Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

Ceramography of MOX fuel rods after Irradiation Test

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1. Introduction

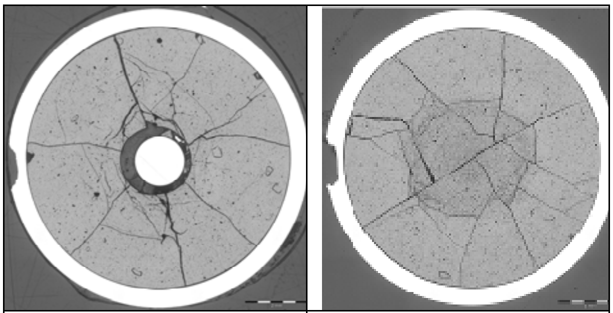
Mixed oxide (KAERI MOX) fuel pellets were fabricated as a framework of the cooperation project between KAERI and PSI for an irradiation test. The MOX pellets were drilled, loaded into cladding and instrumented in IFE. Two KAERI MOX rods including one commercial MOX and three IMF rods were assembled into IFA 651 which was irradiated in Halden reactor. The irradiated MOX rods were transported to IFE, Kjeller and ceramography was performed. Diametral swelling and crack pattern of pellets, gap between pellet and clad were observed on the macrographs of the MOX rods. Pores and metallic fission product precipitates were characterized by image analysis of micrographs on the polished section. Grain sizes of KAERI MOX were measured in three radial positions.

2. Experimental

IFA 651 test assembly was irradiated in the Halden reactor for more than 1000 EFPD and the rod average burnup reached 50 MWd/kgHM. The irradiated MOX rods were transported to IFE (Kjeller). Each rod was transversely cut out in the axial position where the burnup was a maximum, and a piece of radial section was sampled from each MOX rod for ceramography. Three samples for optical microscope examination were prepared by a series of mounting, grinding, polishing, washing and drying in hot cell. Macroscopic and microscopic structures of the MOX rods were observed on the polished sections. After that, the samples were chemically etched and grain structures were observed. Characteristics of pore and metallic precipitate, such as size distribution, area fraction and shape factor were measured by the image analysis on the polished sections. Grain size was measured by the linear intercept method at three radial positions.

3. Results

Macrostructures on the radial section of the irradiated MOX rods were observed with low magnification to review crack pattern and gap between fuel pellet and clad. Fig. 1 shows some crevices on the radial sections of the fuel pellets. The crevices were circumferentially closed and their opening in a hot central region is bigger than that in a periphery region. The inner surface of cladding is covered with oxide layer which is composed of the main cladding elements, oxygen, fuel elements and fission products [2]. Diametral swelling of the irradiated MOX pellets was around 1.41%(rod 6) to 1.65%(rod 3).

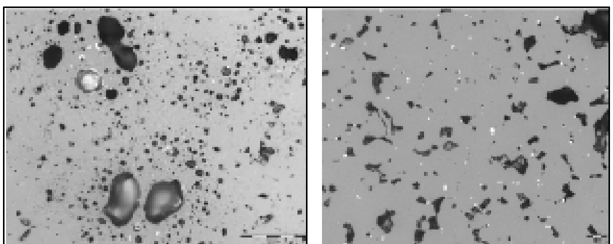


KAERI MOX(rod 3)	KAERI MOX(rod 6)

Fig. 1. Macrographs of MOX fuel rods after irradiation.

Micrographs on the polished section show pores, Pu-rich spots and metallic precipitates. The Pu spots were only observed at middle and periphery regions as shown in Fig. 2(a). The spots can be diffused out at hot central region [1, 3]. The Pu spots are surrounded with a lot of small pores and some bigger pores and metallic fission product precipitates exist inside. Most fission occurs within the Pu spots, a small portion of the fission products migrates to the surrounding matrix by athermal processes such as recoil and knockout [3-5]. As fission gas accumulates within the matrix grains, a halo is formed around the spot by the high density of the small pores and becomes visible in the polished fuel cross section [6]. The halo thickness is on the order of a few fission fragment recoil distances [6]. The halos serve as gas storage sites but most of the fission gases and the solid fission products stay within the spot throughout fuel life.

Fig. 2(b) shows the metallic precipitates which appear as white spots. Most of the precipitates are distributed at fuel center region, as shown in Fig. 2(b). Average contents of the precipitates were 0.41% for rod 6 and 0.32% for rod 3.



(a) Pu rich spots at rim	(b) Metallic precipitates

Fig. 2. Micrographs of MOX fuels on polished section.

Fig. 3 shows the pore distributions of the irradiated MOX fuels at three radial positions. The distribution density was the highest value at periphery and the next at middle then center for small pores less than around 2 ㎛, but large pores distributed at fuel center more than the other regions. Fuel densities at three radial regions were compared on the analogy of the area fraction measurements of pores. The density of periphery was lower than the other regions.

Fig. 4 shows the grain structures of MOX fuels on the radial sections. The grain size was different from center to periphery region. The average grain size of as-fabricated fuel was 10 ㎛. The grains have grown to 12 ㎛ only at central region of rod 6 but for rod 3. The fuel pellets of rod 3 were drilled through whole length for the instrumentation of expansion thermometer, so the center temperature of rod 3 was lower than that of rod 6 during irradiation.

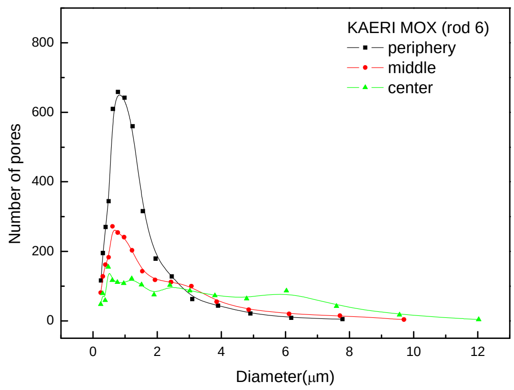


Fig. 3. Pore distributions of the irradiated MOX fuel.

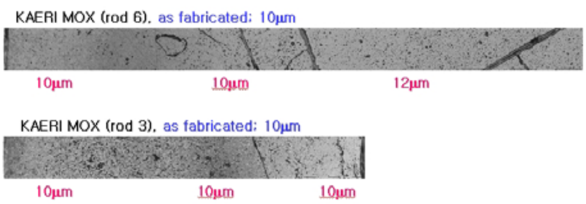


Fig. 4. Grain structures of MOX fuel on the radial sections.

The halos around the Pu spots were observed at periphery of the irradiated MOX fuels. The spots surrounded by the halos did not react with the chemical etchant but they have transformed into a high burnup structure (HBS) [5, 6]. The HBS is formed at the cooler outer region of fuel cross section when a local burnup is higher than about 60 MWd/kgHM and the temperature is below about 1000°C [6]. This structure is formed by a process of recrystallization that produces small (<1 ㎛) grains with many accompanying pores for fission gas storage. Gas storage within the pores of the HBS adds to the effects of the fission product insertions into the fuel lattice, thereby inducing additional local swelling [6].

4. Conclusions

Some crevices were formed in the irradiated MOX fuels. The crevices with big opening were stretched out to radial direction and some of them were circumferentially closed with fine cracks. The inner surface of cladding is covered with oxide layer.

The Pu-rich spots were observed in the outer region of MOX fuel pellets. The halos, high density of small pores surround the spots and the HBS inside.

Metallic fission product precipitates were observed mainly at central region and the Pu spots, and their contents were 0.41% for rod 6 and 0.32% for rod 3.

Pore density with a size smaller than around 2 ㎛ was higher at periphery than the other regions.

The grain growth has occurred only at central region of rod 6 from 10㎛ to 12㎛ after irradiation.

REFERENCES

[1] M.A. Barker, C.P. Chatwin, Fuel Performance activities at Sellafield Ltd and the UK National Nuclear Laboratory, WRFPM 2008, October 19-23, 2008, Seoul, Korea.

[2] K. Tanaka, K. Maeda, S. Sasaki, Y. Ikusawa, T. Abe, J. of Nuclear Materials, Vol.357, p.58, 2006.

[3] H. Kleykamp, J. of Nuclear Materials, Vol.324, p. 198, 2004.

[4] S.B. Fisher, R.J. White, P.M.A. Cook, S.Bremier, R.C. Corcoran, R. Stratton, C.T. Walker, P.K. Ivison, I.D. Palmer, J. of Nuclear Materials, Vol.306, p. 153, 2002.

[5] J. Spino, D. Baron, M. Coquerelle, A.D. Stalios, J. of Nuclear Materials, Vol.256, p. 189, 1998.

[6] J. Noirot, L. Desgranges, J. Lamontagne, J. of Nuclear Materials, Vol.372, p. 318, 2008.