Advanced Mn-base additives doped-UO_2 pellets for high performance and high burn-up LWR fuel applications

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1. Introduction

Thus far, the nuclear power industry has improved plant capacity factors by incremental improvements in fuel reliability, and burn-up. The uranium enrichment, fuel cycle length and fuel discharged burn-up have been increased about 50% during the last 15 years. However, these upgrades have effectively reached their maximum achievable impact within the constraints of existing fuels. Advanced high performance fuels are an essential part of the safe, economic operation of LWRs. The new fuels have improved safety margins and economics and are more reliable. The fuel provides room for additional power uprates and high burnup limits.[1]

Power uprates and high burnup may lead to a faster and higher power variation such as a higher maximum power or normal operating transient (load follow). In such operating conditions, the risk of a fuel failure is related to a pellet-clad-interaction (PCI). The EPRI reported recently that fuel failure due to the PCI started to be observed in the 2000ies. PCI continues to be a significant cause of LWR fuel failures. PCI resistance needs to be satisfactorily addressed in the case that it needs to operate under load follow condition or high duty in the PWRs.

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].

KAERI launched a new project of ′High Performance Fuel Technology Development′. As a part of this project, we started to develop large grained and soft UO_2 pellets by adapting an additives technology.

In this paper, we briefly introduce our research activities. We describe the fabrication process of developed doped UO_2 pellets and evaluation of their thermo-mechanical properties at an elevated temperature. We also compare the pellet properties of developed pellets with those of pellets which were developed by the major nuclear fuel vendors.

2. Experimental

Three kinds of Mn-base additives were prepared. The oxide mixtures were ball milled for 24h in a jar containing zirconia balls and alcohol and then dried in air for more than 3 days at room temperature. The three additives were added to UO_2 powder, and three mixed powders were blended for 2h in a tumbling mixer. The contents of the additives were determined to be a 1000ppm 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 pellets were also prepared.

The prepared additives containing UO_2 powder mixtures were pressed into green pellets at 3 ton/cm^2. The green pellets were sintered at 1730℃ for 4 h in flowing H_2 gas. 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 an initial stress of 60MPa and a temperature at 1450℃. The tests were conducted under a 10% hydrogen containing argon gas mixture in order to maintain the stoichiometry of the specimens constant during the experiment.

3. Results

3.1. Microstructure

Fig. 1 shows the grain structure of the Mn-base additives doped UO_2 sintered pellets. For a comparison, a grain structure of un-doped pure UO_2 pellet was also shown in this figure. The grain structure of un-doped UO2 pellet shows typical UO_2 grain structures and its grain size was measured to be 8μm. The grain sizes of the developed pellets were measured to be more than 50μm. These grain sizes are about 6 times larger than that of un-doped UO_2 pellets. The grain sizes are greatly enlarged in Mn-base additives doped UO_2 pellets.

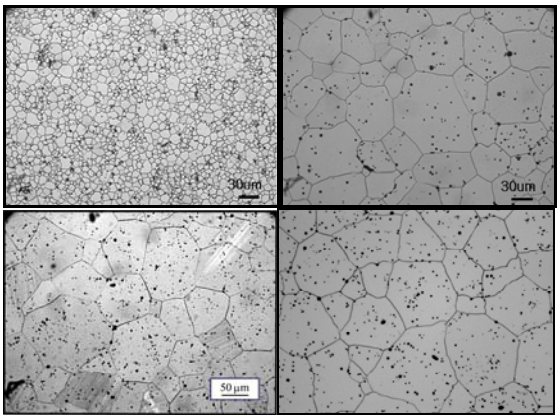

Fig. 1. Microstructure of (a) the pure UO2 and (b)-(d) Mn-base additives doped UO_2 pellets.

3.2. Deformation property

Fig. 2 shows the creep deformation curves of the developed Mn-base additives 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. Deformation curves clearly show that the addition of Mn-base additives increases the creep deformation of the UO_2 pellets considerably. For example, the deformation strains of the doped UO_2 pellets after 4h are five times larger than that of the undoped UO_2 pellet.

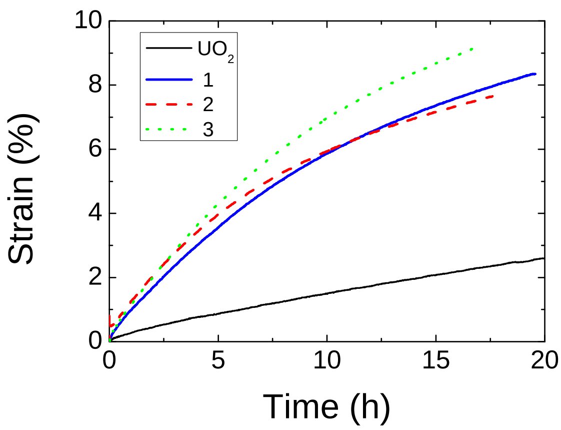

Fig. 2. Compressive creep deformation curves of the developed UO_2 and undoped-UO_2 pellets

The total amount of doped elements and the grain size of the Mn-base additives doped UO_2 pellets are almost the same as each other. However, their deformation curves are rather different from each other. This reveals that not only the grain size of the UO_2 pellets but also the chemicals in the UO_2 pellets are important for the compressive creep deformation behavior of UO_2.

3.3. Comparison with other doped-UO_2 pellets developed by major vendors.

The major nuclear fuel vendors of AREVA, Westinghouse, and GNF have been developing their own additive-doped large grain UO_2 pellets technology in order to improve the PCI behavior since the early 90ies. Fig. 3 briefs the characteristics of developed advanced Mn-base additives doped UO_2 pellets and shows the comparison of pellet property with other advanced fuel pellets developed by major vendors.

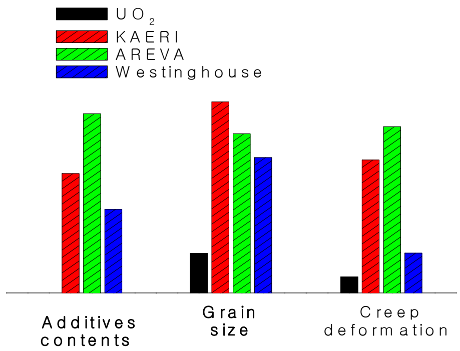

Fig. 3. Comparison of doped UO_2 pellets property

The grain size and creep deformation behavior of our newly developed pellets are similar to or better than those of other developed pellets. Other advantages of our technology are the low additives amount and the good compatibility with the commercial fuel pellet manufacturing process.

Acknowledgements

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