Creep behavior in Cr-doped UO_2 pellets

*Jang soo Oh**, Jae Ho Yang, Ik Hui Nam, Jong Hun Kim, Dong-Joo Kim, Young Woo Rhee, Keon Sik Kim*

Korea Atomic Energy Research Institute,
(150-1 Dukjin-Dong), 1045 Daedeokdaero, Yuseong-gu, Daejeon-si 305-353, Korea
jangsoo@kaeri.re.kr

1. Introduction

Corrosive fission gas escaped from the fuel pellets deteriorates the robustness of nuclear fuel rod and reduces the nuclear fuel safety in a high power density and high burn-up operation. Thermal expansion of pellets induces a PCI (Pellet-Cladding Interaction) and the rapid power uprate should be avoided for the safety of nuclear fuel[1-2].

Large grain pellet can reduce the corrosive fission gas release at high burn up. It also have softness so can improve PCI property. So recent researches are focused on the development of the large grain UO_2 pellets having high plasticity.

The Cr-doped UO_2 pellet is one of the promising candidates for high burn-up fuel in commercial LWRs. Major nuclear fuel vendors initiated the development of Cr-doped or Cr-containing additives doped UO_2 pellets since the mid 90's. Various in-pile tests results revealed that the PCI properties were enhanced considerably. Now, qualification programs are on-going to provide these pellets commercially.

Although optimum composition and sintering process for Cr-doped UO_2 has been suggested by several researchers, developing a new sintering process which could minimize the doped amount of Cr_2O_3, while keeping the grain size and softness of UO_2 is still a challenge because doped Cr itself could reduce neutron economy and fission gas retention ability.

KAERI has been developing a novel and unique sintering process which can reduce the doped amount Cr in UO_2 or enlarge the grain size more with a same doping level of Cr. The results showed that the introduction of a step-wise variation of oxygen partial pressure during the isothermal sintering enhances the grain growth of UO_2 pellets greatly.

In this paper, we investigated creep deformation behavior of Cr-doped UO_2 pellets sintered by the step-wise manner and compared the creep deformation behavior with that of the conventionally sintered pellets. A phenomenological interpretation of deformation hardening observed during the compressive creep test of Cr-doped UO_2 pellets was given. Microstructure of the pellet after the creep test also examined to find the correlation between deformation hardening and microstructure evolution during the compressive creep deformation.

2. Experimental

The starting materials were UO_2 powder produced through the ADU(Ammonium Di-Uranate) process. Cr-doped UO_2 was prepared by using Cr_2O_3 powders and UO_2 powders. These powders were mixed for 12h using tumbling mixer. Amount of the Cr_2O_3 in UO_2 was determined to be 800, 1000, 1200 and 1500ppm in weight ratio of Cr to U.

The mixtures of Cr_2O_3 powders and UO_2 powders were pressed into green pellets at 3 ton/cm^2. The green pellets were sintered at 1700℃ for 10 h in flowing H_2 and mix gas of H_2 and CO_2. In step-wise sintering process, the oxygen potential of sintering gas was increased gradually to control the Cr dissolution rate.

For the examination of grain boundary, The pellets were sectioned axially, ground and polished. The polished pellets were thermally etched at 1290℃ in carbon dioxide. Optical microscope was used to characterize grain structure and the grain size.

The compressive creep tests were performed under 60 MPa at 1450℃. The tests were conducted in a mix gas of 10% hydrogen and 90% argon gas in order to maintain the constant stoichiometry of the specimens during the experiment.

3. Results

Creep tests were carried out for the pellet sintered under various sintering atmospheres. Fig. 1 shows the deformation curves of Cr-doped UO_2 pellets (μg(Cr)/g(U)=1000) which were obtained by sintering under different atmospheres. Figs. 2 and 3 show the typical microstructure of test pellets before creep test. Creep deformation produces dislocations. Small amount of dislocations were formed at the initial stage of creep and those dislocation can move freely without a massive collision with another dislocations or grain boundaries in the large grain pellets. After the massive deformation, dislocations were accumulated, tangled and sub-grain boundaries were made. Then the large grain effect were disappeared and the creep curve entered in the steady-state stage. So the typical creep curve of large grain UO_2 pellets shows a large deformation at primary creep stage and similar creep rate at steady-state stage when compared with that of normal grain UO_2.

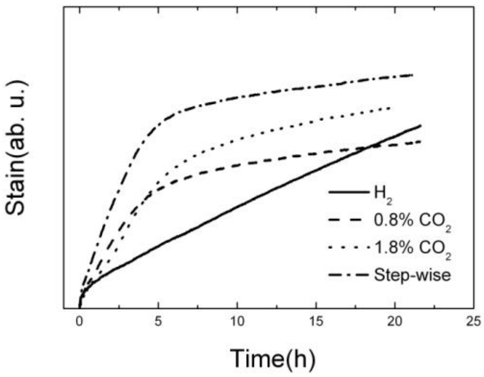

Fig. 1 Compressive creep deformation curves of the Cr-doped UO_2 pellets (μg(Cr)/g(U)=1000) which were sintered at 1700 for 10h (a) in H2 (b) in 0.8CO_2-H_2 (c) 1.8%CO_2-H_2 and (d) in step-wise variation.

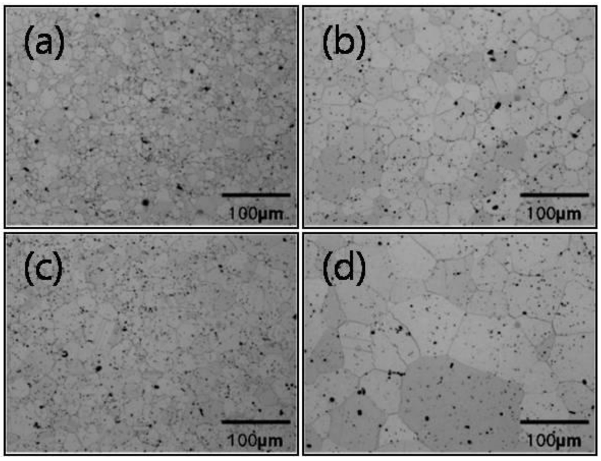

Fig. 2 Grain structures for the samples of Fig. 1 before creep test.

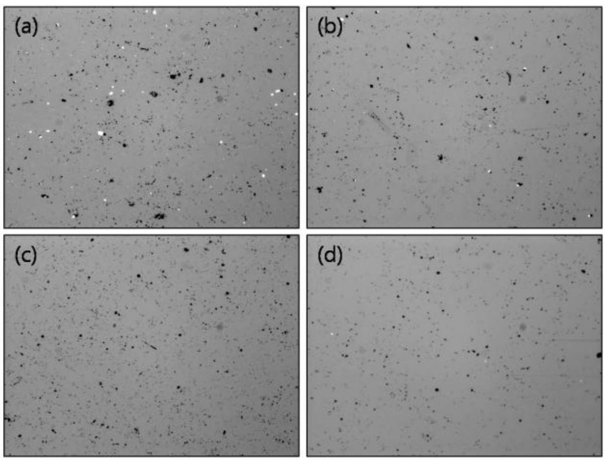

Fig. 3 Pore structures for the samples of Fig. 1 before creep test. Bright spots are the Cr precipitates reduced from Cr_2O_3.

In Cr-doped UO_2 pellets, the creep curves and microstructures indicated that the non dissolved Cr particles, bright spot in fig. 3, reduced the deformation rate of primary creep stage and the dissolved Cr reduced the deformation rate of steady-state creep stage. It seems that when the grain size large enough, Cr precipitates located in the grain can inhibit the dislocation movement. However, since the number of Cr precipitates located in a grain was reduced rapidly after the sub-grain boundaries formed, Cr precipitates does not reduce the steady state creep rate. However, dissolved Cr can act as an obstacle for dislocation movement since dissolved Cr located in the lattice.

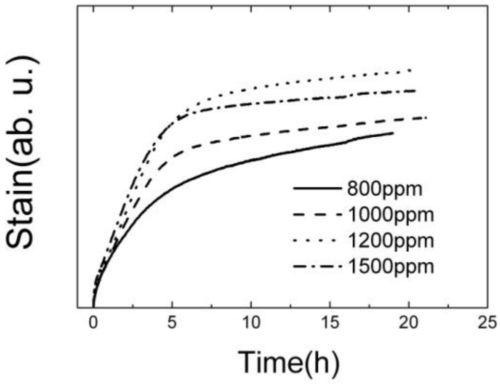

Fig. 4 Compressive creep deformation curves of the Cr-doped UO_2 pellets as a function of Cr contents (μg(Cr)/g(U)). The pellets were sintered by step-wise sintering process.

Fig. 4 shows the creep curves as a function of Cr contents in UO_2. In those pellets, precipitated Cr was not observed. Deformation curves showed that the primary creep was increased with increase of Cr content (grain size). Whereas, the steady-state creep rate decreased with increase of doping level. This results indicated that dissolved Cr is a main factor which occur deformation hardening in Cr-doped UO_2 pellets.

REFERENCES

[1] Ph. Dehaudt et al. Procceding of the IAEA Technical Committed Meeting, “Advanced in fuel pellet technology for improved performance at high-burnup”, Tohyo, October 28-November 1, 27 (1996)
[2] C. Nonon, J-C. Menard, S. Lansiart, J. Noirot, S. Martin, G-M. Decroix, O.Rabouille, C. Delafoy and B. Petitprez, “PCI behavior of chromium oxide-doped fuel”, Pellet-clad interaction in water reactor fuel, seminar Aix-en Provence, France, Mar.9-11, 2004, p305-319, OECD NEA No.6004.