TENSILE PROPERTIES OF VANADIUM ALLOYS IRRADIATED AT 200°C IN THE HFIR*

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SUMMARY

Vanadium alloys were irradiated in a helium environment to ≈10 dpa at ≈200°C in the High Flux Isotope Reactor (HFIR). This report presents results of postirradiation tests of tensile properties of laboratory heats of V-(1-18)Ti, V-4Cr-4Ti, V-8Cr-6Ti, V–9Cr–5Ti, V-3Ti-1Si, and V-3Ti-0.1C alloys. Because of significant loss of work-hardening capability, all alloys except V-18Ti exhibited a very low uniform plastic strain of <1%. For V-Ti alloys, work-hardening capability increased with Ti content ≥ 10%, e.g., uniform strain of ≈2.4% for V-18Ti. The mechanism of the loss of work-hardening capability in the other alloys is not understood.

INTRODUCTION

Recently, attention to vanadium alloys has focused on low-temperature irradiation performance, especially tensile properties at <425°C. Under negligible helium generation, a 30-kg laboratory heat of V-4Cr-4Ti (Heat BL-47) was reported to retain a significant level of work-hardening capability (uniform plastic strain ≈3%) after irradiation to ≈10 dpa at ≈400°C in the High Flux Isotope Reactor (HFIR).[1] In contrast, complete loss of work-hardening capability (negligible uniform plastic strain) was reported for a 500-kg heat of V-4Cr-4Ti (Heat #83665) following irradiation to ≈0.4 dpa at 100-275°C in the High Flux Beam Reactor (HFBR).[2] This report presents results of postirradiation tests of tensile properties of V-1Ti, V-5Ti, V-10Ti, V-18Ti, V-4Cr-4Ti, V–8Cr–6Ti, V–9Cr–5Ti, V-3Ti-1Si, and V-3Ti-0.1C irradiated to ≈10 dpa at ≈200°C in a helium environment in the HFIR.

MATERIALS AND PROCEDURES

The elemental composition of the alloys, determined prior to irradiation, is given in Table 1. Tensile specimens with a gauge length of 7.62 mm and a gauge width of 1.52 mm were machined from ≈1.0-mm-thick sheets. Tensile specimens from the V-Cr-Ti alloys were annealed at a nominal temperature of ≈1125°C for 1 h, whereas specimens from the other alloys were annealed at 1050°C for 1 h. Following irradiation and specimen retrieval, the tensile specimens were cleaned ultrasonically in alcohol and tested without the customary degassing treatment at 400°C (used to expel hydrogen). Tensile properties were measured at 200°C in flowing argon at a strain rate of 0.001 s^{-1}.

Table 1. Chemical composition of vanadium alloys irradiated to ≈10 dpa at 200°C in helium in the HFIR

Heat ID	Nominal Comp. (wt.%)	Impurity Concentration (wt. ppm) O	N	C	Si
BL-50	1.0Ti	230	130	235	1050
BL-46	4.6Ti	305	53	85	160
BL-12	9.8Ti	1670	390	450	245
BL-15	17.7Ti	830	160	380	480
BL-47	4.1Cr-4.3Ti	350	220	200	870
BL-49	7.9Cr-5.7Ti	400	150	127	360
BL-43	9.2Cr-4.9Ti	230	31	100	340
BL-45	2.5Ti-1Si	345	125	90	9900
BL-60	3Ti-0.1C	-	-	-	-

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The tensile specimens were irradiated in the MFE–RB* 200J–1 capsule in the removable beryllium (RB*) position in the HFIR. The specimens were irradiated at ≈200°C to ≈10 dpa in circulating helium. Details of the capsule design and irradiation conditions are reported in Ref. 3. Helium in the line was purified continuously by a Ti–sponge getter located outside the core region. The specimens were shielded from thermal neutrons by an Hf sleeve located outside the capsule and designed to tailor the neutron spectrum to closely simulate the fusion–relevant helium–to–dpa ratio in stainless steels (i.e., ≈14 appm/dpa). In this experiment, the calculated transmutation rate of V to Cr is ≈0.2 %/dpa, or an increase of ≈2 %, in all alloys at the end of irradiation.

RESULTS AND DISCUSSION

Uniform plastic strain, total plastic strain, 0.2% yield strength, and ultimate tensile strength of the nine alloys are shown in Figs. 1-4, respectively. Except for V-18Ti, tensile properties of V-Cr-Ti alloys irradiated at 200°C in a helium environment in the HFIR were similar to the tensile properties reported for the 500-kg heat of V-4Cr-4Ti after irradiation at 100-275°C in the HFBR.[2] That is, significant or complete loss of work-hardening capability was observed in all alloys except V-18Ti, and as a result, uniform elongation was very low. Uniform plastic strain of the 30-kg heat of V-4Cr-4Ti, irradiated and measured at 200°C, was only 0.40-0.79%; significantly lower than the uniform plastic strain of ≈3% measured at 400°C on counterpart specimens irradiated at 400°C.[1] In contrast to irradiation at 400°C, work-hardening capability of the V-Cr-5Ti alloys during irradiation at 200°C does not appear to be influenced by a variation of Cr content from 4 to 10 wt.%. This is shown in Fig. 5.

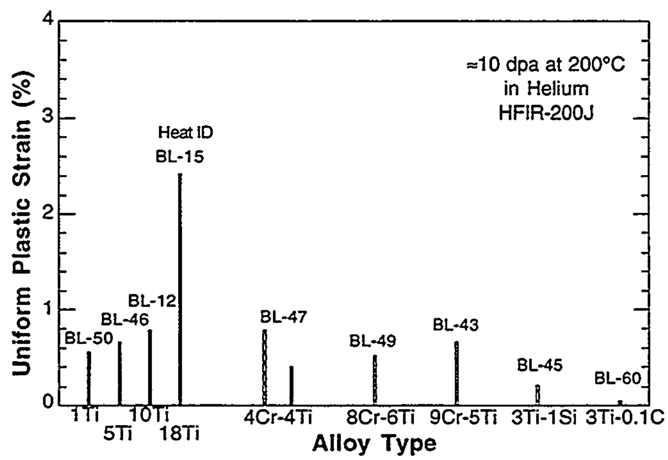

Fig. 1.
Uniform plastic strain of vanadium alloys irradiated at ≈200°C to ≈10 dpa in helium in the HFIR (calculated increase in Cr content of ≈2 % by transmutation).

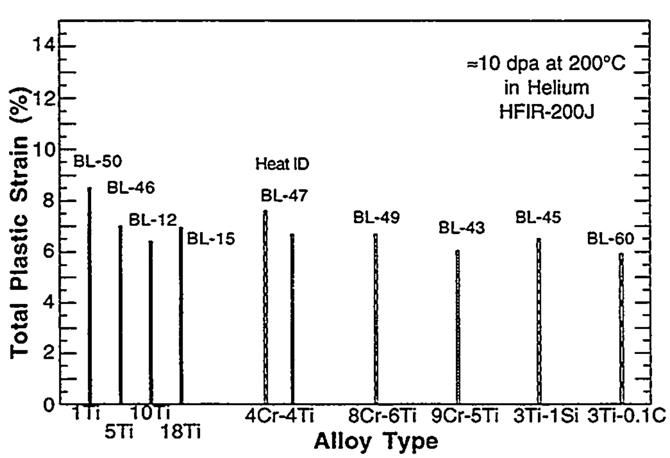

Fig. 2.
Total plastic strain of vanadium alloys irradiated at ≈200°C to ≈10 dpa in helium in the HFIR (calculated increase in Cr content of ≈2 % by transmutation).

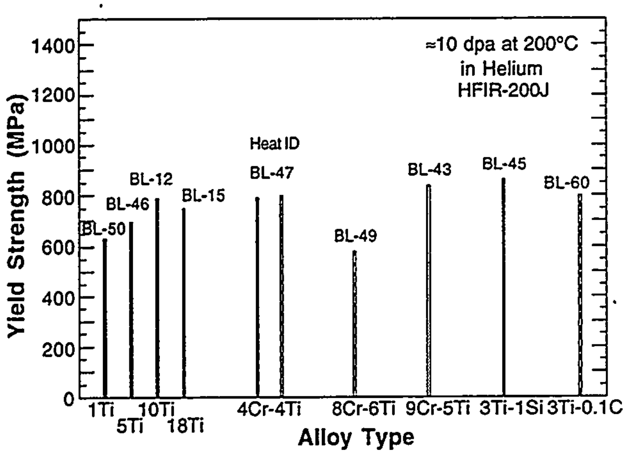

Fig. 3.
0.2%-offset yield strength of vanadium alloys irradiated at ≈200°C to ≈10 dpa in helium in the HFIR (calculated increase in Cr content of ≈2 % by transmutation).

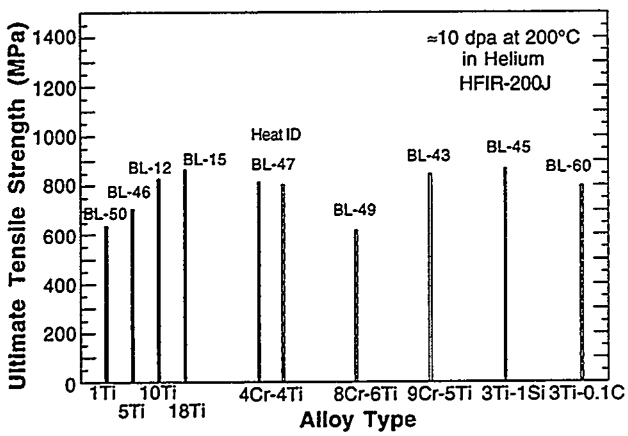

Fig. 4.
Ultimate tensile strength of vanadium alloys irradiated at ≈200°C to ≈10 dpa in helium in the HFIR (calculated increase in Cr content of ≈2 % by transmutation).

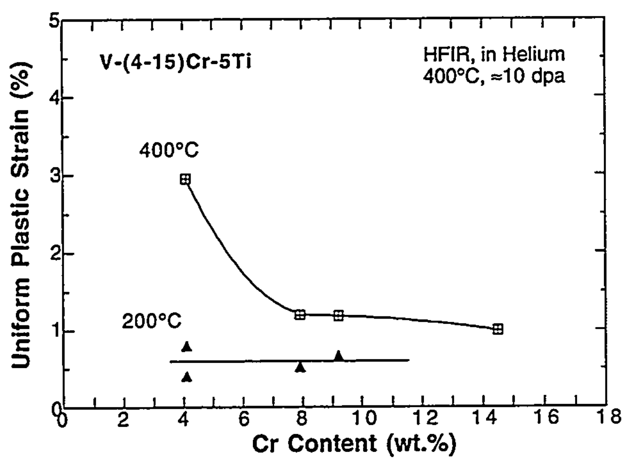

Fig. 5.
Uniform plastic strains of V-Cr-5Ti alloys irradiated at 400 and 200°C as function of starting Cr content (calculated increase in Cr content of ≈2 % by transmutation).

In Fig. 6, effects of Ti on tensile strength and uniform plastic strain are shown for V-Ti alloys (estimated Cr content of ≈2 %). Uniform plastic strain increased significantly for Ti content > 10 wt.%, e.g., to ≈2.4% for Ti ≈ 18 wt.%. This may be interpreted as an indication that loss of work-hardening capability is associated with one or more minor impurities that interact strongly with Ti atoms in solution or on grain boundaries during irradiation at low temperatures. Loss of work-hardening capability through dislocation channeling is also possible. To provide an understanding of the mechanism(s) of loss of work-hardening capability, microstructural characterization is being conducted by means of several metallographic techniques.

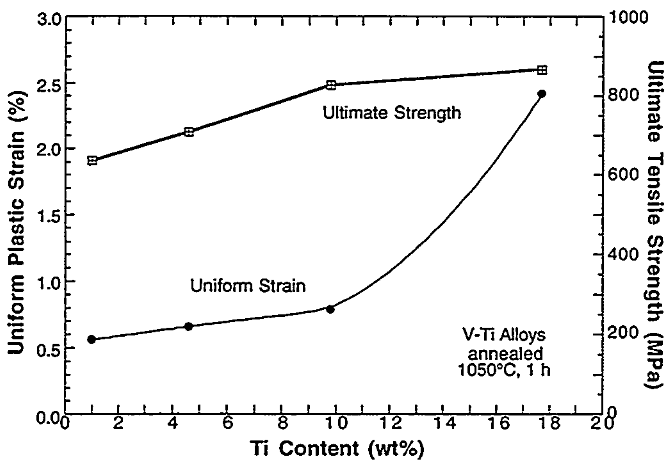

Fig. 6.
Uniform elongation and ultimate tensile strength of V-Ti alloys as function of Ti content (calculated increase in Cr content of ≈2 % by transmutation).

CONCLUSIONS

1. Uniform plastic strain of V-1Ti, V-5Ti, V-10Ti, V-4Cr-4Ti, V–8Cr–6Ti, V–9Cr–5Ti, V-3Ti-1Si, and V-3Ti-0.1C irradiated to ≈10 dpa at 200°C in a helium environment in HFIR were very low (<1%). This is because of significant or complete loss of work-hardening capability in the alloys. Uniform plastic strain of a 30-kg heat of V-4Cr-4Ti, irradiated and measured at 200°C, was only 0.40-0.79%; significantly lower than the uniform plastic strain of ≈3% measured at 400°C on counterpart specimens irradiated at 400°C.

2. In contrast to the above alloys, V-18Ti retained a significant level of work-hardening capability (uniform plastic strain of ≈2.4%). For V-Ti alloys, uniform plastic strain increased significantly for Ti content >10 wt.%. This may be interpreted as an indication that the loss of work-hardening capability is associated with one or more minor impurities that interact strongly with Ti atoms in solution or on grain boundaries during irradiation at low temperatures. Loss of work-hardening capability through dislocation channeling is also a possibility.

3. Loss of work-hardening capability of vanadium alloys at low irradiation temperatures (<430°C) seems to vary strongly from heat to heat, indicating that minor impurities and fabrication procedures are important factors.

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