TENSILE PROPERTIES OF V-(Cr,Fe)-Ti ALLOYS AFTER IRRADIATION IN THE HFIR-11J EXPERIMENT - Y. Yan, H. Tsai, D. O. Pushis, and D. L. Smith (Argonne National Laboratory), K. Fukumoto, H. Matsui (IMR/Tohoku Univ.)

OBJECTIVE

The objective of this work is to develop further understanding of the effects of neutron irradiation on the tensile properties of V-(Cr,Fe)-Ti alloys with compositional variations near the reference V-4Cr-4Ti. The current focus is on moderate-fluence irradiation in the temperature range of 300-500°C.

SUMMARY

Postirradiation tensile tests at room temperature and 300°C were performed on V-(Cr,Fe)-Ti alloy specimens that had been irradiated in the HFIR-11J experiment. The specimens were of the SSJ design. Irradiation temperature was ≈300°C and the attained neutron damage was ≈6 dpa. Results from these tensile tests show significant radiation hardening and ductility reduction in all of the materials. In comparison, hardening was substantially lower in the same materials after the 500°C 12J experiment. These results are consistent with previous findings that the demarcation for low-temperature radiation embrittlement in vanadium alloys is ≈400°C.

INTRODUCTION

Data on mechanical properties for V-base alloys are needed to establish guidelines for the design and operation of fusion devices utilizing this class of materials for in-vessel structures. Two experiments, RB-11J and RB-12J, were performed recently in the HFIR to investigate the effects of irradiation at 300 and 500°C, respectively [1], on the mechanical properties of vanadium alloys with a range of compositions. These experiments were conducted in a collaboration of the Japanese-Monbusho and the U.S./DOE Fusion Energy Sciences Programs.

In this study, ten V-base alloys (six with Cr, Ti, and Si additions and four with Fe, Ti, and Si additions) were irradiated in the 11J and 12J experiments. While the reference alloy has been V-4Cr-4Ti, effects of variations in Cr and Ti are of interest and replacement of Cr with Fe is being explored because iron atoms appear to be a more effective trap for the helium atoms produced in transmutation by neutron reaction [2]. The goals of the present work are to evaluate tensile properties of these alloys after the 300°C 11J irradiation and to compare with the data from the 12J experiment reported in Ref. 3.

EXPERIMENTAL PROCEDURES

Six small heats of V-(4-5)Cr-(3-5)Ti-(0-0.1)Si and four small heats of V-(3-4)Fe-4Ti-(0-0.1)Si alloys were produced by arc melting. Chemical analyses of the heats are shown in Table 1. The SSJ tensile specimens, with overall dimensions of 16.0 x 4.0 x 0.2 mm and gauge dimensions of 5.0 x 1.2 x 0.2 mm, were punched from 0.2-mm-thick as-rolled sheets with the longitudinal direction parallel to the final sheet rolling direction. All specimens were vacuum-degassed at 600°C for 0.5 h and then vacuum-annealed at 1100°C for 2 h. An impurity getter made of Zr and Ta foils was used to protect the specimens during the degassing and annealing. According to previous studies, the mechanical properties of these materials, in terms of yield stress, uniform elongation, and ultimate tensile stress, are not strongly influenced by annealing temperatures in the range of 950 to 1100° [4]. In the 11J experiment, the specimens were irradiated in a temperature range from 274±9 to

307±19°C and attained a dose of 4.2 to 6.2 dpa. Details of the operating history are given in Ref. 1.

Table 1. Composition of Alloys Studied

Heat	Nominal Comp.	Cr (wt.%)	Fe (wt.%)	Ti (wt.%)	Si (wppm)	O (wppm)	N (wppm)	S (wppm)
VM9401	V-4Cr-4Ti-0.1Si	4.43	-	4.07	640	240	5.5	3
VM9402	V-4Cr-4Ti	4.39	-	4.08	5	595	305	3
VM9403	V-5Cr-4Ti	5.56	-	4.05	7	515	4.5	2
VM9404	V-4Cr-3Ti	4.35	-	3.05	6	515	10	3
VM9405	V-5Cr-3Ti	5.53	-	3.07	4	490	5.5	3
VM9406	V-5Cr-5Ti	5.43	-	5.06	5	495	7	9
VM9407	V-4Fe-4Ti-0.1Si	0.06	3.94	4.03	210	370	7.5	4
VM9408	V-4Fe-4Ti	0.05	3.92	3.99	8	470	7.5	3
VM9409	V-3Fe-4Ti	0.05	3.01	3.97	6	515	7.5	2
VM9502	V-3Fe-4Ti-0.1Si	-	2.92	3.96	400	1478	21	8

Postirradiation tensile tests were conducted in the Irradiation Materials Laboratory at Argonne National Laboratory (ANL). The tests were conducted at room temperature and 300°C, the nominal irradiation temperature, at a strain rate of 6.67 x 10^{-4}/s (0.2 mm/min). The 300°C tests were performed in a high-purity flowing argon environment with the specimen protected in a Ti getter foil enclosure. After the tensile tests, fractography was performed with a SEM in ANL's Alpha-Gamma Hot Cell Facility. For reduction-in-area determinations, specimens were mounted in a vertical clip holder and oriented with crosssection parallel to the image plane. For side-view observations, specimens were tilted.

RESULTS

Nine of the ten materials have been tested; the results are summarized in Table 2. Also shown in the table are the sums of weight percentages of the major alloying components, Ti plus Cr or Fe.

Table 3. Summary results of 11J tensile tests[a].

Heat/ Material	(Cr, Fe) +Ti (wt.%)	Spec. No.	Test Temp. (°C)	0.2% YS (MPa)	UTS (MPa)	UE (%)	TE (%)	RA (%)
VM9401 V-4Cr-4Ti-0.1Si	8.65	TH12	RT	1051	1044	0.6	2.4	61
		TH11	300	928	937	0.4	1.5	55
VM9402 V-4Cr-4Ti	8.62	TD24	RT	927	950	0.5	2.1	63
		TD21	300	890	903	0.3	3.3	58
VM9403 V-5Cr-4Ti	9.73	TD34	RT	870	941	0.7	2.1	76
		TD30	300	890	894	0.2	3.0	65
VM9404 V-4Cr-3Ti	7.49	TD45	RT	930	1023	0.8	3.1	54
		TD40	300	777	787	0.4	1.2	66
VM9405 V-5Cr-3Ti	8.66	TD50	RT	1082	1082	0.2	3.7	65
		TD56	300	821	843	0.3	3.6	65
VM9406 V-5Cr-5Ti	10.67	TD60	RT	1020	1023	0.2	3.5	63
		TD64	300	915	915	0.2	2.9	68
VM9407 V-4Fe-4Ti-0.1Si	7.86	TD72	RT	862	989	0.7	3.7	67
		TD70	300	885	900	0.3	3.5	72
VM9408	7.80	TD83	RT	1202	1208	0.3	3.8	66

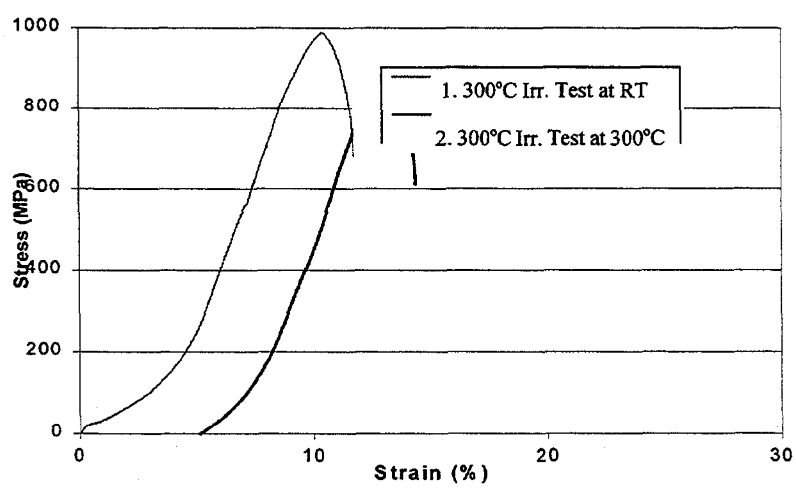
V-4Fe-4Ti		TD80	300	728	925	1.2	3.7	72
VM9409	6.95	TD96	RT	1080	1118	0.4	3.8	74
V-3Fe-4Ti		TD92	300	918	947	0.5	2.9	73

[a] 0.2% offset yield stress (YS), ultimate tensile strength (UTS), uniform elongation (UE), total elongation (TE), and reduction-in-area (RA).

For all materials tested, substantial hardening (manifested in the increased tensile strength) resulted from the 300°C irradiation in the 11J experiment. Compared to the nonirradiated baseline, the strengths are approximately doubled. Concomitantly, ductility of the materials shows a substantial decrease to <≈1 % uniform elongation and <≈4% total elongation. All materials show respectable reduction in area, however. Most of the reduction occurred in the thickness direction; necking in the width direction of the gauge was minimal.

Figure 1 shows the stress–strain curves for the VM9407 material (V-4Fe-4Ti-0.1Si) tested at room temperature and 300°C. At both temperatures, the material showed little work-hardening capability and fractured soon after reaching the yield point. Similar behavior was seen in essentially all of the other materials tested. In contrast, as shown in Fig. 2, the VM9407 materials displayed substantially more ductility and less hardening after the 500°C 12J irradiation. The substantial difference in irradiation behavior of vanadium-base alloys at 300 and 500°C highlights the issue of low-temperature embrittlement, which has been observed at temperatures below ≈400°C .

Fig.1 Stress-strain curves for VM9407/V-4Fe-4Ti-0.1Si from HFIR/11J experiment.



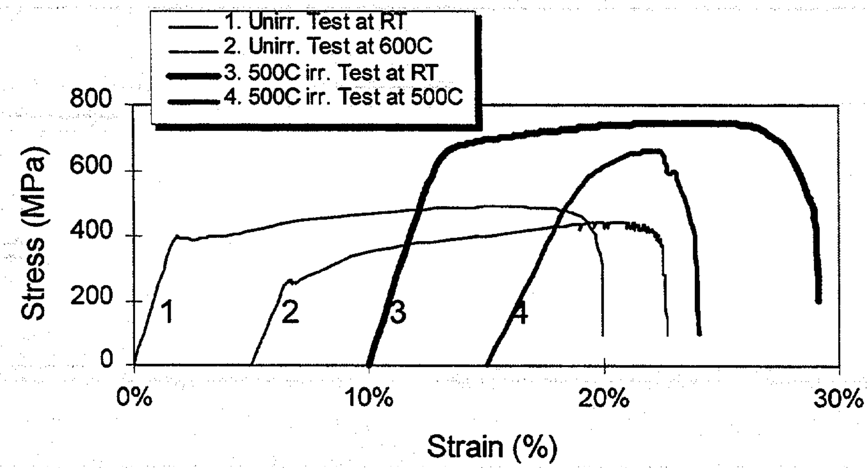


Fig. 2. Stress-strain curves for VM9407/V-4Fe-4Ti-0.1Si from 12J experiment.

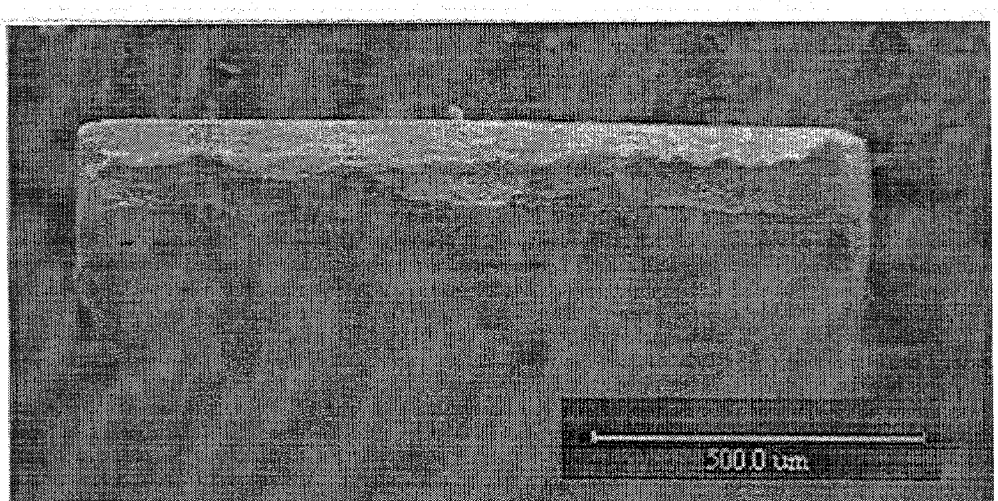


Fig. 3. Perspective view of tip of fractured tensile specimen TD45 with nominal composition of V-4Cr-3Ti. Irradiation was 300°C and test temperature was RT.

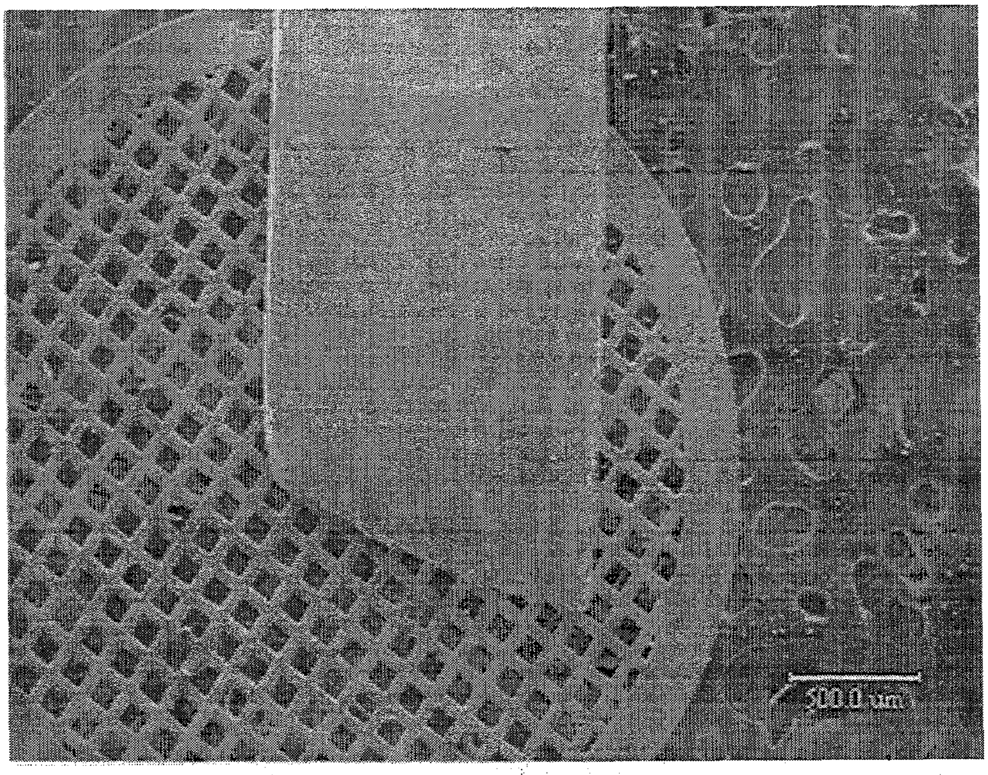


Fig. 4. SEM image showing gauge area of same TD45 specimen.

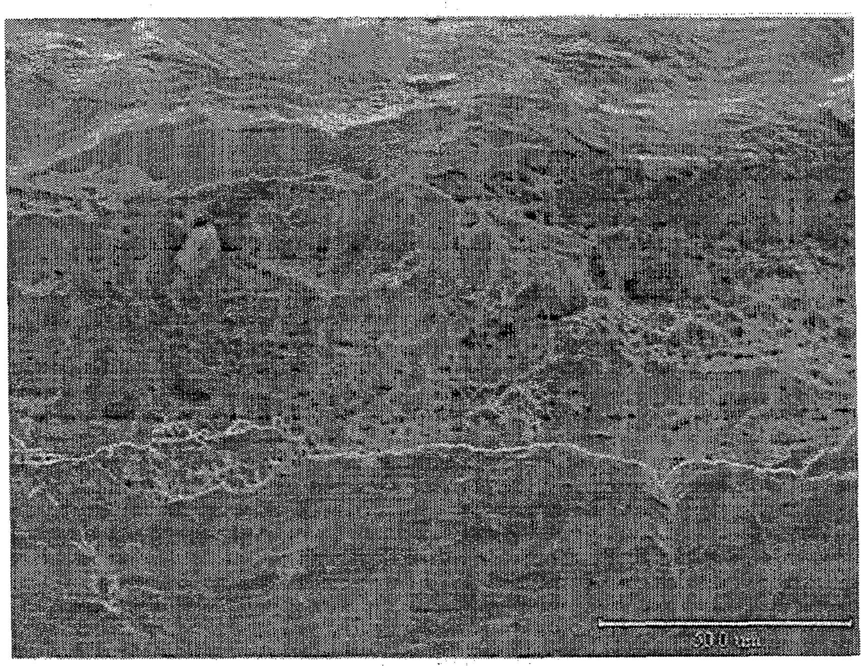


Fig. 5. Higher-magnification SEM fractograph of same TD45 specimen

Figure 3 is perspective view of the fractured tip of a representative specimen, TD45 (VM9404, V-4Cr-3Ti). Reductions in area of the 11J specimens were ≈55-75%, less than those of the 12J specimens (≈85-95%). As can be seen in Fig. 4, there was very little necking in the width direction of the gauge. A higher-magnification SEM fractograph of the same TH36 specimen is shown in Fig. 5. Surface cracks are visible, but, these cracks and slip bands are observed only in the necked region.

FUTURE WORK

Tensile testing for the VM9502 specimens will be completed. Microstructural examination of tested tensile specimens with TEM will be completed to determine the mechanisms of irradiation hardening.

REFERENCES

[1] Operating history of the HFIR MFE-RB-11J and 12J (P3-2 and P3-3) experiments, K. E.Lenox and M.L. Grossbeck; Fusion Materials Semianual Progress Report for Period Ending December 31, 1998 (DOE/ER-0313/25) p. 307.

[2] Effects of implanted helium on the mechanical properties of vanadium-based alloys, M. Tanaka and H. Matsui, Materials Transactions, JIM, Vol. 34 (1993) 1083.

[3] Tensile Properties of V-(Cr,Fe)-Ti Alloys after Irradiation in the HFIR-12J Experiment, K. Fukumoto, H. Matsui, Y. Yan, H. Tsai, R.V. Strain, and D. L. Smith, Fusion Materials Semianual Progress Report for Period Ending December 31, 1999 (DOE/ER-0313/27).

[4] Mechanical properties of vanadium based alloys for fusion reactor, K. Fukumoto, T. Morimura, T. Tanaka, A. Kimura, K. Abe, H. Takahashi and H. Matsui, J.Nucl.Mater., 239 (1996) 170 .