 vol% Mo metallic microplate UO_2 pellet (bright lines are Mo metallic phases).

pellets. The fuel temperature can be effectively decreased via the enhanced pellet thermal conductivity.

The metallic microplate UO_2 pellet is also being developed to effectively enhance thermal conductivity of the UO_2 pellet. A large number of metallic micro-sized plates were homogeneously dispersed in a UO_2 pellet, and arranged in the radial direction of the pellet. Figure 1(b) shows a microstructure image of a 3 vol% Mo metallic microplate UO_2 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.

Figure 2 shows the relative thermal conductivities of metallic microcell and microplate pellets, and the measured thermal conductivities of the fabricated pellets are remarkably increased. The thermal conductivities of the 5 vol% Cr metallic microcell, 3 vol% Mo metallic microcell and 3 vol% Mo metallic microplate UO_2 pellets were increased by about 80 % at 1000 ℃, compared to that of a standard UO_2 pellet.

In the development of enhanced thermal conductive fuel, it was intended to verify the designed fuel performances of the metallic microcell UO_2 pellet by in-pile testing. An irradiation test of the 5 vol% Cr metallic microcell UO_2 pellet was performed at the Halden Reactor in Norway [4].

The measured thermal conductivity of the 5 vol% Cr metallic microcell UO_2 pellet that underwent a Halden irradiation testing is shown in Figure 2 (purple bar graph). The 5 vol% Cr metallic microcell UO_2 fuel 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

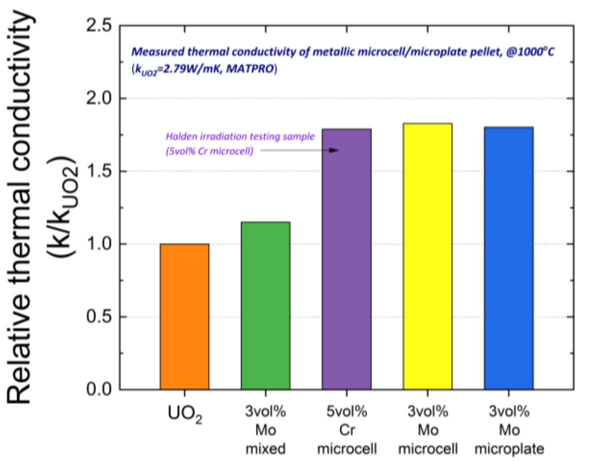

Fig. 2. Relative thermal conductivities of metallic microcell and microplate pellets (puple bar is a measured value of the Halden irradiation testing sample).

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 atomsphere. We are planning to perform the post irradiation examinations of the irradiated sample.

3. Summary

As an ATF pellet, the enhanced thermal conductive UO_2 pellets 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 concepts of metallic microcell and metallic microplate UO_2 pellets have been designed, and the fabrication technology of ATF pellets embodying these designed concepts has been developed.

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