PROPERTIES OF V–(8–9)Cr–(5–6)Ti ALLOYS IRRADIATED IN THE DYNAMIC HELIUM CHARGING EXPERIMENT* H. M. Chung, L. Nowicki, and D. L. Smith
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SUMMARY

In the Dynamic Helium Charging Experiment (DHCE), helium was produced uniformly in vanadium alloy specimens by the decay of tritium during irradiation to 18–31 dpa at 425–600°C in lithium-filled capsules in the Fast Flux Test Facility. This report presents results of postirradiation tests of tensile properties and density change in V-8Cr-6Ti and V–9Cr–5Ti. Compared to tensile properties of the alloys irradiated in the non–DHCE (helium generation negligible), the effect of helium on tensile strength and ductility of V-8Cr-6Ti and V–9Cr–5Ti was insignificant after irradiation and testing at 420, 500, and 600°C. Both alloys retained a total elongation of >11% at these temperatures. Density change was <0.48% for both alloys.

INTRODUCTION

For the vanadium alloys, recent attention has focused on V-4Cr-4Ti for fusion reactor structural components because of its excellent mechanical and physical properties before and after neutron irradiation with and without helium generation. Compared to V–4Cr–4Ti, V–(8–9)Cr–(5–6)Ti alloys are known to exhibit better tensile and creep strengths (Fig. 1). However, impact properties of V–(8–9)Cr–(5–6)Ti alloys are less attractive than those of V–4Cr–4Ti. Ductile–brittle transition temperatures (DBTTs) of the alloys are significantly higher than that of V–4Cr–4Ti , i.e., ≈–70 to –85°C vs. <–196°C (Fig.2). DBTTs of V-(8-9)Cr–(5–6)Ti alloys shown in the figure were obtained on specimens annealed at a nominal temperature of ≈1125°C when the strong effect of annealing temperature on impact properties was not known. Preliminary data obtained recently on V–8Cr–6Ti annealed at ≈1000°C (for 1 h in high vacuum) indicated, however, a significantly improved DBTT, i.e., ≈–125°C vs. ≈–85°C. Therefore, there is some interest in improving the properties of V–(6–9)Cr–(5–6) Ti alloys by optimizing impurity composition and thermomechanical treatment, i.e.,obtaining both higher strength than V–(4–5)Cr–(4–5)Ti and acceptable impact properties.

With this background, we present in this report results of postirradiation tensile testing and density measurements on V–8Cr–6Ti and V–9Cr–5Ti specimens irradiated in the DHCE. Details of the experiment are described in Ref. 1. Tensile specimens (subsize SS–3 geometry) were annealed at a nominal temperature of ≈1125°C before insertion in the DHCE capsules. In the DHCE, fusion–relevant helium-to-dpa damage ratio (≈4–5 appm He/dpa) is simulated by utilizing slow transmutation of controlled amounts of ^{6}Li and a tritium–doped mother alloy immersed in ^{6}Li + ^{7}Li.

MATERIALS AND PROCEDURES

The elemental composition of the V–8Cr–6Ti, and V–9Cr–5Ti 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 that had been annealed at a nominal temperature of ≈1125°C. Following irradiation in the DHCE, tensile properties were measured at 23, 100, and 200°C and at irradiation temperatures (425, 500, and 600°C) in flowing argon at a strain rate of 0.0011 s^{-1}. The thickness and gauge width of each specimen were measured individually before each tensile test.

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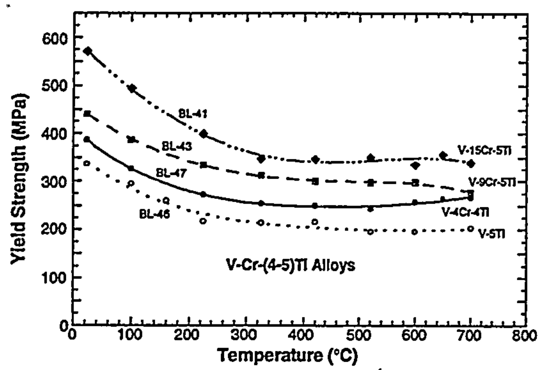

Fig. 1.

Yield strength vs. temperature of V-Cr-(4-5)Ti alloys as function of increased Cr content.

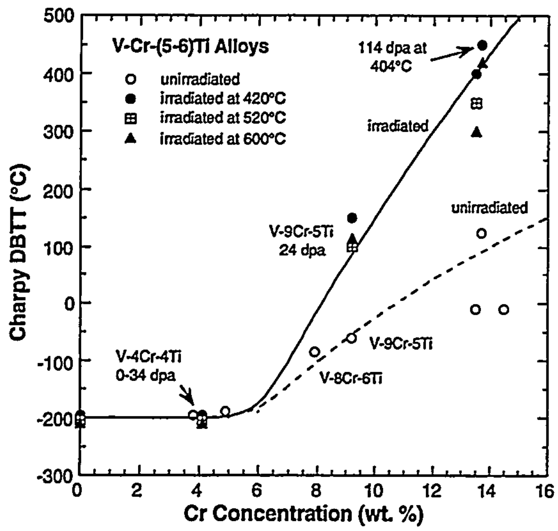

Fig. 2.

Comparison of ductile-brittle transition temperatures of V-4Cr-4Ti and V-(8-9)Cr-(5-6)Ti alloys.

The alloy specimens were irradiated in the Fast Flux Test Facility (FFTF) at 420, 520, and 600°C to neutron fluences (E > 0.1 MeV) ranging from 3.7 x 10^{22} n/cm^2 (≈18 displacements per atom, or dpa) to 6.4 x 10^{22} n/cm^2 (≈31 dpa). Helium in the alloy specimens has not yet been analyzed, but based on the helium contents measured previously on V–4Cr–4Ti, V–5Ti, and V–3Ti–1Si specimens that were irradiated in the same DHCE capsules,[1] helium contents in V–8Cr–6Ti and V–9Cr–5Ti are estimated to be in the range of 10–70 appm (see Table 2). Table 2 summarizes the irradiation parameters of the seven DHCE capsules in which V–8Cr–6Ti and V–9Cr–5Ti specimens were irradiated with V–4Cr–4Ti, V–5Ti, and V-3Ti–1Si alloys.

Table 1. Elemental Composition of V–8Cr–6Ti and V-9Cr-5Ti Alloys (wppm, unless otherwise noted)

Heat ID	Material	Cr, wt.%	Ti, wt.%	Si	O	N	C
BL-49	V-8Cr-6Ti	7.9	5.7	360	400	150	127
BL-43	V-9Cr-5Ti	9.2	4.9	340	230	31	100

Table 2. Summary of Irradiation Parameters of the Dynamic Helium Charging Experiment

Capsule ID NO.	Irradiation Temperature (°C)	Fluence (E > 0.1 MeV) (10^{22}n cm^{-2})	Total Damage[c] (dpa)	Helium Content Measured in V-4Cr-4Ti (appm)
4D1	425	6.4	31	112-13.3
4D2	425	6.4	31	22.4-22.7
5E2	425	3.7	18	3.3-3.7
5D1	500	3.7	18	14.8-15.0
5E1	500	3.7	18	6.4-6.5
5C1	600	3.7	18	8.4-11.0
5C2	500	3.7	18	74.9-75.3

TENSILE PROPERTIES

Yield strength, ultimate tensile strength, uniform elongation, and total elongation, measured on tensile specimens of V–8Cr–6Ti (Heat ID BL-49) and V–9Cr–5Ti (Heat ID BL-43) irradiated at 425°C–600°C to 18–34 dpa in the DHCE, are summarized in Figs. 3 and 4, respectively. For comparison, similar properties measured on non-DHCE-irradiated counterpart specimens (helium generation negligible) are also plotted as a function of irradiation temperature. In the figures, two groups of postirradiation tensile properties are shown, those measured at the irradiation temperatures and those measured at 23–200°C after irradiation at 420-600°C.

As shown in Figs. 3 and 4, after irradiation to ≈30 dpa in either a DHCE or other experiment, the two alloys retained high ductilities, i.e., >7% uniform elongation and >11% total elongation. Tensile properties of DHCE specimens, measured at 600°C (the same as the irradiation temperature), were essentially the same as those measured on non–DHCE specimens. This shows that the effect of helium was insignificant.

For both alloys, ductilities of the DHCE specimens irradiated at 425° were higher at 23°C than at 425°C. This behavior, similar to those observed for V-4Cr-4Ti, V-5Ti, and V-3Ti-1Si, is in contrast to the behavior of non–DHCE specimens in which ductility of specimens irradiated at 425° and measured at 23°C were similar to or slightly lower than the ductility measured at 425°C.[1] A similar comparison for DHCE and non–DHCE specimens irradiated at 500 and 600°C could not be made because no extra specimens of the latter type were available.

In contrast to results obtained from specimens in which helium atoms were produced by the tritium–trick method, low plastic deformation associated with intergranular cracking was not observed in either V-8Cr-6Ti or V-9Cr-5Ti. In the tritium-trick experiments, total elongation measured at room temperature is usually significantly lower than that measured at 500–600°C. This has been attributed to strong susceptibility to intergranular cracking in association with extensive formation of grain–boundary helium bubbles. No such grain-boundary coalescence of helium bubbles was observed in either the V-8Cr-6Ti or V-9Cr-5Ti specimens irradiated in the DHCE.

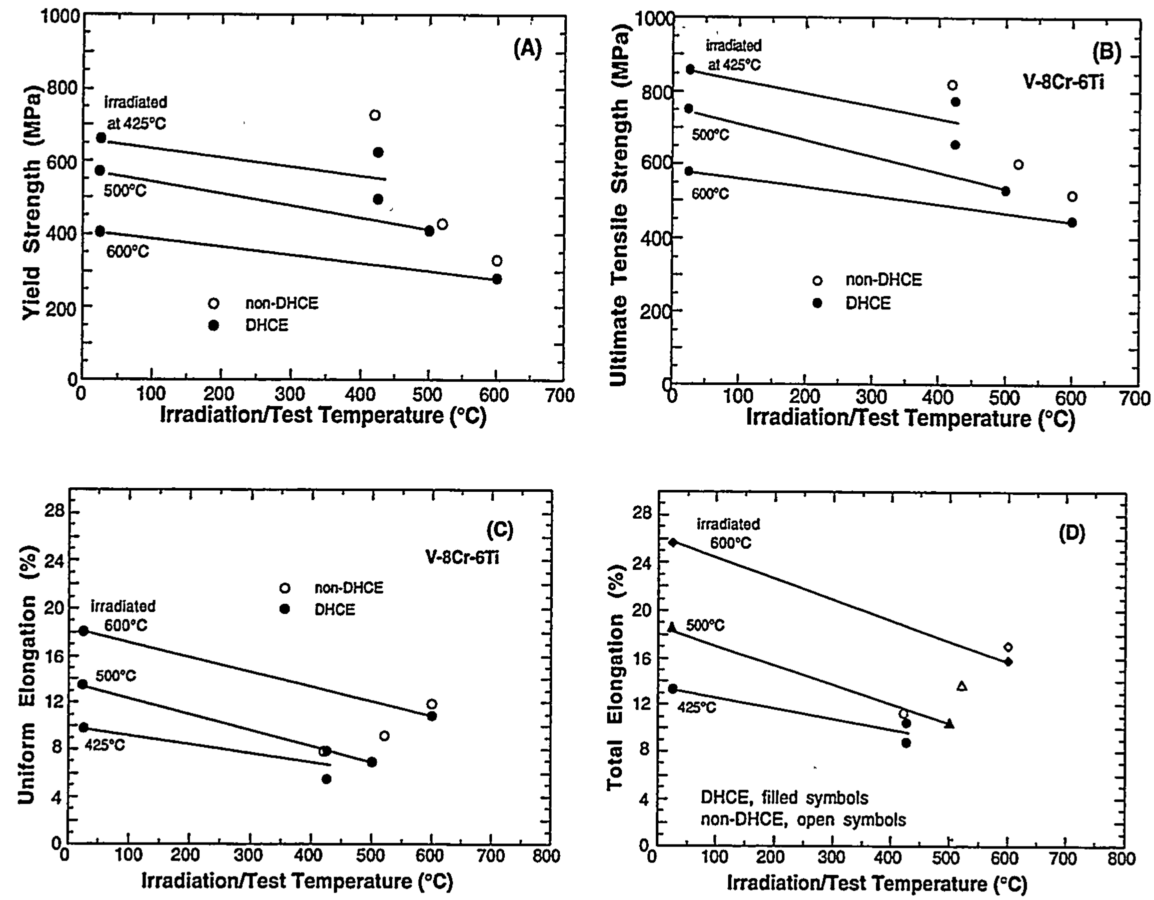

Fig. 3. Yield Strength (A), Ultimate Tensile Strength (B), Uniform Elongation (C), and total elongation (D) of V–8Cr–6Ti after irradiation at 420–600°C to 18–34 dpa in DHCE and other experiments (non-DHCE).

DENSITY CHANGE

Density decreases of V-8Cr-6Ti and V-9Cr-5Ti irradiated in the DHCE are shown in Figs. 5 and 6, respectively. Density was measured on pieces broken from the shoulder region of the tensile specimens. The density change in the figures represents the average of three measurements and was small, i.e., <0.48% after ≈18–31 dpa. However, density change in V–8Cr–6Ti was larger under DHCE conditions than under the non–DHCE conditions.

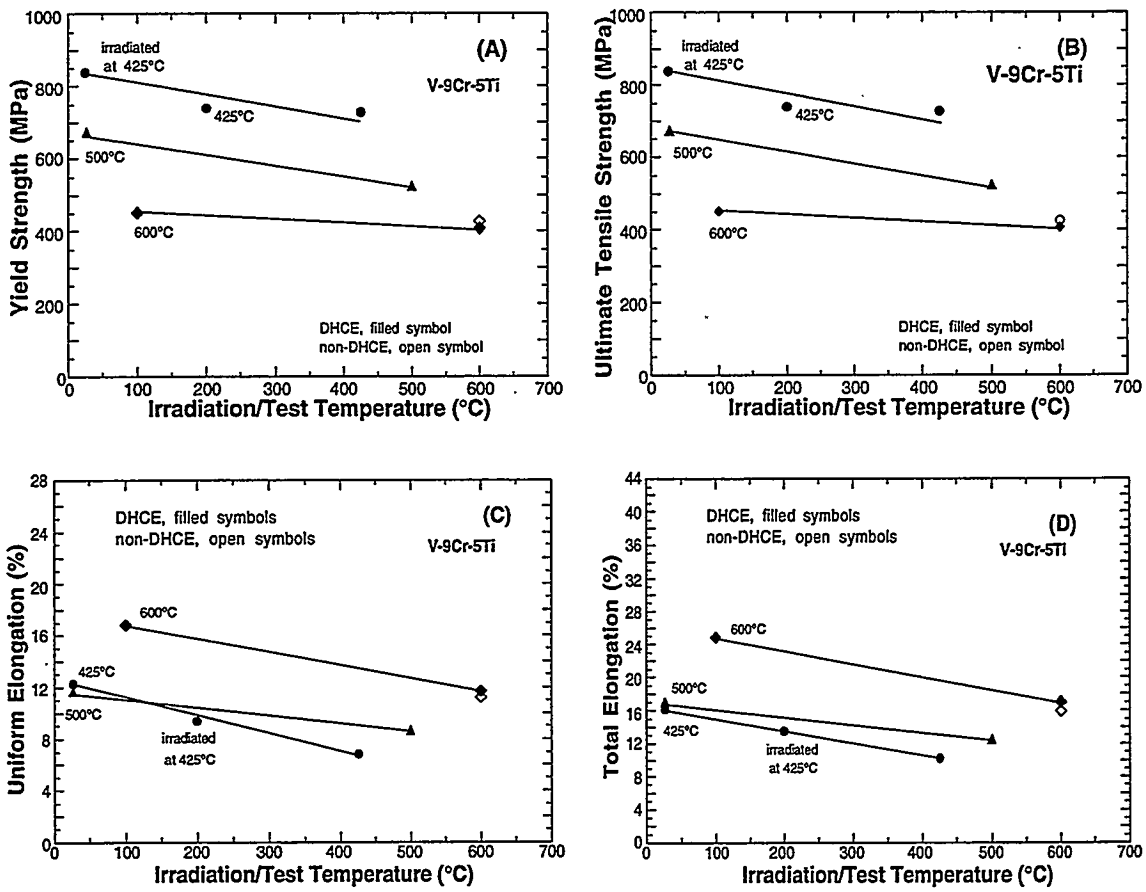

Fig. 4. Yield strength (A), ultimate tensile strength (B), uniform plastic elongation (C), and total elongation (D) of V–9Cr–5Ti after irradiation at 420–600°C to 18–34 dpa in DHCE and other experiments (non-DHCE).

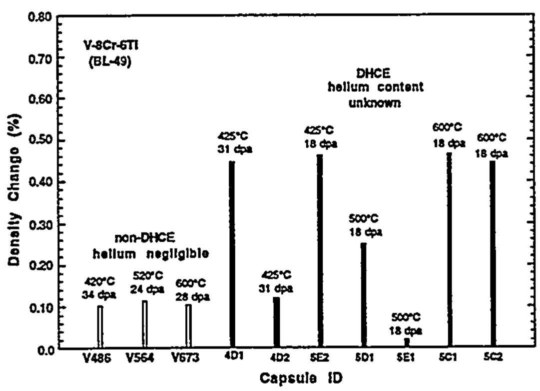

Fig. 5.

Density decrease of V–8Cr–6Ti after irradiation to 18–34 dpa at 420–600°C with (DHCE) and without helium generation (non-DHCE).

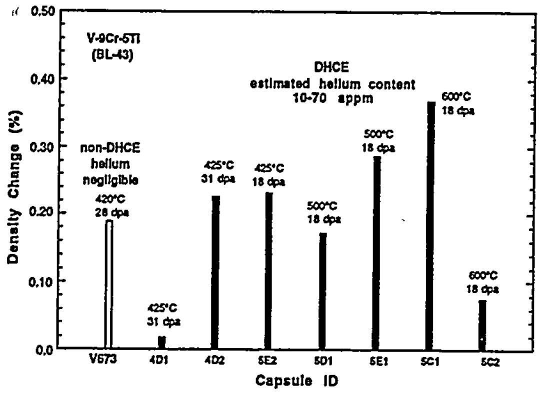

Fig. 6.

Density decrease of V–9Cr–5Ti after irradiation to 18–34 dpa at 420–600°C with (DHCE) and without helium generation (non–DHCE).

CONCLUSIONS

1. Tensile ductilities of V–8Cr–6Ti and V–9Cr–6Ti, irradiated to 18–31 dpa at 425°C to 600°C in the Dynamic Helium Charging Experiment (DHCE) at estimated helium generation rates of 0.4–4 appm He/dpa, remained significantly high at 25–600°C, i.e., >7% uniform elongation and >11% total elongation.

2. Tensile properties of the alloys irradiated and measured at 600°C were essentially the same as those measured on the counterpart non–DHCE specimens (negligible helium generation). No intergranular fracture was observed in tensile specimens irradiated in the DHCE and tested at 20–600°C. This shows that effects of helium were insignificant.

3. Ductilities of the DHCE specimens irradiated at 425° were higher at 23°C than at 425°C. This behavior, similar to those observed for V-4Cr-4Ti, V-5Ti, and V-3Ti-1Si, is in contrast to the behavior under non–DHCE conditions (helium generation negligible) in which ductility of the specimens irradiated at 425° and measured at 23°C were similar to or slightly lower than that measured at 425°C. These observations indicate that different types of hardening centers are produced at ≈425°C in the DHCE condition (probably a helium–vacancy–impurities complex, impurities being O, N, and C) and in non–DHCE condition (defects and defect clusters, impurities in interstitial sites).

4. Density decrease of V-8Cr-6Ti and V-9Cr-5Ti irradiated in the DHCE was small, i.e., <0.48% after ≈18–31 dpa.

REFERENCES

1. H. M. Chung, B. L. Loomis, L. Nowicki, and D. L. Smith, "Effect of Dynamically Charged Helium on V–5Ti, V–4Cr–4Ti, and V–3Ti–1Si," in Fusion Reactor Materials, Semiannual Prog. Rep. DOE/ER-0313/19, Oak Ridge National Laboratory, Oak Ridge, TN (1995), pp. 77–82.