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Deformation hardening in Cr-doped UO_2 pellets

*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 Dukjing-Dong), 1045 Daedeokdaero, Yuseong-gu, Daejeon-si 305-353, Korea
yangjh@kaeri.re.kr

1. Introduction

Extending the fuel discharged burn-up, while enhancing the 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 to a faster and higher power variation such as a higher maximum power or normal operating transient (load follow). In such operation conditions, the risk of a fuel failure is related to a pellet-clad-interaction (PCI).

From 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 a cladding caused by a thermal expansion of a pellet at an elevated temperature during transient operations. So, the recent development of advanced fuel pellet materials is mainly focused on the soft pellet having large grains [2].

Among these, Cr-doped UO_2 pellet is one of the promising candidate. It was shown that the grain size and softness of UO_2 pellets could be enhanced by doping Cr or Cr compound in UO_2. Various in-pile tests results revealed that the PCI properties were been enhanced considerably. Recently, KAERI has shown that grain size of Cr-doped UO_2 pellets could be more enlarged by adjusting process parameters.

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

During the isothermal creep tests of Cr-doped UO_2 pellets, we have found that the deformation rates were abruptly decreased. Decrease of deformation rate indicates that the hardening occurred in the pellets.

This paper deals with a phenomenological interpretation of deformation hardening observed during the compressive creep test of Cr-doped UO_2 pellets. Effect of doped Cr amount, creep test temperature and applied stress on the deformation hardening were observed. The measured curves provided us with the steady state deformation rate dependence on test parameters. Microstructure evolution also examined to find the correlation between deformation hardening and microstructure variation during the deformation. The PCI property of the fuel pellets can be estimated through the investigation.

2. Experimental

Cr_2O_3 powders were added to UO_2 powder, and mixed powders were blended for 12h in a tumbling mixer. The contents of the Cr were determined to be 800, 1000, and 1500ppm in weight. The UO_2 powder used in this work was produced through the ADU (Ammonium Di-Uranate) process. For comparisons, undoped ADU-UO_2 powder was also prepared.

The prepared Cr_2O_3 containing UO_2 powder mixtures were pressed into green pellets at 3 ton/cm^2. The green pellets were sintered at 1700℃ for 6 h in flowing H_2 containing gas. The oxygen potential of sintering gas was increased gradually to control the Cr dissolution rate.

The sintered density of the UO_2 pellets was measured by the water immersion method. The pellets were sectioned axially, ground and polished. The polished pellets were thermally etched at 1290℃ in carbon dioxide gas in order to examine their grain boundaries. The grain structures were examined by an optical microscope and the grain size was determined by the linear intercept method.

The compressive creep tests were carried out under different initial stresses of 50, 60 and 70MPa and a temperature at 1450℃. The tests were conducted under a 10% hydrogen containing argon gas mixture in order to maintain the constant stoichiometry of the specimens during the experiment.

3. Results

Fig. 1 shows the creep deformation curves of Cr doped UO_2 pellets under a compressive stress. Creep tests were performed under an initial applied stress of 60MPa and a temperature of 1450℃. For a comparison, the deformation curve of the undoped UO_2 pellet is presented together. At the initial stage of deformation, strain rate was increased considerably with increasing the Cr contents in UO_2 pellets. For example, the deformation strains of the doped UO_2 pellets after 4h are several times larger than that of the undoped UO_2 pellet. However, deformation hardening occurred and the strain rates were decreased abruptly with time. The deformation rate in steady-state were decreased with increasing the Cr contents in UO_2 pellets. This contradictory effect of Cr on the deformation rate of

UO_2 pellet implies that the deformation hardening was related with Cr in UO_2 pellets. Large grain feature of high Cr containing UO_2 enhances the initial deformation of UO_2 . However, the Cr is considered to act as pinning site when the diffusion governing the deformation.

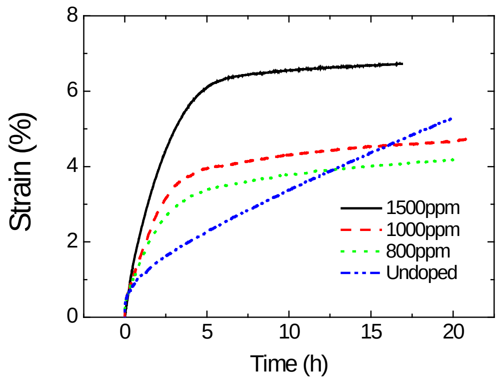

Fig. 1. Compressive creep deformation curves of the Cr-doped UO_2 and undoped-UO_2 pellets

The steady state creep strain rate can be represented in terms of mass transfer equation. According to the equation, in isothermal and isobaric condition, natural logarithm of strain rate is a linear function of activation energy of diffusion. Fig. 2 shows the natural logarithm of strain rate versus Cr concentration curve. In this graph, we could find a linear dependence. This fact implies that the activation energy of diffusion increased with increasing Cr content and the activation energy increase directly correlated with Cr concentration.

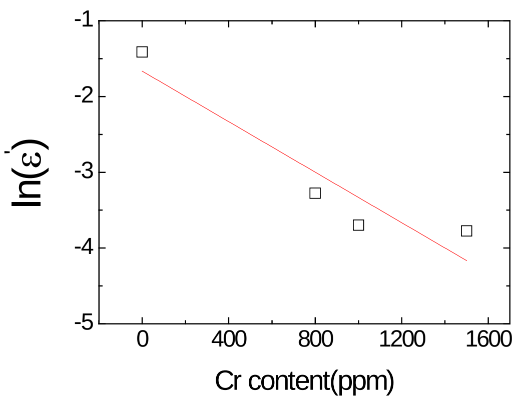

Fig. 2. Relation between strain rate at steady state and Cr concentration in UO2 pellets.

Acknowledgements

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