Tensile Test Technique of Cladding under Hoop Loading Condition in Hot Cell

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1. Introduction

The mechanical properties of fuel cladding materials are degraded during steady state. And the increased reactor exposure associated with higher fuel burnups results in additional cladding degradation. Therefore, it is necessary to determine the mechanical properties of highly degraded cladding quantitatively, taking into account the combined effects of oxidation, hydriding and radiation damage. In this paper, the ring tensile test technique is proposed in order to evaluate mechanical properties of a cladding under hoop loading condition caused by pellet/cladding mechanical interaction (PCMI). Through the tensile test in hot cell, it is found that the proposed technique is appropriate for the estimation of the transverse tensile properties of a cladding in hot cell.

2. Determination of Optimum Tensile Method

2.1 Ring Specimen Geometry

Among various ring specimens, 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. Therefore, the ring specimen is appropriate for the quantitative estimation of the transverse tensile properties. Many researchers have proposed various shapes of the ring specimen, especially in the dimensions of the gage section [4,5,6]. In this paper, we determined the optimum geometry of the ring specimen with 3mm in length and 2mm in width at the gage section [7].

2.2 Grip

The two half-cylinders are design 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 as shown in Figure 1. The diameter of half-cylinder is 8.08mm.

To minimize the friction between the outer surface of the half-cylinder and the inner surface of the ring specimen, the contact surface is lubricated by using the graphite lubricant (Model P-37, Molykote Co., μ=0.1). Kim et al. [7] have reported that the graphite lubricant is applicable for the ring tensile test in hot cell.

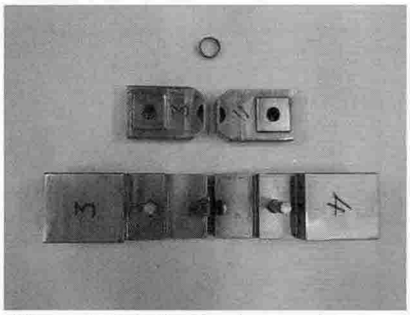

Figure 1. Grip for the ring specimen.

3. Transverse Tensile Test in Hot Cell

3.1 Material and Test Conditions

The tested material is an unirradiated Zircaloy-4 cladding tube for PWR 16x16 type fuel assembly. The tube has an outer diameter of approximately 9.5mm and a wall thickness of about 0.57mm. Ring specimen with the width of 5mm has the two gage sections, 3mm in length and 2mm in width. 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.

3.2 Test Results

3.2.1 Influence of Strain Rate

Figure 2 shows a typical load-displacement curve. In this figure, the increase of strain rate implies an increase of the maximum tensile load and a decrease of the plastic displacement.

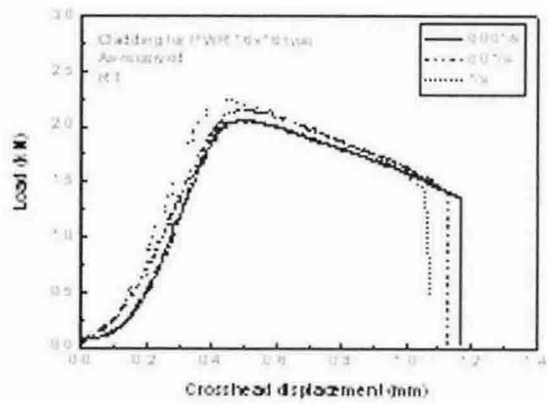

Figure 2. Influence of strain rate.

3.2.2 Influence of Temperature

The dependence of temperature on the transverse mechanical behavior of the cladding is shown in Figure 3. The increase of temperature implies a decrease of the maximum tensile load and an increase of the displacement.

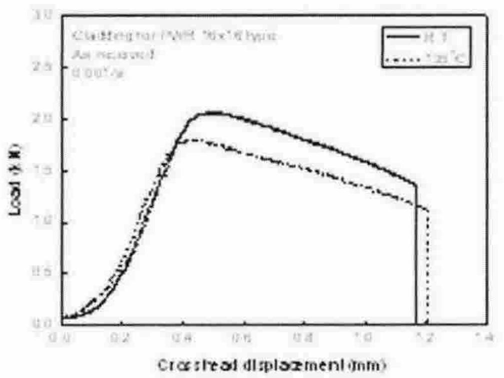

Figure 3. Influence of temperature.

3.2.3 Influence of the location of gage section

Figure 4 shows the influence of the location of a gage section on the transverse mechanical properties. Solid and dot lines indicate that the two gage sections are placed on the top and bottom of half-cylinder(0°), and at the both side of half-cylinder(90°), respectively. The latter indicates smaller displacement and lower maximum tensile load than the former. The plastic displacement is not very significant in latter case: when necking of the ring specimen initiates, the gage section is no longer uniform and bending occurs. As a result, the two gage sections of the ring specimen should be located at the top and bottom of half-cylinders, especially for the determination of the plastic displacement.

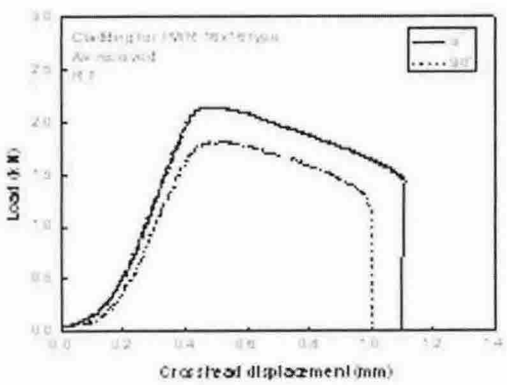

Figure 4. Influence of the location of gage section.

4. Conclusion

To estimate the transverse tensile properties of fuel cladding in hot cell, the ring tensile test technique is newly developed. The unirradiated Zircaloy-4 cladding material is tested in order to verify the applicability of the proposed technique for the usage in hot cell. The following conclusions are made:

1. Specimen geometry has been optimized to determine the mechanical properties of a cladding in the transverse direction. The gage section has 3mm in length and 2mm in width.
2. Grip for testing ring specimen has been designed to mitigate a bending effect by utilizing two half-cylinders with 8.08mm in diameter. Graphite lubricant is used to minimize a friction on the contact surface.
3. Based on the transverse tensile test results in hot cell, the influence of strain rate, temperature and location of gage section was examined. It is found that the test results are consistent with the results reported by other researchers.

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