BIAXIAL THERMAL CREEP OF V-4Cr-4Ti AT 700°C AND 800°C – R. J. Kurtz and M. L. Hamilton (Pacific Northwest National Laboratory)*

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EXTENDED ABSTRACT

A study of the biaxial thermal creep properties of V-4Cr-4Ti (Heat No. 832665) is being performed using pressurized tube specimens. The specimen geometry, stress levels and test temperatures are designed to compliment ongoing efforts to characterize the irradiation creep performance of the same alloy [1-4]. The current study is a companion to another research effort underway at Argonne National Laboratory [5] to evaluate the uniaxial creep behavior of V-Cr-Ti alloys.

Sections of V-4Cr-4Ti tubing with a nominal 4.572 mm OD by 0.254 mm wall thickness and ~45% cold work level were obtained from Argonne National Laboratory for fabricating creep specimens. Details of the tubing fabrication process have been reported previously [2]. Specimens were pressurized with high-purity helium gas to mid-wall effective stress levels below the uniaxial yield strength. The specimens were loosely wrapped with Ti foil and then placed in an ultra-high vacuum furnace and heated to 700 or 800°C. Periodically the specimens were removed from the furnace to measure the change in OD with a high-precision laser profilometer. Effective (von Mises) mid-wall creep strains were computed from the diameter change data.

The stress dependence of the effective secondary creep rate is presented in Figure 1 along with uniaxial data obtained by Chung et al., at 600°C and higher stresses [6]. All of the data in Figure 1 were fitted to

$$\dot{\varepsilon}_e = A\sigma_e^n \qquad (1)$$

where $\dot{\varepsilon}_e$ is the effective secondary creep rate, σ_e is the effective stress, A and n are constants. Note the stress exponent, n, is 9.9 for the 600°C data gathered at stress levels greater than 300 MPa. For the higher temperature data generated at stress levels less than 160 MPa n is between 2.7 and 3.7. This difference in stress exponent is not due to biaxial versus uniaxial specimen geometries, but is characteristic of creep in vanadium and vanadium alloys [3-8]. Values of $n \sim 3$ suggest that dislocation creep is the predominant deformation mechanism for the thermal and stress conditions employed here [7]. Microstructural studies of several failed creep specimens lend additional support for this conclusion [8].

The activation energy for creep in V-4Cr-4Ti was estimated at effective stress levels of approximately 70, 90 and 120 MPa. Equation (2) was used to compute the activation energy, Q, as

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$$Q = \frac{R\ln(\dot{\varepsilon}_1/\dot{\varepsilon}_2)}{1/T_1 - 1/T_2} \qquad (2)$$

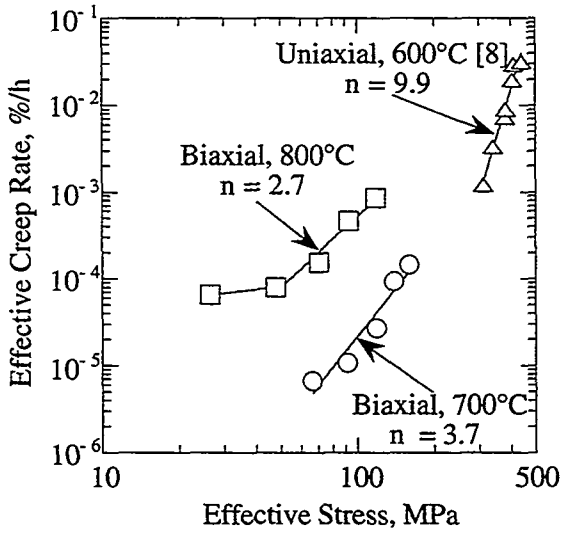

Figure 1. Stress dependence of the minimum creep rate of unirradiated V-4Cr-4Ti (Heat 832665) between 600-800°C.

where R is the universal gas constant, and $\dot{\varepsilon}_1$ and $\dot{\varepsilon}_2$ are the effective creep rates at temperatures T_1 and T_2. Activation energies ranging from 272 to 326 kJ/mole were obtained, with an average value of 299 kJ/mole. The activation energy did not vary inversely with stress as has been observed for pure vanadium [9]. These values are somewhat greater than the activation energy for self-diffusion in pure vanadium, which is about 270 kJ/mole in the 700 to 800°C temperature range [10]. This result lends additional support to the observation that the predominant creep mechanism in V-4Cr-4Ti at the temperatures and stresses investigated in this study is climb-assisted glide of dislocations. It also suggests that solute-drag may limit the rate at which dislocations can climb past obstacles in the microstructure, leading to a higher activation energy for creep. A recent study of the high-temperature deformation behavior of V-4Cr-4Ti shows that dynamic strain aging occurs in this material at temperatures up to 750°C [11]. This indicates that solutes are mobile at the test temperatures investigated in this study and could impede dislocation climb.

A comparison of the creep-rupture behavior of specimens tested here to data gathered on V-Cr-Ti alloys [3,5,6,12] and other fusion relevant materials [13] is presented in Figure 2. Both uniaxial and biaxial data are plotted in Figure 2. The data sets are correlated using the Larsen-Miller parameter (LMP), that is

$$P = T(20 + \log t_r)/1000 \qquad (3)$$

where T is the test temperature in K and t_r is the time-to-rupture in hours. Since failure strains for the vanadium alloys were generally large, a good correlation between uniaxial

(constant load tests) and biaxial (constant stress tests) data might not be expected, but this is obviously not the case here. The trend line for V-4Cr-4Ti is quite reasonable, but the data are too sparse to firmly establish an LMP creep-rupture correlation for this alloy. Comparison with V-(10-15)Cr-5Ti data [3,12] indicates that an additional 6 to 9% Cr

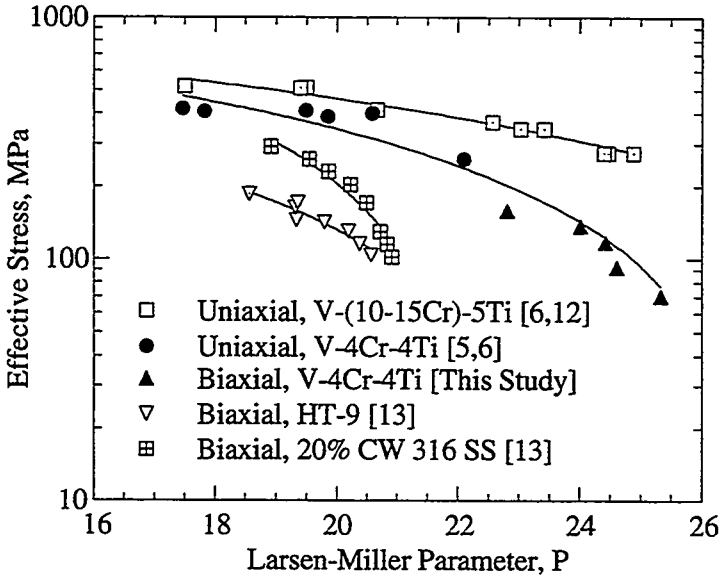

Figure 2. Larsen-Miller Parameter correlation for creep-rupture of unirradiated V-4Cr-4Ti (Heat 832665).

improved the creep-rupture properties of this alloy system considerably. Comparing the performance of V-4Cr-4Ti with HT-9 [13] and 20% cold-worked 316 stainless steel [13] shows that V-Cr-Ti alloys exhibit much better creep-rupture resistance and therefore could tolerate higher average wall temperatures.

An on-going study of the thermal creep properties of V-4Cr-4Ti is being performed using pressurized tube specimens. The secondary creep rate was found to be power-law dependent on the applied stress with a stress exponent of 3.7 at 700°C and 2.7 at 800°C. The average activation energy for creep of V-4Cr-4Ti was 299 kJ/mole, which is quite close to the activation energy for self-diffusion in pure vanadium in this temperature regime. The predominant mechanism of creep deformation for the conditions employed in this study is most likely climb-assisted dislocation motion. Creep-rupture data from uniaxial and biaxial tests of V-4Cr-4Ti specimens yields a reasonable LMP correlation. On this basis the creep-rupture properties of V-4Cr-4Ti were shown to be slightly worse than V-(10-15)Cr-5Ti and significantly better than other candidate fusion structural materials such as HT-9 and 20% cold-worked 316 stainless steel.

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