Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Effect of Hydrogen on the Creep of Zircaloy-4 Cladding Tubes

Tae Wook Oh, Young Suk Kim, Sang Bok Ahn, Kyung Soo Im, Yong Moo Cheong
Korea Atomic Energy Research Institute, 150 Dukjin-dong, Daejeon 305-353, Korea, yskim1@kaeri.re.kr

1. Introduction

Water-side corrosion of Zircaloy-4 produces a hydrogen part which is absorbed by the zirconium matrix. Once the concentration of the absorbed hydrogen exceeds the solubility limit, hydrides precipitate in the zirconium matrix, degrading the mechanical properties. One of the unresolved issues is the effect of hydrogen on the creep rate of zirconium alloys because the creep property of Zircaloy cladding tubes is an important factor in establishing a maximum allowable channel power [1-2].

This study investigated the effect of hydrogen on the creep rate of an unirradiated Zircaloy-4 cladding tube which has been fully annealed. Small creep specimens were taken from the axial directions of a Zircaloy-4 cladding tube and they were charged by using an electrolytic charging method to 60 and 200ppm of hydrogen, respectively. The creep tests were conducted at 350℃ where small deformation twins are effective.

2. Experimental Procedures

Uniaxial creep tests were performed at 350℃, using creep test machines equipped with a lever arm to apply a load with a 20 to 1 ratio. The tensile specimens, as shown in Fig. 1, were cut from the axial direction of a Zircaloy-4 cladding tube and they were subjected to a full annealing at 700℃ for 4hour. This heat treatment caused a complete recrystallization with the equiaxed grains of about 10 ㎛, as shown in Fig. 2. The applied stress on the creep specimen was fixed at 150MPa during the creep tests. The specimens were hydrided by an electrolytical charging method in 0.1M H_2SO_4 followed by homogenization treatments at 303℃ for 7hour and 402℃ for 24hour to contain hydrogen of 60ppm and 200ppm, respectively.

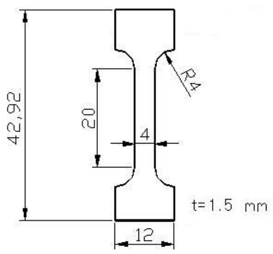

Fig. 1. Schematic drawing of creep specimens.

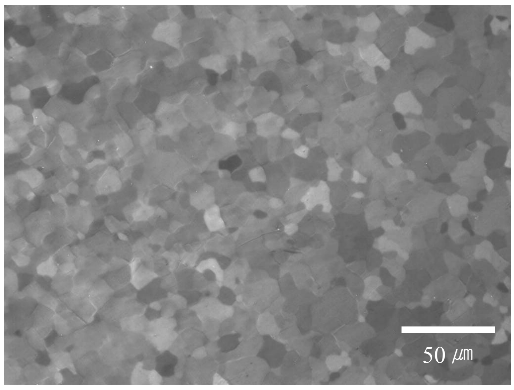

Fig. 2. Microstructure of fully annealed Zircaloy-4 specimen.

3. Results

3.1. Hydrogen effect on creep

Fig. 3 shows the creep strains of the Zircaloy-4 tube with hydrogen at 350 ℃ under the applied stress of 150MPa. Since the terminal solid solubility of hydrogen in zirconium is around 110ppm [3] at 350℃, the actual concentration of the hydrides precipitated in the creep specimens at 350℃ would be zero (all in solid solution) for the Zircaloy-4 with 60 ppm H and 90ppm H for the Zircaloy-4 with 200 ppm H. The creep of the Zircaloy-4 cladding tube increased when all the charged hydrogen was fully dissolved into the zirconium matrix. This result demonstrates that the hydrogen dissolved in the zirconium lattice increases the dislocation velocity. In contrast, when many hydrides corresponding to 90 ppm H were present as precipitates in the zirconium matrix along with the dissolved hydrogen, the creep rate of the Zircaloy-4 slowed down very effectively. This suppressing effect of the hydrides on a longitudinal creep, as shown in Fig. 3, was found to agree with Rupa's creep test results [4].

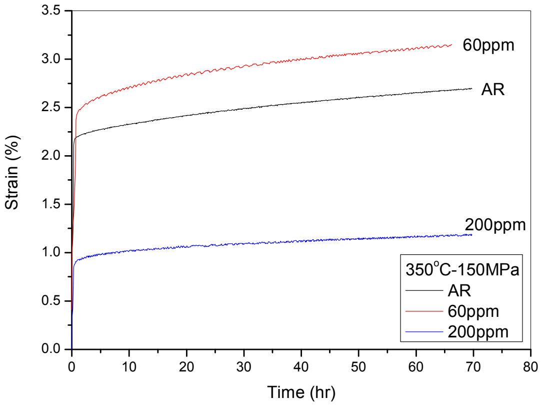

Fig. 3. Creep strains of the Zircaloy-4 cladding tube with hydrogen at 350℃ under the tensile stress of 150MPa.

4. Conclusion

When charged hydrogen was present as a solid solution, the hydrogen concentration increased the creep strain of the Zircaloy-4. However, with many hydrides being precipitated even at a creep test temperature, the hydrides decreased the creep strain of the Zircaloy-4.

Further work is underway to understand the effect of a load and temperature on the creep rate of zirconium by the hydrides.

REFERENCES

[1] Kesterson, R. L., et al., “Impact of Hydrogen on Diamensional Stability of Fuel Assemblies”, proceedings of ANS Meeting on LWR Fuel Performance, Park City, April 2000.
[2] G. J. C. Garpenter and J. F. Watters, Irradiation Damage Recovery in Some Zirconium Alloy, Zirconium in Nuclear Applications, ASTM STP 551, p. 400, 1974.
[3] J. J Kearns, J. Nucl. Mat., 22, p.28, 1967.
[4] N. Rupa, M. Clavel, P. Bouffioux, C. Domain and A.Legris, About the Mechanism Governing the Hydrogen Effect on Viscoplasticity of Unirradiated Fully Annealed Zircaloy-4 Sheet, *Zirconium in the Nuclear Industry:Thirteenth International Symposium*, ASTM STP 1423.