Development of Longitudinal Tensile Test Technique of Cladding in Hot Cell

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1. Introduction

During steady state operation of a reactor, the mechanical properties of Zircaloy fuel cladding are degraded due to oxidation, hydriding and radiation damage. To predict the deformation response of cladding, it is very important to determine its constitutive stress-strain response under the reactor operation condition. In this paper, the longitudinal tensile test technique is proposed in order to evaluate mechanical properties of a cladding under the longitudinal (axial) loading condition in hot cell.

2. Design of Tensile Specimen

To determine the constitutive stress-strain and deformation properties in the longitudinal direction, two kinds of specimens have been used. One is the full-size tube specimen, and the other is dogbone tube specimen. Among those specimens, the dogbone tube specimen is tested without slippage between the specimen and the grip because of a small cross-sectional area of specimen. Balourdet et al.[1,2] studied on the longitudinal tensile properties of unirradiated and irradiated Zircaloy-4 cladding using the dogbone tube specimen with 5 or 15mm in gage length. Daum et al. [3] used the specimen with the gage length-to-width ratio>4 for maximizing uniform strain at the gage section. In this study, we determined the optimum geometry of tensile specimen in accordance with ASTM E8M-01 as shown in Figure 1.

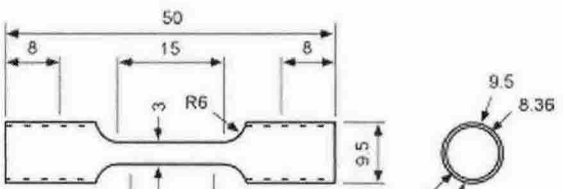

Figure 1. Longitudinal Tensile Specimen.

The dogbone tube specimen is fabricated by using electrical discharge machine (EDM) in hot cell (Figure 2). To do this, using a pair of diamond files, the oxide layer on the outer surface of the cladding is partially removed to establish an electrical circuit.

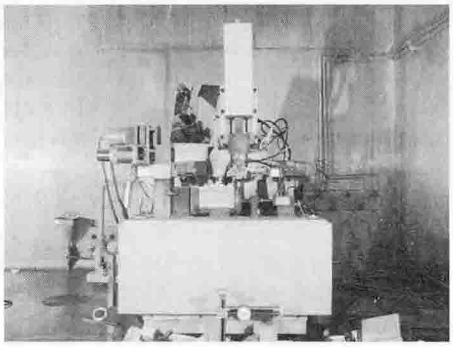

Figure 2. EDM installed in hot cell.

3. Grip Design

The grip for longitudinal tensile test should be designed such that any slippage does not occur during the testing. In addition, the grip could be easily handled by a manipulator in hot cell. Balourdet et al. [1,2] developed a pin-type grip which stretches the specimen by pins attached to the extension rods. And, Daum et al. [3] proposed the grip using Swagelok compression fittings in conjunction with rigid inner plugs and loading yokes to apply an axial load. Figure 3 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 1840kgf for 3/8" x 0.065" wall SUS 316 seamless tubing [4]. According to the test results reported by Daum et al. [3], the maximum tensile load of unirradiated Zircaloy-4 cladding is about 250kgf. Therefore, the Swagelok compression fitting can apply the axial load to the specimen without slippage.

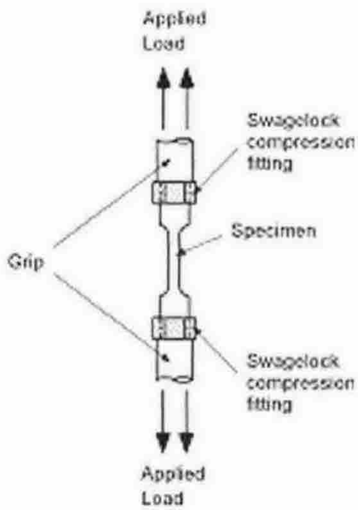

Figure 3. Grip for the dogbone specimen.

4. Constitutive Properties of Cladding

The longitudinal mechanical properties including yield strength, ultimate tensile strength, uniform elongation and total elongation are determined from the stress-strain curves. In general, the engineering stress and strain is calculated from the load measured by a load cell and the displacement measured by an extensometer during the test, respectively. However, because it is very difficult to attach the extensometer to the specimen in hot cell, the strain is determined from the crosshead or actuator displacement. In this case, the measured displacement equals the deformation in the gage length of the specimen plus elastic deflections in the machine frame, load cell, grips, specimen ends, etc., as shown in Figure 4. Therefore, a correction for machine compliance (P/K) is done to obtain the longitudinal stress and strain data.

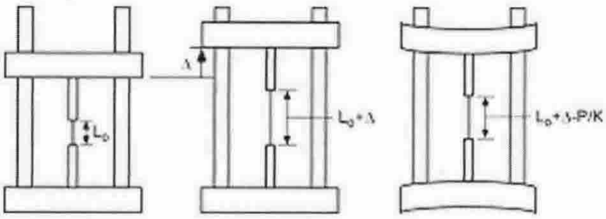

Figure 4. Schematic diagram illustrating crosshead displacement and elastic deflection in a tensile test machine.

4. Conclusion

The new tensile test technique is proposed to estimate the longitudinal tensile properties of fuel cladding in hot cell. The following conclusions are obtained.

1. Dogbone tube specimen is designed to have a uniform strain distribution at the gage section. The gage section is machined by using EDM in hot cell, and has 12.5mm in length and 3mm in width.
2. Grip using Swagelok compression fittings is used for testing the dogbone specimen. It is believed that the load is applied to the specimen with a small cross-sectional area without slippage.
3. To determine the constitutive properties of cladding in the longitudinal direction, the stress-strain curve is obtained. The engineering stress is calculated from the load directly measured by a load cell, and the engineering strain is calculated from the actuator displacement applying a correction for machine compliance.

REFERENCES

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