AN EVALUATION OF THE SUSCEPTIBILITY OF V-4Cr-4Ti TO STRESS CORROSION CRACKING IN ROOM TEMPERATURE DIII-D WATER - R. J. Kurtz (Pacific Northwest National Laboratory), W. R. Johnson (General Atomics Company), and R. H. Jones (Pacific Northwest National Laboratory)

OBJECTIVE

The objective of this research was to evaluate the susceptibility of V-4Cr-4Ti to stress corrosion cracking (SCC) in the DIII-D tokamak water environment.

SUMMARY

Two fatigue precracked compact tension (CT) specimens of V-4Cr-4Ti were statically loaded to a stress intensity factor of about 30 MPa√m in room temperature DIII-D water. The first specimen was tested for a period of about 30 days and the second specimen for about 54 days. At the conclusion of each test the specimens were fractured, and the fracture surfaces examined with a scanning electron microscope (SEM) to determine if SCC had occurred. No SCC was found in either test specimen.

INTRODUCTION

For the past several years the DIII-D Program has been progressing toward installation of a sizeable structural component in DIII-D fabricated from a vanadium alloy. The goals of the DIII-D effort are 1) to provide a meaningful deployment of a low activation material in an operating fusion system, 2) to demonstrate the in-service behavior of a vanadium alloy in a typical tokamak environment, and 3) to gain knowledge and experience in the design, processing, and fabrication of a vanadium alloy. The current plan calls for use of a V-4Cr-4Ti component in the Radiative Divertor of DIII-D known as a private flux baffle, Figures 1 and 2. The private flux baffle is a toroidally continuous, water cooled structure.

During DIII-D plasma operations the private flux baffle will, most of the time, experience very low applied stresses. The main sources of stress include internal water pressure (0.4 MPa) and thermal stresses caused by temperature differences between the private flux baffle and the vessel to which it is mounted. The temperature of the private flux baffle during operation shall be about 30°C with occasional periods when the temperature will rise by about 30 to 40°C as the heat from each plasma shot is radiated to the graphite tiles attached to the water cooling panels. Stress transients will be induced in the private flux baffle due to plasma disruptions. The highest disruption stresses calculated are about 138 MPa [1]. The disruption stresses are mostly normal to the plates and last for only a few milliseconds.

The potential for SCC in the private flux baffle arises from its design. Two vanadium alloy plates will be joined by spot welding, Figure 2. The size of the spot weld will encompass about half the mating surface of the plates. Thus, an artificial crevice exists which, along with the residual stresses from welding and the presence of the water environment, creates the potential for SCC. Fortunately, the stresses during normal operation are low, and the plasma disruption stresses do not appear to act in a manner which would exacerbate the crevice tip stress field. Estimates of the maximum applied stress intensity factor are about 3 MPa√m. In order to assess the potential for SCC of V-4Cr-4Ti in the private flux baffle, two experiments were performed using CT specimens statically loaded to a stress intensity factor approximately an order of magnitude greater than that expected during service.

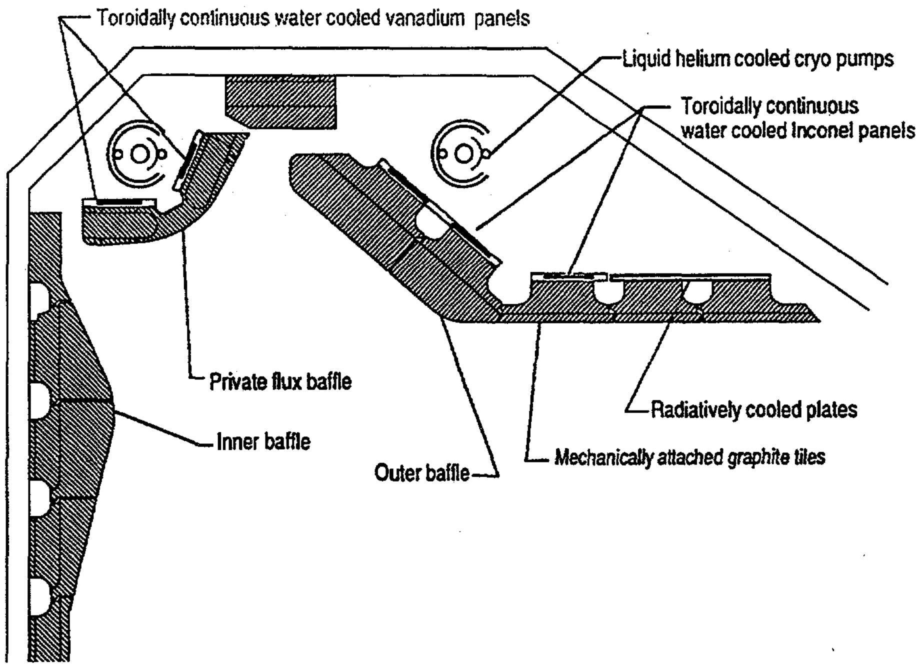

Figure 1: Vanadium Components of the DIII-D Radiative Divertor

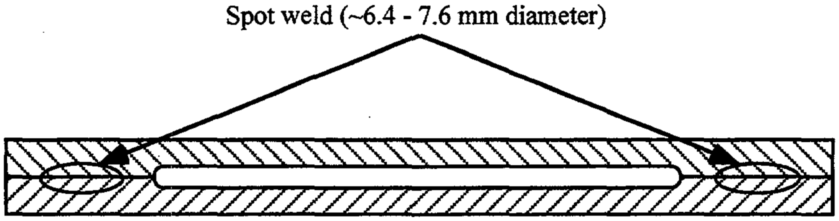

Figure 2: Cross-Sectional View of Vanadium Private Flux Baffle

PROCEDURE

Two CT specimens were machined from 3.81 mm thick V-4Cr-4Ti plate in the as-rolled condition supplied by Argonne National Laboratory (Heat 832665). The specimens were machined in the T-L orientation and were side-grooved 10% on each face. Following machining the specimens were heat treated for one hour at 1000°C in a high vacuum furnace. Fatigue precracking was performed after heat treatment in room temperature air at a maximum load of 1.8 kN and minimum load of 0.18 kN. Specimens were dead-weight loaded to 2.8 kN in a sealed polyethylene container of DIII-D water. Loading pins fabricated from V-4Cr-4Ti were used to connect the test specimens to the load train. Vanadium loading pins were used to remove the potential for galvanic corrosion. Table 1 lists specimen dimensions together with initial crack lengths and applied stress intensity factors. Table 2 gives results of chemical analyses performed on DIII-D water samples.

Specimen C44-15 was exposed to DIII-D water for about 15 days, and then removed to determine if crack growth had occurred. The specimen was loaded in a servo-hydraulic test frame to 2.7 kN and the crack length measured optically with a traveling stage microscope. Initial measurements indicated some crack extension might have occurred so C44-15 was exposed for another 15 days. At the end of the second exposure the specimen was removed and an additional ~2.5 mm of fatigue crack growth introduced at high R-ratio. High R-ratio was used so as to not disturb the existing fracture surface. The specimen was then broken open and examined in the SEM. A similar procedure was followed for specimen C44-14, but instead of two exposure periods only one exposure lasting about 54 days was utilized.

Table 1: Specimen Dimensions, Initial Crack Lengths, and Applied Stress Intensity Factors

ID No.	Width, mm	Height, mm	Net Thickness, mm	Initial Crack Length, mm	Initial Stress Intensity Factor, MPa√m
C44-14	30.5	36.6	3.05	16.93	30.5
C44-15	30.5	36.6	3.05	17.60	33.0

Table 1: Chemistry of DIII-D water.

Anion	mg/L	Element	mg/L	Element	mg/L
Cl^{-1}	0.62	Sn	<0.10	Mg	<0.05
NO_3^{-1}	<0.025	Mo	0.07	Cu	<0.05
SO_4^{-1}	1.6	Cr	<0.05	Ca	<0.10
		Zn	<0.02	Al	<0.10
pH	6.22	Pb	<0.10	Fe	<0.05
Cond.(μS/cm)	10.9	Ni	<0.10		

RESULTS

SEM examination of fracture surfaces from both C44-14 and C44-15 revealed no environmentally induced crack growth. Figure 3 shows the fracture surface of C44-14 at three key locations. Figure 3a shows fracture features associated with the fatigue precrack region. Figure 3b presents a view of the fracture surface at the tip of the fatigue precrack. Figure 3c displays the fracture surface just beyond the tip of the fatigue precrack. No evidence was found for SCC by examination of the fracture surfaces. The fracture surface features seen in Figure 3c are the same as those found in Figure 3a. Fatigue striations are observed in both cases indicating all crack growth is due to fatigue and not to intergranular or transgranular SCC.

CONCLUSION

- V-4Cr-4Ti was not susceptible to SCC in room temperature DIII-D water at a stress intensity factor of about 30 MPa√m for up to 54 days. The results of this work suggest that SCC of the private flux baffle will not be a concern for DIII-D under normal operating conditions.

REFERENCES

1. Hollerbach, M. A., J. P. Smith, C. B. Baxi, A. S. Bozek, E. Chin, R. D. Phelps, K. M. Redler, and E. E. Reis (1995). "Design and Analysis of the DIII-D Radiative Divertor Water-Cooled Structures," in Proceedings of the 16th Symposium on Fusion Engineering, Vol. 1, pp. 817-820.

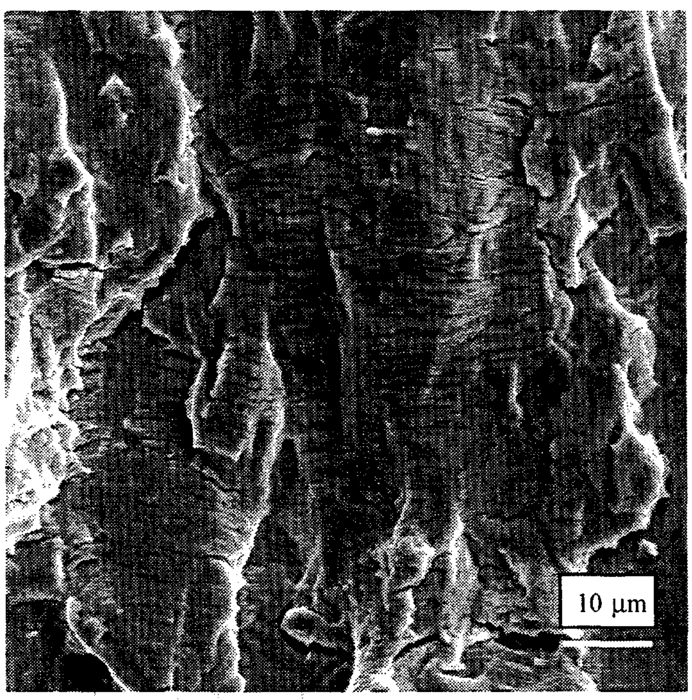

Figure 3a: Fracture Surface of C44-14 - Precrack Region

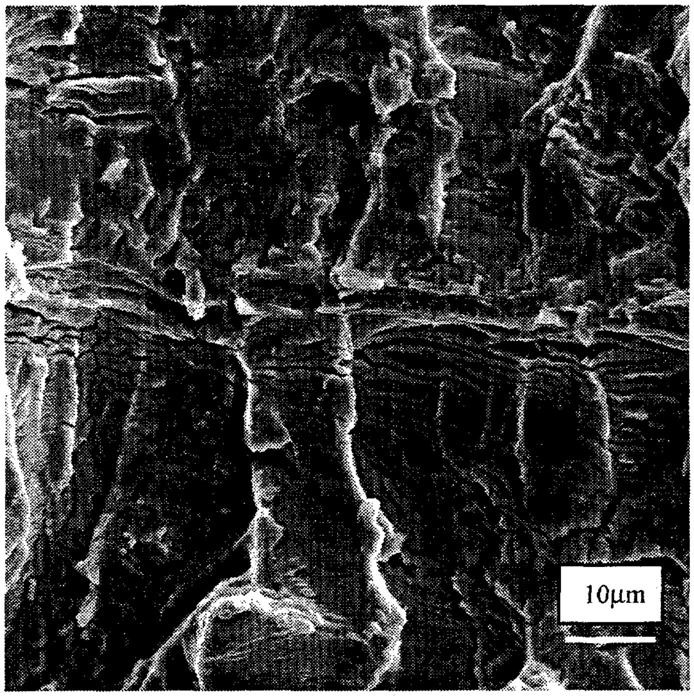

Figure 3b: Fracture Surface of C44-14 - Precrack Tip Region

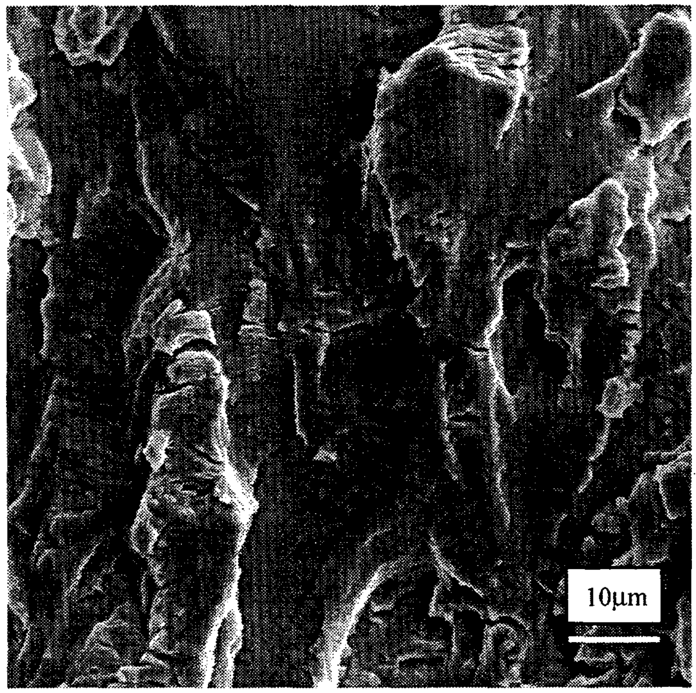

Figure 3c: Fracture Surface of C44-14 - Just Beyond Precrack Tip Region