SWELLING DEPENDENCE OF NEUTRON-IRRADIATED VANADIUM ALLOYS ON
TEMPERATURE, NEUTRON FLUENCE, AND THERMOMECHANICAL TREATMENT*

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ABSTRACT

Swelling of vanadium alloys was determined after irradiation at 420 and 600°C to neutron fluences ranging from 0.3×10^{27} neutrons/m² (17 dpa) to 1.9×10^{27} neutrons/m² (114 dpa). Binary and ternary vanadium alloys with Cr, Ti, Mo, W, Ni, Fe, Zr, and Si additions were irradiated in either the fully annealed, partially annealed, or 10% cold-worked condition. The addition of Cr to vanadium greatly exacerbated swelling of vanadium upon irradiation at 600°C, whereas the presence of Ti, Mo, W, and Ni (3-20%) did not significantly affect swelling of vanadium. The swelling of V-Cr alloys upon irradiation at 600°C was substantially reduced (<0.1%/dpa) by the addition of Ti (1-15%). The swelling of the vanadium alloys was <0.2%/dpa upon irradiation at 420°C. Partial annealing or 10% cold-working had an insignificant effect on swelling of the alloys.

INTRODUCTION

Vanadium-base alloys are candidates for use as structural material in magnetic fusion reactors. In comparison to other candidate structural materials (e.g., Type 316 stainless and HT-9 ferritic steels), vanadium-base alloys such as V-15Cr-5Ti and V-20Ti have intrinsically lower long-term neutron activation, neutron irradiation after-heat, biological hazard potential, and neutron-induced helium and hydrogen transmutation rates.¹⁻³

Moreover, vanadium-base alloys can withstand a higher surface-heat flux than steels because of their lower thermal stress factor.^{4,5} In addition to having

these favorable neutronic and physical properties, a candidate alloy for use as structural material in a fusion reactor must have dimensional stability, i.e., swelling resistance. In this paper, we present experimental results on the swelling of several vanadium-base alloys after irradiation at 420 and 600°C to neutron fluences ranging from 0.3 to 1.9×10^{27} neutrons/m² (17 to 114 atom displacements per atom [dpa]).

MATERIALS AND PROCEDURES

Vanadium alloys with the compositions listed in Table 1 were obtained in the form of 50% cold-worked sheets. Disc-shape specimens with ≈ 3.0 mm diameter and ≈ 0.3 mm thickness were obtained from the cold-worked sheet for the swelling determinations.

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Table 1
Vanadium and Vanadium Alloy Composition^a

ANL I.D.	Nominal Alloy Composition ^b (wt.%)	Concentration (ppm)				
		O	N	C	Si	Al
BL-1	V-4Mo	230	73	90	110	<100
BL-2	V-9W	300	150	120	59	<100
BL-3	V-12Ni	490	280	500	405	<100
BL-4	V-10Cr	530	76	240	<50	1190
BL-5	V-14Cr	330	69	200	<50	2740
BL-10	V-15Ti-7.5Cr	1110	250	400	400	30
BL-11	V-5Ti	1820	530	470	220	115
BL-12	V-10Ti	1670	390	450	245	<100
BL-13	V-14Ti	1580	370	440	205	<100
BL-15	V-18Ti	830	160	380	480	33
BL-16	V-20Ti	390	530	210	480	-
BL-20	V	570	110	120	325	<100
BL-24	V-15Cr-5Ti	1190	360	500	390	40
BL-25	V-14Cr-0.3Ti	390	64	120	<50	3270
BL-26	V-14Cr-1Ti	560	86	140	<50	3090
BL-27	V-3Ti-1Si	210	310	310	2500	160
BL-28	Vanstar-7 ^c	275	540	740	-	-
BL-34	V-9Ti	990	180	420	290	<100
BL-35	V-10Cr	340	45	120	<50	1450
BL-36	V	810	86	250	<50	<100
BL-42	V-3Ti-1Si	580	190	140	5400	290
BL-43	V-10Cr-5Ti	230	31	100	340	140

^aChemical analyses of these materials were performed by the Analytical Department of the Teledyne Wah Chang Albany Company, Albany, OR.

^bComplete analyses for these materials are presented in Reference 6.

^cV-9Cr-3Fe-1Zr.

The cold-worked specimens were annealed at either 1125, 950, or 850°C for 1 h in an ion-pumped vacuum system with a typical pressure of 1.3×10^{-6} Pa. Specimens annealed at 1125°C had an average recrystallized grain diameter of 0.020 mm. In this paper, specimens that were annealed at 950 and 850°C are termed "partially annealed". In addition to these annealed and "partially annealed" specimens, annealed specimens with 10% cold-work were also prepared. The specimens were irradiated in the Materials Open Test Assembly (MOTA) of the Fast Flux Test Facility (FFTF) reactor at Richland, Washington. They were con-

tained in sealed, Li⁷-filled, TZM molybdenum capsules during irradiation to prevent contamination from oxygen, nitrogen, and carbon impurities in the FFTF sodium coolant. The specimens were irradiated at 420 and 600°C to neutron fluences ($E > 0.1$ MeV) ranging from 0.3×10^{27} neutrons/m² (17 dpa) to 1.9×10^{27} neutrons/m² (114 dpa) during Cycles 7, 8, 9, and 10 of the FFTF-MOTA facility. The irradiated specimens were removed from the Li-filled TZM molybdenum capsules by immersion of the opened capsules in liquid NH₃ and subsequent immersion of specimens in a mixture of 50% ethanol and 50% methanol.

The swelling (S) of an irradiated specimen was obtained from a determination of the density of an unirradiated specimen (D_{ann}) and the density of an irradiated specimen (D_{irr}) by immersion in CCl_4 , i.e., $S = (D_{\text{ann}} - D_{\text{irr}}) / D_{\text{irr}}$. Specimen density was determined with a precision of $\pm 0.1\%$ from three to six separate determinations on a specimen.

EXPERIMENTAL RESULTS

The dependence of density change (i.e., swelling) of vanadium-base alloys on Ti concentration after irradiation at 420°C to 114 dpa and at 600°C to 77-84 dpa is shown in Figs. 1 and 2, respectively. The V-3Ti-1Si alloy showed the highest swelling of the alloys on irradiation at 420°C to 114 dpa. Even so, swelling of all of the alloys at 420°C was $< 0.02\%$ per dpa (Fig. 1). The addition of 0.3% Ti to the V-14Cr alloy resulted in reduction of swelling of this alloy from 39% to 14% on irradiation at 600°C to 84 dpa (Fig. 2). An increase of Ti concentration to 5% caused a further reduction of swelling of the V-14Cr alloy to $< 10\%$. The swelling data presented in Figs. 1 and 2 suggest that swelling of V-Ti and V-Cr-Ti alloys is relatively independent of Ti concentration in the range of 3-20%.

Addition of either 9% W, 4% Mo, or 12% Ni to V resulted in a slight decrease in the swelling of V on irradiation at 420°C to 114 dpa and at 600°C to 84 dpa. The Vanstar-7 alloy exhibited 7-10% swelling on irradiation at 600°C to 77 dpa.

The dependence of swelling of V and V-Ti alloys on irradiation damage (dpa) at 420°C is shown in Fig. 3. These results show that V and V-3Ti-1Si exhibit a maximum

swelling ($\sim 3\%$) at 60-80 dpa, whereas swelling of V-(5-20)Ti alloys is relatively independent of irradiation damage.

The dependence of swelling of V-Cr-Ti alloys on irradiation damage (dpa) at 420°C is shown in Fig. 4. These results show that on irradiation at 420°C V-Cr binary alloys have maximum swelling at ~ 30 dpa whereas V-15Cr-(1-5) Ti alloys have maximum swelling at 60-80 dpa.

The dependence of swelling of V-15Ti-7.5Cr, V-15Cr-5Ti, V-10Cr-5Ti, V-3Ti-1Si, and V-20Ti alloys on irradiation damage (dpa) at 600°C is shown in Fig. 5.⁶ Swelling data obtained from transmission electron microscopy (TEM) observations of the irradiated alloys are also shown in Fig. 5.⁶ On the basis of these data, the swelling of V-15Ti-7.5Cr, V-15Cr-5Ti, V-10Cr-5Ti, V-3Ti-1Si, and V-20Ti alloys on irradiation at 600°C to 84 dpa is (in % per dpa) 0.10, 0.03, 0.03, 0.01, and 0.01, respectively.

Swelling of the "partial annealed" and 10% cold-worked V-Ti and V-Ti-Cr alloys was not significantly different from the swelling of "annealed" alloys.

CONCLUSIONS

Swelling of V-Cr-Ti alloys on neutron irradiation at 600°C is strongly dependent on Ti concentration.

V-Cr-Ti alloys with $> 3\%$ Ti exhibit greater resistance to irradiation-induced swelling.

Swelling of V-Ti and V-Cr-Ti alloys is nearly independent of Ti concentration in the range of 3-20% Ti.

Swelling of V-15Ti-7.5Cr, V-

15Cr-5Ti, V-10Cr-5Ti, V-3Ti-1Si, and V-20Ti alloys on neutron irradiation at 600°C to 84 dpa is (in % per dpa) 0.10, 0.03, 0.03, 0.01, and 0.01, respectively.

Swelling of the vanadium alloys on irradiation at 420°C to 114 dpa is <0.02% per dpa.

Partial annealing and 10% cold-work have an insignificant effect on swelling of the vanadium alloys.

References

1. T. Noda, F. Abe, H. Araki, and M. Okada, J. Nucl. Mater. 155-157 (1988) 581.
2. R. Santos, J. Nucl. Mater. 155-157 (1988) 589.
3. S. J. Piet, H. G. Kraus, R. M. Neilson, Jr., and J. L. Jones, J. Nucl. Mater. 141-143 (1986) 24.
4. F. L. Yaggee, E. R. Gilbert, and J. W. Styles, J. Less-Com. Metals 19 (1969) 39.
5. S. Majumdar, Fusion Technology, 15 (1989) 1560.
6. B. A. Loomis and D. L. Smith, in: Fusion Reactor Materials Semiannual Progress Report for Period Ending March 31, 1990, DOE/ER-0313/8, Oak Ridge, TN (August 1990) p. 225.

Fig. 1. Dependence of density change (swelling) on titanium concentration for vanadium alloys irradiated at 420°C to 114 dpa.

Fig. 2. Dependence of density change (swelling) on titanium concentration for vanadium alloys irradiated at 600°C to 77-84 dpa.

Fig. 3. Dependence of density change (swelling) on irradiation damage (dpa) for V and V-Ti alloys irradiated at 420°C.

Fig. 4. Dependence of density change (swelling) on irradiation damage (dpa) for V-Cr-Ti alloys irradiated at 420°C.

Fig. 5. Dependence of swelling of vanadium alloys at 600°C on irradiation damage.

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