UNIAXIAL CREEP BEHAVIOR OF V-4Cr-4Ti Alloy*

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OBJECTIVE

The objectives of the creep test program are to (a) to establish time/temperature relationships for creep properties, such as creep rupture strength, 1% creep in 10,000 hr, onset of third-stage creep, etc., all of which are key parameters in designing structural components for service at elevated temperatures; (b) provide a basis to establish the upper-use temperature associated with creep limits for application of V-base alloys; and (c) evaluate the influence of variations in the concentrations of substitutional and interstitial elements on the creep properties of fusion-reactor-relevant V-base alloys.

SUMMARY

A systematic study is currently being conducted at Argonne National Laboratory (ANL) to evaluate the uniaxial creep behavior of V-Cr-Ti alloys as a function of temperature in the range of 650-800°C and at applied stress levels in the range of 75-380 MPa. At present, the principal effort has focused on the V-4Cr-4Ti alloy of Heat 832665; however, another heat of a similar alloy from General Atomics (GA) will also be used in the study. During this reporting period, additional creep tests were conducted at 700 and 800°C at lower stress levels than in earlier tests. In addition, the tested specimens are examined for O contamination, if any, by vacuum fusion analysis of the tested specimens and by micro hardness measurements of specimen cross-sections. The test results indicate that in the temperature range of 650-800°C, creep deformation follows a power-law creep with stress exponents indicative of a dislocation-climb-controlled process.

INTRODUCTION

Refractory alloys based on V-Cr-Ti are being considered for use in first-wall structures in advanced blanket concepts that involve liquid Li as a coolant and breeding material. Furthermore, advanced concepts that involve He as a coolant also require structural alloys such as V-Cr-Ti, which can withstand thermal loading at high temperature. It is important that for advanced fusion systems, design concepts establish the upper temperature limits for structural components based on various design criteria. At temperatures above 600°C, the time-dependent creep properties of V alloys must be considered when evaluating performance limits.

The long-term creep properties of the V-base alloys will be influenced by the time-dependent nucleation and growth of precipitates that include nonmetallic elements such as O, N, and C. Several of our microstructural studies of V-base alloys have identified precipitates such as face-centered-cubic Ti(O, N, C) with variable O, N, and C ratios. To correlate microstructural development with creep properties, it is essential to establish the time-dependent evolution of type, number, and location of precipitates in V-base alloys. Moreover, development of several of these precipitates can be influenced by the exposure environment during creep testing. Over the long term, creep data are needed for environments with a wide range of chemistries and that encompass high vacuum to low partial pressures of O and H, as well as He of various purities.

SCOPE OF WORK

In the near term, the program will experimentally evaluate uniaxial creep properties of V-Cr-Ti materials in high-vacuum environments at temperatures of 650-800°C, with emphasis on baseline creep behavior of the alloys and correlations between microstructures and properties. Another aspect of the program will be creep

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tests on heats of V-base alloys that represent a range of variations in the concentrations of both substitutional and interstitial elements, in order to provide an understanding of the effects of these variables on creep behavior.

EXPERIMENTAL PROGRAM

The effort is focused on the ANL-procured large heat of nominal composition V-4Cr-4Ti and on the GA heat of a similar composition.[1-3] Flat creep specimens (1 mm in thickness) and specimens with cylindrical cross sections (2.5 mm diameter), were used in the initial phase of the program.[3] All specimens were fabricated according to ASTM Standard E8-96a with the gauge length oriented parallel to the rolling direction. Tests were conducted on specimens annealed at 1000°C for 1 h in vacuum.

During this reporting period, several tests were continued at 700 and 800°C. The specimens were wrapped in Ti foil to minimize contamination of the sample, especially by O. The creep-test procedure is in accordance with ASTM E139-96. Four ATS model 2140 uniaxial direct constant-load creep-test machines have been allocated for this program and test details are given in Ref. 3. The test program is aimed at obtaining the steady-state creep rate, onset of tertiary creep, rupture strain, rupture life, and times for accumulation of 1 and 2% strain. At least four stress levels are planned at each temperature to obtain sufficient data to develop Larson-Miller correlations between time, temperature, and applied stress. The information will be used to assess the upper-use temperature for the material, based on appropriate design criteria and as a basis for alloy improvement.

RESULTS

During this period, several additional creep tests were conducted at 700 and 800°C. Furthermore, two tests were completed at 700°C to complement and compare the data generated in the biaxial creep test program at 700°C conducted at Pacific Northwest National Laboratory (PNNL).[4] Creep strain/time plots were reported earlier for several specimens that we tested in vacuum at 650, 700, 725, and 800°C.[3] The data showed that the primary creep period is negligible in all tests, and the secondary (or linear) creep portion of the curve is small. The curves showed an accelerating creep behavior over the range of the present tests, especially at 725 and 800°C. A linear least-squares analysis function is used to provide a consistent method to extract minimum creep rate, onset of tertiary creep, and creep strain at the onset of tertiary creep.[3] Table 1 provides an update of the creep data obtained in the ANL test program. Figure 1 shows the variation of time to rupture and minimum creep rate as a function of applied stress for the alloy tested at 650, 700, 725, and 800°C. An examination of the results showed that in the temperature range of 650-800°C, the creep deformation follows a power-law creep with stress exponents indicative of a dislocation-climb-controlled process.

To determine the extent of O contamination, if any, in the creep specimen, cross sections of the tested specimen were mounted and polished, after which Vickers hardness measurements were made along the thickness direction; the results were reported earlier.[2-3] In general, hardness values ranged from 145 to 195, and variation was negligible within a given specimen, indicating that the contamination is minimal over the range of the current study. Examination of the fracture surfaces of tested specimens showed a ductile mode of fracture in all specimens. The specimens tested at 800°C showed rupture strains of 30-61%, and thinning of the cross section in the fracture zone was significant.

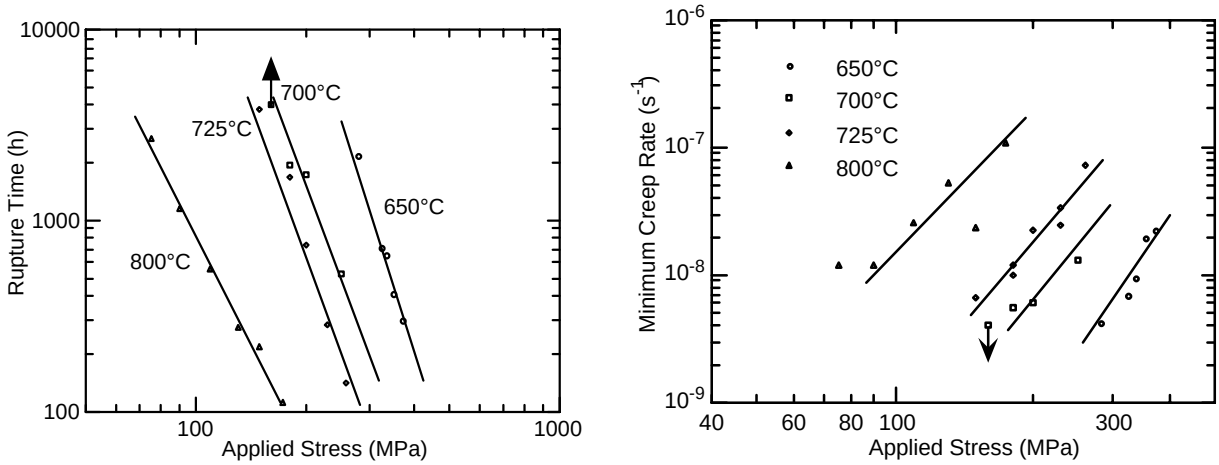

Fig. 1. Variation of rupture time (left) and minimum creep rate (right) as a function of applied stress for V-4Cr-4Ti alloy creep tested at 650-800°C.

Table 1. Creep test data obtained for V-4Cr-4Ti alloy at 650-800°C

Temperature (°C)	Applied stress (MPa)	Time to rupture (h)	Rupture strain	Minimum creep rate (s^{-1})	Time-to-onset of tertiary (h)	Strain-to-onset of tertiary	Time for 1% strain (h)	Time for 2% strain (h)
650	370	300	0.18	2.2×10^{-8}	160	0.021	41	156
	350	415	0.14	2.0×10^{-8}	252	0.023	76	212
	335	661	0.15	9.3×10^{-9}	325	0.017	118	400
	322	719	0.16	7.0×10^{-9}	440	0.029	-	-
	280	2176	0.18	4.2×10^{-9}	1250	0.024	360	1025
700	250	530	0.27	1.3×10^{-8}	250	0.016	120	282
	200	1715	0.28	6.1×10^{-9}	325	0.013	230	510
	180	1959	0.30	5.6×10^{-9}	525	0.014	300	650
	180 [a,b]	>3800	>0.04	1.1×10^{-9}	1050	0.007	1300	2300
	160 [c]	>4000	>0.04	$<4.0 \times 10^{-9}$	-	-	-	-
725	260	139	0.17	7.2×10^{-8}	75	0.024	20	63
	230	280	0.25	3.3×10^{-8}	106	0.024	58	130
	230 [b]	215	0.23	2.4×10^{-8}	105	0.014	61	127
	200	737	0.27	2.2×10^{-8}	265	0.023	78	220
	180	1701	0.32	1.0×10^{-8}	530	0.029	50	315
	180 [b]	2281	0.43	1.2×10^{-8}	475	0.024	140	379
	150	3783	0.38	6.6×10^{-9}	270	0.012	211	458
800	174	112	0.30	1.1×10^{-7}	45	0.023	14	38
	150	215	0.46	2.3×10^{-8}	85	0.011	77	115
	130	275	0.61	5.3×10^{-8}	45	0.013	37	59
	110	559	0.46	2.6×10^{-8}	67	0.012	61	101
	90	1147	0.55	1.2×10^{-8}	150	0.075	-	-
	75	2691	0.45	1.2×10^{-8}	200	0.014	120	270
	75 [b,c]	>3525	>0.09	2.7×10^{-9}	925	0.014	475	1200

[a]In progress.

[b]Round cross-section specimen.

[c]Terminated before failure.

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