STUDY OF IRRADIATION CREEP OF VANADIUM ALLOYS,[1] H. Tsai, R. V. Strain, M. C. Billone, T. S. Bray, and D. L. Smith (Argonne National Laboratory), M. L. Grossbeck (Oak Ridge National Laboratory), K. Fukumoto and H. Matsui (Tohuku University, Japan)

SUMMARY

Pressurized-tube specimens made from V-4 wt.% Cr-4 wt.% Ti (832665 heat) thin-wall tubing were irradiated in the HFIR RB-12J experiment to study creep under neutron-damage conditions. The calculated dose for the specimens ranged from 5.5 to 6.0 dpa and the calculated irradiation temperatures ranged from 400 to 500°C. The results show the creep rate to be linearly dependent on stress. The 12J data, when combined with the previous ATR-A1 data set, indicate the creep rates could be significant even at moderate stress and dpa levels.

OBJECTIVE

Vanadium alloys are candidate structural materials for fusion first-wall/blanket because of their attractive high-temperature properties and low activation. Many of the properties have been extensively studied; however, irradiation-induced creep has not. Data on irradiation creep is important because creep may be one of the principal contributors to deformation and is potentially performance limiting. The objective of this task is to determine the creep rate at 500°C under a range of stres loading conditions.

CREEP SPECIMEN FABRICATION

The creep specimens used in the RB-12J experiment are pressurized tubes, 25.4 mm long x 4.57 mm OD x 0.25 mm wall, with welded end plugs, as shown in Fig. 1. The tubing[1] was fabricated by drawing of an extruded bar stock. Each 25.4-mm-long tube section was nondestructively examined with radiography and profiled with a coordinate measurement machine to determine the wall thickness, ID and OD roundness and concentricity. The circumferential plug-to-tube welds were made with an electron-beam welder in vacuum. The specimens were then vacuum annealed at 1000°C for 1.0 h while wrapped in Ti getter foils. The tubes were then pressurized through a 0.25 mm-dia. hole in the top end plug with high-purity helium in a pressure chamber. The final closure weld of the 0.25 mm-dia. hole was made with a laser through the quartz window in the chamber. Six specimens, with at-temperature hoop stresses ranging from 0 to 200 Mpa, were prepared for irradiation in the RB-12J experiment. The dimensions of the creep specimens were measured with a precision laser profilometer before and after the pressurization. The measurements were made at 5 axial (x/L=0.1, 0.3, 0.5, 0.7 and 0.9) and 19 azimuthal locations (9° apart). The accuracy of the measurements were 10^{-4} mm, or ≈0.01% strain.

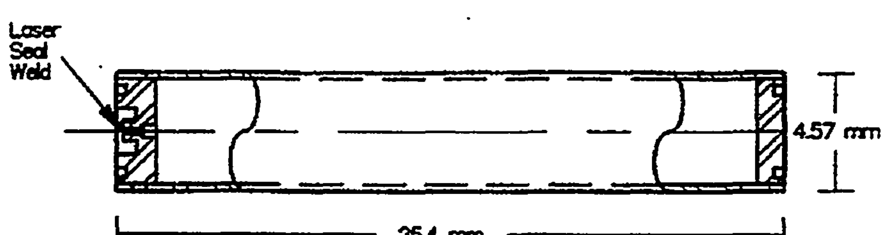

Figure 1. Schematic of the Creep Specimens

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[1] This work has been supported by the U.S. Department of Energy, Office of Fusion Energy Research, under Contract W-31-109-Eng-38.

IRRADIATION SUMMARY

To mitigate gaseous impurity uptake, the six creep specimens were loaded in two sealed thin-wall Zircaloy capsules, which acted as an impurity getter. The inside dimensions of the Zircaloy tubing were 81.3 mm long x 5.05 mm ID and the wall thickness was 0.10 mm. A pinhole was provided in the capsule end plug prevent pressure build-up in case of an unexpected specimen failure.

The irradiation of RB-12J was completed in ten HFIR cycles, from Cycle 352 (February 7, 1997) through Cycle 361 (January 17, 1998). The irradiation location was RB-5B.

The calculated temperature and neutron damage[2] for the six samples are shown in Table 1. The temperature shows a range instead of being constant because of the following reasons:

- changes in HFIR power levels during operation,
- 180° capsule rotation at the end of each cycle,
- movement of the HFIR control plates,
- uncertainties in the relationship between specimen temperatures and thermocouple temperatures, and
- variations in individual thermocouples over the course of the 10 cycles.

In Cycle 353, an attempt to recover from a computer failure led to three separate high-temperature excursions. The total duration was about 4 minutes. The peak temperatures during these times were estimated to be ≈40°C above those shown in Table 1.[2]

Table 1 Creep Specimens for the HFIR-12J Experiment

Specimen No.	Calculated Temp.(°C)	Calculated Dpa
B1 (0 MPa)	496±22	5.96
B12 (50 MPa)	399±21	5.96
B11 (100 Mpa)	496±22	5.75
B3 (150 MPa)	476±22	5.45
B9 (150 MPa)	496±22	5.75
B5 (200 MPa)	476±22	5.45

MEASUREMENT RESULTS AND DATA EVALUATION

The diameters of the specimens were measured after the irradiation with the same laser profilometer for the pretest measurements. The 19 azimuthal readings were averaged to yield the mean diameter for each axial location. To exclude end effects from the welded end plugs, only the middle three diameters were used to determine the average diameter and effective creep strain.

To facilitate a general stress analysis, the specimen's internal pressure loading and the measured diametral strain were converted to the wall-averaged effective von Mises stress and effective strain according to the following formulas:

$$\sigma_e = (0.5)(3)^{0.5}(r_m/t)\Delta P, \text{ and}$$

$$\varepsilon_e^C = 2\,(3)^{-0.5}(r_o/r_i)(\varepsilon_{dia}^C)\,,$$

where σ_e is the effective stress; r_i, r_m, r_o are the internal, midwall and external radii, respectively; ΔP is the difference in internal and external gas pressure at temperature; ε_e^C is the effective creep strain; and $\varepsilon_{dia}^C = (\varepsilon_{dia}^C - \varepsilon_e^{stress\text{-}free})$ is the component of the measured OD hoop strain associated with creep. To obtain the creep coefficient (A), the assumed form of the irradiation creep law is

$$\varepsilon_e^C = A\,\sigma_e D,$$

where D is the neutron damage in dpa. Using this method, the effective creep strains and creep coefficients are determined and the results are summarized in Table 2.

Ovality in specimens after the irradiation was generally small, indicating uniform stress loading in the tube wall. The transverse cross-sectional profile of the highest-stress specimen B5 after the irradiation is illustrated in Fig. 2.

Table 2. Summary data for the six creep specimens irradiated in the HFIR 12J experiment

Spc. ID	ID (in.)	OD (in.)	Irr T. (°C)	ΔP at temp (MPa)	von Mises Stress (MPa)	Preirr. D_o	Postirr. D_o	Avg. $\Delta D/D$ (%)	Creep Strain (%)	dpa	Strain Rate (%/dpa)
B1	.1591	.1800	496	-0.06	-0.45	.18000	.18011	0.0585	0.0000	6.0	0.00
B12	.1591	.1800	399	5.46	38.33	.17979	.18019	0.2238	0.2160	6.0	0.04
B11	.1590	.1800	496	12.77	89.26	.17982	.18073	0.5044	0.5830	5.8	0.10
B3	.1591	.1800	476	18.62	130.83	.18001	.18111	0.6061	0.7154	5.5	0.13
B9	.1590	.1800	496	19.18	134.05	.17988	.18144	0.8603	1.0483	5.8	0.18
B5	.1591	.1800	476	24.93	175.16	.17996	.18183	1.0293	1.2684	5.5	0.23

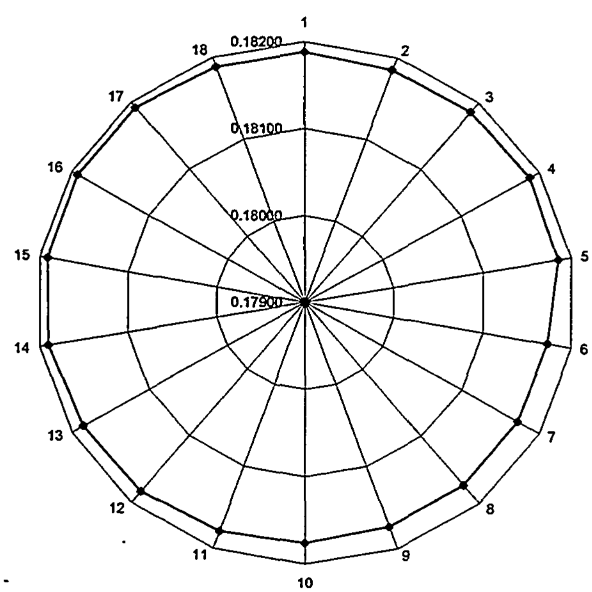

Fig. 2 Cross-sectional profile of Specimen B5 after the irradiation showing little ovality. The diameter was 0.1800 in. prior to the irradiation.

DISCUSSION

Available irradiation creep data for V-base alloys are scarce. For the recent- vintage V-Cr-Ti alloys, data are limited to those from this study, the ATR-A1 experiment in ATR, and an experiment performed by Troyanov et al. In BR-10. The ATR-A1 experiment utilized pressurized tubes (as in the 12J), whereas the BR-10 experiment utilized a single torsional tube [3]. The results from these three studies thus form a preliminary data set for evaluating the irradiation creep of V-4Cr-4Ti alloy. This data set is shown in Fig. 3.

Within the scatter of data, the results from this study, in conjuntion with those from the ATR-A1 experiment, show a trend of increasing strain rate with stress. Part of the data scatter is due to the relatively low attained neutron damage, low measured strains, and limited number of test specimens. This limited HFIR/ATR data set indicates possibly significant creep rates even at modest stresses and dpa levels. Within the data resolution, the HFIR/ATR data set appears not to show the bilinear behavior – sharply increased strain rate at stress >≈120 Mpa – that were observed in the BR-10 torsional experiment. Reducing the data uncertainty, including determining whether a bilinear behavior exists for the vanadium-base alloy, would be an important objective for the future irradiation creep experiments.

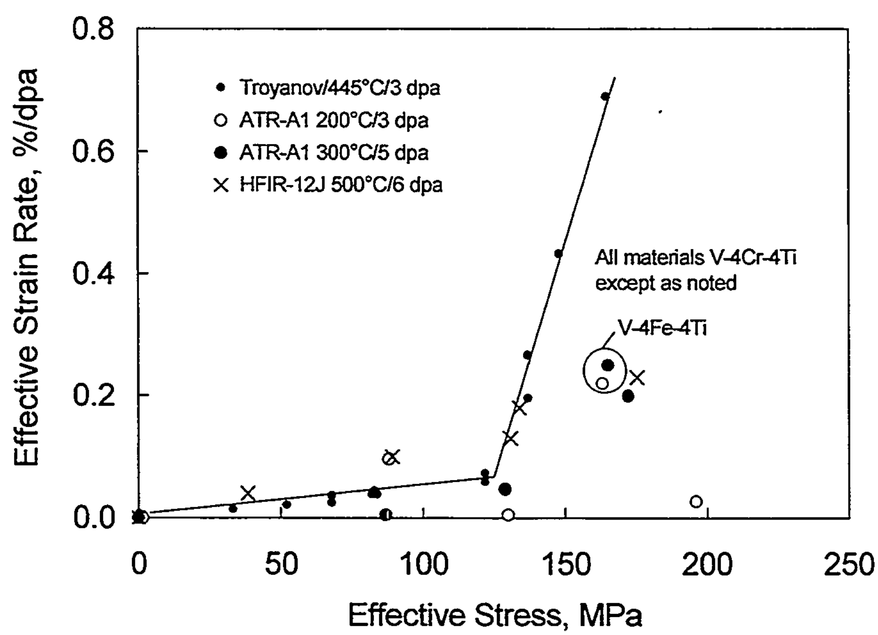

Fig. 2 Summary creep data set from the BR-10, ATR and HFIR experiments.

CONCLUSIONS

A set of six pressurized-tube creep specimens was irradiated in the HFIR-12J experiment. The results show a consistent dependency of creep rate on applied stress. Because of the limited data set, however, uncertainty in irradiation creep is still a major issue. Additional experiments would be necessary to establish a credible irradiation creep database for fusion system design using the V-Cr-Ti alloys.

REFERENCES

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