Ductility Evaluation of High Burn-up Cladding By Using Ring Compression

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1. Introduction

Under LOCA (Loss Of Coolant Accident) scenario, the fuel cladding may suffer thermal shock by ECCS (Emergency Core Cooling System) water quenching. If the fuel claddings are severely embrittled due to irradiatation, high temperature oxidation, and hydrogen pickup, the thermal shock may result in the failure of the fuel rods [1, 2]. In this study, ring compression tests are applied as an evaluating tool for the ductility of cladding material to examine the ductility degradation of the Zr alloy, and some of experimental results are presented.

2. Experimental Part

Ring compression tests was adopted to evaluate the degradation in ductility of oxidized Zr alloy cladding and spent fuel cladding with high burnup of ~60 GWd/tU. A jig module for loading to a specimen was designed and manufactured. Fig. 1 shows the jig module, which is composed of upper plate and lower plate. The movement of the specimen during the compression was intended to minimize by grooving on the lower plate of the jig module. The tube specimen length was fixed to 8 mm. All of the experiments were carried out by using a universal testing machine with the attached jig module in a hot cell. Fig. 2 shows the experimental apparatus installed in a hot cell.

3. Results

The compression characteristics were examined at 25 ^{o}C and 135^{o}C. The fuel rod temperature during reflood stage followed by refill stage in LOCA (Loss Of Coolant Accident) would decrease sharply by quenching and saturated to a temperature, which is known to be approximately 135^{o}C. The Hobson's ring compression tests [3] which presented the base of the US LOCA embrittlement criterion were focused on the cladding embrittlement characterization at that temperature. Hence, the test temperature, 135^{o}C, was employed and also the compression tests at 25^{o}C were added to investigate the ductility under more conservative condition.

First of all, the ring compression test results for high temperature –oxidized Zr alloy cladding examined at 25 ^{o}C and 135^{o}C are shown in Fig. 3 and 4, respectively. Oxidized specimen simulating spent fuel cladding with various ECR (Equivalent Cladding Reacted) such as 0%, 5.9%, 8.6% and 18.3% were prepared by measuring the weight gain due to oxidation with thermo-gravimetric method in the oxidant gas environment at 1200^{o}C.

The results revealed that ultimate strength, displacement (ductility) to fracture and energy to fracture decrease with increasing ECR of the specimen. Especially, the ductility to fracture and the energy to fracture were sharply decreased, which signifies that ductility of Zr alloy cladding degrades significantly due to decrease in load-bearing ligament thickness of cladding as the oxidation degree increases.

And also the ring compression tests for spent fuel cladding were performed at 25^{o}C and 135^{o}C. The results are presented in Fig. 5. As shown in the Fig. 5, while there is no significant difference in strength, the difference in ductility was observed. It can be deduced that the difference in ductility is caused by the difference in oxidation degree (ECR) and hydrogen content as an another embrittling parameter. The quantitative analysis of the ECR and hydrogen content will be performed in PIE.

4. Conclusion

The ring compression tests for spent fuel cladding as well as oxidized cladding simulating spent fuel cladding were performed at 25^{o}C and 135^{o}C. Ductility and energy to fracture of Zr alloy cladding degrades significantly due to decrease in load-bearing ligament thickness of cladding as the oxidation degree increases.

Reference

[1] G. V. Karetnikov *et al.*, "An Investigation of the Survivability of Fuel-Rod Claddings during the First Stage of the Maximum Design Basis Accident at a Nuclear Power Station with a VVER Reactor", *Thermal Engineering*, 53(1), 2006.

[2] H. M. Chung, "Fuel behavior under loss-of-coolant accident situations", *Nuclear Engineering and Technology*, 37(4), 2005.

[3] D. O. Hobson *et al.*, "Embrittlement of Zircaloy clad fuel rods by steam during LOCA transients", ORNL-4758, 1972.

Fig. 1. Jig module for ring compression test

Fig. 2. Experimental apparatus for ring compression test in a hot cell

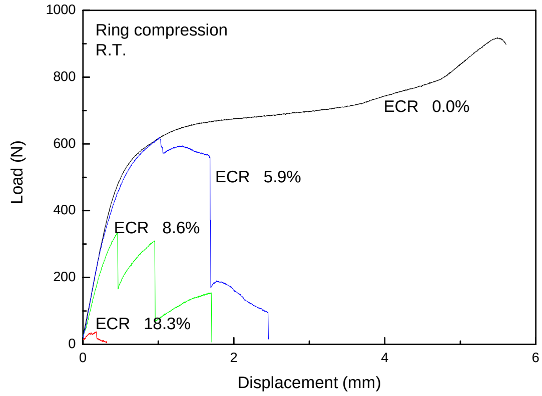

Fig. 3. Load-displacement relations of oxidized Zr alloys (25°C)

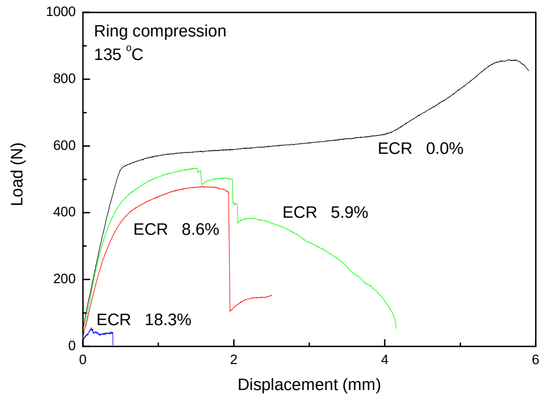

Fig. 4. Load-displacement relations of oxidized Zr alloys (135°C)

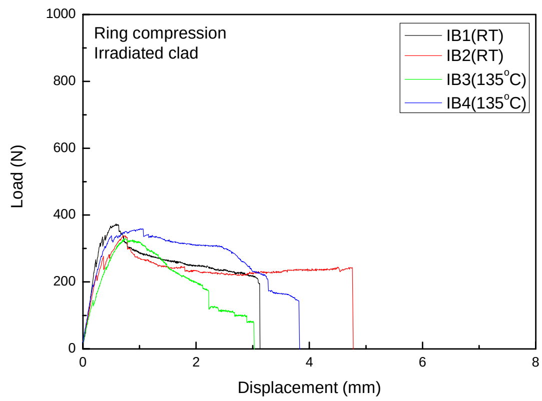

Fig. 5. Load-displacement relations of spent fuel cladding