Breakaway Oxidation of Constrained Zirlo at 1000℃

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1. Introduction

After Fukushima accident occurred in JAPAN, safety of nuclear cladding in accident condition like Loss Of Coolant Accident (LOCA) has become one of the most serious topics on these days. According to Nuclear Regulatory Commission guide line proposed in March 2014[1], cladding performance tests for LOCA are needed to ensure that fuel-rod cladding retains ductility following long-time oxidation in steam at temperatures in the range of 650-1,050degrees Celsius(℃).

During high temperature oxidation of zirconium alloys, transition to breakaway stage causes the most critical degradation, since oxygen and hydrogen pick up are accelerated. There have been many researches about mechanisms of breakaway oxidation. The breakaway mechanism proposed by Leistikow and Schanz (LS)[2] has been widely accepted, many researches have been conducted to prove LS model. LS model basically assumes that breakaway oxidation is initiated by the transition of oxide phase (tetragonal to monoclinic), which causes stress distribution change inside zirconium oxide.

In this study, breakaway oxidation behavior of Zirlo is studied, concentrating on specimen holding state during the experiment, whether specimen is constrained or not. Claddings are being constrained in commercial reactors, however, there have been no researches whether constrained state of a specimen can affect breakaway oxidation or not. According to LS model, onset of breakaway oxidation is related to stress distribution inside Zirconium oxide. When a specimens is constrained, thermal stress within the specimen can cause compressive stress, and this can affect breakaway oxidation.

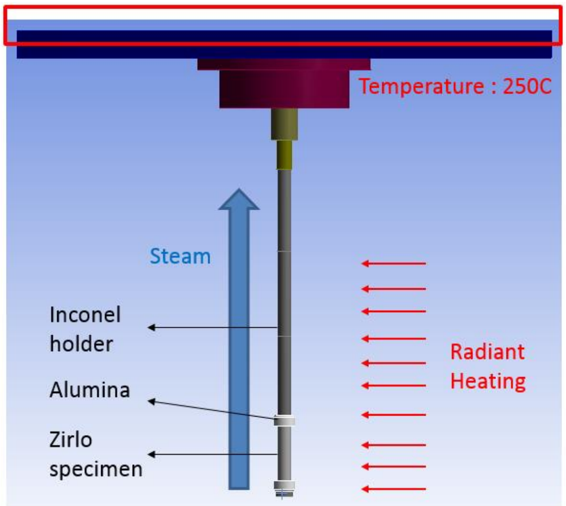

Fig. 1. Schematic illustration of the experiment

Chemical composition(%)		Dimension	
Fe	0.09-0.13	Length	40mm
Nb	0.8-1.2	Thickness	0.58mm
O	0.105-0.145	Outer Diameter	9.5mm
Sn	0.8-1.1		
Zr	Balance		

Table. 1. Basic information of Zirlo specimen used in experiment

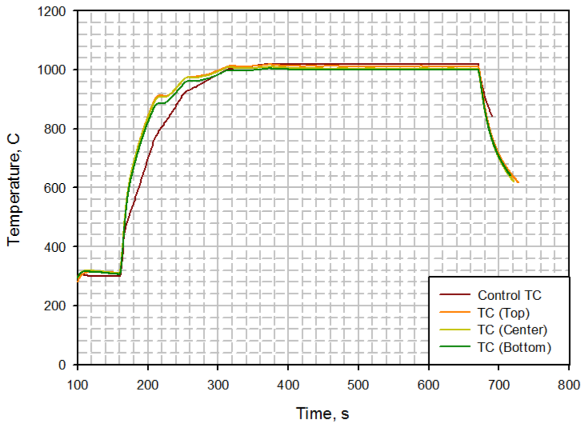

Fig. 2. Thermal benchmark result using sheathed thermo-couple

2. Experimental Setting

Fig. 1. shows a schematic illustration of our equipment. Basic information of the Zirlo specimen is shown in Table. 1. The specimen is heated by radiant heating, and steam is coming from the bottom. Constrained state was made by holding the Inconel holder tightly, and stress free state was made by leaving some spaces between the alumina and the Inconel holder.

Fig. 2. shows temperature calibration results using sheathed thermo-couples. Heating step was determined to minimize overshoot effect, and temperature of a specimen was measured at 10, 20, and 30mm height of the specimen. Measured temperatures are summarized in Table. 2. Circumferential temperature distribution has already been measured in the last experiment and it was proved that circumferential temperature difference is below 8.6 ℃[3].

Effective time of the experiment was calculated considering heat-up and cooling time. Heat-up and cooling time are calculated using the equation below[4].

$$t_{eff} = \int_0^t \frac{\exp\left(-\frac{Q}{RT(t)}\right)}{\exp\left(-\frac{Q}{RT(eff)}\right)} dt \quad (1)$$

	Temperature
Control TC	1020
Top (30mm)	1010.9
Center (20mm)	1003.7
Bottom (10mm)	1000.4

Table. 2. Temperature measured from calibration

Applying effective time, measured weight gain from the experiment was compared with the Cathcart-Pawel correlation[4]. It was proved that weight gain of the Zirlo agrees with the Cathcart-Pawel correlation.

3. Result

Several experiments were performed for Zirlo specimens which are constrained or in free condition for different time steps at 1000℃. It is clear that constrained specimens show different breakaway oxidation. Thermal stress may affect breakaway oxidation. How thermal stress affect stress distribution inside a specimen was analyzed precisely using computer simulation.

4. Summary

Breakaway oxidation of Zirlo specimens oxidized at 1000 ℃ in constrained condition is studied. Before the experiment, heating step, temperature distribution, and effective time were determined. In addition, weight gain of the specimen matches with Cathcart-Pawel correlation. Breakaway oxidation of the constrained specimen clearly shows different breakaway oxidation.

ACKNOWLEDGEMENT

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