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

OBJECTIVE

To determine the biaxial thermal creep characteristics of V-4Cr-4Ti over the temperature range 600 to 800°C at realistic stresses for comparison with uniaxial creep tests and irradiation creep experiments.

SUMMARY

A study of the thermal creep properties of V-4Cr-4Ti is being performed using pressurized tube specimens. In a previous report [1] relevant data on thermal creep of vanadium alloys was reviewed to guide the selection of an initial test matrix. Experimental details and results for exposure times of 1523 h at 700°C and 1784 h at 800°C were also covered [1]. This report provides additional results for exposure times up to approximately 4000 h.

PROGRESS AND STATUS

An initial test matrix was developed from an evaluation of existing thermal creep data for vanadium alloys and consideration of design basis service loads [1]. Three test temperatures were selected, 600, 700 and 800°C. Stress levels were chosen to be below the tensile yield strength at the test temperature of interest. Table 1 gives pertinent information for each specimen in the first series of tests. The complete test matrix is given in Reference 1. Specimen codes in italic type denote failed specimens. Two unpressurized tube samples were also included at each test temperature to enable periodic microstructural and chemical assays to be performed.

Table 1. Unpressurized creep tube dimensions, fill pressures and mid-wall hoop stress levels.

Test Temp., °C	Specimen Code	Specimen OD, mm	Specimen Wall, mm	Fill Press., MPa	Mid-Wall Hoop Stress, MPa
700	AR11	4.5674	0.2601	2.896	72.5
	AR12	4.5662	0.2532	3.909	99.9
	AR13	4.5672	0.2456	4.937	129.6
	AR14	4.5657	0.2499	5.930	151.9
	AR15	4.5659	0.2553	6.964	173.4
800	*AR16*	4.5684	0.2477	2.654	77.3
	AR17	4.5667	0.2507	3.571	101.2
	AR18	4.5664	0.2461	4.482	128.7
	AR19	4.5667	0.2543	5.419	149.4
	AR20	4.5659	0.2527	1.793	52.0
	AR21	4.5679	0.2454	0.910	28.9

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Results and Discussion

Specimens are heated to 700 and 800°C in an ultra-high vacuum furnace for specific time intervals and then periodically removed to measure the change in OD with a high precision laser profilometer. The OD measurements were converted to strain values as described previously [1]. Tables 2 and 3 give the effective mid-wall creep strain at 700°C and 800°C, respectively. Rupture strains are denoted by bold type in the tables. These data are plotted in Figures 1 and 2. An interesting feature of the curves is that they do not show evidence of primary or secondary creep. Their shape is suggestive of tertiary creep from a very early stage in the test. This behavior may be due to the presence of shallow longitudinal scratches or defects found on the tube ID. Results of microstructural examinations of several failed tubes and an as-received specimen indicate that these defects are common [2] and are probably caused by the tube fabrication technique. Further work is needed to fully assess the significance of these defects on the biaxial creep properties of V-4Cr-4Ti.

Table 2. Time dependence of effective mid-wall creep strain for 700°C tests.

Time, h	AR11	AR12	AR13	AR14	AR15
168	0.0072	0.0000	0.0072	0.0072	0.0217
242	0.0072	0.0000	0.0072	0.0145	0.0361
357	0.0072	0.0072	0.0072	0.0289	0.0795
598	0.0072	0.0217	0.0145	0.0578	0.2096
1375	0.0072	0.0145	0.0217	0.1229	0.9246
1523	0.0072	0.0000	0.0361	0.1373	1.2783
2157	0.0361	0.0289	0.0578	0.3468	4.5424
2780	0.0289	0.0217	0.0578	0.8596	10.247
2804	-	-	-	-	**12.956**
2881	0.0289	0.0361	0.0867	0.9896	-
3258	0.0289	0.0217	0.0867	1.5309	-
3365	0.0361	0.0289	0.0939	1.6896	-
3532	0.0289	0.0289	0.0939	2.1008	-
3699	0.0289	0.0361	0.1011	2.3676	-
3890	0.0217	0.0361	0.1445	2.7712	-
4057	0.0217	0.0361	0.1300	3.1820	-

Comparison of the creep behavior of V-4Cr-4Ti at 700°C with results generated on HT-9 tube specimens show that V-4Cr-4Ti has much better creep resistance. The stress required to cause 1% creep strain (a typical design limit) in 3000 h at 700°C is about 140 MPa for V-4Cr-4Ti. For HT-9, 1% creep strain is reached at a stress of 120 MPa and a temperature of only 605°C [3].

Figure 3 and 4 give plots of the dependence of the creep rate on applied stress. The creep rates shown in Figures 3 and 4 are instantaneous values determined from

$$\dot{\varepsilon} = \frac{\varepsilon_{i+1} - \varepsilon_i}{t_{i+1} - t_i} \qquad (1)$$

where ε is the effective mid-wall creep strain and t is time. The times given in Figures 3 and 4 are the mid-point of the interval. Rough estimates of the stress exponent were obtained by fitting the data to the following equation

$$\dot{\varepsilon} = A\sigma^n \qquad (2)$$

where σ is the effective stress and A and n are material constants.

Table 3. Time dependence of effective mid-wall creep strain for 800°C tests.

Time, h	AR16	AR17	AR18	AR19	AR20	AR21
167	-	-	-	-	0.0000	0.0072
168	0.0289	0.0650	0.1445	3.5917	-	-
242	0.0361	0.1156	0.6212	**14.709**	-	-
358	-	-	-	-	0.0217	0.0217
412	0.1156	0.8089	5.7999	-	-	-
488	0.1806	1.5306	10.832	-	-	-
516	-	-	-	-	0.0434	0.0217
578	0.3466	2.9363	**24.141**	-	-	-
727	0.8375	6.4173	-	-	-	-
864	1.5156	**13.561**	-	-	-	-
1031	2.6327	-	-	-	-	-
1343	5.4454	-	-	-	-	-
1491	7.1108	-	-	-	-	-
1784	10.835	-	-	-	-	-
2125	16.000	-	-	-	-	-
2460	21.295	-	-	-	-	-
2812	26.827	-	-	-	-	-
2956	29.201	-	-	-	-	-
3239	33.912	-	-	-	-	-
3346	35.806	-	-	-	-	-
3513	38.907	-	-	-	-	-
3680	42.279	-	-	-	-	-
3871	46.557	-	-	-	-	-
4029	**51.885**	-	-	-	-	-

At 700°C the stress exponent, n, is 5.7 or greater for all time intervals and at 800°C n ranges from 7.2 to 10.6. High values of n suggest that dislocation creep is the predominant deformation mechanism [4]. Microstructural studies [2] of several failed creep specimens support this conclusion. It should be noted, however, that grain boundary sliding and accommodation processes must also contribute significantly to creep deformation since extensive wall thinning is observed [2] near the failure location, but grain boundary cavitation is not found.

A comparison of the creep-rupture behavior of specimens tested here to data gathered on V-4Cr-4Ti (Heat BL-47) by Chung et al. [5] is presented in Figure 5. The data sets are correlated using the Larsen-Miller Parameter, that is

$$P = \frac{T(\log t_r + 20)}{1000} \qquad (3)$$

where T is the test temperature in K, and t_r is the time-to-rupture in hours. The trend line is reasonable, but the data are too sparse to firmly establish a Larsen-Miller Parameter correlation for creep-rupture of this alloy.

Chemical analyses for pick-up of oxygen and nitrogen were performed on one of the unpressurized 800°C tube specimens (Sample ID: 8-2). This specimen was in the vacuum furnace for 2812 h. The chemical analyses were performed at Siemens Power Corporation in Richland, Washington. The specimen was sectioned into three parts and each section was prepared by etching in 10% HNO_3 : 4.8% HF for 30 seconds to one minute, followed by deionized water and acetone rinses with air drying. A LECO TC436 Nitrogen Oxygen Determinator was used for the analyses. The method uses inert gas fusion of the sample in a graphite crucible with nickel as a flux. Nitrogen is measured by thermal conductivity, and oxygen is measured as carbon dioxide by an infrared detector. Four control standards were analyzed along with the three sections of tube 8-2. Data for the control samples and unknowns are presented in Table 4.

Table 4. Chemical analysis results for unpressurized tube specimen 8-2, tested for 2812 h at 800°C.

Sample ID	Certified Content, wppm	Measured Levels	
		N, wppm	O, wppm
NBS 73C	370 N	404	NA
LECO 501-551	148 O	NA	146
LECO 502-047	1340 O	NA	1376
8-2 A	NA	57.1	747
8-2 B	NA	57.3	731
8-2 C	NA	65.1	721

The average oxygen and nitrogen levels after 2812 h at 800°C are 733 wppm O and 60 wppm N. These levels may be compared with the as-received values of 560 wppm O and 95 wppm N [6]. The data indicate that a relatively modest 30% increase in oxygen level was experienced during the course of the 2812 h exposure at 800°C. Additional chemical analyses on as-received and exposed samples are planned to verify this trend.

ACKNOWLEDGEMENTS

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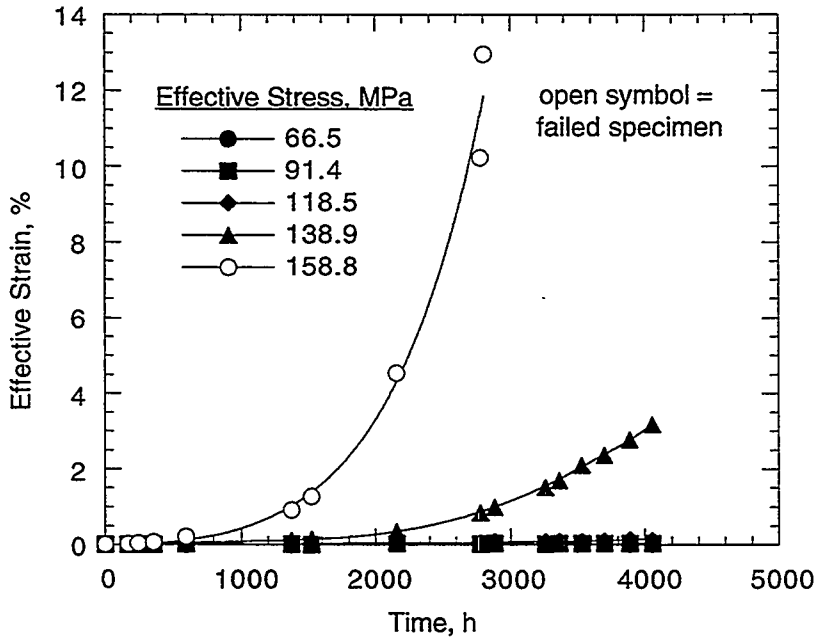

Figure 1. Time dependence of effective mid-wall creep strain at 700°C for unirradiated V-4Cr-4Ti.

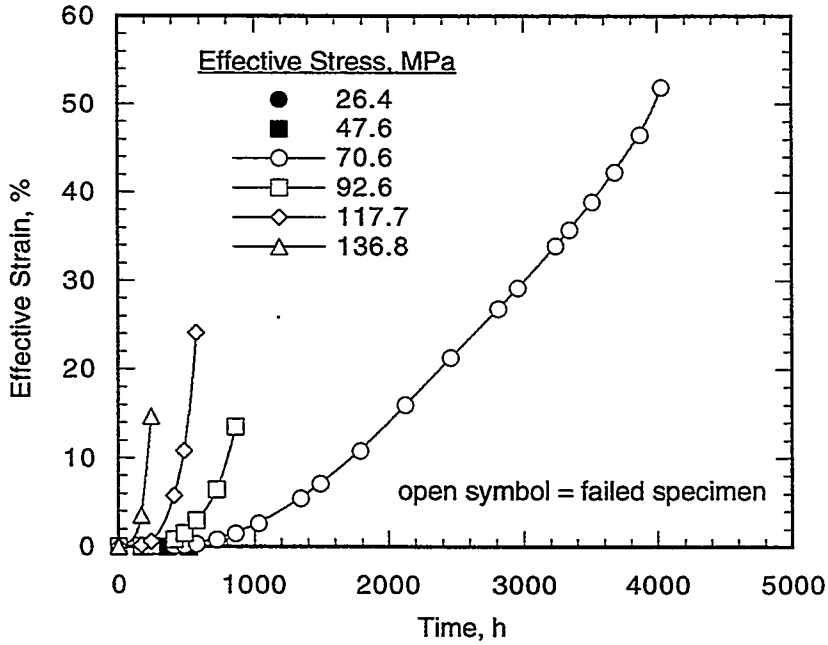

Figure 2. Time dependence of effective mid-wall creep strain at 800°C for unirradiated V-4Cr-4Ti.

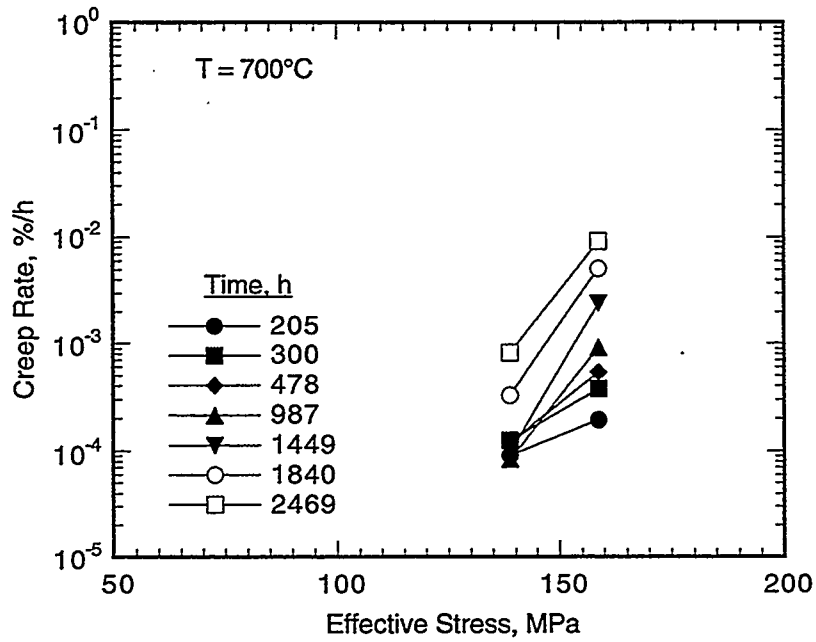

Figure 3. Stress dependence of the creep rate at 700°C for unirradiated V-4Cr-4Ti.

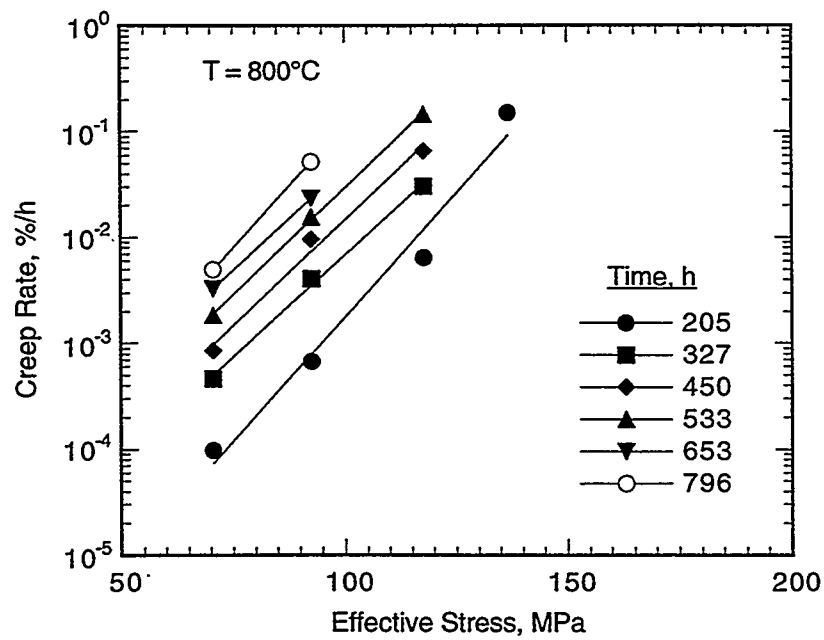

Figure 4. Stress dependence of the creep rate at 800°C for unirradiated V-4Cr-4Ti.

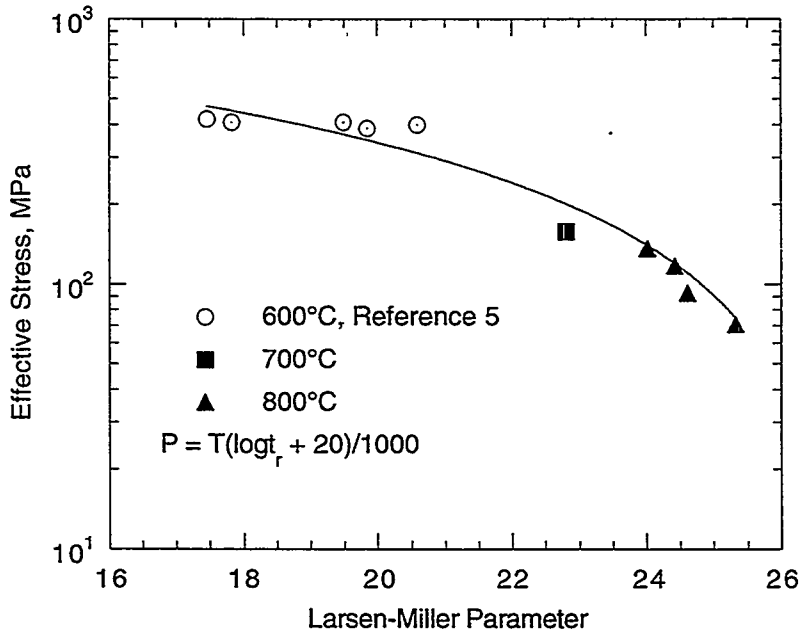

Figure 5. Larsen-Miller Parameter correlation for creep-rupture of unirradiated V-4Cr-4Ti. The 600°C data was taken from Reference 5.