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Fabrication of Micro-Cell Structured UO_2 Fuel Pellets using Mo Platelets

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1. Introduction

Through the decades of developments of nuclear fuel pellets, many of efforts have been focused on increasing the economic efficiency of the LWR power generation such as, increasing the fuel discharged burn-up, extending the fuel cycle, and up-rating the maximum power. However, in the wake of Fukushima accident, it becomes more important recently, and well-known that the current LWR fuel should be tolerable to severe accidents to mitigate their consequence with maintaining the performances. Thus, various concepts of new fuels are being suggested and developed under the name of accident tolerant fuels (ATF).

First of all, current nuclear UO_2 fuel has poor properties due to 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 is greatly attractive in the aspect of fuel performance [1–3] 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 [4–6]. 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 efforts on enhancing the thermal conductivity of the fuel pellet. One of the methods is introducing high thermal conductive materials into fuel pellets. Yang et al. [7] 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 developed two kinds of micro-cell UO_2 fuel pellets consist of grains or granules enveloped by thin cell walls, ceramic and metallic micro-cell pellets. [8, 9] The cell walls in pellets are continuously connected to each other, enhancing thermal conductivity and retention capability of FPs of the micro-cell UO_2 pellet.

In this study, Mo metal micro-cell UO_2 fuel pellet is fabricated using Mo platelets. Micrometer-sized circular thin Mo platelets were used to cover UO_2 granules effectively to have enhanced connectivity of heat transfer channels. Moreover, distribution and homogeneity in the pellet is improved, and also the compatibility in the fuel fabrication process can be enhanced, due to the particle morphology. The thermal properties of the pellets were characterized with the microstructures and the shape of Mo platelets.

2. Experimental and Result

A Mo metallic microcell pellet was fabricated by composing UO_2 granules and Mo platelets.

UO_2 powder (ADU processed, Ammonium Diuranate) was pre-compacted using a uniaxial press at 40-50 MPa, then the pre-compact green was crushed and sieved. A specific range of size of UO_2 granules could be collected by screening with varying sieve meshes; a range 600-850μm of granules was used in this study.

Mo platelets were prepared by milling spherical Mo powder particles. Mo metal powder (SIGMA-ALDRICH, 99.9%) was milled in a planetary milling machine(300 RPM, 2hrs) and three kinds of Mo platelets were prepared varying particle sizes. Fig. 1 shows Mo platelets prepared in this study. After the milling process, spherical Mo particles were transformed to thin circular platelets, having three different size distributions with the prepared powders.

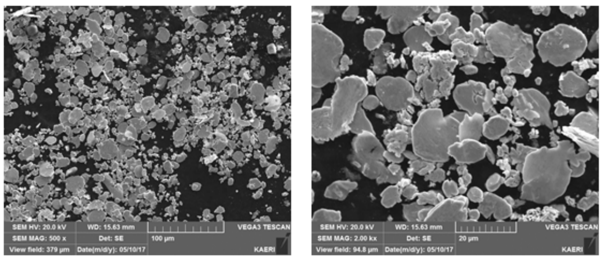

Fig. 1. SEM images of Mo platelets.

5 vol.% of Mo platelets were simply mixed in a tubular mixer with the prepared UO_2 granules. The powder mixtures were compacted using a uniaxial at about 300-400 MPa, and the pelletized green body was sintered at 1730 ºC for 4h in a flowing H_2 atmosphere.

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

Fig. 2 shows the microstructure of a Mo micro-cell UO_2 pellet. The bright phase of Mo metal was covered the UO_2 granules forming continuous network of thermal conductive channels. The UO_2 granules were also flattened by the forming pressure, having elongated aspect ratio and aligned horizontally in the pellet.

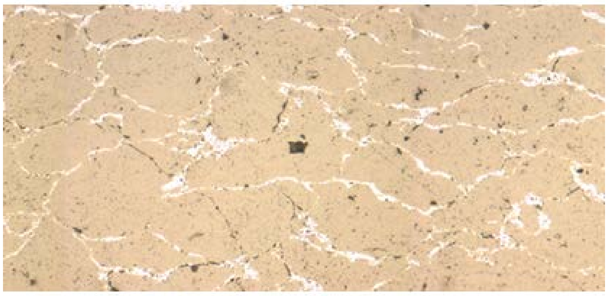

Fig. 2. Microstructure of a Mo micro-cell UO_2 pellet.

Thermal conductivity of the pellet was characterized by LFA method. The pellet was sliced in axial direction to measure the effective radial (horizontal) thermal conductivity. The radial thermal conductivity was much enhanced compared with bare UO_2, and also higher than the conductivity of axial direction of the pellet in this study. This enhancement of the thermal conductivity of the micro-cell UO_2-Mo pellet was mainly affected by the high connectivity of metallic cell walls and the aspect ratio of granules in the pellet. The effect on the thermal conductivity with the Mo platelet size was investigated.

3. Summary

In this study, Mo micro-cell structured UO_2 nuclear fuel pellet was fabricated for enhancing the thermal conductivity of the pellet. Mo metal platelets were used to form cell walls working as heat conducting network channels 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, this micro-cell UO_2-Mo pellet will be one of the promising fuel concepts of ATF pellets in near future.

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