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Behavior of Creep in the Simulated Dual-Cooled Cladding Tubes

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1. Introduction

The concept of a dual-cooled fuel was developed to achieve low temperature operation along with high power density [1-3]. Dual-cooled fuel consists of two claddings and annular pellets, and is designed to provide double coolant channels. Korea Atomic Energy Research Institute (KAERI) is doing the R&D project for the development of dual-cooled fuel technology [3].

In this paper, creep deformations were investigated for the dual-cooled cladding tubes. There are two kinds of tubes, i.e. an inner and an outer cladding tube, which would deform in opposed directions by the creep process. The inner cladding creeps out (diametral increase) due to the tensile stress induced by the pressurized coolant. On the other hand, the outer cladding creeps down (diametral decrease) because of the compressive stress by the coolant. The creep rates are very different between the opposed creep modes. Also, differences in gap closure for the two claddings could be expected, which affect the heat split performance directly. Therefore, the creep should be analyzed for the safe design of dual-cooled fuel. However, to our best knowledge, no report is available on the creep of dual-cooled cladding tubes. There is only a few reports describing the difference in the tensile and compressive creep [4,5]. For this paper, the creep specimens simulating the dual-cooled tubes were fabricated and tested under both high pressure and high temperature conditions.

2. Methods and Results

2.1 Sample Preparation

The dimension of the inner cladding tube is 9.5 mm in outer-diameter and 0.57 mm in thickness. The outer cladding tube is 15.9 mm in outer-diameter and 0.87 mm in thickness. The commercial cladding tube used in PLUS7 or 17ACE7 was used as an inner cladding tube, since its dimension is identical to each other. The outer cladding tube was machined from intermediate tubes. The machined outer cladding tube has a 15.9 mm in outer-diameter and 0.89 mm in thickness. Since milling of the outer surface was the only available option, it was 0.02 mm thicker than the designed outer cladding tube.

End plugs were designed to be compatible with the electron-beam welding. Facilitation of the excess metals at the weld site is a general method in the electron-beam welding as presented in Fig. 1(a). However, zirconium is too stiff to machine the small weld tips on the limited space. The modified design as shown in Fig. 1(b) was compatible to the welding as well as machining. In addition, the tubes can be supported by the end plugs.

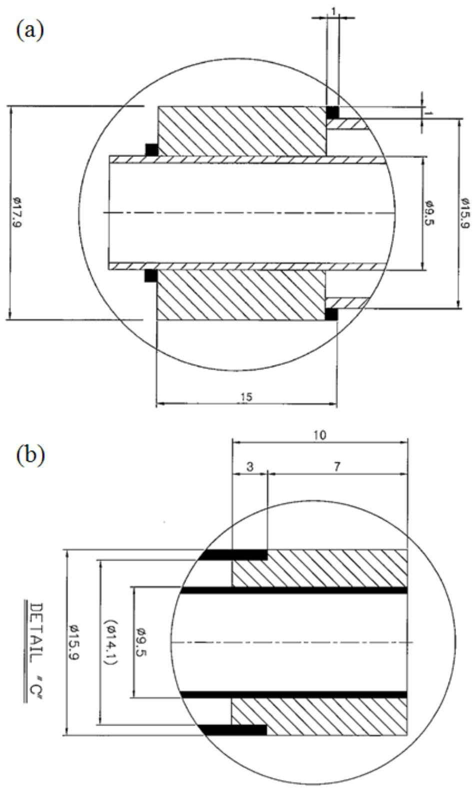

Fig. 1. Design of the end plug: (a) conventional and general for welding, and (b) modified to increase the weldability and machinability.

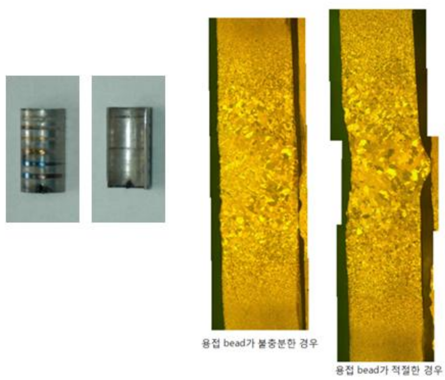

Fig. 2. Weld microstructures formed on the zirconium tubes.

Fig. 3. Fabricated creep specimens for the simulated dual-cooled cladding tube.

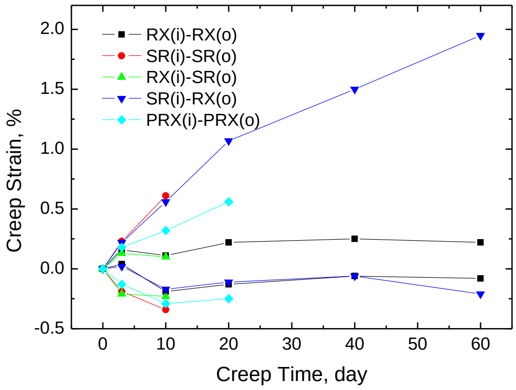

Fig. 4. Creep strains for the simulated dual-cooled cladding tubes under a 9.5 MPa external pressure at 380°C.

Sufficient beads are needed for the successful joining of the samples. If the beads are weak, the broken bonding is worrying. The welding conditions were tuned by using a dummy tube. Fig. 2 shows the corresponding microstructures after the electron-beam irradiation. Finally, the welded samples were pressurized up to 170 atm at 400°C in order to verify the welding quality. Fig. 3 demonstrates the fabricated specimens used in the creep test.

2.2 Creep Test

Creep was tested under an external pressure of 9.5 MPa at 380°C. The test was performed in a pressurized steam atmosphere in an autoclave, and the pressure was controlled by changing the amount of water. The test pressure is identical to the pressure difference between pressurized coolant and the inside of claddings in a real operational condition. The circumferential stresses of 74 MPa and –80 MPa are induced to the inner and outer cladding tubes, respectively. For the experiments, three types of microstructures were prepared, i.e. stress-relieved (SR), partial recrystallized (PRX), and full recrystallized (RX). The final annealing conditions were 460°C x 8 h for SR, 490°C x 8 h for PRX, 520°C x 8 h for RX, respectively.

Fig. 4 shows the creep strains for the dual-cooled cladding tubes. Inner cladding tubes under the tensile stress of 74 MPa were crept out, and outer ones under the compressive stress of 80 MPa were crept down. The secondary creep rate for the SR tube was the highest, and that for the RX one was the lowest. Several samples that deformed too much were collapsed before the end of the test. The creep rates for the tensile creep-out were about two times faster than that of the compressive creep-down. It was also observed that the creep behavior of each cladding was independent to the facing cladding tubes.

3. Conclusions

The creep specimens simulating the dual-cooled tubes were fabricated and tested under a pressurized steam atmosphere of 9.5 MPa at 380°C. Effect of the tensile and compressive stress on creep properties was investigated. The tensile stress induces creep-out of fuel cladding tubes, and the compressive stress causes creep-down of the tubes. The tensile creep was about two times faster than the compressive creep. Depending on the microstructures, the secondary creep rate for the SR tube was the highest, and that for the RX one was the lowest. The current investigation is expected to be informative to the R&D of the dual coolant annular fuel technology.

Acknowledgement

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