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Fabrication of nano-structured UO_2 fuel pellets

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1. Introduction

Nano-structured materials have received much attention for their possibility for various functional materials. Ceramics with a nano-structured grain have some special properties such as super plasticity [1,2] and a low sintering temperature [3].

To reduce the fuel cycle costs and the total mass of spent LWR fuels, it is necessary to extend the fuel discharged burn-up [4]. In order to increase the fuel burn-up, it is important to understand the fuel property of a highly irradiated fuel pellet. Especially, research has focused on the formation of a porous and small-grained microstructure in the rim area of the fuel, called High Burn-up Structure (HBS). The average grain size of HBS is about 300nm [5,6].

This paper deals with the feasibility study on the fabrication of nano-structured UO_2 pellets. The nano-sized UO2 particles are prepared by a combined process of a oxidation-reducing and a mechanical milling of UO_2 powder. Nano-structured UO_2 pellets (~300nm) with a density of ~93%TD can be obtained by sintering nano-sized UO_2 compacts.

The SEM study reveals that the microstructure of the fabricated nano-structure UO_2 pellet is similar to that of HBS. Therefore, this bulk nano-structured UO_2 pellet can be used as a reference pellet for a measurement of the physical properties of HBS.

2. Experimental

For nano-structured UO_2 pellets, nano-sized UO_2 powders were prepared by a mechanical milling of U_3O_8 powder. As-received ADU-UO_2 powders were oxidized to U_3O_8 at 450 °C under air. These powders were mechanically milled for 2h. After a milling, the powders were reduced to the UO_2 phase at 450 °C in H_2. The reduced powders were mechanically milled again for 1h.

The prepared UO_2 powders were pressed into green pellets. Its densification behavior was investigated by using a dilatometer, where the sample was heated at a rate of 5 K/min up to 1400 °C in H_2.

Sintering temperature for the nano-structured UO_2 pellets was determined from a densification curve. The temperature showing the maximum densification rate was chosen for the sintering temperature.

The nano-structured UO_2 pellets were fabricated by sintering the green pellets at the determined temperature from a dilatometer curve at several different times in H_2.

The sintered density of the UO_2 pellets was measured by the water immersion method. The pore and grain structure were examined by SEM.

3. Results

Because both a densification and grain growth are thermally activated processes, it is difficult to obtain fully dense bulk ceramic pellet that retains its original nano-scale grain size. In order to avoid an exaggerated grain growth, it is necessary to decrease the sintering temperature to as low as possible. The nano-sized UO_2 compact shrinks rapidly between 1200 °C and 1300 °C, and reveals a much reduced densification rate at a higher temperature. The densification curve shows the maximum densification rate at around 1250 °C. In our present study, we determined 1250 °C as a sintering temperature.

The nano-sized UO_2 compacts were sintered at 1250 °C for 2, 10 h in H_2, respectively. Fig. 1 shows the SEM microstructure of the sintered pellets surface. Both pellets show a relatively dense and nano-structured grain shape. The sintered pellet densities were 87 and 93%TD of pure UO_2 and the estimated grain sizes were ~200 and ~300nm, respectively.

For a comparison, a photo representing the typical HBS is shown in Fig. 2 [5]. The pore structure of the HBS is slightly different from that of Fig.1. However, the grain size and grain shape are quite similar to each other.

4. Summary

Nano-structured UO_2 pellets which resemble the HBS of an irradiated fuel have been prepared. We are expecting that these bulk UO_2 pellets can be used as a reference pellet for a measurement of the thermo-physical properties of HBS. Study for a more detailed fabrication process to simulate HBS is in progress.

Acknowledgements

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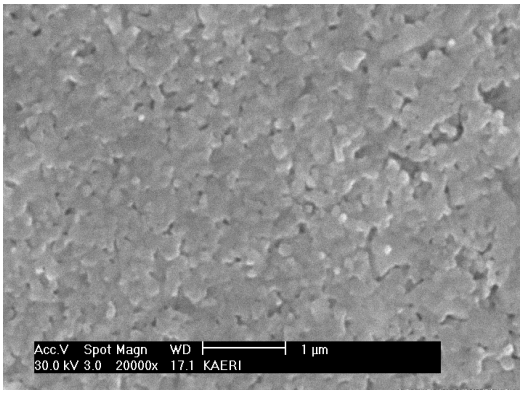
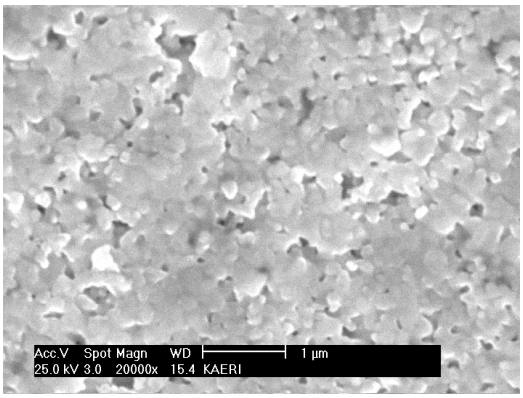


(a)



(b)

Fig. 1. SEM high magnification observation of the nano-structured UO_2 pellets surfaces, which are sintered at 1250 °C for (a) 2h and (b) 10h in H_2, respectively

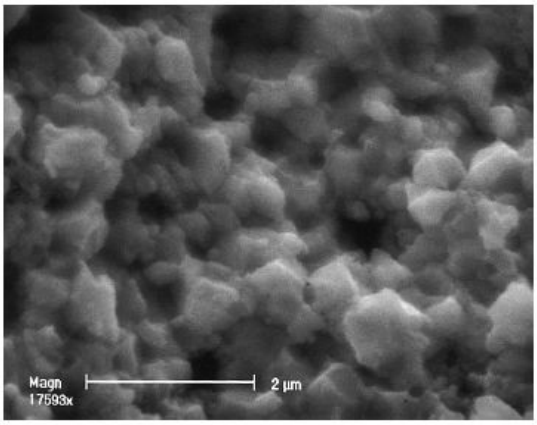


Fig. 2. Typical SEM micrograph of HBS. [5]

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