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Behavior of Stress-Relaxation phenomena in Zr-1.1Nb-0.05Cu

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1. Introduction

Zirconium alloys have anisotropic mechanical properties depending on their physical orientations and are widely used as nuclear materials such as cladding tube material [1,2]. An operation condition of the nuclear reactor requires a high creep resistance, because it is subjected to long period operations, high temperature and high pressure. Generally, it takes a few days or months to do the creep experiment, so it is difficult to get a data in short period. However, there is a way to predict a creep property by using the stress-relaxation in the short term [3]. These studies realized the stress-relaxation through a compressive test of HANA-6 (Zr-1.1Nb-0.05Cu) alloy that was developed by KAERI (Korea Atomic Energy Research Institute), and then predicted the creep property.

2. Methods and Results

As a criterion which estimates inelastic strains, stress relaxation describes how materials relieve stress under constant strain. This nonlinearity is described by both stress relaxation and a phenomenon known as creep, which describes how materials strain under constant stress [4].

The zirconium tubes with the chemical compositions of Zr-1.1Nb-0.05Cu (HANA-6). The tube was cut into 5 mm in length, and then the stress relaxation test was performed along the vertical direction. The compression test was conducted by using Instron 3367 device equipped with 3 ton load cell. For the test, compressive stress with a constant displacement rate of 0.2 mm/min was applied until the sample deformed to 0.1 mm, 0.2 mm, 0.5 mm, respectively. Sequence was for an increasing stress to minimize deformation history sensitivity associated with any recovery phenomena on unloading [5]. Once the designated compressive strain was reached, the cross-head movement stopped, and the decrease in compressive stress was measured for at least 6 h. The test was performed at 380 ℃. It was observed that the maximum compressive stress and the stress relieve during the test, was also able to creep property through the analysis of stress relaxation.

2.1 Stress Relaxation

Fig. 1. shows the compressive stress according to the displacement and time at 380 ℃. The more the displacement increases (0.1 mm, 0.2 mm, and 0.5 mm), the more the maximum compressive stress increases (78.22 MPa, 247.44 MPa, and 322.85 MPa) during the compression test. The increase in maximum compressive stress is related to the increase in dislocation density increase.

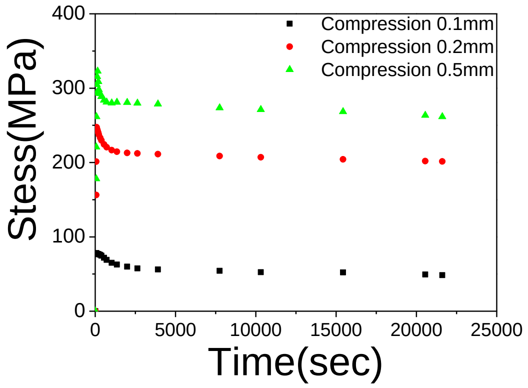

Fig. 1. Variation in compressive stress depending on time at 380 ℃

2.2 Creep Rate

The transformation process is developed from following formula [5] :

$$e_e + e_i = e_t = constant$$

$$\dot{e}_i = -\dot{e}_e = \frac{-1}{E} \cdot \frac{ds}{dt} \qquad \text{Eq. (1)}$$

where e_e is the elastic strain, e_i the inelastic strain, e_t the total strain, s the stress, and E the elastic modulus, respectively. The elastic modulus is calculated by the slope of stress to strain graph. The elastic modulus is calculated by the slope of stress to strain graph. The measured modulus vales used in the annuluses at 380℃ was 4828 MPa

Fig. 2 indicates the relationship between the stress and strain rate. The strain rates were calculated using the Eq. (1). As the strain rate decreased, the stress was decreased.

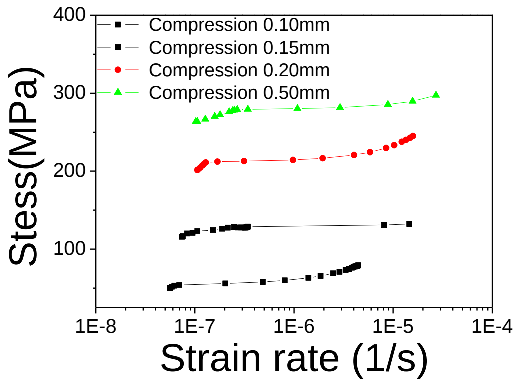

Fig. 2. Stress to strain rate curve at room temperature at 380 ℃

Stress-strain rate data was used to generate pseudo-tensile curves as shown in Fig. 3 from vertical cut taken at selected strain rates. The pseudo-tensile curves lay in higher position as the strain rate increased.

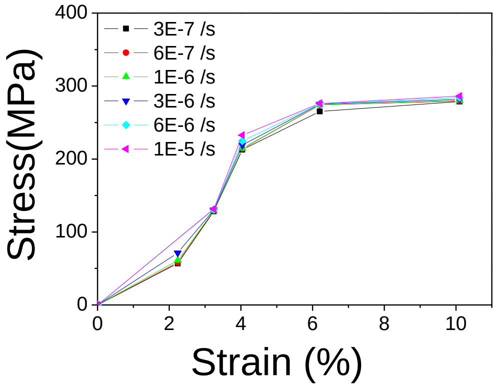

Fig. 3. Pseudo stress to strain curve as a function of stress rate at 380 ℃

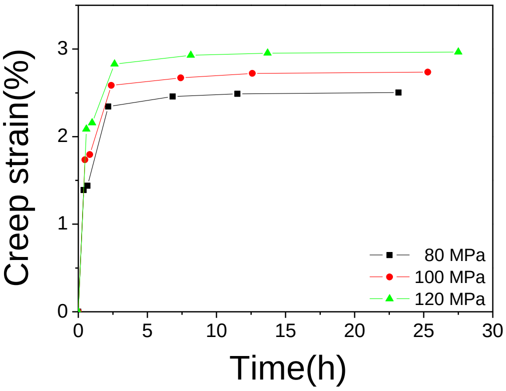

Fig. 4. Creep strain to time curve according to various stress at 380 ℃

Fig. 4 shows the estimated creep strains through the stress relaxation test. Creep curves were generated from the horizontal cut taken at selected stresses. Creep strains became larger as the creep stress increased. It was able to predict the creep strains up to 28 h from the stress relaxation for 6 h.

2.3 Microstructures

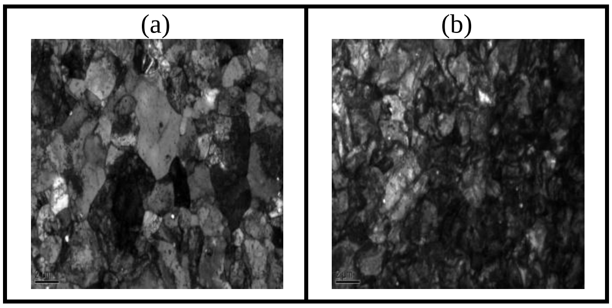

Fig. 5. TEM images of the samples after stress-relaxation at 380℃: (a) 0.1 mm, (b) 0.5 mm compressive deformation.

Fig. 5 is the TEM microstructures after the stress relaxation test with 0.1 mm and 0.5 mm compressive deformations. It is observed that the more the deformation, the more the amounts of dislocation increase.

3. Conclusions

The maximum load was measured and stress-relaxation was performed in HANA-6 tube using a compression test. In addition, the creep property was predicted from the stress relaxation test of the short time. The compression stress was increased as the displacement increased. And, the behaviors of stress relaxation were similar regardless of the compressive displacement. Through the stress relaxation test for a relatively short time, creep can be predicted in this study.

4. REFERENCES

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