STATUS OF ATR-A1 IRRADIATION EXPERIMENT ON VANADIUM ALLOYS AND LOW-ACTIVATION STEELS*

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SUMMARY

The ATR-A1 irradiation experiment was a collaborative U.S./Japan effort to study at low temperature the effects of neutron damage on vanadium alloys. The experiment also contained a limited quantity of low-activation ferritic steel specimens from Japan as part of the collaboration agreement. The irradiation started in the Advanced Test Reactor (ATR) on November 30, 1995, and ended as planned on May 5, 1996. Total exposure was 132.9 effective full power days (EFPDs) and estimated neutron damage in the vanadium was 4.7 dpa. The vehicle has been discharged from the ATR core and is scheduled to be disassembled in the next reporting period.

OBJECTIVE

The principal objective of the ATR-A1 irradiation experiment was to obtain mechanical property data, including in-reactor creep, on vanadium alloys irradiated at two low temperatures (≈200 and 300°C). Such data, important for fusion first-wall/blanket applications, are presently lacking.

SUMMARY DESCRIPTION OF EXPERIMENT

The irradiation vehicle was a drop-in capsule consisting of four gas-filled segments. The test specimens were contained in 15 lithium-bonded subcapsules and placed in the capsule as shown in Fig. 1. With a few exceptions, the capsule segments were constructed according to the ASME Boiler & Pressure Vessel Code, Section III. The materials for both the capsule and subcapsule components were Type 304 stainless steel. The size of the gap between the capsule and subcapsules and the selection of the fill gas in the gap established the temperature for the test specimens in the subcapsules. The fill gas was pressurized to 130 psig at room temperature to partially counterbalance the ATR system pressure of ≈335 psig.

A total of 154 tensile, 144 Charpy, 19 compact tension, 10 creep, and 610 transmission-electron-microscope disk specimens (combined vanadium alloys and ferritic steels) were used in the experiment. All subcapsules but two (AS4 and AS16), which contained only ferritic steel specimens, contained only vanadium alloy specimens. A gadolinium filter set, consisting of a tube, a top end disk, and a bottom end disk, was used in each subcapsule to reduce thermal flux and mitigate vanadium-to-chromium transmutation. Flux dosimeters and melt-wire temperature monitors were incorporated in selected subcapsules.

U.S. Vanadium Alloy Test Matrix

The key variables of the U.S. test matrix were

- Material (Heats 832665, T87, T89, T90, T91, T92, BL-47, and boron-doped BL-70).
- Heat treatment conditions (final vacuum annealing at 1000°C for 1.0 or 2.0 h).
- Weldment (EB, laser, and resistance).
- Irradiation temperatures (≈200 and 300°C).

The test specimen types were Charpy (MCVN, PCVN), tensile (SS-3 and Matron-size), compact tension (DCT), transmission-electron-microscope (TEM) disks, and biaxial creep (pressurized tubes). A summary of the test matrix is presented in Table 1.

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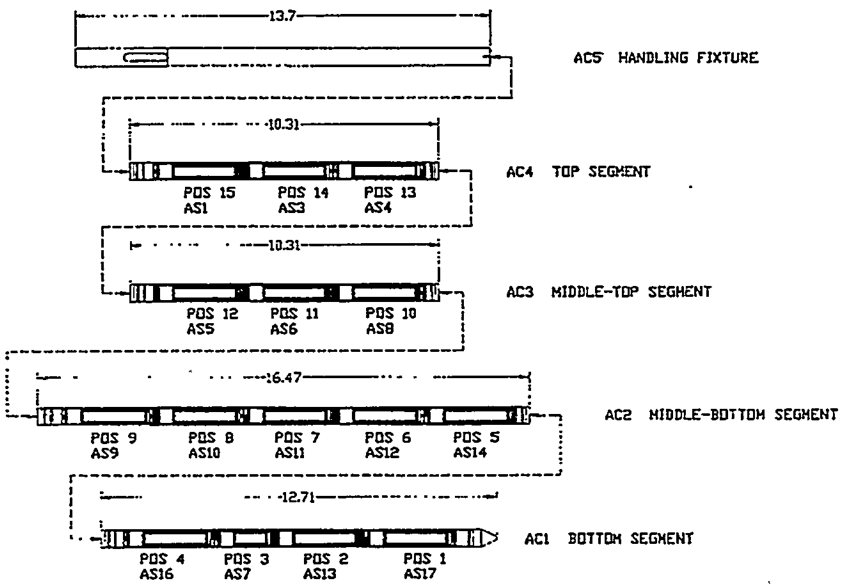

Fig. 1 Schematic Drawing of ATR-A1 Showing Capsule Segments and Subcapsule Locations

Table 1. U.S. Vanadium Alloy Test Matrix

T (°C)	Material[1]	MCVN	PCVN	SS-3	Matron	DCT	Creep	TEM
300	832665 (Prim. Anneal)	4	3	3	2	3	4	16
	832665 (Sec. Anneal)	4		2		3		10
	832665, EB Weld			2				
	832665 Lz, TIG Weld	2		1				1
	BL-47	4		2		2		10
	BL-47 TIG Weld	4[2]						
	T89							10
	T87			2	2	2		16
	T91			2	2			16
	BL-70							10
	T92			2				16
	T90							10
	Total	18	3	16	6	10	4	115
200	832665 (Prim. Anneal)	5		3	2	3	4	16
	832665 (Sec. Anneal)	4		2		2		10
	832665, EB Weld							
	832665 Lz, TIG Weld	2		2				1
	BL-47	4		2		2		10
	T89							10
	T87			2	2	2		16
	T91			2	2			16
	BL-70							10
	T92			2				16
	T90							10
	Total	15	0	15	6	9	4	115

[1]Primary Anneal: 1000°C for 1.0 h.
Secondary Anneal: 1000°C for 2.0 h.
[2]1.5 CVN size specimens.

Japanese Vanadium Alloy Test Matrix

The main variables of the Japanese vanadium test matrix were materials and temperature. The major JP vanadium alloys were V-4Cr-4Ti-0.1Si, V-3Fe-4Ti-0.1Si, and V-5Cr-5Ti-1YSiAl. A small number of specimens were made from the U.S. V-4Cr-4Ti (Heat 832665) for comparison to check the effects of specimen geometry on measured data. The test specimen types were Charpy, tensile, compact tension, transmission-electron-microscope disks, and biaxial creep tubes. A summary of the test matrix is shown in Table 2.

Table 2. JP Vanadium Alloy Test Matrix

T (°C)	Material	CVN	TS	DCT	Creep	TEM
	V-4Cr-4Ti-0.1Si	7	9		1	6
	V-3Fe-4Ti-0.1Si	5	8	3		3
300	V-5Cr-5Ti-1YiSiAl	14	18			25
	V-4Cr-4Ti (832665)	4				0
	Other V Alloys					30
	Total	30	35	3	1	64
	V-4Cr-4Ti-0.1Si	10	9		1	6
	V-3Fe-4Ti-0.1Si	5	8	3		3
200	V-5Cr-5Ti-1YiSiAl	10	17			25
	V-4Cr-4Ti (832665)	5				0
	Other V Alloys					30
	Total	30	34	3	1	64

Irradiation History

The experiment was irradiated in three ATR cycles (108A, 108B, and 109A), for a total of 132.9 EFPDs as follows:

- 108A: 11/30/95 -- 1/14/96, 25.0 MW SE lobe power, for 42.8 EFPDs.
- 108B: 1/20/96 -- 3/3/96, 27.0 MW SE lobe power, for 43.3 EFPDs.
- 109A: 3/17/96 -- 5/5/96, 25.0 MW SE lobe power for 46.8 EFPDs.

The peak damage (at near the axial midplane) was ≈4.7 dpa. Because of the increased reactor lobe power in Cycle 108B, the specimen temperatures were modestly higher than in the other two cycles. The calculated specimen temperatures and dpa values are summarized in Table 3.

Table 3. Calculated Temperature and DPA in ATR-A1 Subcapsules

Position	Subcapule Number	Test Mat'l	Gas Gap (mils)	Gas Composition	Target Temp. (°C)	Specimen Temp. (°C)[1]	dpa
15 (top)	AS1	V	8	He-15%Ar	200	139/144	0.7
14	AS3	V	8	He-15%Ar	200	186/194	1.5
13	AS4	FS	8	He-15%Ar	low	263/277	2.2
12	AS5	V	5	He	200	198/212	3.0
11	AS6	V	5	He	200	223/234	3.5
10	AS8	V	5	He	200	246/259	3.9
9	AS9	V	5	He	300	273/286	4.3
8	AS10	V	5	He	300	288/302	4.6
7	AS11	V	5	He	300	285/300	4.7
6	AS12	V	5	He	300	281/295	4.5
5	AS14	V	6	He	300	284/300	4.1
4	AS16	FS	8	He-5%Ar	high	337/355	3.8
3	AS7	V	8	He-5%Ar	300	287/303	3.0
2	AS13	V	8	He-5%Ar	300	245/258	2.3
1	AS17	V	8	He-5%Ar	200	204/213	1.5

[1]Averaged specimen temperatures in subcapsules, some with two tiers of specimens. First value is for Cycles 108A and 109A (25 MW lobe power), and second value is for Cycle 108B (27 MW lobe power).

FUTURE ACTIVITIES

The four segments of the capsule will be separated by underwater cutting in the ATR canal. This step is necessary because of the size limitation on the shipping cask. The work plan for this cutting activity has been generated and forwarded to the ATR. The separated segments will be shipped to ANL for disassembly. A suitable cask for this shipment has been identified and the contract for the cask rental is being prepared. Opening of the subcapsules to retrieve the test specimens at ANL is expected to be a routine operation that uses previously established procedures. The cleaned specimens will be disseminated to participating U.S. and Japanese laboratories for postirradiation examination and testing. The gadolinium filters will be removed and analyzed to determine their effectiveness, i.e., extent of burnout. This information may be useful in planning future experiments in the ATR. The flux and thermal monitors will be analyzed to determine actual irradiation conditions.