COMPRESSION TESTING OF UNIRRADIATED V-4Cr-4Ti—M. M. Fryd (Lawrence University),[1] M. B. Toloczko, and R. J. Kurtz (Pacific Northwest National Laboratory)[2]

OBJECTIVE

The objective of this effort is to better understand the deformation behavior of vanadium alloys after irradiation.

SUMMARY

The NIFS-1 heat and heat 832665 of unirradiated V-4Cr-4Ti were tested in compression at temperatures of 25°C, ~ 250°C, and ~ 420°C. Test traces at all temperatures show an upper and lower yield point. Yield strength in compression and a strain hardening exponent were extracted from the test traces. The yield strength in compression mirrors yield strength values in tension from the literature. The strain hardening exponent at room temperature matches uniform elongation values in tension, but at elevated temperatures, the strain hardening exponent from the compression tests was much greater than uniform elongation values in the literature. Values for the yield strength in compression of the NIFS-1 heat were about 10% lower than heat 832665 which is probably due to the lower oxygen content in the NIFS-1 heat.

PROGRESS AND STATUS

Introduction

Vanadium alloys are of interest to the Fusion program as potential first wall structural materials because of their good thermal conductivity, good elevated temperature tensile strength, good high temperature creep resistance, and relative resilience to becoming radioactive [1–12]. The expected irradiation conditions for the first wall structural material include a range of temperatures where very high hardening caused by a high density of small, but shearable defect clusters results in a type of deformation called "localized deformation" [3,4,9,12–15]. At the onset of yield in a tensile test, a dislocation may move through a grain shearing the obstacles and clearing out a channel. Subsequent dislocations may easily pass through this channel. As the test progresses, more channels form. Up to the point of tensile instability plastic deformation is confined to these channels. One important macroscopic result of this deformation behavior is rapid onset of necking in a tensile test and very low uniform elongation. As a means to help understand the range of stress states where localized deformation may adversely affect macroscopic ductility in vanadium alloys, compression test specimens fabricated from two heats of V-4Cr-4Ti are currently under irradiation in the High Flux Isotope Reactor (HFIR). The results of 25°C, ~ 250°C, and ~ 420°C compression tests on the unirradiated control materials are presented here and compared with uniaxial tensile values from the literature.

Experimental Procedure

Cylindrical compression specimens were fabricated from V-4Cr-4Ti heats 832665 and NIFS-1. Heat 832665 is reported to have an oxygen content of 330 wppm, and the NIFS-1 heat is reported to have an oxygen content of 181 wppm [2]. The cylindrical specimens are 3mm in diameter and 3.5 mm tall. Heat 832665 was received in a 40% cold-worked condition, while the NIFS-1 heat was received in a 98% cold-worked condition. Before testing, individual specimens from both heats were wrapped in tantalum and titanium foil and annealed in a vacuum furnace for two hours at 1000°C at 1×10^{-6} torr or better. Identification codes were laser engraved onto one end of each specimen.

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[1]Undergraduate student, Lawrence University, Appleton, Wisconsin.
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Compression tests were performed in a 10,000 lb screw-driven Instron test frame with a 1000 lb load cell. A special compression test fixture, as shown in Fig. 1, was constructed for the testing. The upper and lower loading surfaces of the fixture were made from a high modulus tungsten carbide composite with a polished surface. The upper loading surface is in the form of a piston that is guided by a cylinder made from machineable carbide composite. A tight tolerance was maintained between the piston and cylinder to limit axial misalignment between the upper and lower loading surfaces. Silicon powder was used as a lubricant on upper and lower loading surfaces. Specimen displacement was monitored with a capacitance-type displacement transducer with a resolution better than 0.0002 mm (better than 0.006% strain).

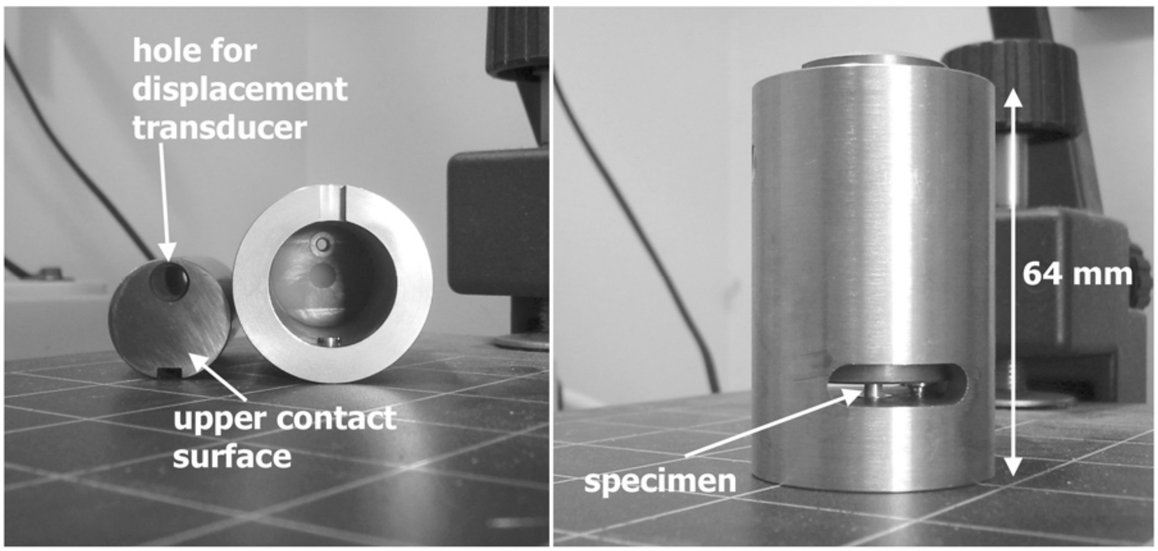

Fig. 1. Pictures of the compression test fixture.

Compression tests were performed at constant crosshead speed and with an initial strain rate of $5x10^{-4}$ s^{-1}. The target test temperatures were 250°C and 425°C. Heating was performed in a vacuum furnace capable of operation in an inert atmosphere or in a vacuum. Tests at 250°C were performed in 99.99% purity argon flowing at a rate of 2 L/min, and tests at 425°C were performed in a vacuum at 0.150 torr in an attempt to lower the partial pressure of oxygen during testing. The vacuum furnace was heated at a rate of 5.1°C/min for tests at 250°C and 9°C/min for tests at 425°C. All data were monitored and recorded electronically. The 0.2% offset yield stress and, when present, the upper yield point was measured from engineering stress versus engineering strain plots. The power law strain hardening (PLSH) exponent was measured from true stress versus true plastic strain plots in the range of 1–2% true plastic strain.

Results

The actual test temperatures were 25°C, 250–255°C, and 405–435°C. Engineering stress versus engineering strain curves for heat 832665 and the NIFS-1 heat are shown in Fig. 2. In most all of the tests, an upper and lower yield point was observed. The yield stress at 250°C was approximately 30% lower than at room temperature. The yield stress at ~ 415°C is essentially the same as at 250°C. Heat 832665 is consistently stronger than Heat NIFS-1 at all temperatures. All samples showed a continuous load increase during plastic deformation up to the load limit of the load cell. Serrations from dynamic strain aging occurred only in CA06. As is common in a compression test, some barreling of the samples occurred.

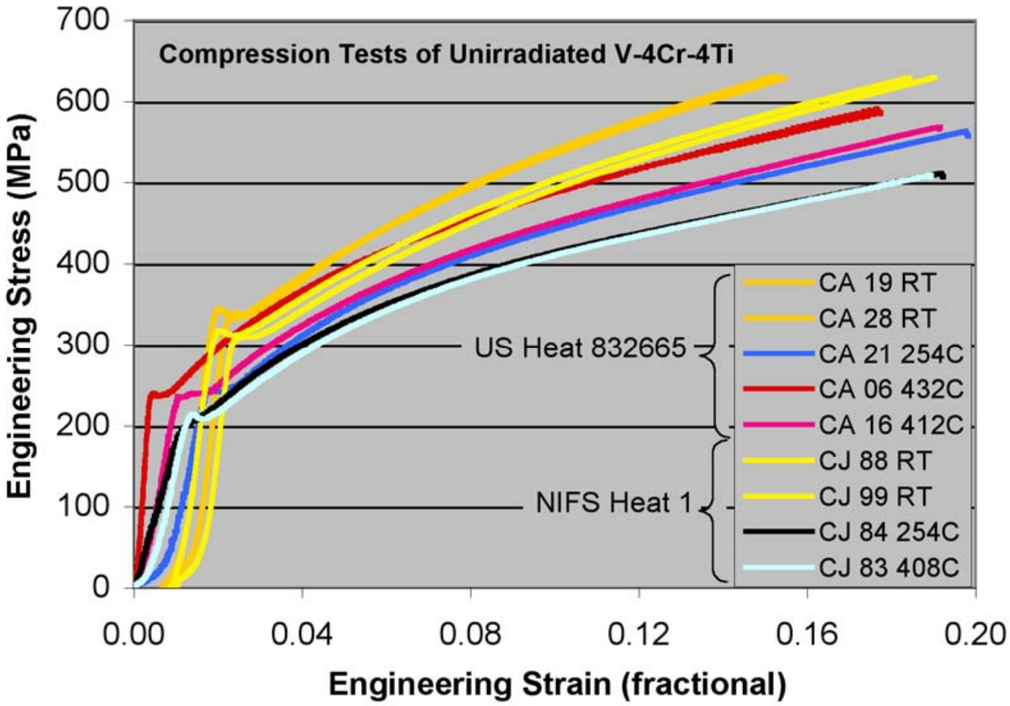

Fig. 2. Engineering stress vs. engineering strain curves for unirradiated V-4Cr-4Ti at 25°C, 250°C, and ~ 420°C.

Table 1 shows the average test temperature, 0.2% offset yield stress, upper yield points, elastic moduli, and PLSH exponents. All values except temperature were calculated by hand. The upper yield point and 0.2% offset yield point were within 4 MPa for all heats. The 0.2% offset yield stress for heat 832665 samples remained approximately 22 MPa higher than the NIFS-1 samples at all test temperatures as

Table 1. Compression test properties of unirradiated V-4Cr-4Ti at 25°C, 250°C, and ~420°C. CA** = 832665 Heat and CJ** = NIFS-1 Heat.

Specimen ID	Average Test Temp (˚C)	0.2% Offset Yield Stress (MPa)	Upper yield point (MPa)	PLSH exponent from $.01 \le \varepsilon_{pl} \le .02$
CA 19	RT	340	340	0.17
CA 28	RT	344	344	0.16
CA 21	254	244	245	0.3
CA 06	432	236	240	0.25
CA 16	412	235	235	0.28
CJ 88	RT	310	310	0.16
CJ 99	RT	315	315	0.17
CJ 84	254	222	none	0.28
CJ 83	408	213	214	0.34

shown in Fig. 3. Strain hardening exponents were calculated from 0.01 to 0.02 true plastic strain following the reasoning from [16] and assuming V-4Cr-4Ti follows the power law strain hardening equation ($\sigma = k\varepsilon^n$). Fig. 4 shows the strain hardening exponent versus temperature.

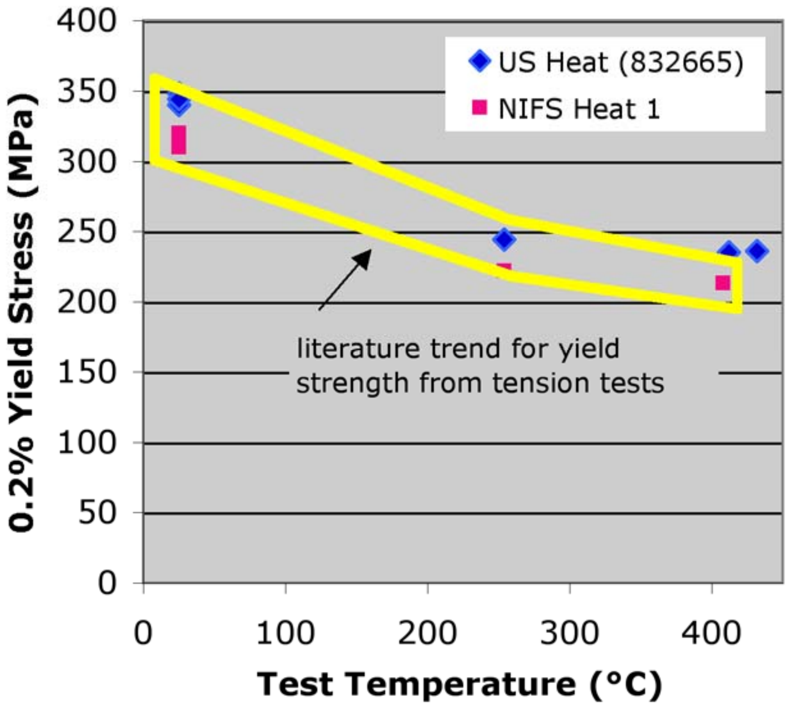

Fig. 3. Temperature dependence at 25°C, 250°C, and ~ 420°C of 0.2% offset yield stress for unirradiated V-4Cr-4Ti.

Discussion

Yield stress values from the literature for uniaxial tensile tests on heat 832665 are 315–355 MPa at 25°C, 220–260 MPa at 250°C, and 195–235 MPa at 400°C [8,9,11,12]. NIFS-1 yield stress values in tension were not found, but the NIFS-2 heat has a yield strength of around 300 MPa at 25°C [17]. Yield stress values from heat 832665 and the NIFS-1 heat measured in compression fall within the range of values in the literature for these materials in tension as expected (Fig. 3) because polycrystalline vanadium with a random grain orientation should have isotropic deformation properties. Figure 3 graphically shows that the elevated temperature compression yield stress is about 30% lower than the room temperature compression yield stress. Heat 832665 may be consistently stronger than the NIFS-1 heat due to heat 832665 having higher oxygen content [7,18]. Strain serrations as exhibited in CA06 (heat 832665) are seen in uniaxial tensile data from 300–750°C [9], but were not seen in some other published V-4Cr-4Ti tensile traces [12]. Dynamic strain aging causes the strain serrations.

Necking does not occur in compression tests, so uniform elongation cannot be measured to compare with tensile data. The PLSH exponent, however, can be used to compare deformation behavior in a compression test to deformation behavior in a tensile test. If there is a sufficient amount plastic strain during the test where the deformation along the length of the compression test specimen is uniform (i.e., minimal barreling for some part of the plastic deformation during the compression test), and if the true stress versus true plastic strain data fit well to the PLSH equation, then the PLSH exponent should be equal to the true uniform elongation (TUE) measured from an equivalent tensile test. The TUE from

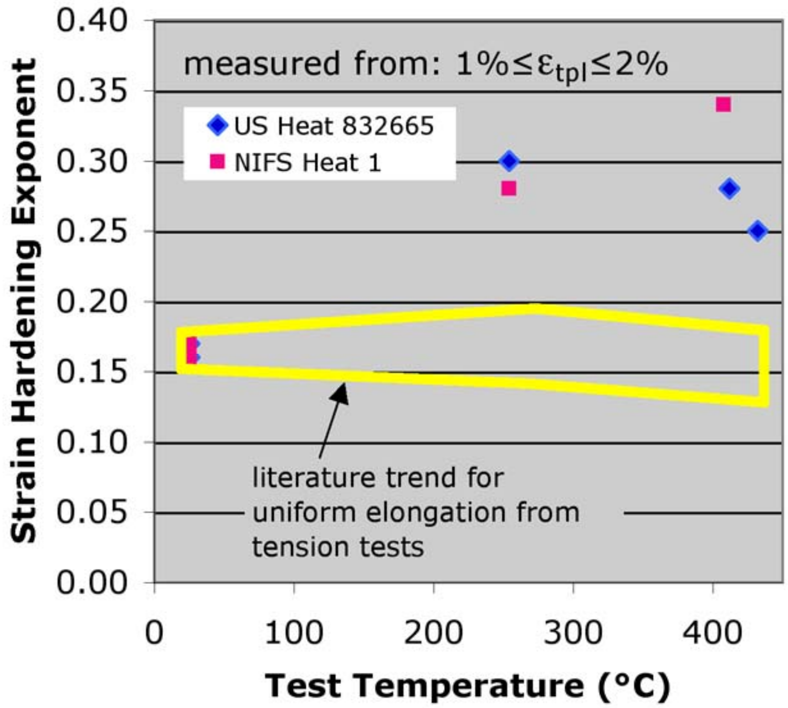

Fig. 4. Temperature dependence at 25°C, 250°C, and ~ 420°C of the strain hardening exponent for unirradiated V-4Cr-4Ti.

tensile data can be calculated from the engineering uniform elongation values in the literature using $\varepsilon_{UE} = \ln(e_{UE}+1)$ where ε_{UE} is the true uniform elongation and e_{UE} is the engineering uniform elongation. Literature values of uniform elongation for heat 832665 are 0.14–0.20 at 25°C and 250°C and 0.13–0.18 at 400°C [8,11,12]. Literature values for NIFS-1 are 0.18–0.2 for temperatures between 25°C and 400°C [19]. The TUE values are thus 0.13–0.18 at 250°C and 0.12–0.17 at 400°C for heat 832665 and approximately 0.18 for the NIFS-1 heat between 25°C and 400°C. A comparison of the measured PLSH exponent values from the compression tests with literature values of TUE from tensile tests are showing in Fig. 4. For the 25°C compression tests, the PLSH exponent ranged from 0.16–0.18 which is in good agreement with the TUE values calculated from tensile data in the literature. For the compression tests at elevated temperature, the PLSH values were considerably higher than the TUE values calculated from tensile data in the literature. The reason for this is not clear and will be investigated further.

Conclusions

Compression tests were performed on unirradiated V-4Cr-4Ti as part of a larger program to better understand the deformation behavior of irradiated V-4Cr-4Ti after irradiation. The yield stress in compression from two unirradiated heats of V-4Cr-4Ti are similar to the yield stress values in tension reported in the literature. The PLSH exponents from compression tests at 25°C are in agreement with TUE values from the literature, but at elevated temperature, the PLSH exponents were higher than the literature values for the TUE from tensile tests. This will be investigated.

Future Work

These results will be used to compare with future compression test studies on neutron irradiated V-4Cr-4Ti alloys.

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