Aligning Mo Metal Strips in UO_2 Fuel Pellets for Enhancing Radial Thermal Conductivity

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ABSTRACT: *Enhancing the thermal conductivity of UO_2 LWR fuel pellets are important, which leads to be able to reduce fission product release, and to increase safety and operation margin of the fuels. In this study, Mo metal strips were horizontally aligned in a UO_2 pellet for enhancing the thermal conductivity of the UO_2 pellet in radial direction. Mo strips were prepared by thermal evaporation of MoO_3 powder and reducing heat treatment. The strips and UO_2 powder were simply mixed and then sintered with conventional method to concern the compatibility with a conventional UO_2 pellet fabrication process. The aligned Mo strips work as heat conducting channels in the pellet, enhancing the thermal conductivity of the UO_2 pellet in radial direction. The thermal properties and microstructures of the pellets with the shape of Mo strips included were investigated.*

KEYWORDS: *LWR Fuel Pellets, UO_2, Thermal Conductivity, Molybdenum*

I. Introduction

Through the developments of fuel pellets, the efforts have been focused on increasing the economic efficiency of the LWR nuclear power generation such as, increasing the fuel discharged burn-up, extending the fuel cycle, and up-rating the maximum power. However, very recently, it becomes more important 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 for the accident tolerant fuels (ATF).

One of the most disadvantages of conventional UO_2 fuel pellets is poor 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 high thermal conductive pellet has lower fuel temperature, reducing 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) 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 are 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.

In this study, Mo metal strips were horizontally aligned in a UO_2 nuclear fuel pellet for enhancing the thermal conductivity of the pellet. The aligned Mo strips in the UO_2 pellet work as heat conducting channels in the pellet, enhancing the thermal conductivity of the UO_2 pellet in radial direction. The thermal properties of the pellets were characterized with the microstructures and the shape of Mo strips.

II. Experimental & Discussion

Mo metal strips were prepared by thermal evaporation method. MoO_3 powder was placed in the heat zone of a horizontal tube furnace and then heated to ~800°C, with Ar gas flow. Thermally evaporated MoO_3 powder was recrystallized in the collection zone of the furnace with elongated thin-belt shape. Collected MoO_3 thin-belts were heat treated again in a tube furnace at 600^{o}C with H_2 gas flow. The MoO_3 belts were reduced to Mo metal, maintained the elongated high aspect ratio. The size and the shape of the Mo strips can be controlled by changing heat-treatment conditions such as, temperature and holding time, which affected on the growth kinetics of MoO_3 crystals. Figure 1 shows the elongated MoO_3 particles and reduced Mo strips.

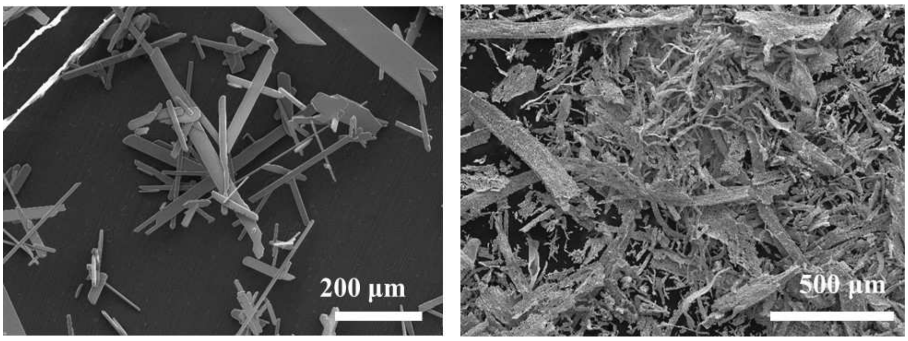

Fig. 1. The elongated MoO_3 particles(left) and reduced Mo metal strips(right).

The UO_2-Mo strip fuel pellet was fabricated by a conventional ceramic process to concern the compatibility with a conventional UO_2 pellet fabrication process. UO_2 powder(ADU processed, Ammonium Diuranate) and 2 vol.% of Mo strips were simply mixed in a tubular mixer, and then uniaxially pressed into pellets having cylindrical shape. Pelletized green body was sintered at 1700^{o}C, 4 hours with H_2 atmosphere. Figure 2 shows the UO_2-Mo strip pellet and its microstructure. The sintered pellet had 97.1% relative density and homogeneous microstructure. Mo strips were well dispersed and horizontally aligned in the pellet. The interface between the strips and UO_2 matrix is intact and clear, but some cracks were found at the end edge of the strips. The cracks mainly observed from the large sized strips, especially depends on the thickness of strips. Thus, it is important to optimize the size and maintain narrow distribution of the Mo metal strips.

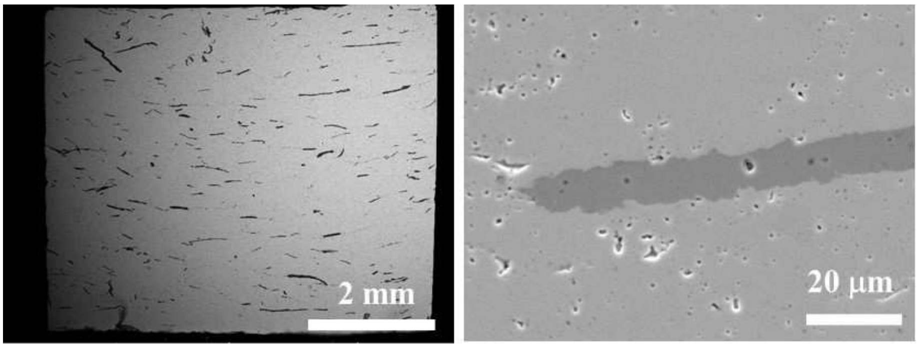

Fig. 2. The microstructures of UO_2-Mo strip pellet.

The characterization of thermal conductivity of the pellet is now ongoing. The pellet was sliced in axial direction to measure the effective radial (horizontal) thermal conductivity by LFA method. The radial thermal conductivity is believed to be much enhanced compared with bare UO_2, and also be higher than the conductivity of axial direction of the pellet in this study. This anisotropy of the thermal conductivity of the UO_2-Mo strip pellet was mainly affected by the high aspect ratio of the Mo strips and its alignment in the pellet. The detailed investigation and the comparison of the thermal conductivities will be provided in the conference.

III. Summary

In this study, Mo metal strips were horizontally aligned in a UO_2 nuclear fuel pellet for enhancing the thermal conductivity of the pellet. The aligned Mo strips in the UO_2 pellet work as heat conducting channels in the pellet, enhancing the thermal conductivity of the UO_2 pellet in radial direction, which can lead to reduce thermal gradient of the pellet when in operation in a reactor. Considering the compatibility of the fabrication method with conventional process and the fuel pellet characteristics, this UO_2-Mo strip pellet will be one of the promising fuel concepts of ATF pellets in near future.

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REFERENCES

1. B.H. Lee, Y.H. Koo, J.S. Cheon, J.Y. Oh, H.K. Joo, D.S. Sohn, J. Korean Nucl. Soc. 34 (5) (2002) 482–493
2. B.H. Lee, Y.H. Koo, J.Y. Oh, J.S. Cheon, Y.W. Tahk, D.S. Sohn, Nucl. Eng. Technol. 43 (6) (2011) 499–508.
3. A.F. Williams, B.W. Leitch, N. Wang, Nucl. Eng. Technol. 45 (7) (2013) 839–846.
4. C.R.A. Catlow, Proc. R. Soc. Lond. Ser. A 364 (1978) 473–499.
5. K. Forsberg, A.R. Massih, J. Nucl. Mater. 135 (1985) 140–148.
6. Y.H. Koo, J.Y. Oh, B.H. Lee, Y.W. Tahk, K.W. Song, J. Nucl. Mater. 405 (2010) 33–43.
7. J.H. Yang, K.S. Kim, D.J. Kim, J.H. Kim, J.S. Oh, Y.W. Rhee, Y.H. Koo, Micro-cell UO2 pellets for enhanced accident tolerant fuel, TopFuel 2013, American Nuclear Society, Charlotte, September 15–19, 2013