TENSILE PROPERTIES OF V–(4–15)Cr–5Ti ALLOYS IRRADIATED AT 400°C IN THE HFIR*

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SUMMARY

V–(4–15)Cr–5Ti alloys were irradiated in a helium environment to ≈10 dpa at ≈400°C in the High Flux Isotope Reactor (HFIR). This report presents results of postirradiation tests of tensile properties of V-4Cr-4Ti, V–8Cr–6Ti, V–10Cr–5Ti, and V–15Cr–5Ti. Despite concerns on the effects of transmutation of vanadium to Cr and impurity pickup from the helium environment, all of the alloys exhibited ductile tensile behavior. However, the alloys exhibited ductilities somewhat lower than those of the specimens irradiated to a similar dose and at a similar temperature in an Li environment in fast reactors. Uniform plastic strain in the V–Cr–(4–5)Ti alloys decreased monotonically with increasing Cr content.

INTRODUCTION

Recently, attention to the vanadium alloys has focused on V-Cr-Ti ternary alloys containing ≈5 wt.% Ti. Most of the data base information on the irradiation performance of these alloy class was obtained from specimens irradiated in an Li environment in fast reactors such as the Fast Flux Text Reactor (FFTF) and EBR–II. In the present irradiation experiment in the HFIR, a large number of vanadium–base alloys were irradiated to investigate their performance at 200 and 400°C in a helium environment. A primary concern on the irradiation performance at 400°C in the HFIR has been the effects of corrosion of the alloys by uptake of impurities (such as O, C, and N) from the helium environment.

A higher Cr content in V–Cr–5Ti ternary alloys is known to provide better resistance to corrosion, as well as higher strength, whereas more pronounced irradiation–induced embrittlement is a major drawback of the high–Cr alloys. Therefore, several alloys of the V–(4–15)Cr–5Ti family, i.e., V–4Cr–4Ti, V–8Cr–6Ti, V-10Cr–5Ti, and V–15Cr–5Ti, were irradiated at ≈400°C to determine the effects of Cr on mechanical properties and density change. This report presents results of postirradiation tests of tensile properties of these alloys irradiated at 400°C. Tensile tests on alloys irradiated at 200°C are in progress, and initial results indicate very different brittle–type behavior for most of these alloys. Therefore, the irradiation performance at 200°C will be reported in separate.

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 that had been annealed at a nominal temperature of ≈1125°C. 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 400°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.

The tensile specimens were irradiated in the MFE–RB* 400J–1 capsule in the removable beryllium (RB*) position in the HFIR. The specimens were irradiated at ≈400°C to ≈10 dpa in circulating helium. Details of the capsule design and irradiation conditions are reported in Ref. 1. 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. The Hf shield was designed to tailor the neutron spectrum to closely simulate the fusion–relevant helium–to–dpa

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ratio in stainless steels (i.e., ≈14 appm/dpa) rather than in vanadium. Under these irradiation conditions, appreciable transmutation of vanadium to Cr is expected. According to the calculation reported by Gomes and Smith, Cr content in V–4Cr–4Ti is predicted to increase to ≈5.6 wt.% after irradiation to ≈10 dpa in the Hf–shielded capsules in HFIR.[2] At this time, however, results of chemical analysis of Cr in the vanadium alloys are not available.

Table 1. Chemical composition of vanadium alloys irradiated at 400°C in HFIR

	Nominal Comp.	Impurity Concentrations (wt.ppm)			
Heat ID	(wt.%)	O	N	C	Si
BL-41	14.5Cr-5.0Ti	450	120	93	390
BL-43	9.2Cr-4.9Ti	230	31	100	340
BL-49	7.9Cr-5.7Ti	400	150	127	360
BL-47	4.1Cr-4.3Ti	350	220	200	870

RESULTS AND DISCUSSION

Tensile properties of the alloys irradiated at 400°C in a helium environment in HFIR were similar to the tensile properties measured after irradiation in a lithium environment in the sodium–cooled fast reactor FFTF. Ductile behavior of V–4Cr–4Ti, V–8Cr–6Ti, V–10Cr–5Ti, and V–15Cr–5Ti alloys was manifested by significant levels of uniform plastic elongation, total elongation, and work-hardening capability. This is shown, as an example, in the stress–strain curve of V–8Cr–6Ti (Heat ID BL–49) in Fig. 1. Similar stress–strain curves of the same heat, determined after irradiation in Li–bonded capsules in the FFTF, are also shown in the figure for comparison.

In the latter types of irradiation in an Li environment, tensile properties of V–8Cr–6Ti were determined after irradiation at the comparable temperature of ≈420°C under the condition of significant helium generation in the Dynamic Helium Charging Experiment[3] (DHCE) and under a non–DHCE condition (with negligible helium generation). In spite of the lower damage level of ≈10 dpa in the HFIR, total elongation was somewhat lower than the elongation measured after irradiation to ≈31–34 dpa in Li environment under both DHCE and non–DHCE conditions. Although the relative effect of increased Cr (from transmutation) and impurities (from the helium environment) must be determined quantitatively from postirradiation chemical analysis, the lower elongation in the HFIR specimen is believed to be associated primarily with vanadium–to–Cr transmutation and higher impurity contamination such as oxygen from the circulating helium. The slightly lower irradiation temperature is also conducive to somewhat lower tensile ductility.

In Figs. 2 and 3, effects of Cr (concentration measured before irradiation) on tensile strength and ductility are shown for the present family of V-(4-15)Cr–5Ti alloys. Uniform plastic elongation decreased significantly (to <2%) for Cr > 7 wt.%. However, V–4Cr–4Ti retained good ductility and high strength.

CONCLUSIONS

1. Despite concerns about the effects of vanadium–to–Cr transmutation and impurity pickup from the helium environment, V–4Cr–4Ti, V-8Cr–6Ti, V–10Cr–5Ti, and V–15Cr–5Ti alloys exhibited ductile tensile behavior after irradiation at 400°C to ≈10 dpa in the HFIR.

2. The alloys exhibited ductilities somewhat lower than those of the specimens irradiated to a similar dose at similar temperature in an Li environment in fast reactor. Vanadium–to–Cr transmutation by thermal neutrons and impurity uptake from helium such as oxygen are believed to be the primary factors.

3. Uniform plastic elongation in V–(4–15)Cr–5Ti alloys decreased significantly (to <2%) for Cr > 7 wt.%. However, the V–4Cr–4Ti alloy specimens, predicted to have a composition close to V-5.6Cr-5Ti after the irradiation to ≈10 dpa, retained good ductility and high strength.

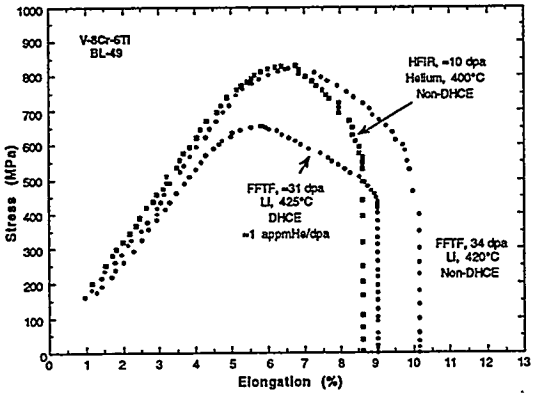

Fig. 1.

Comparison of stress vs. strain curves of V-8Cr–6Ti irradiated at 400–420°C in helium in HFIR and in lithium in FFTF in non-DHCE and DHCE.

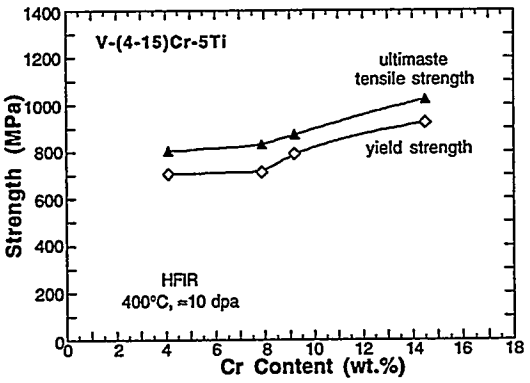

Fig. 2.

Effects of Cr content on yield and ultimate tensile strength of V–(4–15)Cr–5Ti alloys irradiated at ≈400°C to ≈10 dpa in helium in the HFIR.

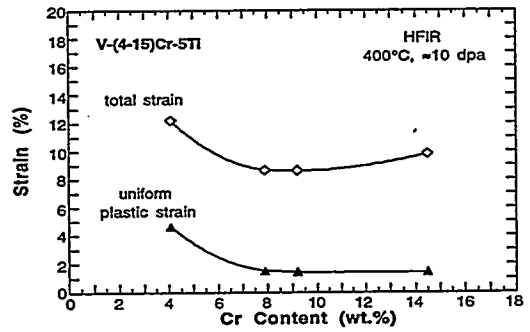

Fig. 3.

Effects of Cr content on total strain and uniform plastic strain of V–(4–15)Cr–5Ti alloys irradiated at ≈400°C to ≈10 dpa in helium in the HFIR.

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