Conf-911111--28

PNL-SA--19559

DE92 006479

HIGH SWELLING RATES OBSERVED IN NEUTRON-IRRADIATED V-Cr V-Si BINARY ALLOYS

F. A. Garner
B. A. Loomis
H. Takahasi
S. Ohnuki
D. S. Gelles
H. Kinoshita

November 1991

Presented at the
5th International Conference on
Fusion Reactor Materials
November 17-22, 1991
Clearwater, Florida

Work supported by
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

High Swelling Rates Observed in Neutron-Irradiated V-Cr and V-Si Binary Alloys

F. A. Garner and D. S. Gelles
Pacific Northwest Laboratory
Richland, WA 99352

H. Takahashi, S. Ohnuki and H. Kinoshita
Hokkaido University
Sapporo, Japan

B. A. Loomis
Argonne National Laboratory
Argonne, IL 60439

Abstract

Additions of 5 to 14 wt% chromium to vanadium lead to very large swelling rates during neutron irradiation of the binary alloys, with swelling increasing strongly at higher irradiation temperatures. Addition of 2 wt% silicon to vanadium also leads to very large swelling rates but swelling decreases with increasing irradiation temperature. Addition of 1 wt% zirconium does not yield high swelling rates, however.

1. Introduction

It was recently shown by Matsui and coworkers that V-5 at% Fe could reach very large levels of void swelling during irradiation in either the FFTF or JOYO fast reactors, especially at 600°C, the highest irradiation temperature studied.[1-3] Swelling was also accelerated at lower irradiation temperatures, but to a lesser extent. These data cast doubt on the prevailing assumption that the bcc lattice structure automatically confers immunity against the ~1%/dpa swelling rates observed in fcc metals.[4] The swelling rates observed by Matsui and coworkers were at least twice that level.

Loomis, Smith and Garner also found that vanadium-chromium binaries (with small amounts of aluminum) irradiated in FFTF Cycles 7-9 also exhibited substantially enhanced neutron-induced swelling at 600°C,[5] although the early temperature history of that particular irradiation was very complex. Vanadium with chromium additions in the range 9-14 wt% exhibited irradiation-induced density decreases of 38.9 to 42.4% at 77 dpa, corresponding to 63.6-73.6% volumetric swelling, as shown in Figure 1. These data implied that the post-transient swelling rates were on the order of 1%/dpa or more. There was also some indication that the swelling at intermediate chromium levels (~5%) might be even higher, as illustrated in Figure 2, and comparable to that observed in V-5Fe.

Studies by Ohnuki and coworkers conducted on V-Cr alloys irradiated to lower displacement levels have confirmed that chromium additions indeed accelerate the void swelling phenomenon in vanadium.[6,7] In addition, silicon additions have also been observed recently to accelerate the swelling of vanadium.[2]

This paper presents a few additional details from the irradiations conducted by Loomis and coworkers in FFTF Cycles 7-9, as well as the results of a new study conducted in FFTF Cycle 11.

2. Experiment Details

Both of these studies were conducted in the Materials Open Test Assembly (MOTA) in different cycles. Under normal operating conditions, MOTA canisters are actively controlled within ±5°C of their target temperatures during irradiation.[8] However, in FFTF Cycle 7 a severe overtemperature event caused many of the irradiation canisters in MOTA-ID to overheat (as much as 200°C at 600°C) for a period of ~1 hour. The presumed loss of experimental integrity lead to a programmatic decision to leave the MOTA in place but shift the priority of reactor operation to concerns not involving MOTA, these being primarily reactivity feedback tests. The MOTA was kept in the helium-purged mode while a large number of transient reactor tests were conducted during FFTF Cycle 8. Thus after the overtemperature event, subsequently all capsules operated over a range of temperatures, all of which were lower than the target temperatures. For those specimens that were reinserted into MOTA-IE in Cycle 9, however, the normal temperature control was followed, and those specimens reached a cumulative exposure of 77 dpa.

The temperature control in the MOTA-2A experiment in FFTF Cycle 11 was essentially flawless, with all canisters controlled within ±5°C of their target temperatures. Three binary alloys (V-5Cr, V-2Si and V-1Zr, wt%) were irradiated in the annealed condition to 42-46 dpa at target temperatures of 427, 430, 519 and 600°C (Table 1). The specimens were in the form of microscopy disks and were irradiated in sealed helium-filled packets. An automated immersion density technique known to be accurate to ±0.16% swelling was used to determine the density changes of these alloys.

Results

Transmission electron microscopy of the Cycles 7-9 specimens with ~70% swelling was attempted but was found to be very difficult. Void sizes on the order of a micron or more were found, but penetration of the electropolishing solution into and through adjacent voids caused a loss of the void surface layers, rendering segregation studies of doubtful use. Figure 3 illustrates the extensive intersection of voids with the electropolished surface.

Figure 4 shows the swelling values obtained from the Cycle 7-8 irradiation sequence at a target temperature of 420°C and 520°C. Chromium appears to affect the swelling of vanadium at 400°C and possibly 520°C. In each case the swelling is less that at 600°C, although the swelling is not monotonic with temperature, however. In general, the levels reached in this highly complex irradiation were much larger than were observed in later isothermal irradiations that proceeded to higher displacement levels in Cycles 9 and 10 only.[9] This indicates that the complex temperature history strongly influenced the swelling.

The swelling values measured in the well-controlled MOTA-2A Cycle 11 experiment are shown in Figure 5. Where more than one nominally identical specimen was measured, swelling was somewhat variable. This is not surprising, considering the high rate at which the specimens were found to be swelling. Assuming a very small incubation period, the V-2Si alloy reached a swelling rate of ~1%/dpa or greater.

The V-5Cr binary alloy exhibited a strongly temperature-dependent and monotonic swelling behavior during isothermal irradiation, in agreement with the general results of the non-isothermal experiment conducted at 420 and 600°C in Cycles 7-9. The V-2Si alloy also reached high swelling levels but did so with a temperature dependence opposite to that of V-5Cr alloy. The V-1Zr alloy swelled much less than either of the other two alloys, reaching only 2.7% at 600°C, and smaller amounts at lower temperatures. Density change measurements were not performed on pure vanadium from this experiment, since the irradiated specimens were found to be very brittle and might not have survived the automated measurement procedure. Several specimens disintegrated upon being picked up with tweezers.

Discussion and Conclusions

Nakajima and coworkers[10] have interpreted their swelling results in terms of the relative atomic size of each solute and found good agreement for data at 600°C for Fe, Cr and Si additions. The results of the current study at 600°C agree with their observations. As shown in Figure 5, however, a different relative swelling behavior was observed in this experiment at 420 and 520°C. Thus, atomic size arguments may not be generally applicable to these alloys.

Whatever mechanisms are later found to control the swelling of binary vanadium alloys, it appears that the role of both crystal structure and irradiation temperature history will need to be closely examined in future studies on these and other specimens.

References

1. H. Matsui, D.S. Gelles and Y. Kohno, Proc. 15th International Conference on Effects of Radiation on Materials (1991) in press.

2. H. Nakajima, S. Yoshida, Y. Kohno and H. Matsui, in this conference.

3. H. Matsui and H. Nakajima, in this conference.

4. F. A. Garner, J. Nucl. Mater., 122 & 123 (1984) 459.

5. B. A. Loomis, D. L. Smith and F. A. Garner, J. Nucl. Mater., 179-181 (1991) 771-774.

6. S. Ohnuki, D. S. Gelles, B. A. Loomis, F. A. Garner and H. Takahashi, J. Nucl. Mater., 179-181 (1991) 775-778.

7. S. Ohnuki, H. Takahashi, H. Kinoshita and R. Nagasaki, J. Nucl. Mater., 155-157 (1988) 935.

8. R. J. Puigh and R. E. Schenter in Effects of Radiation on Materials, Twelfth International Symposium, ASTM STP 870 (1985) pp. 795-802.

9. B. A. Loomis, K. Abe, L. J. Nowicki, H. Chung and D. L. Smith, Fusion Reactor Materials Semiannual Progress Report DOE/ER-0313/9, (1991) pp. 172-176.

10. H. Nakajima, S. Yoshida, Y. Kohno and H. Matsui, in Annual Progress Report for Fusion Year 1990, Japan-USA Collaboration in FFTF MOTA (1991) pp. 71-77.

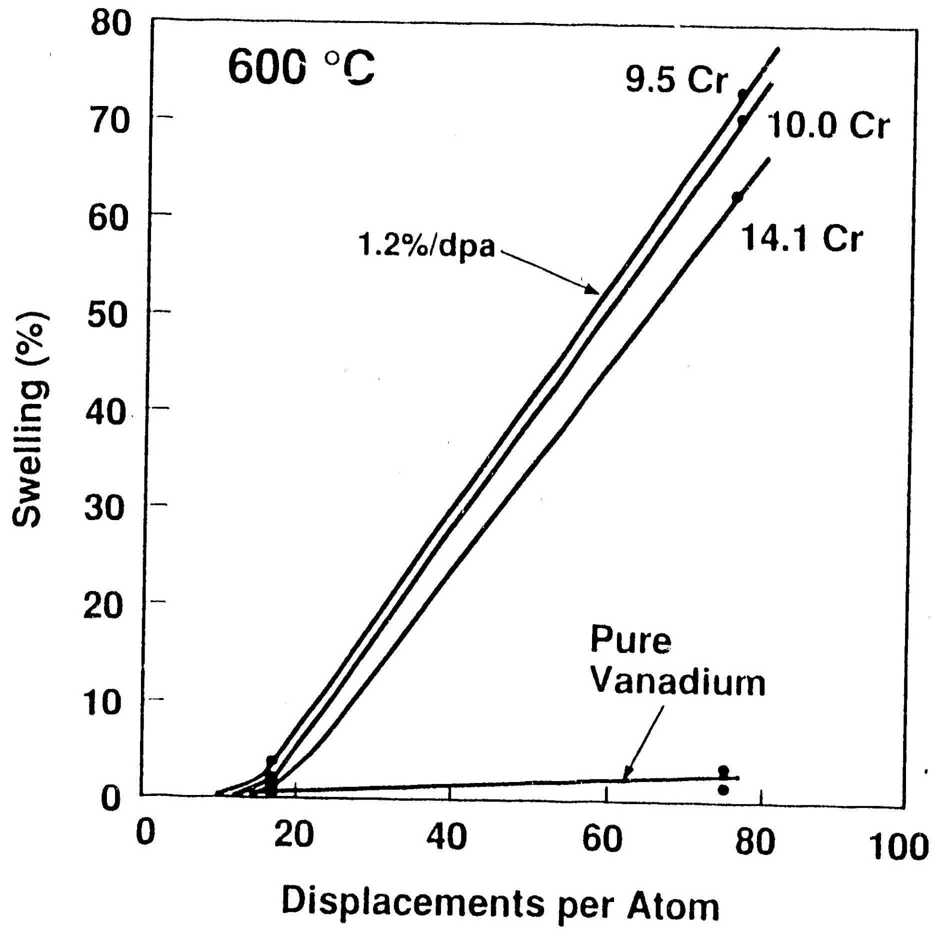

Figure 1. Swelling observed in V-Cr alloys after irradiation to 17 and 77 dpa in FFTF Cycles 7-9 at a target temperature of 600°C (5). The actual temperature in the first half of the irradiation was rather complex, however.

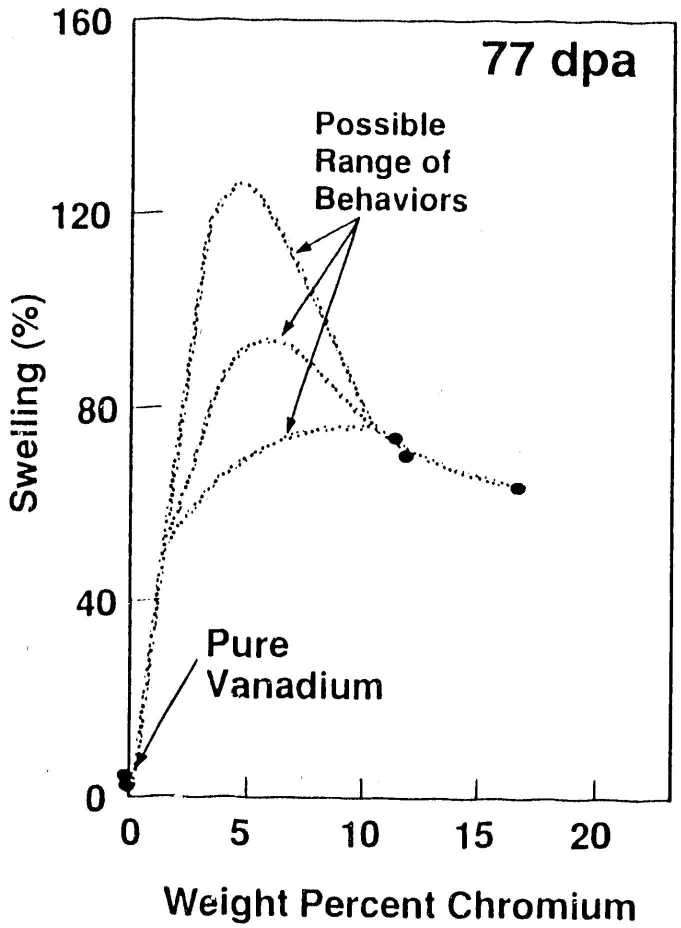

Figure 2. Swelling data at 77 dpa from Figure 1, plotted vs. chromium content.

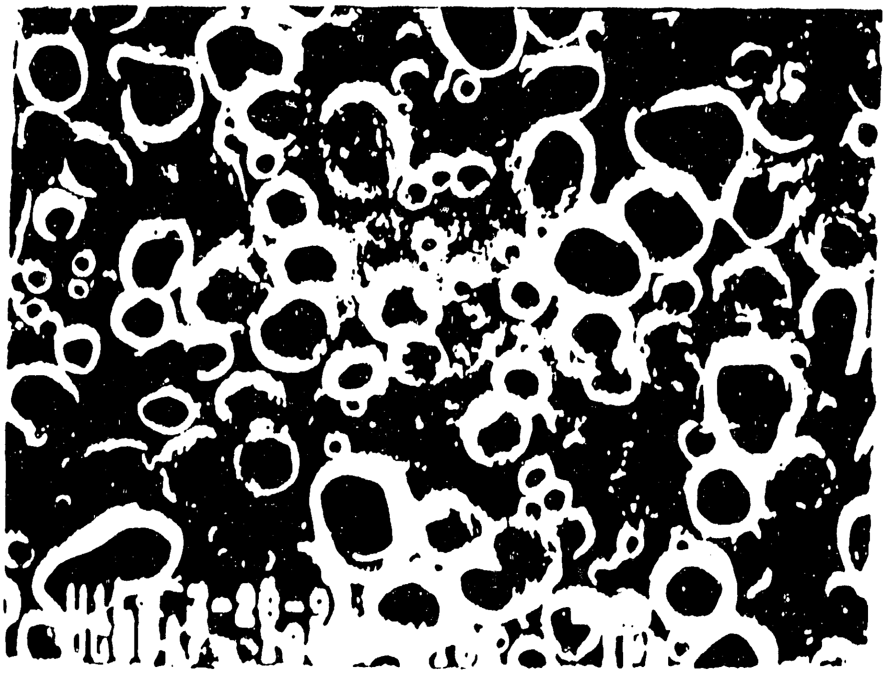

Figure 3. Scanning electron micrographs of V-10.0Cr-0.1Al (wt %) at 77 dpa and 600°C, demonstrating the large level of void intersection with the electropolished surface. The size markers shown denote 10 μm (top) and 1 μm (bottom).

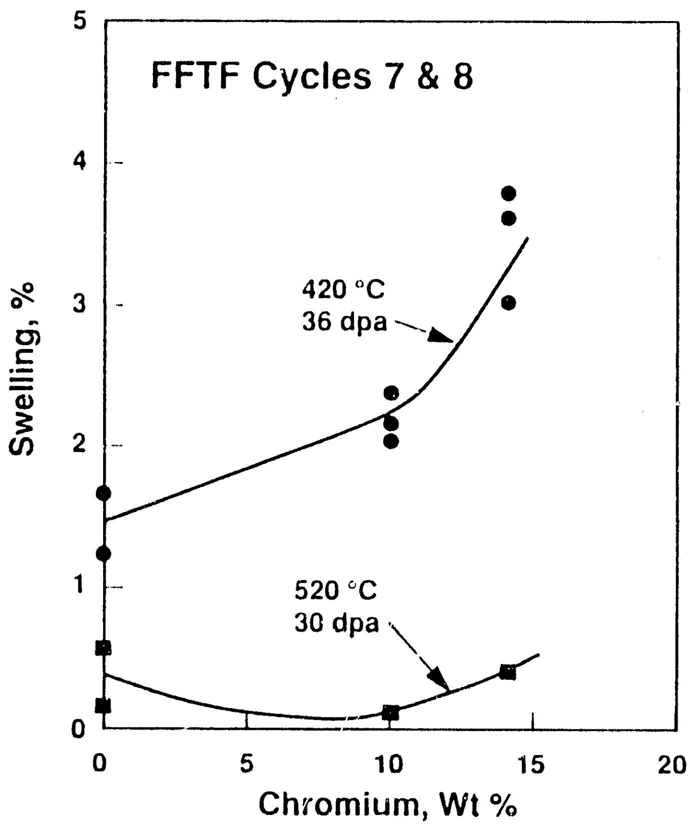

Figure 4. Swelling observed in V-Cr alloys at 420 and 520°C after irradiation in FFTF Cycles 7-8.

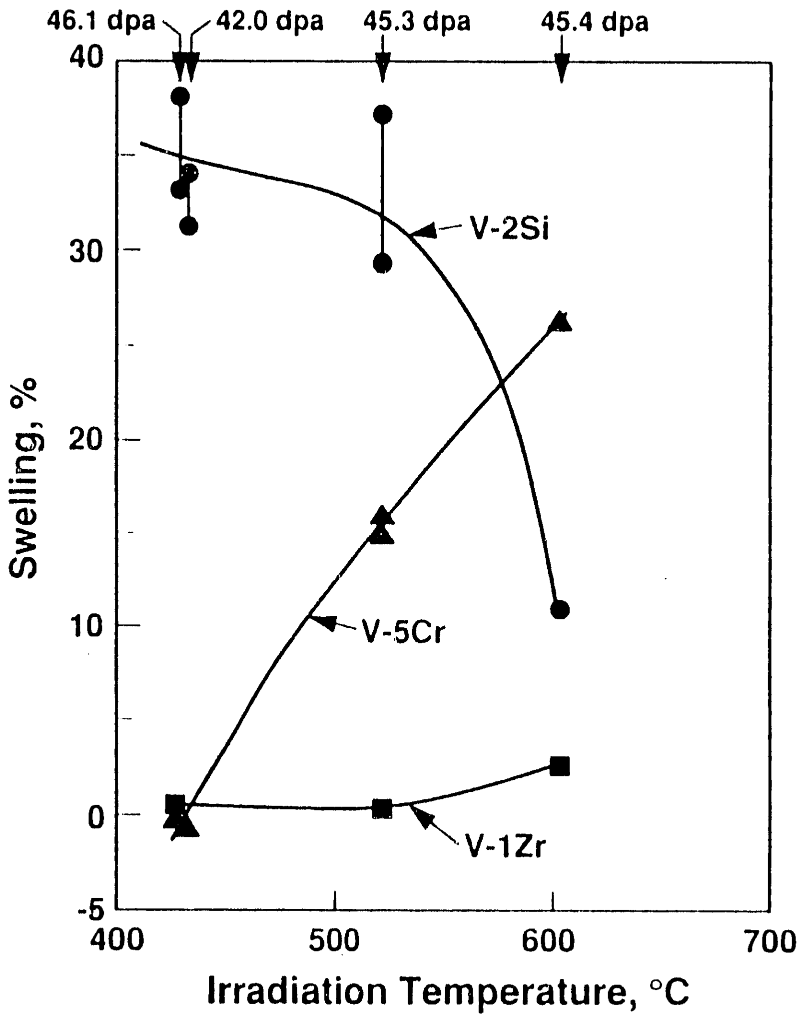

Figure 5. Temperature-dependent swelling of three vanadium-binary alloys after irradiation in FFTF Cycle 11.

END

DATE
FILMED

2 /24/92