Advanced Tensile Test Techniques of Cladding Tube in Hot Cell

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1. Introduction

The mechanical properties of fuel cladding materials are degraded during steady state operation, through the mechanisms of oxidation, hydriding and irradiation damage. And the increased reactor exposure associated with higher fuel burnups results in additional cladding degradation. Therefore, it is necessary to determine the mechanical behavior taking into account the combined effects of oxidation, hydriding and radiation damage in both the transverse and longitudinal directions. In this paper, the modified tensile test techniques are proposed in order to evaluate mechanical properties of a cladding under hoop loading condition caused by pellet/cladding mechanical interaction (PCMI) and longitudinal loading condition.

2. Transverse Tensile Test Technique

2.1 Ring Specimen Geometry

Among various ring specimens for the transverse tensile test, the notched ring specimen (called as the ring specimen) is designed to limit a deformation within the gage section and to maximize a uniformity of strain distribution at the gage section. In this paper, we determined the optimum geometry of the ring specimen with 3 mm in length and 2 mm in width at the gage section based on the FEA and test results [1].

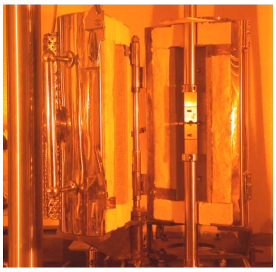

Figure 1. Grip in hot cell.

2.2 Grip Design

The two half-cylinders are designed such that a constant specimen curvature is maintained during deformation. The ring specimen is placed around two half-cylinders which are attached to the grip, and is pulled apart. The diameter of half-cylinder is 8.08 mm, and the material is AerMet 100(HRC=55). To minimize the friction between half-cylinder and specimen, the contact surface is lubricated by using the graphite lubricant (Model P-37, Molykote Co.)[1]. Figure 1 shows the grip assembly installed in hot cell.

2.3 Transverse Tensile Test Results

The tested material is an unirradiated Zircaloy-4 cladding tube for PWR 16x16 type fuel assembly. The tube has an outer diameter of approximately 9.5 mm and a wall thickness of about 0.57 mm. The ring specimen is fabricated by the precision grinding machine specially designed for the cladding material (Figure 2). The tensile tests were performed at the initial strain rate of 0.001, 0.01 and 1/s, and at the room temperature and 135°C using a resistive furnace in hot cell.

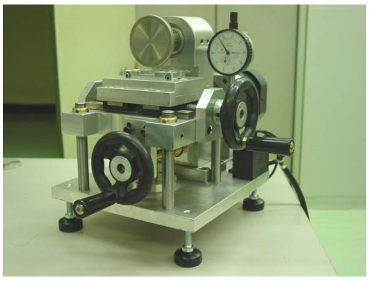

Figure 2. Precision grinding machine.

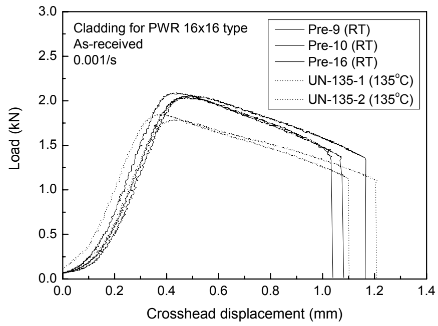

Figure 3. Load-displacement curves

Figure 3 shows typical load-displacement curves of unirradiated Zircaloy-4 cladding tube. It is found that the test results are consistent with the results reported by other researchers.

3. Longitudinal Tensile Test Technique

3.1 Dogbone Specimen Geometry

To evaluate the constitutive properties of a cladding in the longitudinal direction, several kinds of specimens have been developed [2~5]. Among those specimen geometries, the dogbone tube specimen is designed with a small cross-sectional area and, thus low load capacity to accommodate Swagelok fittings without slippage between the specimen and the grip. Daum et al. [5] used the dogbone tube specimen with the gage length-to-width ratio>4 for maximizing uniform strain at the gage section and deriving a constitutive stress-strain response. In this study, we determined the optimum geometry of longitudinal tensile specimen in accordance with ASTM E8M-01 as shown in Figure 4. The gage section is machined by using EDM, and has 12.5 mm in length and 3 mm in width.

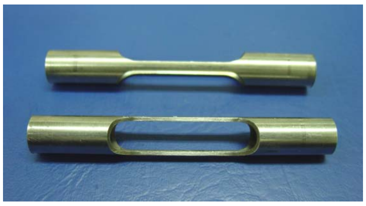

Figure.4. Longitudinal tensile specimen

3.2 Grip Design

The grip for the longitudinal tensile test should be designed such that any slippage at the gripping section does not occur during the testing. In addition, the grip could be easily handled by a manipulator in hot cell. Figure 5 shows the grip for the longitudinal tensile test of cladding in hot cell. In the product test report produced by Swagelok Company, the average peak tensile load is 18 kN for 3/8” x 0.065” wall SUS 316 seamless tubing [6]. According to the test results reported by Daum et al. [5], the maximum tensile load of unirradiated Zircaloy-4 cladding is about 2.45 kN. Therefore, the Swagelok compression fitting can apply the longitudinal load to the specimen without slippage.

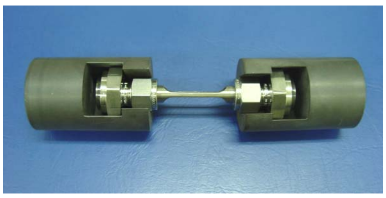

Fig. 5. Swagelok grip for the longitudinal tensile specimen

4. Conclusion

To estimate the transverse and longitudinal tensile properties of fuel cladding in hot cell, the tensile test techniques were developed. The following conclusions are made.

1. Ring specimen geometry is 3 mm in length and 2 mm in width at the gage section. Grip for testing a ring specimen has been designed to reduce a bending effect by utilizing two half-cylinders with 8.08 mm in diameter. Graphite lubricant is used to minimize a friction on the contact surface. It is found that the test results are consistent with the results reported by other researchers.
2. Dogbone tube specimen has 12.5 mm in length and 3 mm in width. Grip using Swagelok compression fittings is designed for testing the dogbone specimen. It is believed that the load is fully applied to the specimen with a small cross-sectional area without slippage.

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