Creep analysis of Zr-1.1Nb-0.05Cu alloy using stress relaxation data

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1. Introduction

Zirconium alloys are widely used as nuclear materials such as cladding tube material [1,2]. An operation condition of the nuclear reactor requires an excellent creep property, because it is subjected in long period operations, high temperature and high pressure. Generally, it takes a few days or months to do the creep experiment, so it is little bit hard to get a data in short period. However, there is a way to predict a creep property by using the stress-relaxation in a 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 alloy which was used in this test has compositions of Zr-1.1Nb-0.05Cu (HANA-6). A forged ingot was cut in a rectangular parallelepiped feature with a size of 17 mm x 12 mm x 12 mm. The parallelepiped specimens were compressed vertically with a reduction rate of 53 %, which made the size of specimens about 8 mm x 15 mm x 15 mm. For the relaxation test, the final specimens were manufactured with a dimension 7 mm x 4.5 mm x 5 mm. The compression test is conducted by using Instron 3367 device equipped with 3 ton load cell. For the test, compressive stress with constant displacement rate of 0.2 mm/min was applied until the sample deformed 1.0 mm, 1.5 mm, 2.0 mm, respectively. Once the designated compressive strain had reached, the cross-head movement was stopped, and the decrease in compressive stress was measured for at least 6 h. The test was performed at room temperature. It was observed the maximum compressive stress and the stress relieve during the test, and was also able to the creep property through the analysis of the stress relaxation.

2.1 Compressive load and stress relaxation

Fig. 1 shows the compressive stress according to the displacement and time at room temperature. The more the displacement increases (1.0 mm, 1.5 mm, and 2.0 mm), the more the maximum compressive stress increases (836.8 MPa, 905.7 MPa, and 966.2 MPa) during the compression test. The increase in maximum compressive stress is related to the increase in dislocation density increase.

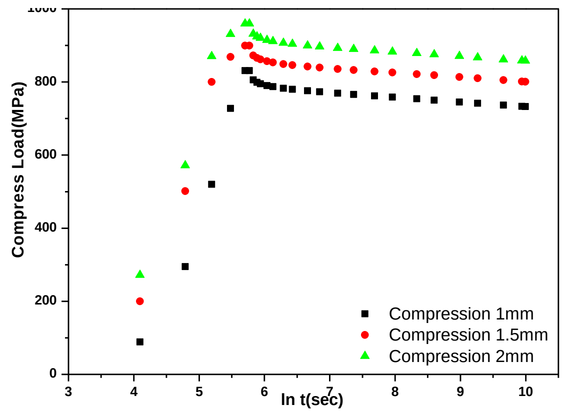

Fig. 1. Variation in compressive stress depending on time at room temperature

The stress relaxation is a microstructural response of a material that induces decrease in internal stresses with time. According to Fig. 2, the stress relaxation revealed a similar tendency regardless of the specimens' displacement.

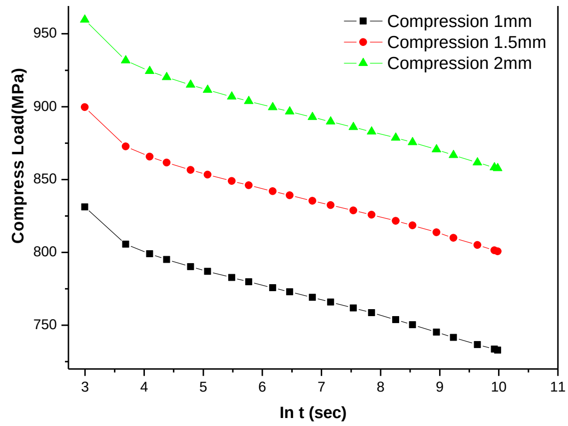

Fig. 2. Stress relaxation with time for successive runs at room temperature

2.2 Creep rate

Information on creep can be deduced from the relaxation data as shown in Fig. 2. The transformation process is developed from following formula [5].

$$e_e + e_i = e_t = \text{constant}$$

$$\dot{e}_i = -\dot{e}_e = \frac{-1}{E} \bullet \frac{ds}{dt}$$

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. Fig. 3 shows a compressive stress–strain curve for samples deformed by 1.0 mm, according to the graph elastic modulus was 7468 MPa.

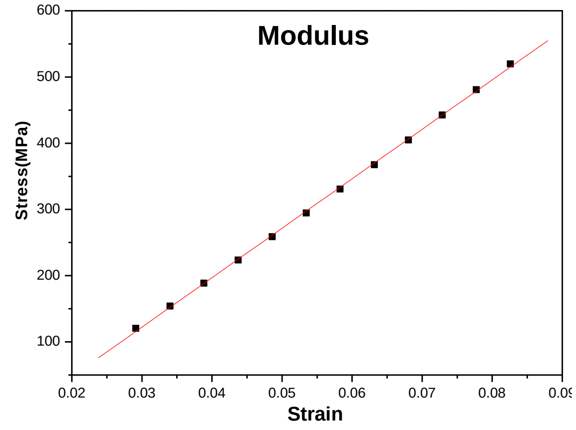

Fig. 3. Compressive stress–strain curve for sample deformed by 1mm at room temperature

Fig. 4 indicates the relationship between the logarithm of stress and strain rate. The strain rates were calculated using the modulus measured in Fig. 3. As the strain rate decreased, the stress was decreased. Creep behaviors were obtained with the stress-relaxation data as presented in Fig 1, 2 and 4.

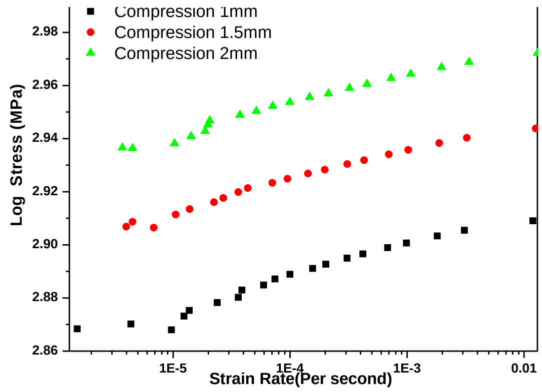

Fig. 4. Stress to strain rate curve at room temperature

3. Conclusions

The maximum load was measured and stress-relaxation was performed in HANA-6 using a compression test. In addition, the creep property is predicted from the stress relaxation data. The compression stress is 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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