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A study on the creep deformation mechanism of Zr-1.5Nb-0.4Sn-0.1Fe-0.1Cu alloy sheet under applied stresses

[a]Yong Deog Kim, , [c]Kwang Su Na, [b]Yong Hwan Jeong, [c]Seon Jin Kim
a Korea Electric Power Research Institute, 103-16 Munji-dong, Yuseong-gu, Daejeon, Korea
ydkim@kepri.re.kr
b Korea Atomic Energy Research Institute, Yusung P.O. Box 105, Daejeon, Korea
yhjeong@kaeri.re.kr
c Division of Materials Science and Engineering, Hanyang University, Seoul 133-791, Korea
n781111@nate.com, alloylab@hanyang.ac.kr

1. Introduction

Creep of Zr-alloy cladding is one of the important mechanical properties for determining the nuclear fuel cladding performance, especially heat transfer from fuel to cladding besides mechanical wear between cladding and grid. An understanding of the creep behaviour of Zr-alloy cladding is required to secure safety and reliability of the thermal performance and mechanical integrity of fuel rods.

The creep characteristics of the Zr-1.5Nb-0.4Sn-0.1Fe-0.1Cu alloy sheet which is one of the Korea candidate nuclear fuel cladding materials were investigated in the temperature range from 300℃ to 400℃ and in the stress range from 50 MPa to 180 MPa along the rolling direction. The creep rates ranges in these tests were 8.8 x 10^{-10} s^{-1} to 4.7 x 10^{-7} s^{-1}. The activation energies for the creep were also estimated to make an assessment the creep mechanisms in this alloy.

2. Experimental Procedures

2.1 Test Specimen Preparation

The studied material Zr-1.5Nb-0.4Sn-0.1Fe-0.1Cu sheet was obtained in the form of beta-quenching, hot and cold rolling with annealing. The final annealing process was recrystallization for 8 hours at 510℃. Its gauge length and width are 25 and 0.8 mm. Figure 1 shows the test specimen preparation process.

2.2 Creep Tests and Microstructure Analysis

The creep tests were carried out using mechanical creep machine under static load control in the temperature range from 300℃ to 400℃ and in the stress range from 50 MPa to 180 MPa along the rolling direction. For each conditions, creep tested specimens were sectioned for TEM study. TEM micrograph study was preformed to analyze the microstructure with the creep mechanisms.

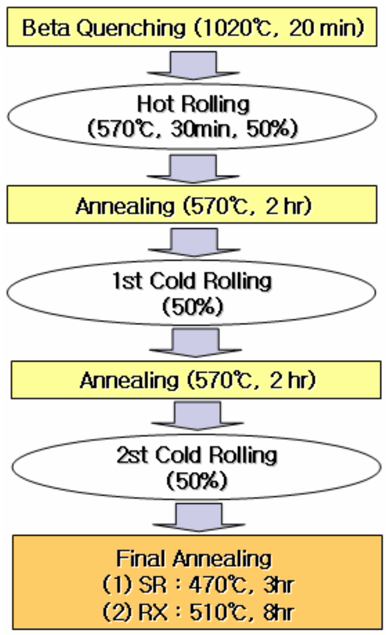

Figure 1. The test specimen preparation process.

3. Results and discusson

Figure 1 to Figure 3 show the stress exponent with the stress and strain rate in the temperature range 300℃ to 400℃. The stress exponent is generally represented by equation 1[1].

$$\dot{\varepsilon} = A\sigma^n \exp\left(-\frac{Q}{RT}\right) \qquad \therefore n = \frac{\log \dot{\varepsilon}}{\log \sigma} \qquad ......(1)$$

The strain rates ranges in these tests were 8.8 x 10^{-10} s^{-1} to 4.7 x 10^{-7} s^{-1}. The strain rates were different with the stress level, i.e. the strain rate was 1.27X10^{-9} s^{-1} in the stress range 70 – 120 MPa, however it was increased to 9.1X$10^{-8}$$s^{-1}$ at 160 Mpa at 300℃.

The stress exponents of this alloy were increased with increasing applied stress at all test temperatures. The creep rates were slightly different in the diffusion-controlled, while a big difference is showed at high stresses.

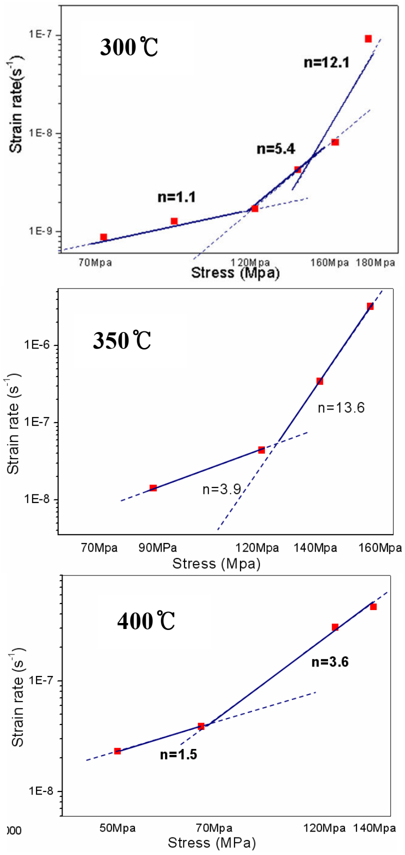

Figure 2. The plot of creep rate vs. stress at temperatures 300, 350 and 400 ℃.

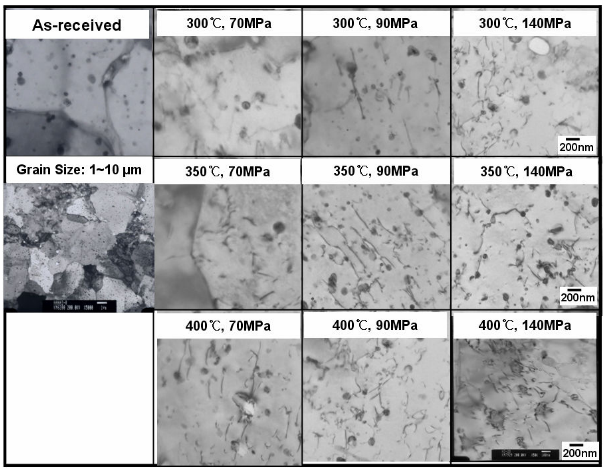

Figure 3. Microstructure (TEM) of the as-received and creep-tested specimens at temperatures 300, 350 and 400 ℃.

The dislocations were integrated enormously and the interaction between dislocations and particles were also showed with increasing applied stresses (Figure 3).

Figure 4 shows the activation energies calculations with the stresses. The activation energies were estimated to 242, 197, 270 and 246 kJ/mol at stresses 70, 90, 120 and 140 Mpa respectively. Transitions in creep mechanisms are noted, with dislocation diffusion-controlled creep at low stresses and the dislocations glide-controlled and dislocations climb-controlled creep at higher stresses.

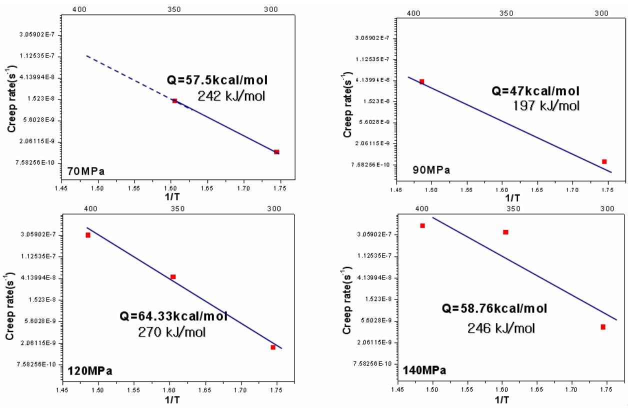

Figure 4. Activation energies calculations for Zr-1.5Nb-0.4Sn-0.1Fe-0.1Cu alloy for the creep

3. Conclusion

The creep characteristics of the Zr-1.5Nb-0.4Sn-0.1Fe-0.1Cu alloy sheet which is one of the Korea candidate nuclear fuel cladding materials were investigated in the temperature range from 300℃ to 400℃ and in the stress range from 50 MPa to 180 MPa along the rolling direction. The creep rates ranges in these tests were 8.8×10^{-10} s^{-1} to 4.7×10^{-7} s^{-1}. The activation energies for the creep were also estimated to make an assessment the creep mechanisms in this alloy. The stress exponents of this alloy were increased with increasing applied stress at all test temperatures. The creep rates were slightly different in the diffusion-controlled, while a big difference is showed at high stresses. Transitions in creep mechanisms are noted, with dislocation diffusion-controlled creep at low stresses and the dislocations glide-controlled and dislocations climb-controlled creep at higher stresses.

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