UNIAXIAL CREEP BEHAVIOR OF V-Cr-Ti Alloys*

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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 substitutional and interstitial element concentrations on the creep properties of fusion-reactor-relevant V-base alloys.

SUMMARY

A systematic study has been initiated at Argonne National Laboratory 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 identified as BL-71; however, another heat of a similar alloy from General Atomics (GA) will also be used in the study.

INTRODUCTION

Refractory alloys based on V-Cr-Ti are being considered for use in first-wall structures in advanced blanket concepts that employ liquid Li as a coolant and breeding material. Further, advanced concepts that use He as a coolant also require structural alloys such as V-Cr-Ti alloys that can withstand the thermal loading at high temperature. For the advanced fusion system design concepts, it is important to 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.

Limited data on the creep and stress-rupture properties of unirradiated V and V-base alloys have been reported by Chung et al.,[1] Schirra,[2,3] Bohm and Schirra,[4] Bajaj and Gold,[5] Kainuma et al.,[6] Van Thyne,[7] Carlander,[8] Bohm,[9] and Tesk and Burke.[10] Results from these studies showed that alloying of V with up to 3 wt.%Ti produces a significant increase in creep strength, but that additional Ti concentrations cause a substantial decrease in creep resistance. Addition of up to 15 wt.% Cr to V-(3-5)Ti alloy also produces significant strengthening in creep, while addition of 1 wt.% Si to V-3 wt.% Ti causes a significant decrease in the creep strength of this alloy. The data reported in these studies indicate that substitutional and interstitial element contents in V-base alloys have a significant effect on the creep properties. There are insufficient data available on the reference composition of V-4 wt.%Cr-4 wt.%Ti, especially at temperatures above 650°C.

The long-term creep properties of the V-base alloys will be influenced by the time-dependent nucleation and growth of precipitates that involve nonmetallic elements such as O, N, and C. Several of the 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. It is essential to establish the time-dependent evolution of type, number, and location of precipitates in V-base alloys to correlate the microstructual development with the creep properties. Further, 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 chemistry and that encompass high vacuum to low

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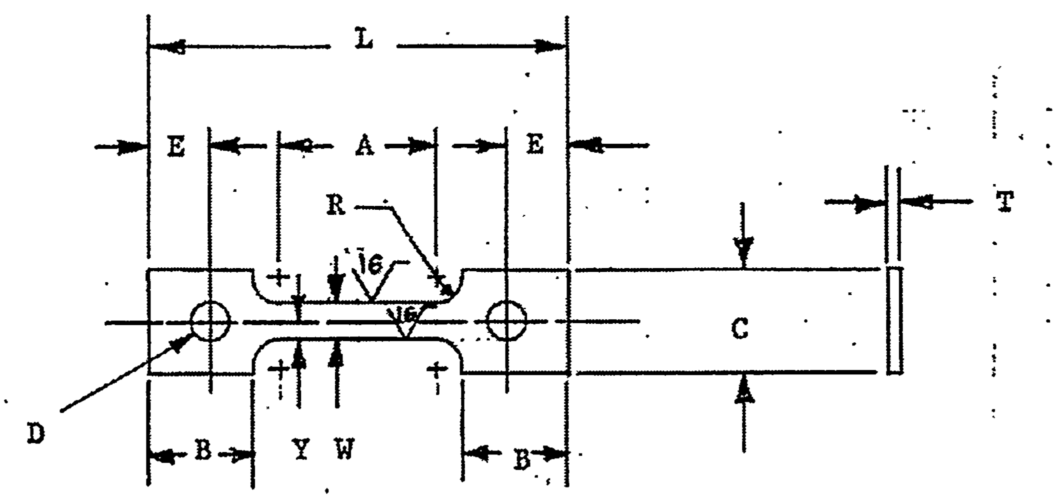
partial pressures of oxygen and hydrogen, and helium of various purities.

SCOPE OF WORK

The program in the near term will experimentally evaluate uniaxial creep properties of V-Cr-Ti materials in high-vacuum environments at temperatures of 650 to 800°C, with emphasis on baseline creep behavior of the alloys and correlations between microstructures and properties. Another aspect of the program will be to conduct creep tests on different heats of V-base alloys with a range of both substitutional and interstitial concentration variations, in order to provide an understanding of the effects of these variables on creep behavior.

EXPERIMENTAL PROGRAM

The effort will initially focus on the ANL-procured large heat of nominal composition V-4Cr-4Ti and on the GA heat of a similar composition. Four uniaxial creep-test machines have been allocated for this program. Two of the machines are equipped with high-vacuum systems and with furnaces capable of 900°C. The other two machines have vacuum capability and gas flow systems capable of conducting tests in low-partial-pressure environments and helium of various purities. We plan to use 1-mm-thick flat creep specimens (see Fig. 1 for details) of the alloy designed and fabricated according to ASTM Standard E8-69. A few specimens with cylindrical cross sections will be tested to validate the effects, if any, of specimen geometry on creep properties. Initial tests are conducted on specimens annealed at 1000°C for 1 hr in vacuum. During this period, a test was conducted at 725°C and 260 MPa. The specimen was wrapped in Ti foil to minimize contamination of the sample, especially by oxygen.



Dimensions in mm

A = 19 ± 0.50	Y = 2.2
B = 12.7	W = 4.5
C = 12.7	T = 1.0
D = 4.0	R = 3.175
E = 7.6	L = 50.8

Fig. 1. Schematic diagram of creep specimen designed according to ASTM Standard E8-69.

Creep strain in the specimen is measured by a linear-variable-differential transducer (LVDT), which is attached between the fixed and movable pull rods of the creep assembly. Displacements of 5×10^{-3} mm could be accurately determined with the LVDT. Before each test, the LVDT was calibrated by measuring its output for displacements that were set manually on a micrometer. The linear portion of the calibration curve is used to measure strain in a specimen during creep testing. The strain measurements are made at sufficiently frequent intervals during a test to define the creep strain/time curve.

A three-zone resistance-heated furnace is used in each testing machine to conduct creep tests at elevated temperatures. Chromel-Alumel thermocouples with small beads are used to measure specimen temperatures. Ceramic insulators are used on the thermocouples in the hot zone. In general, three thermocouples are fed through the specimen chamber, one spot-welded onto each end of the grips on the specimen near the shoulder region. The third thermocouple is held in the vacuum environment adjacent to the gauge-length portion of the specimen. Temperature is maintained within 2°C of the desired value for each test. The specimens are loaded at a constant rate to full load at the test temperature.

A detailed microstructural evaluation of the tested specimens is planned to characterize the morphologies as a function of exposure temperature and time and to establish the mechanisms of creep failure. The test program is aimed at obtaining the steady-state creep rate, onset of tertiary creep, rupture strain, and rupture life. At least four different stress levels are planned at each temperature to obtain sufficient data to develop Larson-Miller correlation 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, creep test facilities were set up with computerized data acquisition systems. Figure 2 shows the creep strain/time plot for a V-4Cr-4Ti alloy specimen tested in vacuum at 725°C and 260 MPa. Figure 3 is a scanning electron microscopy (SEM) photomicrograph of the specimen fracture surface. It is evident that the fracture morphology is indicative of ductile mode of failure. Figure 4 is an SEM photomicrograph of the polished cross section of the same specimen near the fracture surface, after creep testing at 725°C and 260 MPa. Grain size is in the range of 20-25 µm, and a significant number of minute cavities are seen at the grain boundaries.

To examine the extent of O contamination, if any, on the creep specimen, cross sections of the tested specimen were mounted and polished, after which Vickers hardness measurements were made at two locations along the thickness direction. Figure 5 shows the hardness profile for the tested specimen. Hardness values ranged from 150 to180, with most of the region in a range of 150-160, indicating that the contamination is minimal even at the test temperature of 725°C. Additional tests are in progress at 650, 725, and 800°C, and the results will be reported in the future as they become available.

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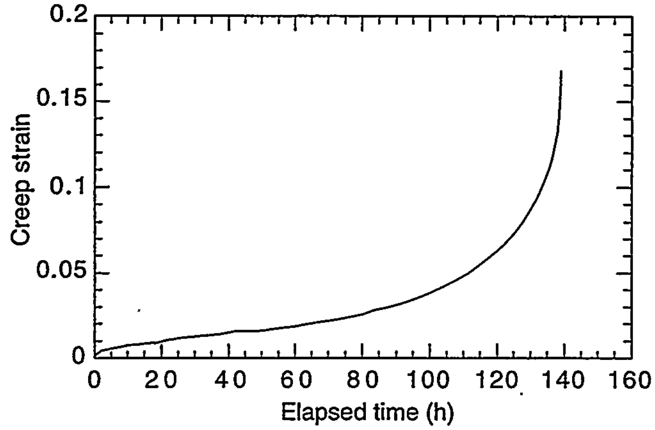

Fig. 2. Creep strain vs. time plot for V-4Cr-4Ti specimen creep tested at 725°C and 260 MPa in vacuum environment.

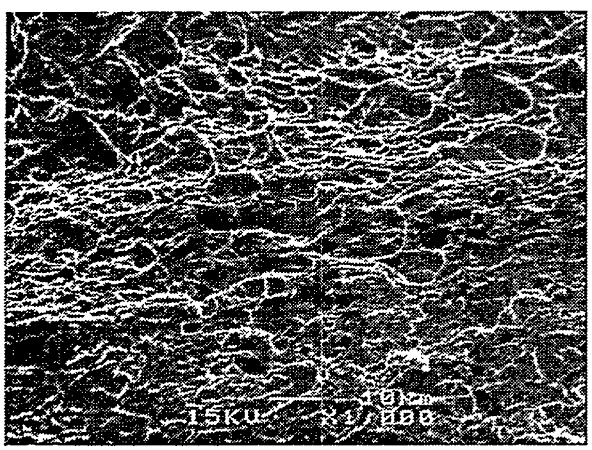

Fig. 3. SEM photomicrograph of cross section of fracture surface of V-4Cr-4Ti specimen, after creep testing at 725°C and 260 MPa.

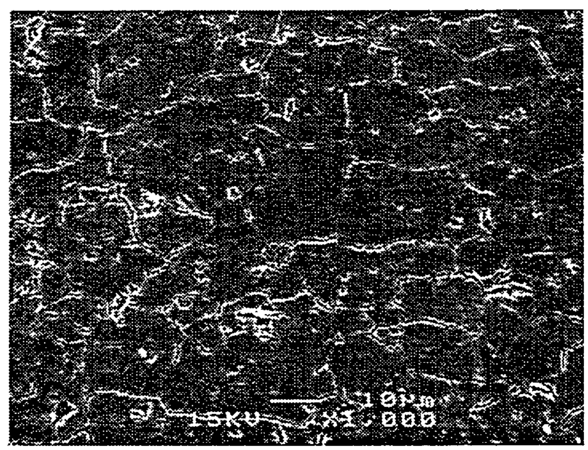

Fig. 4. SEM photomicrograph of polished cross section of V-4Cr-4Ti specimen near fracture surface, after creep testing at 725°C and 260 MPa.

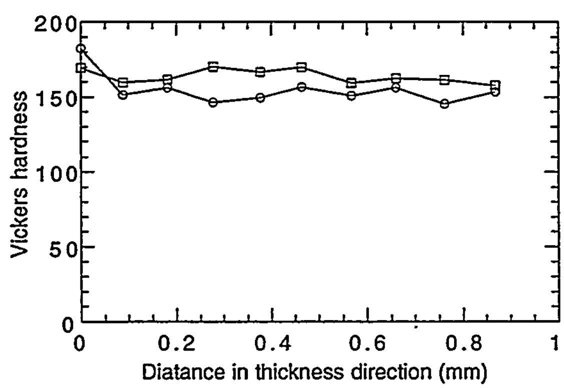

Fig. 5. Vickers hardness profile in thickness direction for V-4Cr-4Ti specimen, after creep testing at 725°C and 260 MPa.

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