Transactions of the Korean Nuclear Society Autumn Meeting
Goyang, Korea, October 24-25, 2019

Thermo-physical Properties of UO_2-Mo Fuel Pellets under the Thermal Gradients

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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).

There are two main features needed for ATF pellet concept, one is enhanced thermal conductivity of the pellet and the other is fission product retention. 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.

KAERI has also developed metallic and ceramic micro-cell UO_2 fuel pellets consist of granules or grains enveloped by thin metallic/ceramic cell walls. [4, 5] The metallic cell walls in pellets are continuously connected to each other, enhancing thermal conductivity and the ceramic additives form walls surrounding grains in the UO_2 matrix which can immobilize the volatile fission products.

In this study, in order to develop fuel pellets one step furthermore in the perspective of the normal operation and accident condition, the cracking behavior of the fuel pellets is investigated. During the initial rise to power, the thermal stresses caused by the large radial temperature gradient of the pellets, leads to crack into pieces. This relocation and restructuring might affect to the claddings(PCMI) by possible locally focused contacts. Also, cracking of the UO_2 pellets will effectively reduce its thermal conductivity[6] and the cracking increases the probability of fission gas release by diffusion and direct and recoil release.[7] It is expected to confirm the reduced in cracking behavior of the Mo metal aligned UO_2 fuel pellets by the reduced in centerline temperature and complexation with metallic materials.

2. Experimental and Result

The main objective of the study is to evaluate the thermo-physical properties of fuel pellets under thermal gradient, with investigating behaviors of cracks on the pellets.

To generate the radial temperature gradients on the fuel pellets, an electrical induction furnace was used in this study. Firstly, the pellets were formed and sintered with having a hole in the center of cylindrical pellets. The pellets used in the study were Mo microcell, Mo microplate, and pristine UO_2 pellet samples. The samples were fabricated as same conventional method, mixing with Mo microplates with UO_2 granules or powder. The center of pellets was heated by a tungsten rod penetrated in the center, and the rod was heated by induction in the furnace. The heated rod will act as the heat source in the core of the pellet, and the power being controlled by the electrical current around the tungsten rod. The pellets were surrounded by refractory materials which support the bounding of the pellet periphery region acting as the cladding tube.

Temperature gradient on a fuel pellet was established by heating the tungsten rod at the core, the radial temperature gradient between the sample core and the outer face is controlled by the core temperature, the tungsten rod, by the induced energy, and the temperature of the vessel interior. Photo images of this apparatus and the sample configuration can be found in Fig. 1.

Fig. 1. Photo images of the temperature gradient heating test apparatus and the configuration.

In order to observe the temperature gradient of the pellets, several methods of temperature measurement were conducted. The core of the pellet was measured by a pyrometer and the outer face was measured by a thermocouple in the preliminary experiments, after the setting of the experimental configuration, a thermal imaging camera was used to visualize the temperature gradient of the pellets. The apparatus has the capability of heating up the temperature of the fuel pellet core up to 1500ºC and the stabilizing the outer face temperature around 500~600ºC.

Fig. 2 is the picture of the sample after the preliminary heating test on the pristine UO_2. It can be found that the sample was divided into three pieces with radial cracks. Characterization of the samples were determined by observing cracks after the heating tests, varying heating rates and the magnitude of the temperature gradient, center to periphery(ΔT). The experiments are still being in the progress; the cracking behaviors of the pellets will be compared in the presentation.

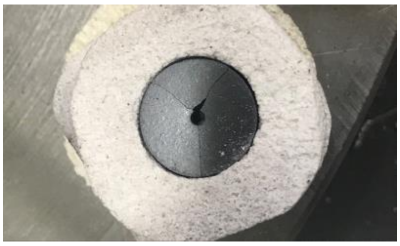

Fig. 2. Picture of the UO_2 sample after the preliminary heating test.

3. Summary

In this study, the thermo-physical properties of Mo microcell and microplate UO_2 pellets were characterized by investigating behaviors of cracks on the pellets under the radial temperature gradients. The Mo metal aligned pellets presented reduced in cracks under the thermal gradient stress, compared than UO_2. Mo metal cell walls and dispersed microplates were working as heat conducting paths, even also affects to the structural integrity of the pellet. Therefore, the thermal conductivity of the UO_2 pellet in radial direction could be enhanced, and the thermal stress induced from the temperature gradient could be lowered, leads to maintain the pellet integrity 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.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT: Ministry of Science and ICT) (No. 2017M2A8A5015056).

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