IMPACT AND TENSILE PROPERTIES OF VANADIUM ALLOY AFTER LONG-TERM EXPOSURE IN THE DIII-D EXPERIMENTAL TOKAMAK,[1] H. Tsai, Y. Yan, D. O. Pushis, A. Storey, D. L. Smith (Argonne National Laboratory), and W. R. Johnson (General Atomics)

OBJECTIVE

In service, components in fusion vessels will be exposed to a range of temperature and impurity conditions, including alternating vacuum/low-pressure hydrogen plasma operation, thermal cycles and periodic bakeout, glow discharge cleaning, and occasional reexposure to air during vents for maintenance. The objective of this task is to determine the effects of these exposures on the performance of components made of vanadium-base alloys. Of particular importance is the determination of whether the absorption of interstitial impurities would lead to material embrittlement.

SUMMARY

Tensile and Charpy specimens of Heat 832665 of V-4Cr-4Ti alloy were exposed in the DIII-D experimental tokamak to investigate the effect of environment on the impact and tensile properties of this alloy. In this last test of the four-test series, specimens were mounted next to the chamber wall behind a divertor baffle plate and received an exposure of ≈3 yr. The results of this test, consistent with the results of the previous three tests, indicate no significant degradation of the mechanical properties of the alloy.

TEST PROCEDURE

The present test, designated W2, was the fourth and last test of the series. It was discharged in 1999 after ≈3 yr of exposure in the DIII-D experimental tokamak. During the test, the specimens experienced several full DIII-D operating cycles, which included multiple air and nitrogen vents, postvent bakeouts at 150-350°C, and boronizations at 280°C. The five 1/3-size Charpy and five SS-3 tensile specimens were mounted in a bracket on the vessel wall behind a divertor baffle plate, as shown in Fig. 1. The Charpy specimens measured 3.3 x 3.3 x 25.4 mm and contained a 0.6 mm-depth, 30° blunt notch with a root radius of 0.08 mm. The direction of the crack plane was perpendicular to the rolling direction and through the thickness of the plate from which the specimens were prepared. The tensile specimens were 25.4 mm long, with a gauge section that measured 7.62 x 1.52 x 0.76 mm. The long direction of the gauge section was parallel to the final rolling direction of the plate. All specimens were vacuum-annealed at 1000°C for 1.0 h before testing in the DIII-D. Thermocouples were welded onto two each of the tensile and Charpy specimens to monitor temperatures during the exposure. All specimens were made from Heat 832665 of the V-4Cr-4Ti material.

RESULTS

The results of the previous three exposure tests, of shorter exposure duration than the present one, were reported earlier [1,2]. After the discharge from the DIII-D in the present investigation, two specimens were subjected to tensile tests: one at 350°C, the peak temperature experienced in the DIII-D; the other at room temperature. To preclude oxidation, the 350°C test was performed in high-purity argon. The specimens were tested as-discharged, i.e., without a hydrogen outgassing operation before the tensile tests. The strain rate for both tests was 1.1 x 10^{-3}/s. Machine operation and tensile data acquisition were controlled by commercially acquired software. The test conduct for both was good. Fig. 2 shows the engineering stress and strain curves for the tests. Serration, possibly due to enhanced solute mobility at the higher temperature, can be seen in the 350°C data.

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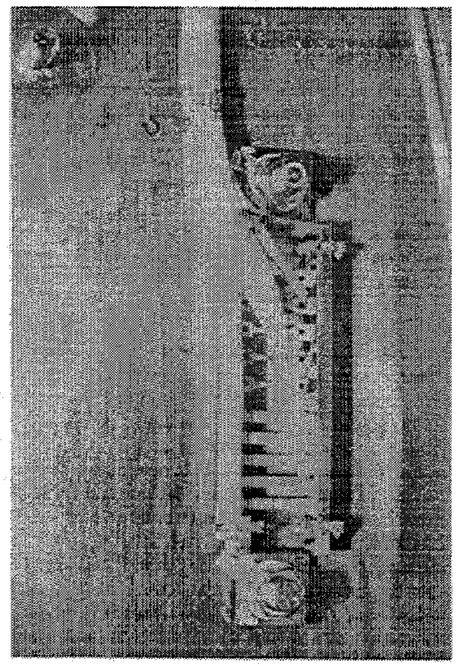

Figure 1. Mounting of W2 test specimens on DIII-D vessel wall behind a divertor baffle plate.

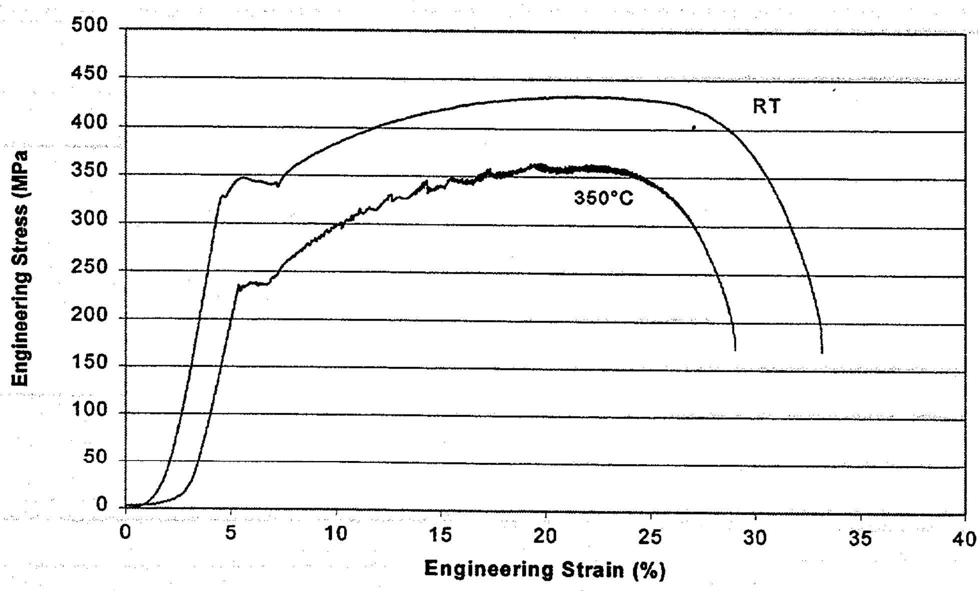

Figure 2. Engineering stress and strain curves for specimens tested at room temperature and 350°C after DIII-D exposure. Data are consistent with those of the nonexposed control, indicating little or no degradation due to exposure.

The calculated engineering tensile data are summarized in Table 1, along with nonexposed baseline data for Heat 832665. Also shown in Table 1 are the results of the W1 test in which the exposure duration was 1 yr. The results indicate no significant degradation of tensile properties due to the DIII-

D exposure, after either 1 or 3 yr. All specimens exhibit high uniform and total elongation and little change in yield and ultimate strength.

Table 1 Tensile properties at 25 and 350°C of Heat 832665 of V-4Cr-4Ti alloy before (baseline) and after one year (W1) the three years (W2) of exposure test in DIII-D tokamak.

	Test temperature (°C)					
	25			350		
Properties[a]	Baseline	W1	W2	Baseline	W1	W2
YS (MPa)	357	334	327	205	241	235
UTS (MPa)	428	449	434	359	377	365
UE (%)	19.1	19.0	16.0	17.6	14.8	16.3
TE (%)	29.2	27.0	29.5	25.4	22.0	24.4

[a] YS: 0.2% offset yield stress; UTS: engineering ultimate tensile stress; UE: uniform elongation; TE: total elongation.

Charpy impact properties of the W2 specimens were determined in a temperature range of -180 to 200°C with a Dynatup impact tester. Tests were conducted on the specimens "as removed," without hydrogen degasssing. The results are summarized in Fig. 3, along with the data of the nonexposed base metal and those from the previous two DIII-D exposure tests, D2 and W1. (Test D2 utilized the DIII-D's Divertor Materials Evaluation System, DiMES; exposure was ≈1 mo. W1 was a wall-mounted experiment similar to W2; exposure was ≈1 yr.) The W2 specimens indicate that the ductile-brittle transition temperature remains below -180°C after three years of exposure in the DIII-D. The upper-shelf energies are slightly lower than those of the baseline material, but similar to the results from the previous D2 and W1 tests.

CONCLUSIONS

This series of four DIII-D exposure tests has been concluded successfully. The results from the four tests, including those from Test W2 with a 3-yr exposure reported in this article, suggest no significant degradation of either the tensile properties at room temperature or 350°C or the ductile-brittle transition temperature of V-4Cr-4Ti alloy by environment of the DIII-D chamber. By design, the test specimens were not exposed directly to the plasma. Conditions permitting, experiments in which specimens are exposed to the plasma may be of value for the next phase of the investigation to further demonstrate the suitability of V-base alloys for tokamak in-vessel applications.

ACKNOWLEDGMENTS

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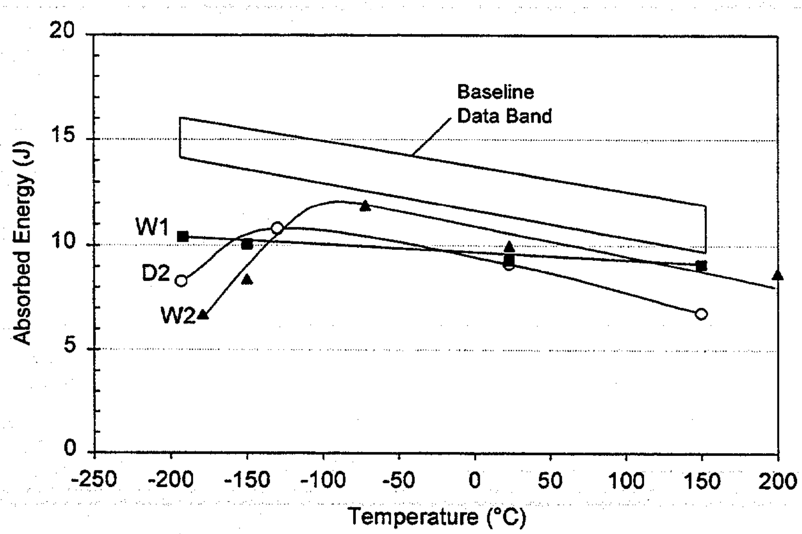

Figure 3. Charpy impact data for the DIII-D-exposed specimens showing ductile behavior.

References

1. H. Tsai, H. M. Chung, D. L. Smith, W. R. Johnson and J. P. Smith "Performance of V-4Cr-4Ti Material Exposed to DIII-D Tokamak Environment," Fusion Reactor Materials Semiannual Progress Report for Period Ending December 31, 1996, DOE/ER-0313/21, pp. 10-14.
2. H. Tsai, W. R. Johnson, D. L. Smith, W. R. Johnson, J. P. Smith and H. M. Chung, "Performance of V-4Cr-4Ti Material Exposed to DIII-D Tokamak Environment," Journal of Nuclear Materials, 258-263 (1998) 1466-1470.