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# Axial Tensile Tests for Evaluation of Mechanical Properties of Ballooned and Ruptured Nuclear Fuel Cladding

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## 1. Introduction

Ballooning and rupture phenomenon of fuel cladding during loss-of-coolant accident(LOCA) scenarios occurs due to pressure difference between inner and outer cladding at high temperature. These phenomena have a significant impact on the integrity of nuclear fuel. Ballooning may cause the fuel relocation and fuel dispersal can occur due to its rupture opening during accidents. However, a current LOCA criterion is based on the results obtained from non-pressurized and relatively short claddings specimens under simulated LOCA condition. In this study, the mechanical properties of ballooned and ruptured cladding were evaluated and its applicability to existing LOCA criteria was also investigated.

## 2. Methods and Results

In this section some of the experimental procedure and technical details of apparatus are described. Highlight data obtained from axial tensile test of ballooned and ruptured cladding sample is also presented.

### *2.1 Integral LOCA Test*

For the integral LOCA tests, 400 mm long tubular zircaloy-4 cladding samples were filled with 10 mm long alumina pellets to simulate the heat capacity of the fuel. The furnace was heated to a pre-test hold temperature of 300℃ within 240 s, where the steam flow and sample temperature were stabilized for 500 s. A heating rate of 5℃/s from 300℃ to 1200℃ was used. After exposure for a time corresponding to 13 to 20% of equivalent cladding reacted (ECR) at 1200°C, the tube was cooled slowly to 800℃ and then quenched by flooding from the bottom of the chamber with water. Further details of the test equipment and experimental procedures can be found in our previous paper [1].

### *2.2 Axial Tensile Test*

After quenching, cooling water was drained and tensile test was carried out by pulling the specimen from the bottom. Axial tensile test can be performed at seven different rates, as shown in Fig. 1. In this study, the cladding specimens were stretched at a speed equivalent to RPM1 (tensile speed about 10N/s). JAEA argued that axial restraint loads had to be less than 1,000 N. It adopted 540 N for its partially restrained tests using irradiated cladding samples [2, 3]. All the tensile test were conducted with maximum loads of 500N.

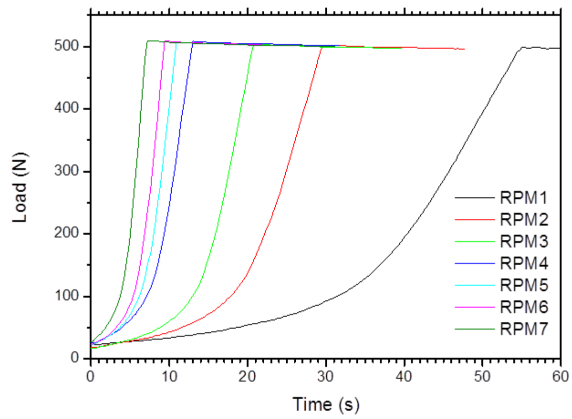


Fig. 1. Load obtained tensile test performed at room temperature with different RPM of motor.

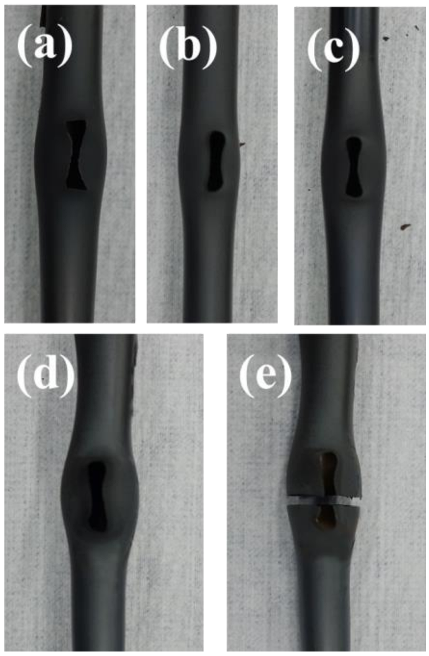


Fig. 2. Appearance of fuel cladding after exposure for (a) 1, (b) 14, (c) 56, and (d) 125s at 1200°C and failure appearance of (d) after tensile test .

Fig. 2(a)-(d) shows the ballooned samples with different exposure time at 1200°C. All the samples showed dog bone shape rupture opening and similar rupture temperature. Tensile test results obtained those samples were shown in Fig. 3.

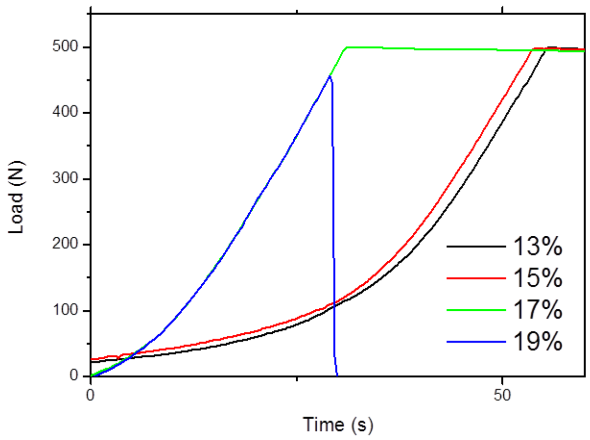


Fig. 2. Load as a function of time obtained tensile test for cladding samples with different ECR.

Under maximum load of 500N, all samples with 13, 15, and 17 %ECR were survived without failure after axial tensile test. However ballooned and ruptured sample with 19% ECR was failed under a load of less than 500N. It is noteworthy that the abrupt change of mechanical property is similar to the existing criteria based on the ring compression test. However, it is necessary to confirm it through more repeated tests.

## 3. Conclusions

Post transient axial tensile tests were performed using ballooned and ruptured claddings. Zircaloy 4 fuel claddings under 17% ECR did not fail at a maximum load of 540 N but cladding specimen with 19% ECR showed failure at the rupture node. Tests on Zr-4 with different controlled load rates and balloon shapes are planned to confirm their dependency of the fracture load

## REFERENCES

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