Autoclave washout test to simulate exposure of the UO_2 pellets under PWR conditions

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1. Introduction

The development of UO_2 fuel containing additives capable of enhancing PCI resistance performance has been conducted worldwide for the past 30 years. For that purpose, it is aimed at weakening the adverse effect of the nuclear fuel itself on the safety of the cladding tube, not only in the high burnup but also in the load following operation. In particular, the creep test to evaluate the high temperature plasticity of UO_2 fuel was an important improvement which reduces stress to cladding tube [1,2]. However, not only the performance effect of maintaining the integrity of the cladding tube but also its oxidation behavior when exposed to the water chemistry environment in reactor has been evaluated [3]. The results of these characterization tests are important for the evaluation of its oxidation resistance, which are included in the topical reports for licensing of UO_2 fuel which are doped with Cr_2O_3 developed by Framatome and Al_2O_3-SiO_2 developed by GNF [4,5].

In the UO_2 pellets exposed to the oxidizing environment, the oxidation reaction occurs actively along the grain boundaries. At this time, the O/U ratio becomes higher and the crystal structure changes due to increasing oxygen ratio, resulting in fragmentation [6,7]. This phenomenon eventually accelerates from outside to inside of the pellets through grain boundaries. Therefore, it has been reported that the fragmentation of UO_2 sintered body can be prevented by reducing the grain boundary area vulnerable to oxidation or applying a second phase material having excellent oxidation resistance [3].

At present, KNF is developing PCI additives for enhancing PCI failure resistance of UO_2, and developed a washout autoclave system to evaluate oxidation resistance when UO_2 containing additives is exposed to water chemistry environment in pressurized light water (PWR) reactor. In this work, we confirm that water chemistry and other conditions including reactor temperature and system pressure in primary system of PWR were simulated by using the autoclave washout equipment. In addition, the oxidation tendency of UO_2 which varies with the sintering additive can be measured by weight increment.

2. Methods and Results

2.1 Washout autoclave system for simulating PWR water chemistry and its performance

Fig. 1. Schematic view of the washout equipment

The washout autoclave system was fabricated and installed as shown in Fig. 1 in order to evaluate the washout performance of UO_2 exposed to the water chemistry environment after cladding failure. The loop system is a structure in which water is supplied from external water storage tank to the autoclave in which the corrosion test is performed. DO and pH sensors were installed to measure the water chemistry of the supplied water, and pressure sensor and thermocouple were installed in the autoclave to measure system temperature and pressure.

The washout autoclave equipment was run to verify whether it simulates the PWR water chemistry and environment conditions or not. As shown in Fig. 2. DO and pH of the water were measured to be maintained at less than 5 ppb and pH 6.4, which satisfied the PWR primary water chemistry standard. The temperature and pressure inside the autoclave were measured as shown in Fig. 4 at a set temperature and pressure of 18.5 MPa and 360ºC respectively.

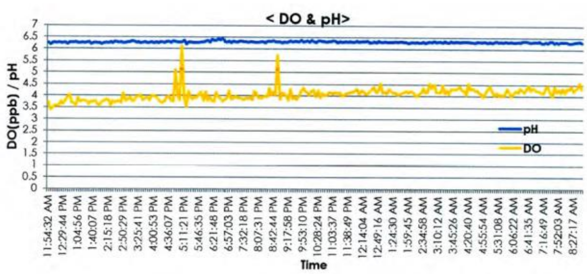

Fig. 2. DO, pH measurement data in water

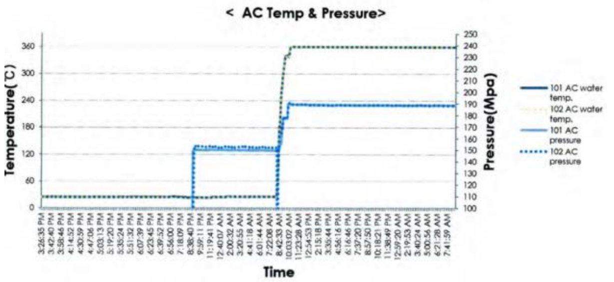

Fig. 3. Water temperature and pressure measurement data

2.2 UO_2 exposure in autoclave washout system

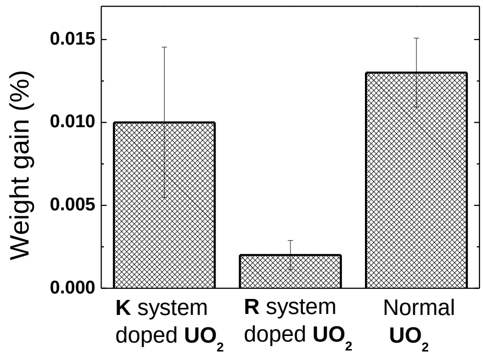

Fig. 4. Weight gain of additives doped UO_2 as a result of washout test

Figure 4 shows the results of an oxidation test using the autoclave washout equipment to evaluate the washout performance of UO_2 containing two (K, R) oxide additive systems under development. Five specimens were tested for each type and the results were measured by weight gain. The reason for analyzing the oxidation tendency through the weight increase measurement is that the O/U ratio changes to 2 (UO_2), 2.33 (U_3O_7) and finally 2.66 (U_3O_8) as UO_2 is oxidized,

As a result, the weight increase of UO_2 with R additive was 0.002% up to a factor of 5 ~ 6 times in comparison K system and general UO_2. However, typically UO_2 oxidation occurs largely only when the dissolved oxygen level was more than 3 ppm [8]. The weight gain data in Fig. 4 are in agreement with the work of Une et al. [8]. Therefore, it is concluded that the rate of corrosion progression was slow during the experiment. Figure 5 shows the surface of the oxidized UO_2 fuels. As can be estimated from the weight gain data in Figure 4, the surface oxidation of pellets appears not to be noticeable.

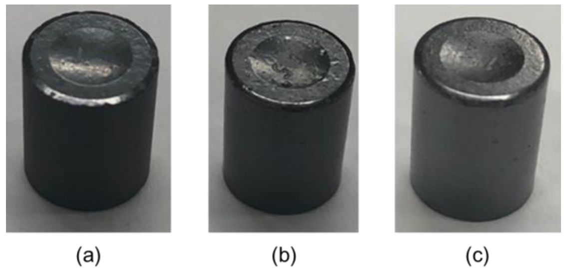

Fig. 5. External examination of samples oxidation test in PWR conditions, which are (a) K, (b) R system doped UO_2 and (c) normal UO_2, respectively.

3. Conclusions

Autoclave washout equipment of loop type was fabricated to measure the corrosion performance of UO_2 in PWR water chemistry and environment conditions. The measured DO, pH, system pressure, and autoclave temperature satisfied the primary water chemistry. Oxidation resistance of UO_2 containing K, R oxide additives has been evaluated using the equipment. As a result, the weight increase rate due to oxidation of UO_2 with the R system were measured to have 5 to 6 times better corrosion resistance than the K added and general UO_2.

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