Thermal expansion measurement under compressive pressure to simulate the PCI of fuel pellets

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1. Introduction

Extending the fuel discharged burn-up, while enhancing safety features is one of the major challenges to nuclear energy industries because it can reduce the maintenance and fuel cycle costs [1]. Increasing the burn up may lead faster and higher power variation such as a higher maximum power or normal operating transient (load follow). In such operation conditions, the risk of fuel failure is related to pellet-clad-interaction (PCI).

In a fuel pellet's aspect, PCI improvement can be achieved by enlarging the pellet grain size and enhancing the fuel deformation at an elevated temperature. Large grain pellet can reduce the corrosive fission gas release at high burn up. Soft pellets can lower the pressure to cladding caused by thermal expansion of pellet at an elevated temperature during the transient operations. So, the recent development of advanced fuel pellet materials is mainly focused on the soft pellet having large grains [2].

Out-of-file mechanical property of the soft pellet can be characterized by a conventional compressive creep test. Creep test is performed by compression the pellet at a constant temperature and under a controlled atmosphere. The dimensional change of pellets with time is measured and compared.

In conventional creep test, dimensional variation is measured under a static condition. So it might be difficult to intuitively compare the PCI property of fuel pellets because the PCI is a dynamic interaction in which fuel expansion and deformation are occurred simultaneously.

This paper deals with the modified mechanical test method to characterize the PCI property of fuel pellets. We simulated the fuel average temperature change during the transient condition and measured the compressive deformation of pellets. The measured curves give us the total deformation of the fuel pellets during the simulated transient temperature condition. The PCI property of fuel pellets can be estimated and easily compared through the modified method.

2. Experimental

Two kinds of UO_2 pellets of a conventional and a large grain pellets are fabricated to measure mechanical properties. For conventional UO_2 pellets, as-received ADU-UO_2 powders were pressed into green pellets, and then sintered at 1730°C for 4h in H_2 gas. Large grain UO_2 pellets were fabricated by a developed doping process. Suitable amount of doping element powder was mixed with as-received ADU-UO_2 powders. This powder mixture was pressed into green pellets and sintered at 1730°C for 6h. The sintered density of the UO_2 pellets was measured by the water immersion method. The pore and grain structure were examined by optical microscope.

The mechanical properties of two kinds of sintered pellets were measured by a high temperature compressive creep machine. Conventional creep test was performed by applying a compressive pressure of 60MPa at 1450°C. The longitudinal deformation with time was measured by LVDT.

In order to measure the PCI simulated mechanical deformation, pellets were heated to 750°C. This temperature is corresponding to the average temperature of fuel pellets under normal operation. At 750°C, 60MPa of load were applied to the pellet and the sample was heated to 1450°C with heating rate of 140°C/h. The target temperature and heating rate were determined by considering the ramp schedule during the power transients operation. The longitudinal deformation with time was measured by LVDT.

3. Results

The theoretical pellet density and grain size of conventional and large grain pellets were 97.6%, 98.4% and 7.6μm, 45μm, respectively.

Fig. 1 show the conventional creep deformation curves for fuel pellets, measured at 1450°C with 60MPa of compression. Creep curves reveal that the large grain pellet is more deformed under applied compression condition. So, we can conclude qualitatively that the developed large grain pellet is more beneficial to PCI.

The average pellet temperature is elevated from about 750°C to about 1450°C by the ramp of linear power in the transient operation. As the pellet temperature raise, the fuel pellets are thermally expanded. Thermal expansion of pellets imposes a hoop stress to the claddings which wrap up the pellet. Then, pellets feel compressive forces and likely to be contracted. Competition between the two opposite deformation vectors determines the total deformation of the pellets.

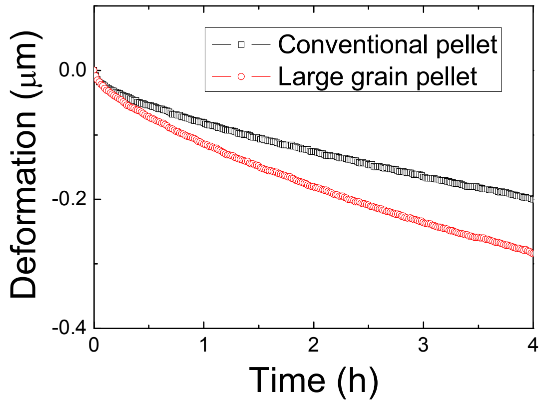

Fig. 1. Creep deformation curves of fuel pellets

Fig.2 shows the deformation curves of fuel pellets, measured under a simulated transient condition. At low temperature, pellets are thermally expanded. Whereas, when the temperature of pellets is elevated to about 1200°C, the pellets begin to contract. These curve shapes are coincident to expectation because the pellets are softened at an elevated temperature.

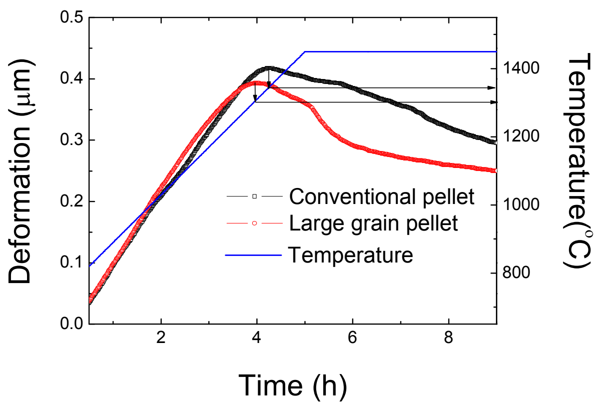

Fig. 2. Pellet deformation curves under simulated PCI condition

There are two distinct differences in the deformation curves;

-Large grain pellets are contracted at lower temperature than conventional pellets.

-Total expansion of large grain pellet is smaller than that of conventional pellets.

These two facts directly reveal that the large grain pellet can effectively reduce the hoop stress to the cladding during the transient operation. That is, large grain pellet shows relatively good PCI performance than conventional pellet.

Acknowledgements

This study has been carried out under the Nuclear R&D Program by the Ministry of Education, Science and Technology in Korea.

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