TENSILE AND IMPACT PROPERTIES OF A V-3.1Ti-0.5Si ALLOY AFTER IRRADIATION IN THE FAST FLUX TEST FACILITY - H. Tsai, L. J. Nowicki, T. S. Bray, M. C. Billone, and D. L. Smith (Argonne National Laboratory)

SUMMARY

Tensile and Charpy specimens made of alloy BL-42 (with a nominal composition of V-3.1Ti-0.5Si) were irradiated in the Fast Flux Test Facility (FFTF) in Cycle 11 at 520 and 600°C to up to 51 dpa. Some of these specimens were retrieved from storage and tested in this reporting period. The interest of this material stems from recent findings that show binary alloys of this class appear to exhibit lower susceptibility to radiation-induced embrittlement than other V-base alloys in low-temperature irradiation (<≈400°C). The results of our tests show the BL-42 material to have good tensile properties and fair impact properties after the 520-600°C irradiation and that alloys of this class may warrant further development for improved low-temperature performance.

OBJECTIVE

The objective of this task was to determine the tensile and impact properties of the BL-42 specimens (with a nominal composition of V-3.1Ti-0.5Si) irradiated in FFTF at 520 and 600°C to 41-51 dpa.

BACKGROUND

In the last several years, significant efforts have been devoted to the development of ternary alloy V-4Cr-4Ti for fusion reactor applications. Prior to that, binary V-(3-5)Ti alloys with Si additions up to ≈1% were also considered as promising candidates. The V-4Cr-4Ti alloys were selected as the reference because of their overall superior performance in terms of strength, ductility, and most importantly, radiation resistance determined in irradiation tests in temperatures >≈400°C. Recent irradiation experiments at temperatures <≈400°C, however, show these alloys may be susceptible to significant low-temperature embrittlement[1,2,3]. In the same low-temperature irradiation experiments, the binary V-Ti alloys appear to exhibit less irradiation hardening and embrittlement than the V-4Cr-4Ti alloys[4,5]. For this reason, it was decided to retrieve the BL-42 V-3.1Ti-0.5Si specimens from storage and to complete their postirradiation evaluation.

EXPERIMENTAL PROCEDURE

Test Specimens

BL-42 was a small laboratory heat produced by Teledyne Wah Chang. The composition of the material is shown in Table 1.

Table 1. Composition of the BL-42 alloy

Concentration (wt.%)		Interstitial Concentration (ppm)			
Ti	Fe	O	N	C	Si
3.1	0.02	580	190	140	5400

The tensile specimens were of the SS-3 design, which is the de facto standard for the fusion materials program. The nominal dimensions of the gauge section were 0.76 (t) x 1.52 (w) x 7.6 (l) mm, and the longitudinal direction of the gauge was parallel to the final rolling direction of the plate.

*Work supported by U.S. Department of Energy, Office of Fusion Energy Research, under Contract W31-109-Eng-38.

The Charpy impact specimens were 1/3-size, 3.3 mm (t) x 3.3 mm (w) x 25.4 mm (l), with a 45°, 0.61-mm-deep, 0.08-mm-root radius machined notch. The notch orientation (i.e., crack propagation direction) was perpendicular to the final rolling direction and into the thickness of the plate. This Charpy specimen design is also a de facto standard and has been used extensively in previous fusion materials tests.

The test specimens were irradiated in Li-bonded capsules in the Materials Open Test Assembly (MOTA) of FFTF in Cycle 11. The irradiation conditions of the specimens are summarized in Table 2.

No hydrogen-outgassing (e.g., at 400°C for one hour) was performed on these specimens prior to the mechanical testing.

Table 2. Irradiation conditions of the BL-42 test specimens in FFTF Cycle 11

Specimen Type	Specimen No.	MOTA Capsule No.	Irradiation Temp. (°C)	dpa
SS-3 Tensile	143	V549	520	41
	144	V552	520	46
	146	V653	600	47
	147	V656	600	51
	148	V656	600	51
	149	V657	600	51
1/3-Size Charpy	152	V656	600	51
	153	V656	600	51
	154	V657	600	51
	155	V657	600	51

Test Procedure

Only one tensile test (with specimen 149) was conducted at room temperature; all others were conducted at the specimens' respective irradiation temperatures. The room-temperature test was conducted in air; the elevated-temperature tests were conducted in high-purity flowing argon with the specimens protected by a Ti-foil impurity getter. The tests were performed with an Instron machine without an extensometer attached to the specimen gauge. Extensions due to slack in the grip and deformation of the load frame were subtracted from the crosshead displacement to obtain the correct gauge-section extension. The strain rate for all tests was 1.09×10^{-3}/s, which is the reference used in many previous fusion materials tensile tests.

All Charpy impact tests were conducted in air with a Dynatup drop-weight tester. Specimen temperature during the impact test was measured with a thermocouple spot-welded to the end of the specimen. For the above-ambient-temperature tests, a hot-air blower was used to provide the heating. For the below-room-temperature tests, liquid nitrogen was used to chill the specimens.

RESULTS AND DISCUSSION

Tensile Tests

The results of the tensile tests are summarized in Table 3. A representative load/displacement

curve (for specimen 146) is shown in Fig. 1. Reduction-in-area measurements and fractographic examinations have not yet been conducted.

Table 3. Tensile properties of BL-42 specimens after the FFTF irradiation

Spec. No.	dpa	Irradiation Temp. (°C)	Test Temp. (°C)	0.2% Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Uniform Elongation (%)	Total Elongation (%)
143	41	520	520	525	624	4.2	8.1
144	46	520	520	453	559	7.7	16.4
146	47	600	600	373	541	11.0	15.9
147	51	600	600	368	566	10.4	14.4
148	51	600	600	380	539	11.7	17.2
149	51	600	22	424	615	11.7	15.0

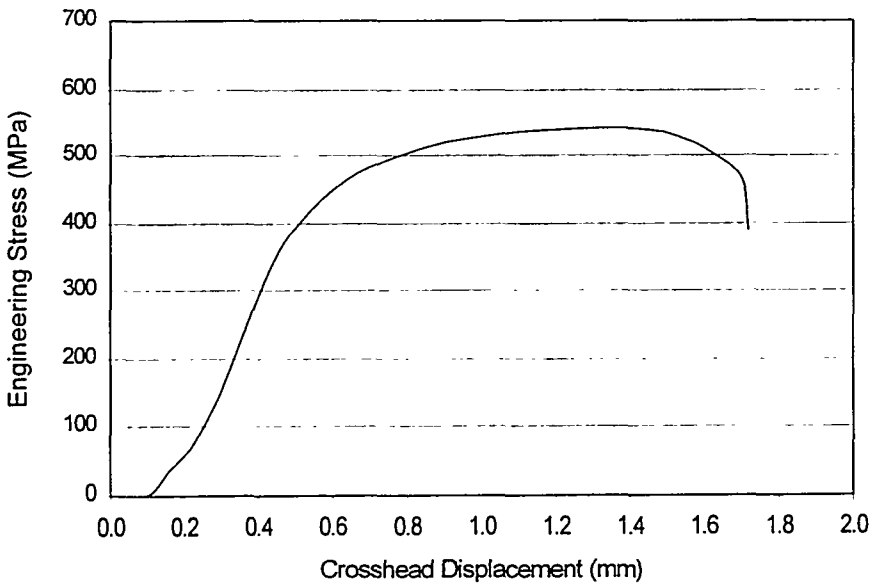

Fig. 1. Load-displacement curve for a 600°C tensile test (with specimen 146)

In all six tests, the specimens show only moderate irradiation hardening when compared with the nonirradiated yield and ultimate tensile strengths of ≈300 and 480 MPa, respectively, for this heat of material at 520°C[6]. As shown in Figs. 2 and 3, these measured strengths are fairly consistent with previously reported data for MOTA-irradiated specimens of several other vanadium-base alloys.

All BL-42 specimens tested displayed high ductility, with the uniform elongation ranging from ≈4 to 12% and total elongation from ≈8 to 17%.

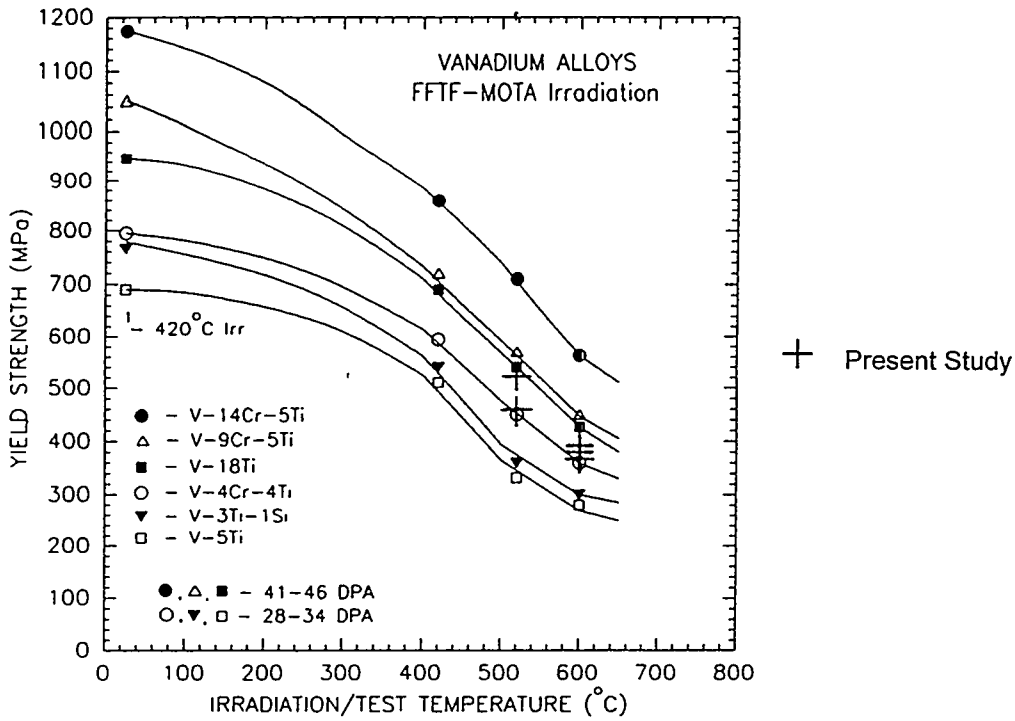

Fig. 2 Comparison of the yield strength from this work with the existing database.

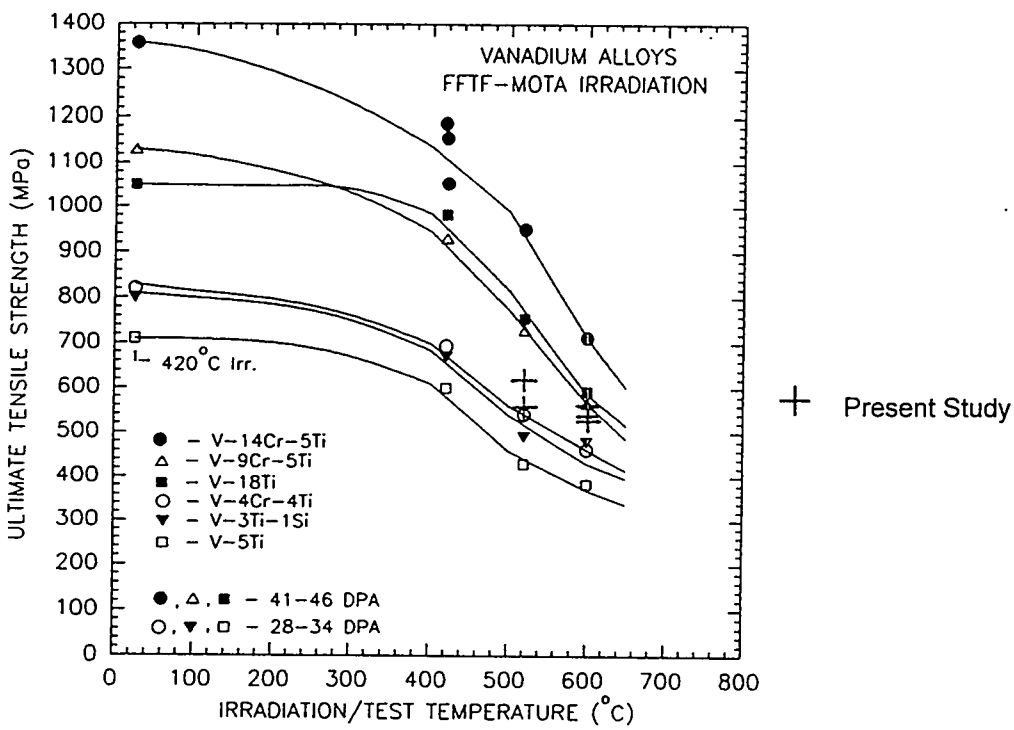

Fig. 3 Comparison of the ultimate tensile strength from this work with the existing database.

Charpy Impact Tests

The results of the Charpy tests are summarized in Table 4 and Fig. 4. There appears to be no clear ductile-to-brittle transition and the absorbed energies are relatively low (<5 J). SEM fractography showed the mode of fracture to be ductile tear at 23 and 100°C and a mixture of ductile tear and brittle cleavage at –50 and –195°C (Fig. 5). The mixed-mode fracture at low temperatures is consistent with the "non-zero" absorbed-energy measurement at –195°C and at least partially explains the lack of marked ductile-to-brittle transition in the absorbed-energy curve. Further evaluation is necessary to fully assess the fracture behavior of these specimens. (Ref. 7 reported an absorbed energy of 5.5 J at room temperature from a test of a specimen from this group. That data point, also shown in Fig. 4, is essentially consistent with the present work.)

Table 4. Charpy impact properties of BL-42 specimens after the FFTF irradiation

Spec. No.	dpa	Irradiation Temp. (°C)	Test Temp. (°C)	Absorbed Energy (J)
152	51	600	23	4.6
153	51	600	100	3.9
154	51	600	-50	3.6
155	51	600	-195	2.2

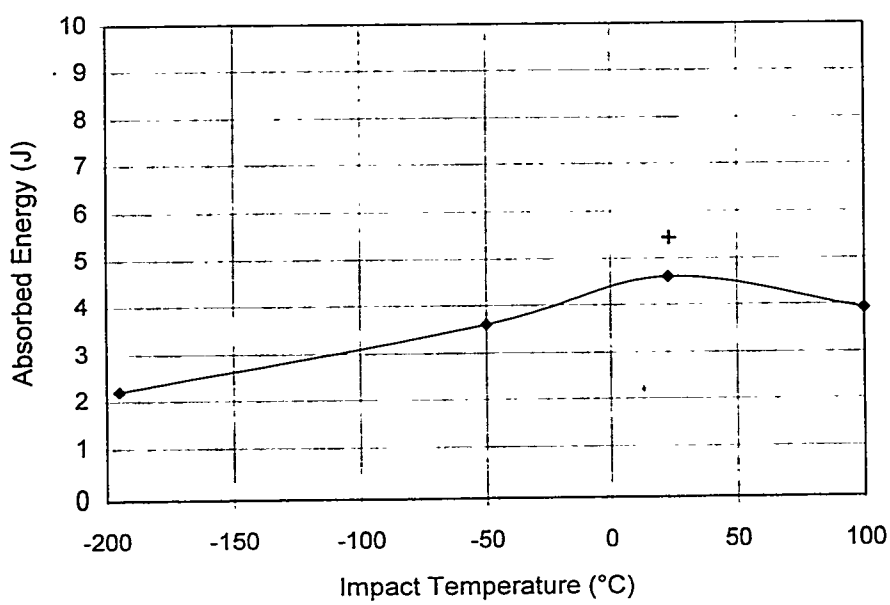

Fig. 4. Charpy impact properties of BL-42 specimens after the FFTF irradiation. "+" denotes the data point reported in Ref. 7.

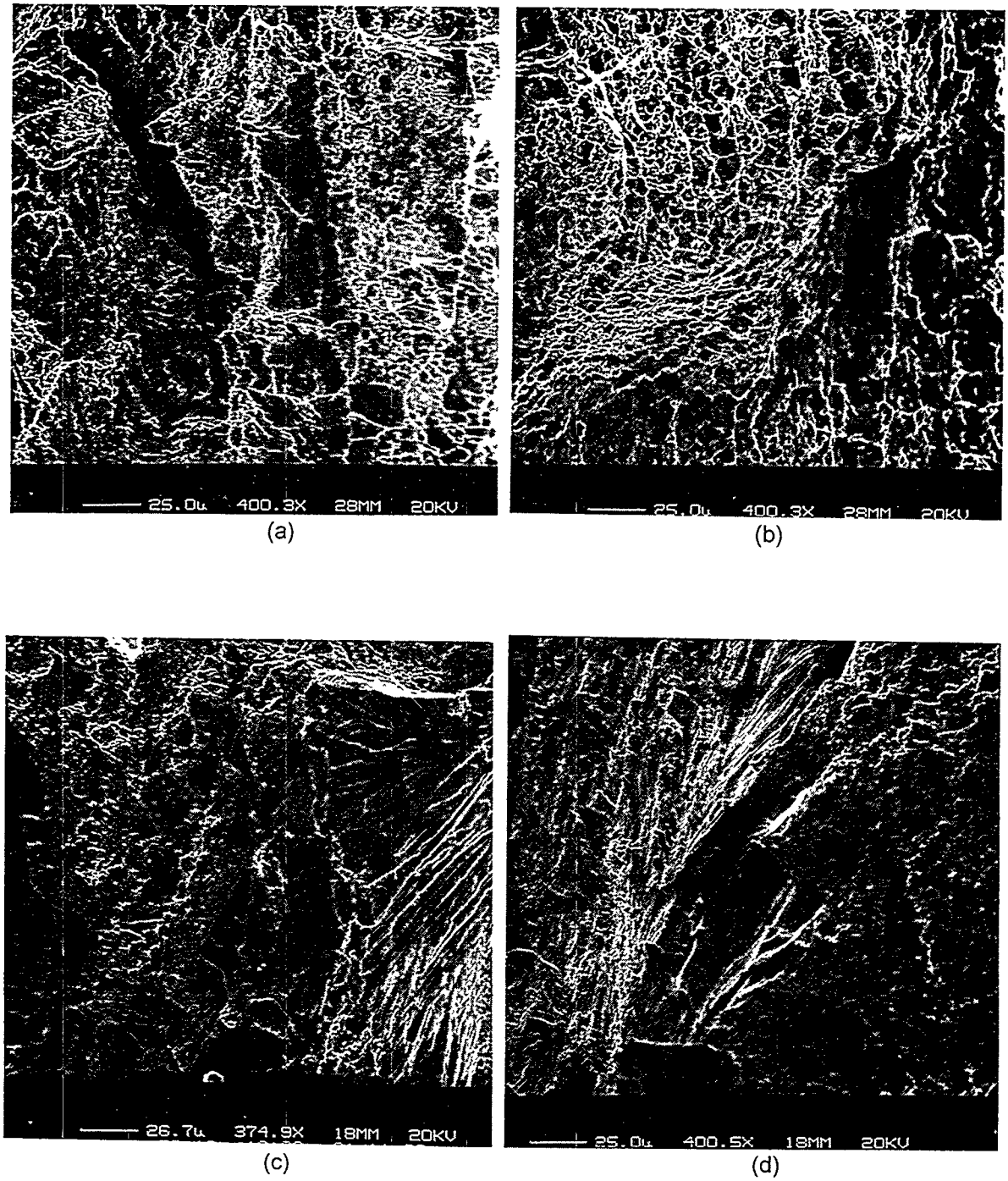

Fig. 5 SEM fractography of the BL-42 Charpy specimens showing ductile tear in the 23°C (a) and 100°C (b) specimens and mixed ductile tear and brittle cleavage in the –50°C (c) and –195°C (d) specimens.

FUTURE ACTIVITIES

Fractographic examination of the test specimens will be completed to determine the areal reduction in the tensile specimens and to further elucidate the fracture behavior of the Charpy specimens.

REFERENCES

1. H. M. Chung, H. Tsai, L. Nowicki, and D. L. Smith, Fusion Materials Semiannual Progress Report, DOE/ER-0313/22, June 1997, pp. 18-21.
2. D. J. Alexander et al., "Effects of Irradiation at Low Temperature on V-4Cr-4Ti," Fusion Materials Semiannual Progress Report for Period Ending June 30, 1996, DOE/ER-0313/20, pp.87-95.
3. H. Tsai, J. Gazda, L. J. Nowicki, M. C. Billone, and D. L. Smith, Fusion Materials Semiannual Progress Report for Period Ending June 30, 1998, DOE/ER-0313/24, pp.15-19.
4. H. M. Chung, H. Tsai, L. Nowicki, and D. L. Smith, Fusion Materials Semiannual Progress Report, DOE/ER-0313/22, June 1997, pp. 18-21.
5. H. M. Chung, H. Tsai, L. Nowicki, and D. L. Smith, Fusion Materials Semiannual Progress Report, DOE/ER-0313/22, June 1997, pp. 33-38.
6. M. C. Billone, Fusion Materials Semiannual Progress Report, DOE/ER-0313/23, December 1997, pp. 3-61.
7. B. A. Loomis, ANL memorandum to D. L. Smith, "Vanadium and Vanadium-Base Alloys – Summary of Current and Previous Irradiations, November 23, 1992.