Study of Irradiation Creep of Vanadium Alloys* H. Tsai, R. V. Strain, and D. L. Smith (Argonne National Laboratory), and M. L. Grossbeck (Oak Ridge National Laboratory)

Summary

Thin-wall tubing was produced from the 832665 (500 kg) heat of V-4 wt.% Cr-4 wt.% Ti to study its irradiation creep behavior. The specimens, in the form of pressurized capsules, were irradiated in Advanced Test Reactor and High Flux Isotope Reactor experiments (ATR-A1 and HFIR RB-12J, respectively). The ATR-A1 irradiation has been completed and specimens from it will soon be available for postirradiation examination. The RB-12J irradiation is not yet complete.

Objective

Vanadium alloys are candidates for first-wall/blanket structural materials in fusion reactors, because of their attractive high-temperature properties and low activation. Although many of the properties have been extensively studied, irradiation-induced creep has not received much attention. Data on irradiation creep are important because creep is one of the principal contributors to deformation and is potentially performance limiting. The objective of this task to determine the creep rate under various loading and irradiation conditions.

Experimental Procedure

Creep Tube Fabrication

The starting material for fabrication of the tubing was a 28.6-mm-thick plate from the 832665 heat of V-4 wt.% Cr-4 wt.% Ti. Two 28.6 x 28.6 x 200-mm bars, with the long dimension parallel to the rolling direction, were cut from the plate and used in our experiments. An industrial vendor performed the tube fabrication according to specifications provided by Argonne National laboratory.

The two square bars were pressed straight and a 19.1-mm-diam hole was gun drilled through the center. The bars were then turned round to an OD of 27.9 mm concentric to the drilled hole. Following cleaning and vacuum annealing at ≈1025°C for 1 hr, the two pieces were drawn at room temperature in three steps, each producing an areal reduction of 12-15%. After the total areal reduction of ≈40%, the bars were cleaned, annealed and drawn again. This cleaning/annealing/drawing operation was repeated eight times to produce finished tubing with a nominal 4.57-mm OD, 4.06 mm ID, and ≈45% cold work. To limit the impurity uptake during the process, all annealing was conducted with the pieces wrapped in Ti getter foil. The intermediate tubes were shortened, whenever necessary, to fit them in the vendor's small annealing furnace, which gave a better vacuum (≈7×10^{-5} torr) than their big furnace. Approximately 12 m of tube sections of various lengths was produced in this manner.

Sections of the finished tubing were analyzed for major alloying elements and interstitial impurities according to ASTM testing methods E-663 and E-1019. The results, shown in Table 1, indicate discernible uptake of interstitial impurities. The extent of the uptake, however, is limited and not expected to have a deleterious effect on material performance.

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Table 1. Results of Analysis of Finished Creep Tubing

Element	Finished Tubing	Starting Material
O (wppm)	560	310
N (wppm)	95	85
C (wppm)	300	80
Cr (wt.%)	3.6	3.8
Ti (wt.%)	3.5	3.9
V (wt.%)	92.4	Bal.

Attempts were made to inspect the finished tubes by either ultrasonic or eddy-current methods; however, the trials were unsuccessful because of the small dimensions of the tubing and the demanding specification for flaw detection (<0.025-mm flaw size). Radiography was the only nondestructive method used to evaluate the internal condition of the tubing. The radiographs were taken along with a machined defect standard (0.025-mm-deep longitudinal groove in a creep tube) to establish the sensitivity of every exposure. Tube sections with any questionable mass densities were excluded from use as specimens.

The 25.4-mm-long tube blanks intended for making test specimens were measured for OD, ID, OD roundness, ID roundness, concentricity and wall thickness. These measurements were performed at two axial (8.4 mm from each end) and 8 azimuthal (45° interval) locations with a coordinate measurement machine. The results showed the dimensional attributes, in particular, the standard deviations, of these sections to be excellent. For example, for the 16 tubing sections that were selected for the ATR-A1 experiments, the measurements yielded an average ID of 4.041 ± 0.002, an average OD of 4.569 ± 0.001, ID roundness of 0.007 ±0.003, OD roundness of 0.005 ±0.002, concentricity of 0.007 ± 0.003, and wall thickness of 0.264 ± 0.001 (all in mm).

Creep Specimen Fabrication

The creep specimens are 25.4-mm-long tubes with welded end plugs, as shown in Fig. 1. The end plugs were produced by electro-discharge machining of plate stock. 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 foil. They were then pressurized, through a 0.25-mm-diam hole in the top end plug, in a pressue chamber that contained high-purity helium. The final closure weld of the 0.25-mm-diam hole was made with a laser through the quartz window in the chamber. The calculated hoop stresses in the specimens for the two experiments are shown in Table 2. The specified pressure loading was determined with a code that takes into account the thermal expansion of the creep tubing and the compressibility of the helium gas. Following a leak check, the dimensions of the assembled creep specimens were measured with a precision laser profilometer at five axial and 19 azimuthal locations to an accuracy of 10^{-4}mm.

Fig. 1. Schematic of Creep Specimens

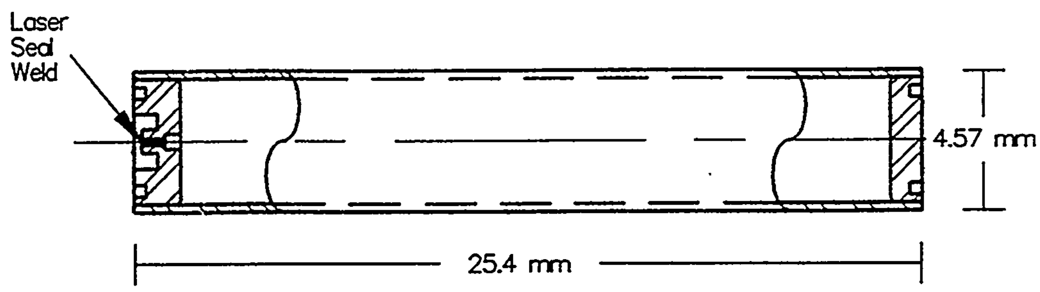

Table 2. Nominal Hoop Stress in the ATR-A1 and HFIR-RB-12J Creep Specimens

Experiment	Target Temp. (°C)	Specimen No.	Nominal Midwall Hoop Stress (MPa)
ATR-A1	200	A5	0
		A4	100
		A2	150
		A3	200
	300	A1	0
		A10	100
		A7	150
		A11	200
HFIR 12J	500	B1	0
		B12	50
		B11	100
		B3	150
		B9	150
		B5	200

Status of Experiments

The irradiation of the ATR-A1 experiment is completed and the creep specimens have been retrieved from the irradiation capsule and subcapsules. Preliminary data from subcapsule gas sampling indicate that all specimens are intact after irradiation. The RB-12J experiment is still ongoing in the HFIR reactor.

Future Activities

The diameters of the irradiated specimens will be measured again, with the same laser profilometer. The stress and temperature dependence of the creep strains will be evaluated. The stress-free swelling of the material from the 0 MPa specimens will also be evaluated. These results will be compared with the limited previously-published in-reactor creep data on vanadium alloys. The microstructure of the creep tubes, particularly the dislocation morphology, will be evaluated from the stand point of correlating it with the observed creep behavior.