Characterization of the Thermal Conductivities of KAERI's Accident-Tolerant Fuel Pellets with Aligned Metal Particles

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1. Introduction

After the wake of Fukushima accident, various concepts of new fuels were being suggested and developed under the name of accident tolerant fuels (ATF). It is well-known that the current LWR fuel should be tolerable to severe accidents to mitigate their consequence with maintaining the performances. One of the focuses on the nuclear UO_2 fuel pellet is about its low thermal conductivity. The low thermal conductivity leads to increase thermal gradient in the fuel pellet and centerline temperature when in operation. Enhancing the thermal conductivity of UO_2 fuel pellet can be greatly attractive in the aspect of fuel performance [1] and also for its safety margin. The fuel pellets having high thermal conductivity can lower fuel temperature and reduce the mobility of the fission gases [2]. In addition, a reduced temperature gradient within the pellet probably enhances the dimensional stability, with lower thermal stress of the fuel pellet, thus the pellet cladding mechanical interaction (PCMI) and even in fuel fragmentation, relocation and dispersal (FFRD) can be mitigated. A thermal margin gained from the high thermal conductivity of pellet would be utilized in a safe operation of LWR or even power-uprate operation also.

There have been many efforts on enhancing the thermal conductivity of the fuel pellet. Yang et al. [3] have shown experimentally that the thermal conductivity of a UO_2 pellet can be increased substantially by providing a UO_2 pellet with connected tungsten channel. KAERI has also developed micro-cell UO_2 fuel pellets consist of granules enveloped by thin metallic cell walls. [4, 5] The metallic cell walls in pellets are continuously connected to each other, enhancing thermal conductivity. On the other hand, in order to enhance the thermal conductivity focused in radial direction, metallic microplate was dispersed in a UO_2 fuel pellet. Micrometer-sized thin molybdenum particles were aligned horizontally in a UO_2 pellet to have enhanced thermal conductivity with heat transfer paths in radial direction. Moreover, the compatibility in the fuel fabrication process can be enhanced, due to the simple pellet fabrication method.

In this presentation, the thermal conductivities of the molybdenum metal aligned pellets (microcell and microplate) were characterized with the variation of metal fractions and its microstructures of the fuel composites.

2. Experimental and Result

Mo microcell and microplate UO_2 pellet were fabricated by composing UO_2 and Mo microplate particles.

Mo metal powder was milled in a planetary milling machine and several kinds of Mo microplates were prepared with varying particle sizes. Fig. 1 shows Mo microplate particles prepared in this study. After the milling process, spherical or irregular shaped Mo particles were transformed to micro-sized thin plates, having different size distributions according to the prepared powders.

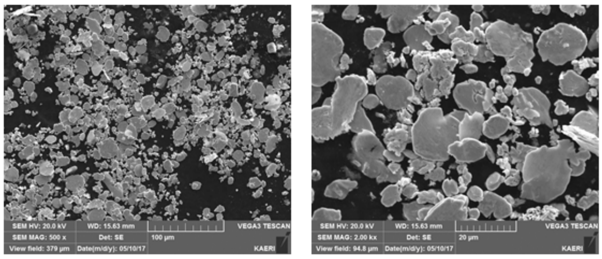

Fig. 1. SEM images of Mo microplates with different magnifications. (500x and 2000x)

Microcell and microplate UO_2 pellets were fabricated by mixing UO_2 granules and UO_2 raw powder, respectively, with Mo microplates; 2-5 vol.% of Mo microplates were simply mixed in a tubular mixer.

The mixtures were compacted using a uniaxial press at about 300 MPa, and the pelletized green bodies were sintered at 1730 ºC for 4h in a flowing H_2 atmosphere.

The sintered densities of UO_2-Mo pellets were determined using an immersion method, and a microstructure of the sintered pellet was observed using optical microscopy and SEM.

Fig. 2 shows the microstructures of Mo Microcell and microplate UO_2 pellets. The bright phase of Mo microplates were forming cell walls in pellets are continuously connected to each other in microcell UO_2 pellet, and on the other hand, microplates were dispersed homogeneously and aligned in horizontal direction in microplate UO_2 pellet that is forming effective thermal conductive paths for radial heat transfer.

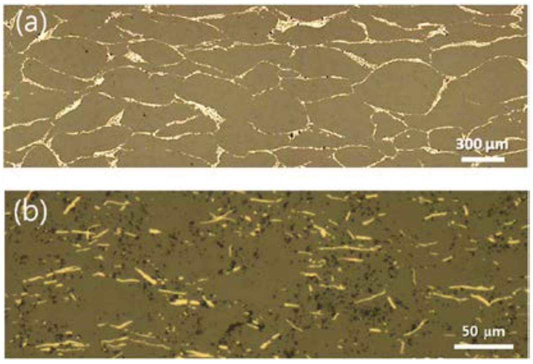

Fig. 2. Microstructure of Mo (a) Microcell and (b) microplate UO_2 pellet.

Thermal conductivities of the pellets were characterized by LFA method. The pellets were sliced in axial direction to measure the effective radial thermal conductivity. The radial thermal conductivity was much enhanced compared with bare UO_2, and even also higher than the conductivity of the UO_2 pellet with same amount of spherical Mo particles included. (Fig. 3) These enhancements of the thermal conductivities of the Mo microcell and microplate UO_2 pellets were mainly affected by the shape and arrangement of the metallic particles in the pellet. The effect on the thermal conductivity with the Mo microplates was investigated.

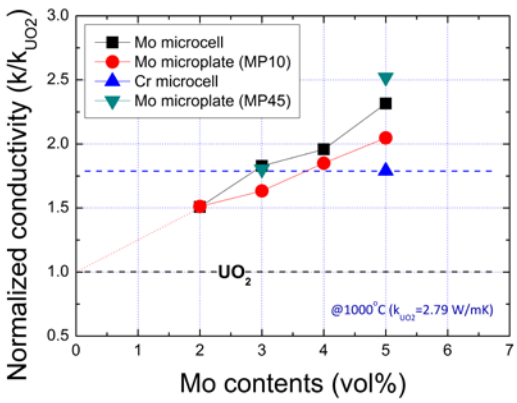

Fig. 3. Comparison of thermal conductivities of UO_2 fuel pellets with 5 vol% Mo at 1000^{o}C.

3. Summary

In this study, the thermal conductivities of Mo microcell and microplate UO_2 were characterized and presented enhanced the thermal conductivities of the pellets. Mo metal cell walls and dispersed microplates were aligned working as heat conducting paths in the pellet. Therefore, the thermal conductivity of the UO_2 pellet in radial direction could be enhanced, which can lead to reduce thermal gradient of the pellet when in operation in a reactor. Considering the outstanding fuel pellet characteristics, both of Mo microcell and microplate UO_2 pellets are promising fuel concept of ATF pellets in near future.

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