Hydrogen Effects on hoop directional creep behaviors of Zr-based nuclear fuel cladding

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1. Introduction

It is essential to warrant the mechanical integrity of the discharged cladding under the interim dry storage condition. In the dry storage, the cladding temperature may be higher than that in the wet storage and can reach up to 400℃. The cladding under the interim dry storage condition may degrades or end to fail some possible mechanisms such as creep rupture, delayed hydride cracking(DHC), hydride re-orientation and stress-corrosion cracking etc.[1].

Among the failure mechanisms causing the degradation of mechanical properties or failure of the fuel cladding under the dry storage condition, the creep mechanism is believed to be most dominant. Especially, the hoop-directional creep property is concern due to the difference of pressure between fuel-cladding gap and storage environment. Accordingly, it is essential to evaluate the hoop-directional creep property of the spent fuel. In this paper, experimental results concerning the hoop-directional creep properties of as-received Zr alloy cladding tube and pre-hydrided Zr alloy cladding tube are introduced.

2. Creep Behavior

In the dry storage environment, the spent fuel cladding is placed in high temperature and hoop stress conditions. Creep rate can be expressed as the following equation.

$$\varepsilon = K\sigma^{n}\exp(-Q/RT) \qquad (1)$$

ε : creep rate
σ : hoop stress of the spent fuel cladding
Q : activation energy
R : gas constant
T : absolute temperature of the cladding
K : proportional constant
n : stress exponent

The above equation suggests that the temperature and hoop stress of the spent fuel cladding are the main driving forces for the creep deformation. Accordingly, it is crucial to limit the maximum temperature of the stored fuel cladding and the maximum hoop stress and fuel rod internal pressure in order to maintain the mechanical integrity of the fuel cladding tube.

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3. Experimental Methods and Results

3.1 Experimental conditions

The hoop directional creep test specimens used in this study are as-received Zircaloy-4 cladding and pre-hydrided Zr alloy cladding tube(alloy A).

The dimensions and shape of the hoop-directional creep specimen were designed in order to ensure that any deformation is limited to the gage section of the specimen, so that the uniform uniaxial hoop strain in the gage section could be at its maximal[2]. The gage sections of the specimens were oriented at the top and bottom of the half cylinder of the grip, such that a constant curvature of the specimen can be maintained during a creep deformation. The interface was lubricated with a graphite-containing vacuum grease lubricant at the beginning of each test to minimize a loss of the applied load. The hoop directional creep tests were performed with the Instron Servohydraulic System, Model 8562 in the temperature range from 365°C to 550 °C.

3.2. Experimental Results

Hoop directional creep tests of as-received Zircaloy-4 and alloy A were performed in the temperature range from 365°C to 550°C. Fig. 1 shows kinetic data for creep deformation of as-received Zircaloy-4, as-received alloy A and prehydrided alloy A containing a previous research data[3]. The logarithmic strain rate correlates linearly with logarithmic stress. The logarithmic stress can be also evaluated with time to failure as shown in Fig. 2.

Fig. 3 shows the correlation between logarithmic stress and LMP. It is seen that LMP, the measure of creep resistance, of hydrided Zr alloy is inferior to non-hydrided Zr alloy.

Quantitative analysis results for hydrogen effects are to be performed. Creep rate and rupture time with increasing hydrogen content are to be drawn after hydrogen content analysis.

In additional experiments, secondary creep rate with increasing hydrogen content will be drawn, and then kinetic data such as pre-exponential factor and activation energy for creep process will be also drawn. In addition, creep life will be predicted by obtaining LMP(Larson-Miller parameter) correlation in the function of hydrogen content and applied stress to yield stress ratio.

5. Summary

The hoop directional creep tests for Zr based nuclear fuel claddings were performed in the temperature range from 365°C to 550°C. As-received Zr alloy and pre-hydrided alloy were used to investigate hydrogen effects on creep characteristics in a given temperature ranges. In a given temperature and stress range, time to failure of pre-hydrided Zr alloy was shown to be shorter than that of as-received Zr alloy. That is, it was revealed that the creep resistance of hydrided Zr alloy is inferior to non-hydrided Zr alloy.

REFERENCES

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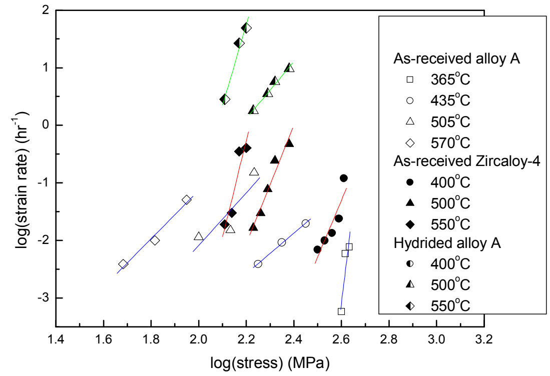

Fig. 1. Correlation between logarithmic strain rate and logarithmic stress

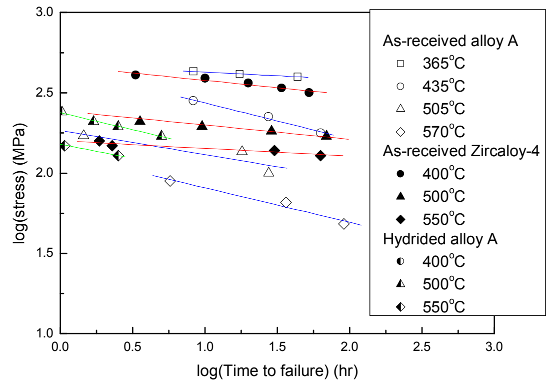

Fig. 2. Correlation between logarithmic stress and logarithmic time to failure

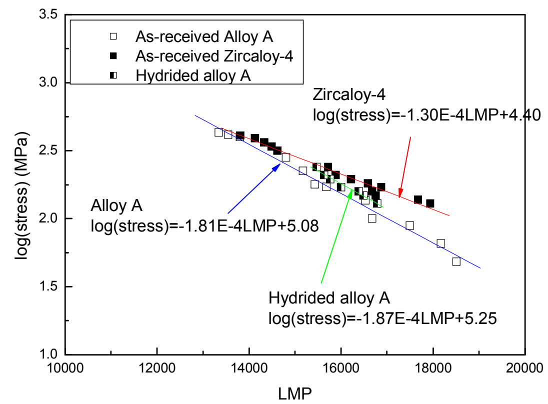

Fig. 3. Correlation between logarithmic stress and LMP