TENSILE PROPERTIES OF V-(CR,FE)-TI ALLOYS AFTER IRRADIATION IN THE HFIR-12J EXPERIMENT - K. Fukumoto, H. Matsui (IMR/Tohoku Univ.), Y. Yan, H. Tsai, R. V. Strain and D. L. Smith (Argonne National Laboratory)

OBJECTIVE

The objective of this work is to determine the tensile properties of V-(Cr,Fe)-Ti alloys after the irradiation at 500°C to ≈6 dpa in HFIR-12J experiment.

SUMMARY

Postirradiation tensile tests at room temperature and 500°C were performed on V-(Cr,Fe)-Ti alloy specimens irradiated in the HFIR-12J experiment. The specimens were of the SSJ design with overall dimensions of 16.0x4.0x0.2 mm and gauge dimensions of 5.0x1.2x0.2 mm. The irradiation temperature was ≈500°C and the attained neutron damage was ≈6 dpa. Results from these tensile tests show all specimens retained respectable elongation and irradiation hardening was modest. The properties of the V-(3-5)Cr-(3-5)Ti alloys appears not to be strongly affected by the Ti and Cr composition variations. For the V-(3-4)Fe-4Ti-(0-0.1)Si alloys, significantly, the uniform elongation was nearly 10%. The reduction-in-area in all specimens was high, >85%, indicating ductile behavior. These findings show good mechanical properties of V-(Cr,Fe)-Ti alloys after the 500°C neutron irradiation to 6 dpa.

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. Recently two irradiation experiments, RB-11J and RB-12J, were performed in HFIR to investigate the mechanical properties at the temperatures of 300 and 500°C, respectively[1]. These experiments were conducted under the auspices of the Japanese Monbusho, the Japan Atomic Energy Research Institute (JAERI), and the U.S. Fusion Energy Sciences Program.

In this study, ten V-base alloys, six with Cr, Ti and Si additions and four with Fe,Ti, and Si additions, were included. Whereas the reference alloy has been V-(3-5)Cr-(3-5)Ti, replacement of Cr with Fe is being explored because it is perceived that iron atoms may be a more effective trap for the helium atoms produced in transmutation by neutron reaction [2]. The goals of the present work were to evaluate the mode of fracture and the reasons of irradiation hardening and loss of ductility should it occur.

EXPERIMENTAL PROCEDURES

Six ingots of V-(4-5)Cr-(3-5)Ti-(0-0.1)Si and four ingots 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 (16 x 4 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 2h. An impurity getter made of Zr and Ta foils was used to protect the specimen at temperature. According to previous studies, mechanical properties of these materials, in terms of yield stress, uniform elongation and ultimate tensile stress, are not strongly influenced by the annealing temperature in the range of 950 to 1100° [3].

In the 12J experiment, the specimens were irradiated at 497 ± 22°C and attained a peak dose of 5.7 dpa. Details of the operating history are given in a previous report [1].

Table 1. Composition of the 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

The postirradiation tensile tests were conducted using the facilities in the Irradiation Materials Laboratory of the Argonne National Laboratory. The tests were conducted at room temperature and 500°C. All tests were performed at a strain rate of 6.67×10^{-4}/s (0.2mm/min). The 500°C tests were performed in a high-purity (99.999%) flowing argon environment with the specimen protected in a Ti getter foil. After the tensile tests, fractography was performed with a SEM in the ANL's Alpha-Gamma Hot Cell Facility. For the reduction-in-area determinations, specimens were mounted in a vertical clip holder and oriented with cross-section parallel to image plane. For the side view observations, specimens were tilted. TEM examinations were performed in Tohoku University with specimens punched out from the deformed tensile gauge sections and polished with a Tenupole-3 machine.

RESULTS

Table 2 summarizes the tensile test results: 0.2% offset yield stress (YS), ultimate tensile strength (UTS), uniform elongation (UE) and reduction-in-area (RA). Also shown in the table are the sums of weight percentages of the major alloying components, Ti plus Cr or Fe.

Table 2. Summary results of the 12J tensile tests

Heat/ Material	(Cr, Fe) +Ti (wt%)	Spec. No.	Test Temp. (°C)	0.2% YS (MPa)	UTS (MPa)	UE (%)	RA (%)
VM9401 V-4Cr-4Ti-0.1Si	8.65	TH13	RT	491	577	3.4	91
		TH18	500	368	449	2.3	95
VM9402 V-4Cr-4Ti	8.62	TH21	RT	420	519	4.8	92
		TH24	500	399	439	1.5	93
VM9403 V-5Cr-4Ti	9.73	TH34	RT	435	530	6.7	91
		TH36	500	355	435	3.2	90
VM9404 V-4Cr-3Ti	7.49	TH46	RT	395	491	9.1	93
		TH41	500	330	428	5.7	89
VM9405 V-5Cr-3Ti	8.66	TH50	RT	460	558	8.0	93
		TH58	500	374	443	4.5	NA
VM9406 V-5Cr-5Ti	10.67	TH65	RT	385	477	4.3	93
		TH63	500	368	449	2.3	92
VM9407 V-4Fe-4Ti-0.1Si	7.86	TH73	RT	635	745	10.6	90
		TH76	500	555	660	2.7	89
VM9408 V-4Fe-4Ti	7.80	TH80	RT	490	657	9.4	87
		TH81	500	505	608	5.3	85
VM9409 V-3Fe-4Ti	6.95	TH92	RT	518	600	9.2	89
		TH95	500	530	608	3.0	89
VM9502 V-3Fe-4Ti-0.1Si	6.78	TB05	RT	663	750	4.9	88
		TB07	500	462	575	4.5	90

Figure 1 shows a typical example of stress – strain curve on tensile tests for unirradiated and irradiated vanadium alloys, VM9407 with a nominal compositiion of V-4Fe-4Ti-0.1Si. The yield stress and ultimate strength of unirradiated V-Cr-Ti and V-Fe-Ti alloys at RT are ≈350 and 450 MPa, respectively. The ultimate tensile strengths of the irradiated materials were found to have increased over those of the unirradiated. However, the magnitude of hardening was limited, <≈66%. There were noticeable losses of ductility in the irradiated samples, but they still retain elongations up to 10% at RT. Even in 500°C tests, about 5% of elongation could be seen in some alloys.

Fig. 2 shows the dependence of strength and uniform elongation on the amount of major alloying components, measured in wt% of (Cr,Fe) + Ti. From the figures, it can be seen that the V-Fe-Ti alloys are more susceptible to irradiation hardening than the V-Cr-Ti alloys. In these experiments, the production of helium and hydrogen is negligibly small, <1 ppm. Therefore, the greater increase in irradiation hardening in the V-Fe-Ti alloys than in the V-Cr-Ti alloys might not be due to a trapping effect of helium at undersized solute atoms. At low levels of (Cr,Fe) + Ti alloy addition, both V-Fe-Ti and V-Cr-Ti alloys show good uniform elongation, up to ≈10% in RT tests.

Figure 3 shows the dependence of alloying component weight on the yield stress, ultimate tensile strength and uniform elongation in 500°C tests. The tendency in the 500°C tests is comparable to that in RT tests, with the uniform elongation decreased to about 5%. After the stress reached to ultimate tensile strength in 500°C tests, serration on stress-strain curve can be seen until the onset of crack extension.

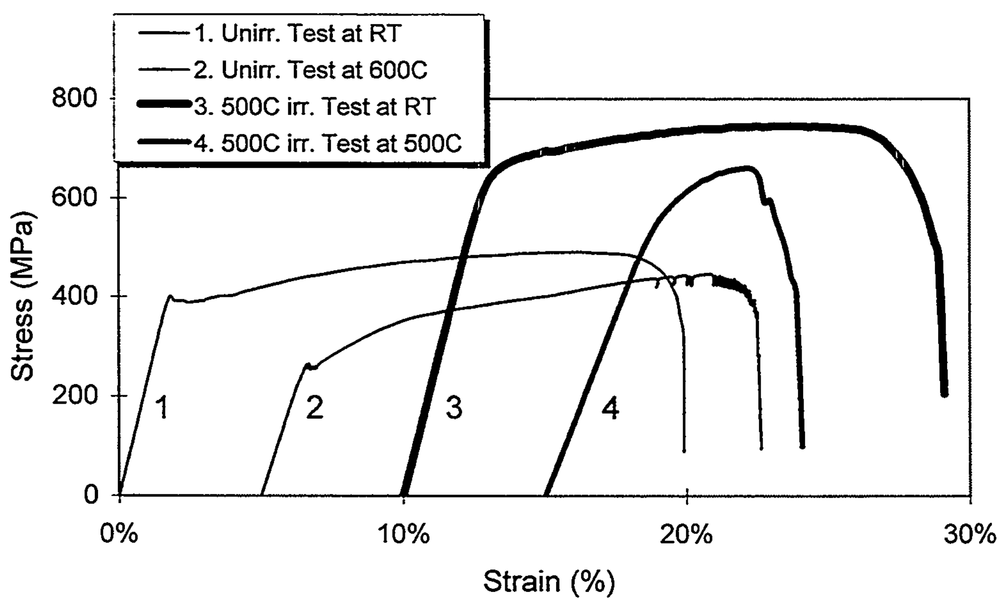


Fig.1 Stress-strain curves for VM9407/V-4Fe-4Ti-0.1Si.

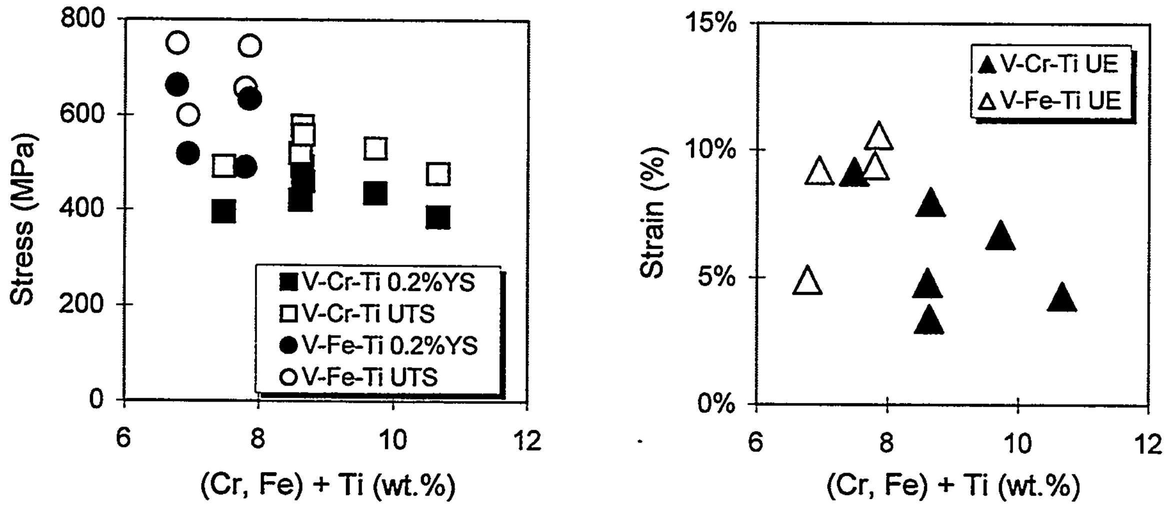
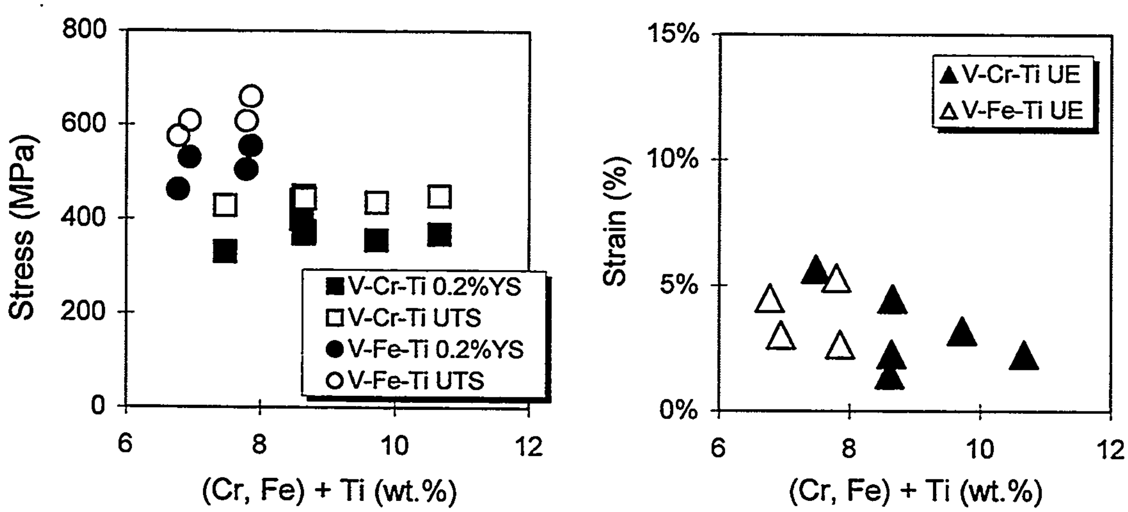


Fig. 2. Comparison of tensile strength of V-Cr-Ti and V-Fe-Ti alloys in room temperature tests. Left figure shows dependence of yield stress and ultimate tensile strength on (Cr,Fe)+Ti addition. Right figure shows the dependence of uniform elongation on (Cr,Fe)+Ti addition.



Figs.3 : Comparison of tensile strength and ductility of V-Cr-Ti and V-Fe-Ti alloys in 500°C tests. Left figure shows dependence of yield stress and ultimate tensile strength on (Cr,Fe)+Ti addition. Right figure shows the dependence of uniform elongation on (Cr,Fe)+Ti addition.

A perspective view of the fractured tip of a representative specimen, TH36 (VM9403/V-5Cr-4Ti), is shown in Fig. 4. Necking at the fracture part can be seen. The reductions in area in all specimens were >80%, which corroborated with the ductile features noted in the SEM fractography. A typical example is shown in Fig. 5. There are no intergranular fractures and clevage patterns on the fracture surfaces. Surface cracks are visible; however, these cracks and slip bands are observed only in the necked region. This localized structure might be related to plastic instability.

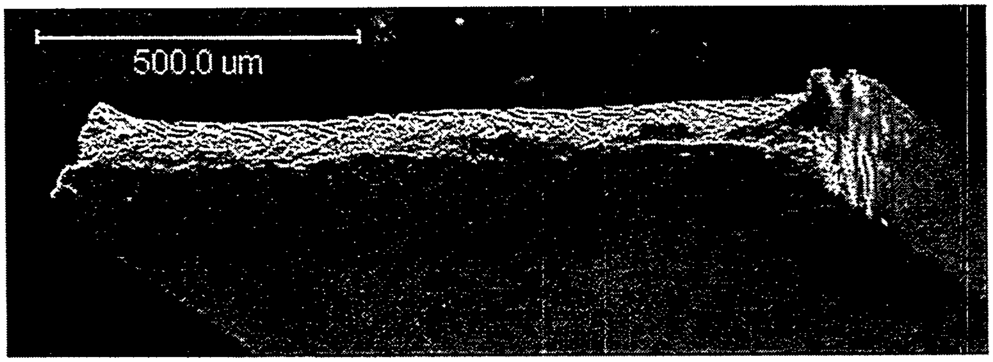


Fig.4 A perspective view of the tip of fractured tensile specimen TH36 with a nominal composition of V-5Cr-4Ti. Both the irradiation and test temperatures were 500°C.

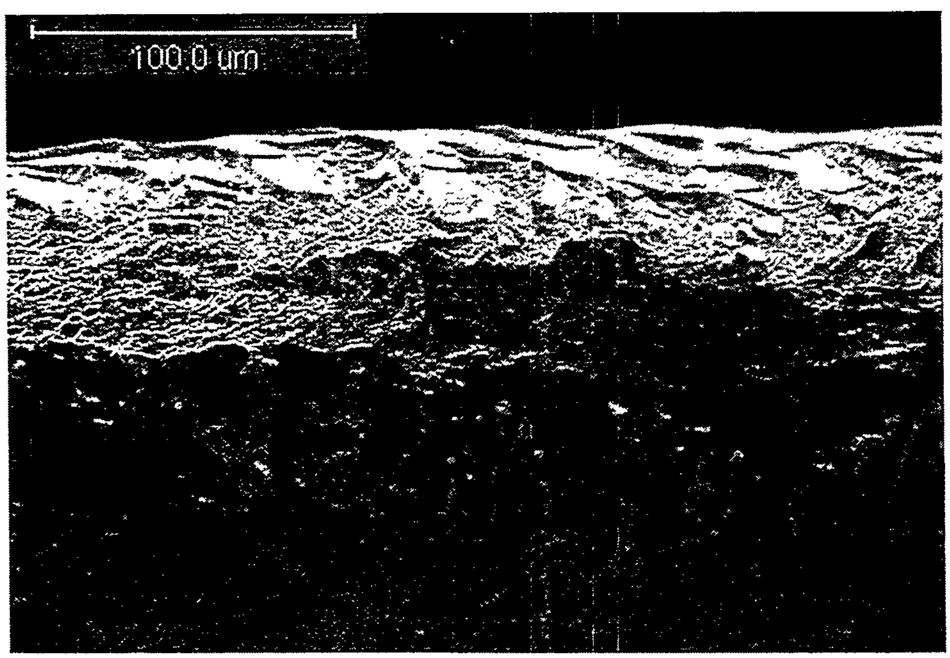


Fig.5 Higher magnification SEM fractograph of the same TH36 specimen showing ductile features at the fracture.

Fig. 6A shows the TEM micrograph of irradiated specimen TH13 (VM9401/V-4Cr-4Ti-0.1Si). The features seen are typical in other specimens. Dislocation network and dislocation loops formed in the matrix at high density. Also formed were precipitates, which have an average size of 30nm. While there were no detectable cavities in the grains, they could be seen close to and/or on the grain boundaries, as shown in Fig.6B. These microstructural features are consistent with the previous data [4,5] obtained from FFTF and EBR-II irradiation in temperature regimes of 430 or 500°C. The relationship between the tensile behavior and microstructure in this work are therefore in good agreement with the previous work in FFTF or EBR-II.

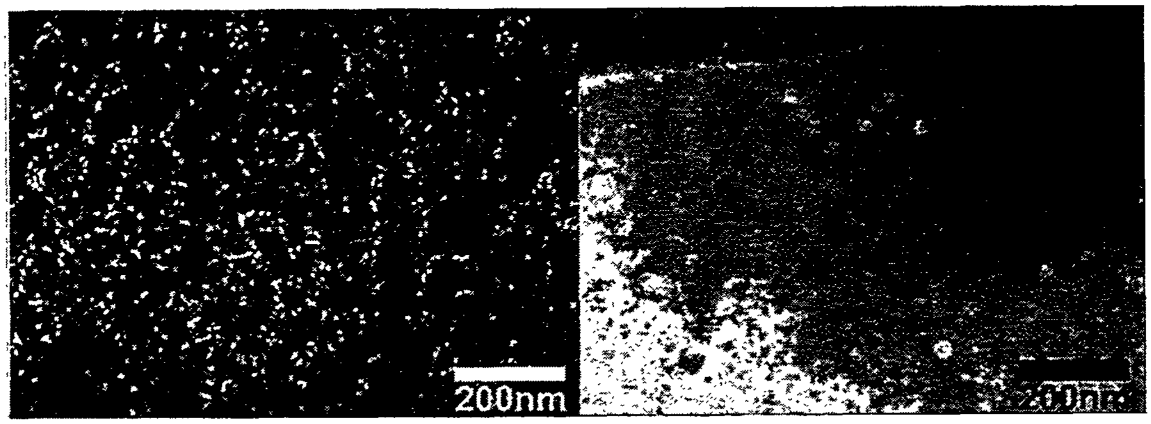


Fig. 6A (left) TEM weak-beam dark-field micrograph of sample TH13 (VM9401/V-4Cr-4Ti-0.1Si). High density of dislocation can be seen.
Fig. 6B (right) TEM bright-field image of the same sample TH13. Cavities can be seen close to and on the grain boundary.

FUTURE WORK

TEM observations at the necking parts of tested tensile specimens will be completed to determine the mechanisms of irradiation hardening. As well as subsequent experiments of HFIR-12J, a series of examination for specimens irradiated at 300C in HFIR-11J is undergoing.

REFERENCES

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