DEVELOPMENT STATUS OF MICROCELL UO_2 PELLET WITH ENHANCED THERMAL CONDUCTIVITY FOR ATF

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ABSTRACT

As an ATF (Accident Tolerant Fuel) pellet, a microcell UO_2 pellet is being developed to enhance the accident tolerance of nuclear fuels under accident conditions as well as the fuel performance under normal operation conditions.

Microcell UO_2 pellets are being developed to enhance the thermal conductivity and/or retention capability of the fission products of UO_2 pellets. The key idea of a microcell UO_2 pellet is to immobilize the FPs by reducing the fuel temperature and/or provide multiple chemical traps in a pellet. The microcell UO_2 pellet consists of UO_2 grains or granules enveloped by thin cell walls.

Especially, the enhanced pellet thermal conductivity is the distinct feature of a metallic microcell UO_2 pellet. The fuel temperature can be effectively decreased by the enhanced thermal conductivity. In addition, as another concept of high thermal conductive UO_2 pellet, a metallic microplate dispersed UO_2 pellet is being developed.

1. Introduction

Microcell UO_2 pellets are being developed to enhance the thermal conductivity and/or retention capability of the fission products (FPs) of UO_2 pellets [1-4]. The key idea of a microcell UO_2 pellet is to immobilize the FPs by reducing the fuel temperature and/or provide multiple chemical traps in a pellet. Fig. 1 shows a conceptual schematic of a microcell UO_2 pellet in which the UO_2 grains/granules are enveloped by a thin cell wall. The volume occupied by cell wall material in a pellet ranges from 1 vol% to 5 vol%. There are two kinds (metallic and ceramic) of microcell UO_2 pellets according to the material type composing the cell wall. A high thermal conductive metallic cell wall effectively enhances the thermal conductivity of a UO_2 pellet. The ceramic wall, which has chemical affinity to volatile FPs, acts as a chemical trap for FPs movement.

Microcell UO_2 pellets are expected to enhance the performance and safety of current LWR fuels under normal operational conditions as well as during transients/accidents. A high thermal conductive pellet can reduce not only the FPs diffusivity/mobility but also the thermal

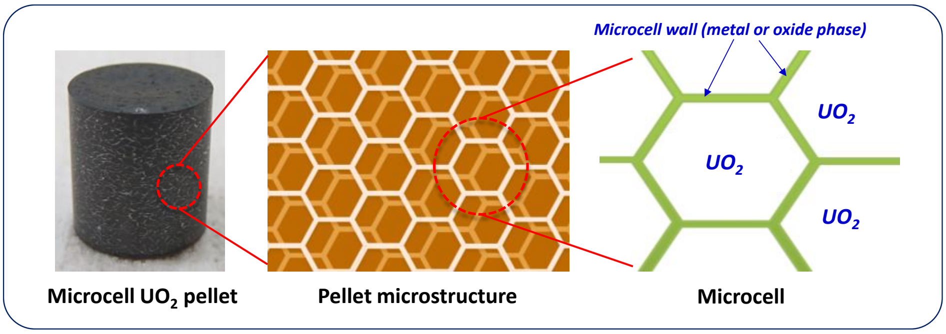

Fig. 1. Conceptual schematic of microcell UO_2 pellet.

stress by lowering the pellet temperature and temperature gradient. A lessening of stored energy in low temperature pellets significantly increases the 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 the internal pressure of the fuel rod. A soft/ductile thin wall facilitates the fast creep deformation of the pellets, because of the very higher ductility of metal phase compared to that of UO_2, thereby reducing the mechanical loading of the cladding under operational transients. These benefits are expected to preserve the robustness of a fuel rod under accident conditions as well as normal operational conditions. A mesh-like rigid wall structure is also expected to prevent the massive fragmentation of pellets during accidents thereby reducing the release of retained radio-toxic FPs into the environment.

2. Fuel Material Development

2.1. Metallic microcell UO_2 pellet

Fig. 2(a) shows the shape of a 5 vol% of Mo containing metallic microcell UO_2 pellet. This pellet was fabricated by co-sintering of metal powder over-coated UO_2 granules through a conventional sintering process. The density of the sintered pellets is about 97.5 %T.D. [3]. Fig. 2(b) shows a typical microstructure of metallic microcell UO_2 pellets in which the microcell concept was successfully implemented. It is a panoramic image of metallic microcell pellet from end to end (pellet radial direction). The averaged UO_2 grain size is about 8 μm. The metallic cell wall thickness ranges from 4 to 6 μm and the averaged diameter of the UO_2 granules is about 300-400 μm.

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

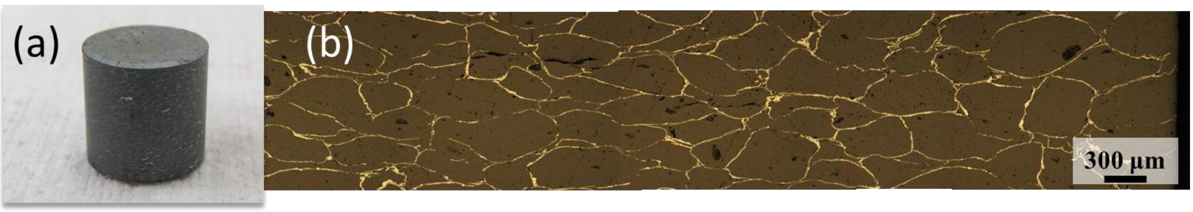

Fig. 2. (a) Pellet shape and (b) microstructure of 5 vol% Mo metallic microcell UO_2 pellet (brighter lines are Mo metallic phase).

pellets. Fig. 3 shows an enhancement of the thermal conductivity. The thermal conductivity of 5 vol% of Mo containing microcell UO_2 pellets was increased by about 100 % at 1000 °C, compared to that of a standard UO_2 pellet. The fuel temperature can be effectively decreased by the enhanced thermal conductivity of the pellet.

The linear thermal expansion coefficient of the Mo metallic microcell UO_2 pellet decreased with increasing Mo content because of the lower thermal expansion coefficient of Mo (~4.8×10^{-6} /K at 25 °C) than that of UO_2 (~10×10^{-6} /K). Under the transient conditions, it is expected that the mechanical stress loading on the cladding due to pellet expansion can be reduced by this feature of the metallic microcell UO_2 pellet.

Maintaining pellet-structural stability under a high-temperature steam environment is an important property for fuel pellets. In the steam oxidation test at 500 °C, pulverization and fragmentation of UO_2 pellet due to oxidation was occurred. On the other hand, in Mo metallic microcell UO_2 pellet, pulverization and fragmentation due to oxidation were retarded and metallic phases of pellet inside were even preserved. In the test at 800 °C and above 800 °C, UO_2 pellet sample was gradually fragmented owing to oxidation from the pellet surface. In the case of Mo metallic microcell UO_2 pellet, pellet sample cracking was occurred due to Mo-oxide formation. Nevertheless, pellet-structural stability of metallic microcell UO_2 pellet was preserved longer than that of UO_2 pellet.

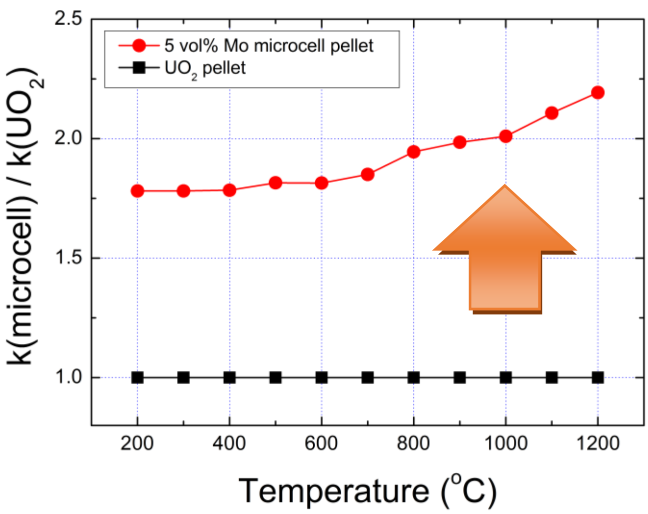

Fig. 3. Comparison of relative thermal conductivity of standard UO_2 pellet and 5 vol% Mo metallic microcell UO_2 pellet.

2.2. Metallic microplate dispersed UO_2 pellet

A metallic microplate dispersed UO_2 pellet is being developed through modification of metallic microcell UO_2 pellet techniques. A large number of metallic micro-sized plates are dispersed in UO_2 pellet, and arranged to radial direction of pellet. Heat transfer in the fuel pellet can be efficiently enhanced by radially arranged metallic microplates. In addition, fabrication processes of the metallic microplate dispersed UO_2 pellet can be more simplified,

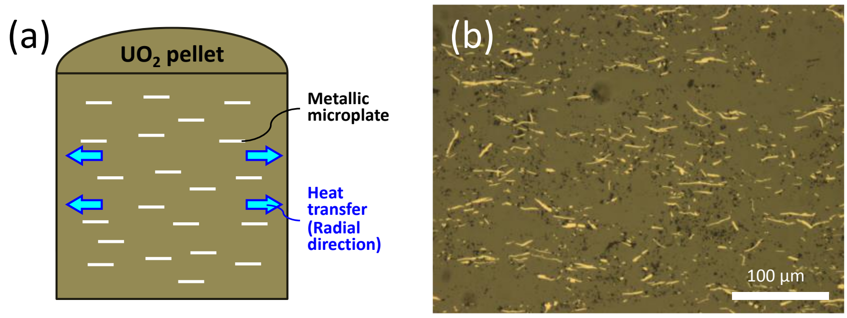

Fig. 4. (a) Conceptual schematic of microplate dispersed pellet, (b) a typical microstructure of 5 vol% Mo metallic microplate dispersed UO_2 pellet (brighter lines are Mo metallic phase).

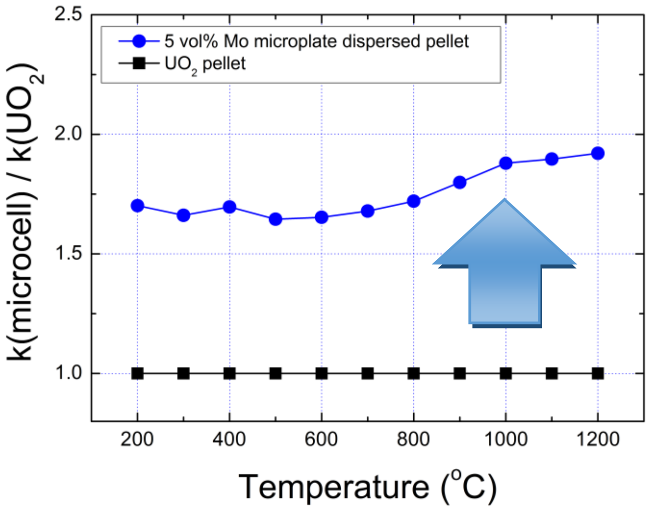

Fig. 5. Comparison of relative thermal conductivity of standard UO_2 pellet and 5 vol% Mo metallic microplate dispersed UO_2 pellet.

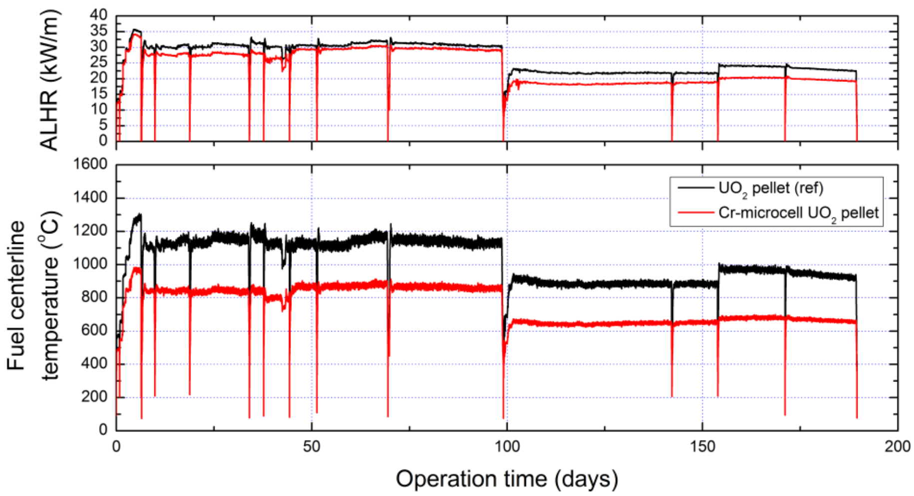

Fig. 6. Online measurement data of ALHR and fuel centerline temperature of UO_2 reference pellet and Cr metallic microcell UO_2 pellet as a function of the operation time [5].

compared to that of the metallic microcell UO_2 pellet, because the metal powder over-coated UO_2 granules preparation step in metallic microcell pellet fabrication processes can be skipped. It is expected that we can provide various options of enhancing thermal conductivity of fuel pellet by metallic microcell and microplate dispersed UO_2 pellet.

Fig. 4 shows a conceptual schematic of metallic microplate dispersed UO_2 pellet, and a typical microstructure of radially arranged Mo metallic microplates containing the fabricated pellet. In Fig. 4(b), the averaged microplate size is about 30-60 μm. As it can be seen in Fig. 5, a thermal conductivity of the Mo metallic microplate dispersed UO_2 pellet is also remarkably enhanced, compared to that of UO_2 pellet (increased by about 85 % at 1000 °C).

3. Summary

As an ATF pellet, microcell UO_2 pellets are being successfully developed to enhance the thermal conductivity and/or retention capability of the fission products of UO_2 pellets. In addition, a metallic microplate dispersed UO_2 pellet is being developed through modification of metallic microcell UO_2 pellet techniques. It is expected that we can provide various options of enhancing thermal conductivity of fuel pellet by metallic microcell and microplate dispersed UO_2 pellet.

The assessment of the out-of-pile properties of the developed pellet is being performed. Especially, the observation of the in-reactor performance and behavior of the microcell UO_2 pellets is in progress through a Halden irradiation test. The excellent performances of the microcell UO_2 pellets are being shown by the online measurement data of the Halden irradiation test.

4. Acknowledgement

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5. References

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