Preliminary Study for Temperature Variation Verification of Radiant Heating Furnace for High Temperature Corrosion Test

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1. Introduction

The possibility of breakaway oxidation and resultant embrittlement of zirconium alloy cladding has been the concern for fuel rod integrity in accident conditions such as LOCA(Loss-Of-Coolant-Accident). In order to simulate LOCA condition which is represented by the high temperature steam oxidation of rapidly heated cladding and subsequent quenching by water, a radiant heating system with steam and water supply system is used for the test. The system is shown in Fig. 1.

A radiant heating system, used in most LOCA simulation tests, adopts 4 or 6 line bulbs in order to achieve uniform heating in a circumferential direction. It is important to verify that the circumferential temperature variation is within the reasonable range. In this study the temperature variation is measured using a thermocouple (TC) welded specimen and the effect of different parameters are discussed.

2. Methods and Results

Temperature control to achieve rapid heating to a test temperature level and to keep a steady temperature at the target temperature is described, as well as the method to measure temperature variation.

2.1 Temperature Control

The draft guide of the NRC for a breakaway oxidation test [1] recommends to hold and stabilize the steam flow and sample temperature at 300 °C and then rapidly heat the sample at > 50 °C/s to within 50-100 °C of the target temperature and then reduce the heating rate to 2-3 °C/s) from that temperature to the target temperature. However the test time to go from 650 °C to the target temperature is recommended to be less than 100 sec.

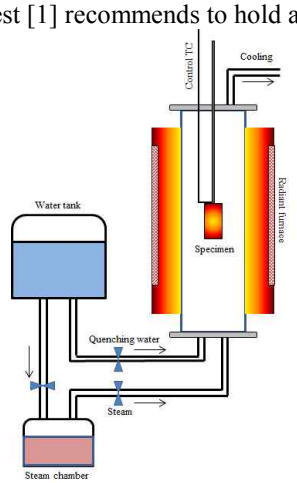

Fig 1. Schematic diagram of the LOCA simulation test equipment

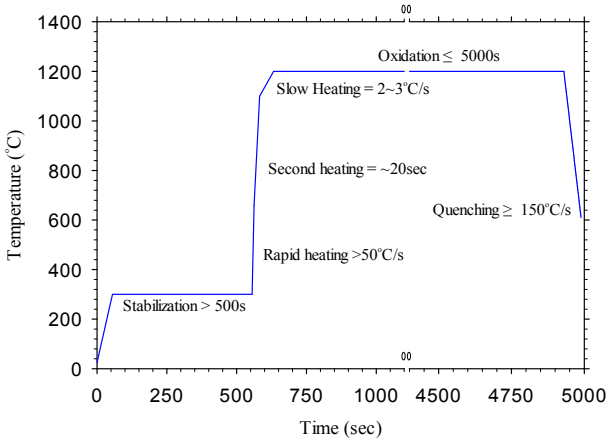

Fig 2. Temperature control to reduce the overshoot in sample temperature

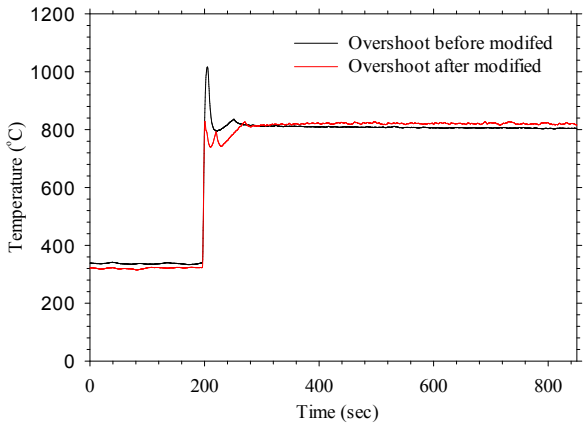

Fig 3. Overshoot before and after modified

The temperature is controlled using the signal from the control TC, which is in contact with the Inconel holder. When we measured the sample temperature, it showed a much greater temperature overshoot than the control TC temperature, probably due to the greater

thermal mass of the Inconel holder than the Zr alloy tube sample. In order to reduce the temperature overshoot in the sample temperature, a two-step approach to achieve the target temperature was used, as shown in Fig. 2, but still within 100 sec (~ 80 sec) from 650 °C to the target temperature. The thermal mass of the Inconel holder was also reduced by cutting and removing some portion of the structure. Fig. 3 shows the temperature overshoot in the sample before and after the changes.

2.2 Sample Temperature Measurement

A 9.5mm diameter Zr alloy tube with 0.5mm thickness and 40mm length was used as the test sample for temperature variation measurement. 3 K type TCs were welded at 120 degrees apart from each other at the same axial height to the sample for the circumferential and 3 K type TCs were welded at a 10mm, 20mm, and 30mm height from the bottom of the tube for the axial temperature variation measurement. The TCs were welded by a laser using a welding rod of Ag and Au. The welded samples are shown in Fig. 4.

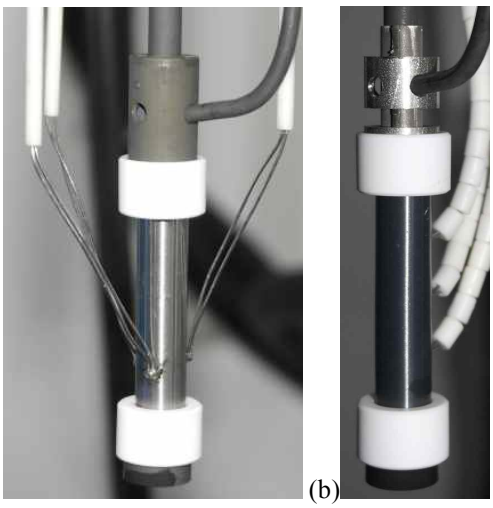

Fig 4. TC welded sample tubes for (a) circumferential and (b) axial temperature variations measurement.

The maximum temperature difference in 6 repeated tests using 2 welded samples was 8.6 degree which is well below the limit. However, the axial temperature variation was greater than expected. And the shadowing of the TC wires, heat loss through the 6 0.65mm diameter TC wires (compared to tube thickness of 0.5mm) surface covering by the alumina sample holders are some of the possible contributors for this over variation observed from the measurement.

3. Discussion and Future Plan

The radiant heating system used in most LOCA simulation tests employ 4 circumferentially arranged line bulbs [2] and the measured results showed bigger temperature variation in the circumferential direction than the variation in the axial direction. The radiant heating system used in this study adopts 6 line bulbs and showed a smaller circumferential temperature variation than other reported results.

The measured temperature variation in the axial direction was greater than that of circumferential variation. Possible contributors for this greater-than-expected temperature variation may be the heat loss through the 6 TC wires (a 0.65mm diameter compared to 0.5mm thickness of the sample tube), covering of the heat receiving sample surface (2.15mm at both ends by the alumina sample holder), and shadowing of the radiant heat transfer by the alumina protection of TC wires on the upper part of the tube.

The above effects will be studied further and improvements of the related parts will be pursued.

ACKNOWLEDGEMENT

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