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Temperature Variation in Radiant Heating Furnace for High Temperature Corrosion Test of Zirconium Alloy Tubes

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1. Introduction

The possibility of breakaway oxidation of zirconium alloy cladding at high temperatures around 1000C during small and large LOCA has been of concern in recent years. In March 2014, NRC proposed the revision of the ECCS acceptance criteria in recent Federal Register[1] to add breakaway oxidation to the previous criteria: the peak cladding temperature, cladding embrittlement, maximum hydrogen absorption, etc. The proposed 10CFR50.46 requires to set up the breakaway oxidation criterion based on actual performance of the fuel cladding and to confirm the criterion by periodic tests of the plant produced cladding tube[2].

The high temperature corrosion test equipment using radiant heating has been reported elsewhere [3] and the excessive axial temperature variation in the specimen was reported. In this paper, we will report how we reduced the axial temperature variation and meet the requirements specified in the guideline. [2]

2. Improvement of the axial temperature variation

In order to reduce the temperature variation in the specimen, the temperature control method was optimized and the upper torr seal, which was identified to release great amount of heat, was sealed with insulation materials and wrapped with heating coil to minimize the heat loss.

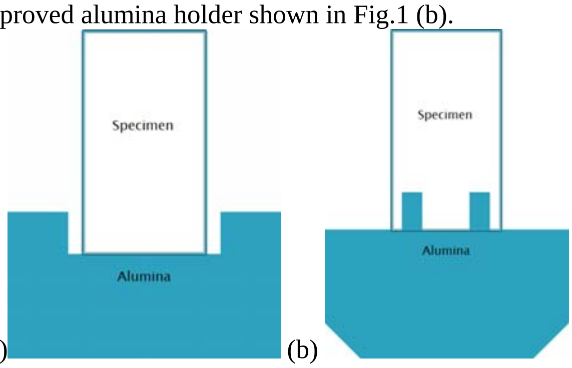
2.1. Previous study

Temperature overshoot was observed using recommended heating methods. This problem was solved by modifying some heating steps.

The axial temperature difference should be lower than 10 degree, and the circumferential temperature difference should be lower than 20 degree for same corrosion kinetics to be applied to a specimen.[1] The maximum circumferential 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.

2.2. Improvement of the axial temperature variation

The covering of the specimen at the lower end part of the specimen by the alumina specimen holder, as shown in Fig. 1(a), may shield the radiative heat transfer to a specimen and cause greater axial temperature variation in a specimen. This structure was removed by using the improved alumina holder shown in Fig.1 (b).



(a) (b)

Fig. 1. Alumina holder (a) before change the design and (b) after change the design

In order to achieve better temperature distribution in the quartz tube, the heat loss through upper torr seal was minimized by wrapping it with heating coil and seals it by insulators, as shown in Fig.2. It prevented the condensation of the steam at the torr seal area and enabled the steam to flow out to the environment. The condensation of the steam at the upper torr seal and subsequent falling of the water drops can cause disturbance in the temperature distribution in the tube and cause the axial temperature difference to be increased. By the improvements mentioned above, the

Fig. 2. The upper torr seal which is wrapped by coil heaters and covered by insulators.

axial temperature variation was reduced to be maximum 3 degrees and satisfied the requirement. The maximum circumferential temperature difference was 7 degrees and satisfied the requirement.

3. Verification of the test equipment

If a thermocouple is directly welded to a specimen during the experiment, the corrosion behavior of the specimen could be altered. Thus, temperature of a specimen is usually measured by an indirect method, using the control TC which is used to control furnace temperature. Control TC is welded on the Inconel holder, as shown in Fig.3.

According to the experimental guideline, the correlation between the specimen temperature and the control TC temperature should be established. This correlation was found by measuring the difference between the temperature of thermocouple which is welded onto a specimen and the temperature of the control TC.

The validity of the thermal benchmark was verified by measuring the weight gain of specimens which are not welded with the thermocouple and comparing it with the value predicted by Cathcart-Powel correlation[4].

Fig. 3. Control TC and specimen locations

4. Conclusion

The high temperature corrosion test equipment using radiant heating system is verified for the axial and circumferential temperature distribution in the specimen. And the specimen temperature and weight gain were verified by weight gain test using C-P correlation.

The system may be used for the high temperature corrosion test of different zirconium alloy tubes.

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