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

The creep deformation properties of HANA-3 and HANA-6 alloys under applied stresses

[a]Kim Yong Deog, , [c]Na Kwang Su, [b]Jeong Yong Hwan, [c]Kim Seon Jin, [a]Bae Seong Man
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

The creep deformation 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 not only secure the safety and the reliability of the fuel rods in a reactor but also the thermal performance and mechanical integrity of fuel rods.

The creep characteristics of the Zr-1.5Nb-0.4Sn-0.1Fe-0.1Cu (HANA-3) and Zr-1.1Nb-0.05Cu (HANA-6) alloys which are Korea's prospecting candidate nuclear fuel cladding materials were investigated in the temperature range from 300℃ to 500℃ and in the stress range from 50 MPa to 250 MPa along the rolling direction. The creep rates ranges in these tests were 1.27×10^{-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.

2. Experimental Procedures

2.1 Test Specimen Preparation

The studied materials, HANA-3 and HANA-6 sheet, ware 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 500℃ and in the stress range from 50 MPa to 250 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.

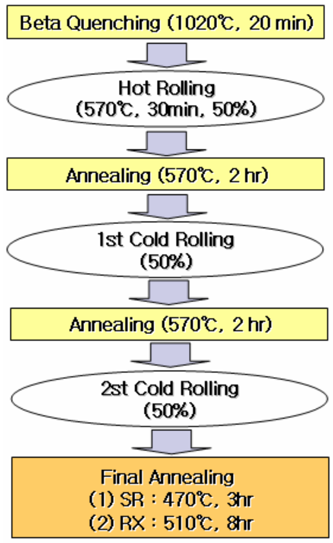


Figure 1. The test specimen preparation process.

3. Results and discusson

Figure 2 shows the stress exponents with the stress and strain rates in temperature range 300℃ to 500℃ for the HANA-3 and HANA-6 alloys respectively. The stress exponent is generally represented by equation 1[1].

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

The strain rates ranges in these tests were 1.27×10^{-10} s^{-1} to 4.7×10^{-7} s^{-1}. The strain rates were different with the stress level, i.e. the strain rate was $1.27\text{X}10^{-9}$ s^{-1} in the stress range 70 – 120 MPa, however it was increased to $9.1\text{X}10^{-8}s^{-1}$ 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 4 and 5 show the creep deformation map and activation energies calculations with the stresses for the HANA-3 and HANA-6 alloys respectively. The activation energies for the HANA-3 creep deformation were estimated to 56, 62.5, 64.3 and 63.8 kcal/mol at stresses 120, 150, 200 and 250 Mpa respectively.

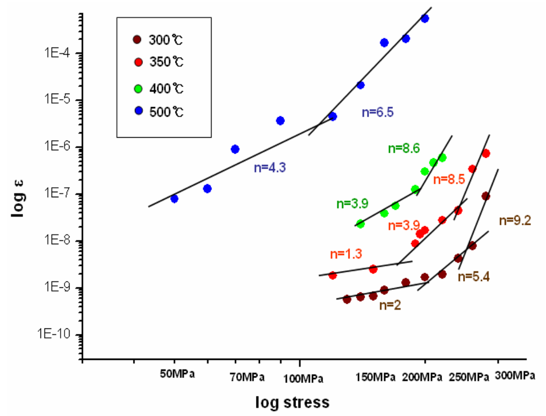


Figure 2. The plot of creep rate vs. stress for HANA-3 alloy at temperatures 300, 350, 400, and 500 ℃.

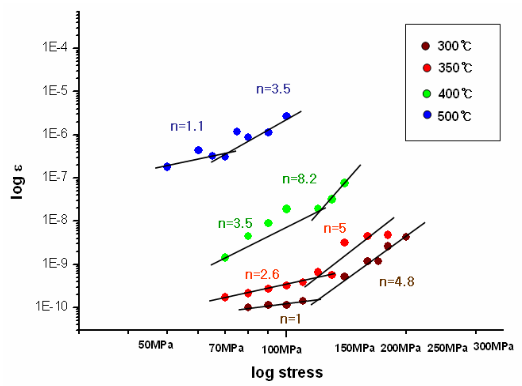
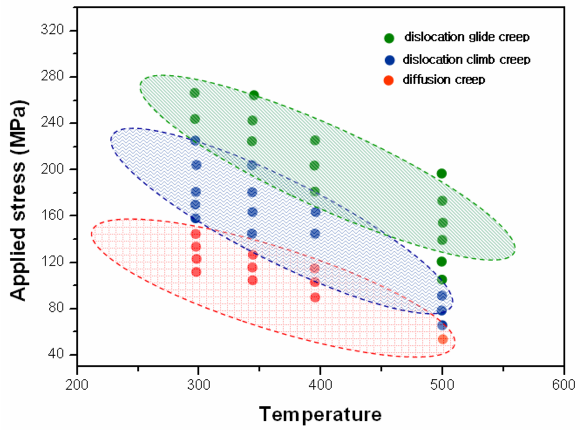


Figure 3. The plot of creep rate vs. stress for HANA-6 alloy at temperatures 300, 350, 400, and 500 ℃.

The activation energies for the HANA-6 creep deformation were estimated to 50.8, 59.7, 60.3 and 58.8 kcal/mol at stresses 120, 150, 200 and 250 Mpa respectively. Transitions in creep mechanisms are noted, with dislocation diffusion-controlled creep at low stresses and the dislocations climb-controlled and dislocations glide-controlled creep at higher stresses [2,3,4].

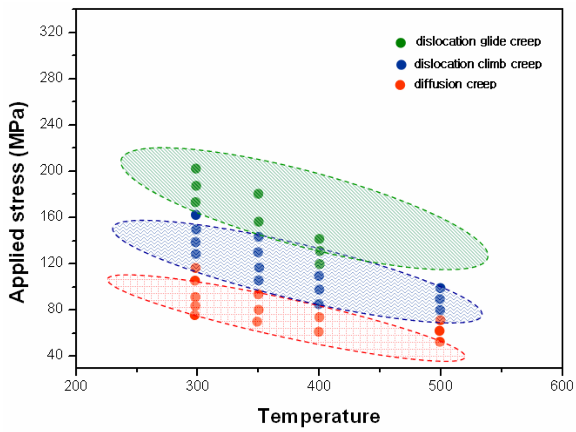
3. Conclusion

The creep characteristics of the HANA-3 and HANA-6 alloys which are Korea's prospecting candidate nuclear fuel cladding materials were investigated in the temperature range from 300℃ to 500℃ and in the stress range from 50 MPa to 250 MPa along the rolling direction. The creep rates ranges in these tests were 1.27 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. 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.



load	120MPa	150MPa	200MPa	250MPa
Q (kcal/mol)	56	62.5	64.33	63.76

Figure 4. Creep deformation map and activation energies calculations for HANA-3 alloy



load	70MPa	100MPa	120MPa	140MPa
Q (kcal/mol)	50.8	59.7	60.33	58.76

Figure 5. Creep deformation map and activation energies calculations for HANA-6 alloy

REFERENCES

1. D.Kaddour, S.Frechinet : "Experimental determination of creep properties of Zirconium alloys together with phase transformation" Scripta Materialia 51 (2004) 515-519.
2. K.L.Murty : "Significance and role of deformation micromechanisms in life-predictive modeling of aging structures" Appl Mech Rev vol 46 (1993) no 5.
3. D.B.Knorr, M.R.Notis : "Deformation Mechanism mapping of a-Zr and Zircaloy-2" JNM 56(1975) 18-24 .
4. J.J.Holmes : "The activation energies for creep of Zircaloy-2" JNM 13 No.2 (1964) 137-141.