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THE CORROSION AND STRESS-CORROSION
CRACKING OF WELDED
URANIUM-6 WEIGHT PERCENT NIOBIUM

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THE CORROSION AND STRESS-CORROSION CRACKING OF WELDED URANIUM-6 WEIGHT PERCENT NIOBIUM

James M. Macki and Robert L. Kochen

Abstract. The resistance of corrosion and stress-corrosion cracking of welded U-6 wt% Nb in oxygen-saturated water containing 50 ppm chloride ions was investigated. The tests showed that a post-weld heat treatment consisting of solution quenching and underaging (350°C for 42 min.) provided the best resistance to corrosion and pitting corrosion. Although selective corrosion and pitting corrosion were observed on many of the specimens tested, no evidence of stress-corrosion cracking was found.

INTRODUCTION

U-base alloys have been shown to be susceptible to stress-corrosion cracking (SCC).¹⁻¹⁰ Two modes of stress-corrosion crack propagation, intergranular and transgranular, and a mixed transgranular and intergranular SCC mode have been observed.^{1, 5, 7, 8} The simultaneous presence of chloride ions, oxygen, and moisture appear to be required for the nucleation and/or propagation of intergranular stress-corrosion cracks in U-Nb and U-Nb-Zr alloys.^{1, 8, 10} The U-6 wt% Nb binary alloy has possible applications that would involve welding of the alloy.

The welding operation used on U-6 wt% Nb alloy parts could produce residual stresses that would render the material susceptible to SCC in environments containing chloride ions, moisture, and oxygen. The welded material could also be susceptible to localized or selective corrosion through the welded microstructure.

This investigation was undertaken to determine whether the as-welded material is susceptible to selective corrosion or SCC and to determine how these susceptibilities are affected by post-weld heat treatments and post-weld machining.

EXPERIMENTAL

The SCC tests utilized welded cylinders of U-6 wt% Nb that were welded in the solution-quenched (gamma-quenched) condition.

The cylinders were obtained from forward-extruded tubes. Each cylinder had a 6-in. outside diameter and a 0.125-in. wall thickness. The 6-in.-high cylinder was made by welding two 3-in.-high cylinders together using full-penetration gas-tungsten-arc (GTA) welds.

The post-weld heat treatments and surface treatments were selected for this study by E. D. Brandon and are summarized in Table 1.¹¹ The post-weld heat treatments, which were selected by J. F. Boland,¹¹ include solution quench (solutionize at 800°C for 5 min. and water quench), underage

Table 1. Welded U-6 wt% Nb Test Parameters.

Cylinder ^a	Welding ^b	Post-Weld Heat Treatment	Post-Weld Surface Treatment
38,39,40	GTA	None	None
22,23,24	GTA	None	Machined
34,35,37	GTA	γ -quench ^c +underage ^d	Machined
31,32,33	GTA	γ -quench +overage ^e	Machined
42,43,44	GTA	Overage	Machined
27,28,29	GTA	γ -quench	Machined
45,46,47	GTA-Tack	None	None

^aCylinder numbers are those assigned during fabrication.

^bGTA designates gas-tungsten-arc, single pass welds.

^c γ -quench denotes solutionizing at 800°C for 5 minutes followed by a water quench.

^dUnderage denotes aging at 350°C for 42 minutes followed by a water quench.

^eOverage denotes aging at 575°C for 22 minutes followed by a water quench.

(age at 350°C for 42 min. and water quench), and overage (age at 575°C for 22 min. and water quench).

The welded cylinders were tested for SCC by immersing them in oxygen-saturated water containing 50 ppm chloride ions. The solution was prepared by adding NaCl to distilled water to achieve a 50 ± 1 ppm chloride ion concentration, and oxygen saturation (8.2 ± 0.3 ppm oxygen) was achieved by bubbling oxygen through the water during the test. All tests were at room temperature ($26 \pm 2^\circ\text{C}$).

The tests involved three 30-day test periods for a total of 90 days. The 50 ppm chloride ion solution was changed after each 30-day test period. After the first and third 30-day test periods, the cylinders were cleaned and x-radiographed. At the end of the 90-day test, some of the cylinders were cut up to provide specimens for metallographic and chemical analyses.

RESULTS AND DISCUSSION

Results of the chemical analyses of parent metal and fusion zone samples taken from welded cylinders after the 90-day tests are shown in Table 2.

Table 2. Results of Chemical Analyses Tests on Parent Metal and Fusion Zones of Welded Cylinders.

Sample	Wt% Nb	Concentration (ppm)				
		C	H	N	O	S
22 Parent	5.40	205	5,9	107	101	45
22 Weld	5.00	220	3,11,3	—	—	50
27 Parent	5.08	170	7,3	75	70	60
27 Weld	4.96	485	17,25	—	—	—
31 Parent	5.48	195	7,25	82	240	45
31 Weld	5.44	220	5,6	—	—	50
34 Parent	5.28	310	25,24	121	1000	45
38 Parent	5.16	180	30,16,6	88	70	50
38 Weld	5.12	240	21,58,148	—	—	60
42 Parent	5.48	200	9,20	51	850	40
42 Weld	5.12	270	29,34	—	—	80

Hardness transverses across cross-sections of the welds were made with measurements taken at the positions shown in Figure 1. Results of these hardness measurements are shown in Table 3.

Photomicrographs of U-6 wt% Nb welds, heat-affected zones (HAZ), and parent metal are shown in Figures 2 through 7. Figure 8 shows a welded cylinder after a 30-day immersion in oxygen-saturated water containing 50 ppm chloride ions.

Selected x-radiographs are shown in Figures 9 through 16. The light spots in the radiographs are corrosion pits. Some of the x-radiographs of machined specimens show a light band about 1 to 2 in. wide where the surface was machined (e.g., Figures 10 and 11). The absence of light

Figure 1. Positions of Hardness Measurements Across U-6 wt% Nb Welds.

Table 3. Hardness Measurements Across Welds at Positions Shown in Figure 1.

Position ^a	Hardness (Knoop, 500g load) ^b					
	No. 22	No. 38	No. 27	No. 34	No. 31	No. 42
1 PM	217	209	162	418	355	475
2 PM	192	212	172	432	370	488
3 PM	178	214	173	442	365	450
4 HAZ	190	218	152	432	390	478
5 HAZ	192	224	173	460	390	480
6 WELD	196	204	266	452	400	488
7 WELD	215	266	250	460	390	462
8 WELD	220	250	258	450	390	473
9 HAZ	210	244	208	437	390	460
10 HAZ	208	224	197	444	390	470
11 PM	205	244	200	457	365	473
12 PM	200	200	178	448	380	473
13 PM	197	202	188	448	365	445

^aPM denotes parent metal; HAZ denotes heat-affected zone; and WELD denotes fusion zone of weld.

^bNo. 22 and No. 38 are as-welded; No. 27 is solution quenched; No. 34 solution quenched and underaged; No. 31 is solution quenched and overaged; and No. 42 is overaged.

spots (corrosion pits) indicates uniform corrosion (e.g., Figure 11).

Figures 2 and 3 (as-welded) show selective corrosion similar to knife-line attack (KLA) along the bond line of the weld. The as-machined surface (Figure 3) also exhibited general corrosion of the fusion zone. The x-radiograph of the as-welded specimens (Figure 9) shows the as-welded specimen was subject to pitting corrosion in the HAZ and parent metal in addition to general corrosion of the fusion zone and KLA along the bond line.

The x-radiograph of the machined only (as-welded microstructure) specimen in Figure 10 shows that machining the surface reduces the amount of pitting corrosion. The contrast within the fusion zone shown in Figure 10 indicates some chemical inhomogeneity.

The solution-quenched and machined-after-welding treatment (Figures 4 and 11) did not affect the corrosion of the fusion zone and bond line (Figure 4a).

The post-weld treatment resulting in the most resistance to corrosion and pitting corrosion was post-weld solution quenching, underaging, and machining as shown in Figures 5, 12, and 13. The x-radiograph in Figure 12 shows no pitting. The x-radiograph in Figure 13 shows corrosion pits but they are uniformly distributed independently of the weld region.

The specimens that were solution quenched, overaged, and machined after welding exhibited pitting corrosion to the parent metal (Figure 14) and selective corrosion along the bond line and in the fusion zone (Figure 6).

The specimens that were not solution quenched after welding but only overaged and machined exhibited general corrosion and pitting corrosion which was independent of the weld zone (Figures 7 and 15).

An x-radiograph of GTA tack weld is shown in Figure 16. The x-radiograph shows a ring of pits around the weld in the HAZ that is similar to the lines of pits observed for the as-welded specimens in Figure 9. The welds were also subject to selective or knife-line corrosion that resulted in several fusion cones being detached. To provide satisfactory corrosion resistance, the tack welds would have to be annealed.

CONCLUSIONS

The post-weld heat treatment producing the most corrosion resistant binary material is solution quenching followed by aging at 350°C for 42 minutes (underaging).

Although selective corrosion and pitting were observed, no evidence of stress-corrosion cracking was found on any of the welded specimens.

Figure 2. Photomicrographs of Specimen Number 22. Machined after welding—as-welded microstructure.

Figure 2a. Note the selective corrosion or KLA (knife-line attack) along bond line and lack of full penetration. 20X.

Figure 2b. Parent metal microstructure. 100X.

Figure 2c. Heat affected zone (HAZ) microstructure. 100X.

Figure 3. Photomicrographs of Specimen Number 38. As-welded.

Figure 3a. Note the selective corrosion along bond line and weld material lost by corrosion. 20X.

Figure 3b. Parent metal microstructure. 100X.

Figure 3c. HAZ microstructure. 100X.

Figure 4. Photomicrographs of Specimen Number 27. Solution quenched and machined after welding.

Figure 4a. Note the corrosion along bond line and within weld. 20X.

Figure 4b. Parent metal microstructure. 100X.

Figure 4c. HAZ microstructure. 100X.

Figure 5. Photomicrographs of Specimen Number 34. Solution quenched, underaged, and machined after welding.

Figure 5a. Note the lack of full penetration and absence of selective corrosion. 20X.

Figure 5b. Microstructure of parent metal. 100X.

Figure 5c. HAZ microstructure. 100X.

Figure 6. Photomicrographs of Specimen Number 31. Solution quenched, overaged, and machined after welding.

Figure 6a. Note the corrosion along bond line and within weld. 20X.

Figure 6b. Microstructure of parent metal. 100X.

Figure 6c. HAZ microstructure. 100X.

Figure 7. Photomicrographs of Specimen Number 42. Overaged and machined (no solution quench) after welding.

Figure 7a. Note the lack of full penetration and nearly uniform corrosion attack. 20X.

Figure 7b. Parent metal. Note the 2-phase structure within prior solution-quenched grains. 400X.

Figure 7c. HAZ microstructure. 100X.

Figure 8. Welded Cylinder after 30 Days Immersion in Oxygen-Saturated Water Containing 50 ppm Cl^- .

Figure 9. X-Radiograph of Specimen No. 39 (as-welded).

Figure 10. X-Radiograph of Specimen No. 24 (machined only after welding).

Figure 11. X-Radiograph of Specimen Number 29 (gamma-quenched and machined after welding).

Figure 12. X-Radiograph of Specimen No. 34 (gamma-quenched underaged, and machined after welding). Note light machined strip.

Figure 13. X-Radiograph of Specimen No. 35 (gamma-quenched underaged, and machined after welding).

Figure 14. X-Radiograph of Specimen No. 32 (gamma-quenched, overaged, and machined after welding). Note bright corrosion pit which has nearly penetrated metal.

Figure 15. X-Radiograph of Specimen No. 44 (overaged and machined after welding).

Figure 16. X-Radiograph of Specimen No. 47: GTA tack welded.

REFERENCES

1. J. M. Macki and R. L. Kochen, "Stress Corrosion Cracking of Aged U-4.5 wt% Nb," *Corrosion*, 29, p. 153 (1973).
2. N. J. Magnani, "Stress Corrosion Cracking of Mulberry," *Corrosion*, 26, p. 406 (1970).
3. C. A. W. Peterson and W. J. Steele, *Delayed Cracking Study in U-7.5 wt% Nb-2.5 wt% Zr*, UCID-15256, Lawrence Berkeley Laboratory, University of California, Berkeley, December 1967.
4. C. A. W. Peterson and R. R. Vandervoort, *Stress Cracking in the U-10 wt% Molybdenum Alloy*, UCRL-7767, Lawrence Berkeley Laboratory, University of California, Berkeley, March 1964.
5. B. D. McLaughlin, L. L. Stephenson, and C. J. Miglione, "Influence of Aging Time and Temperature on the Susceptibility of γ -Quenched U-5 wt% Nb Alloy to SCC," *Corrosion*, 28, p. 35 (1972).
6. N. J. Magnani, H. Romero, and C. J. Miglione, *A Study of the Stress-Corrosion Cracking Behavior of Mulberry (U-7.5 wt% Nb 2.5 wt% Zr)*, SC-RR-70-371, Sandia Laboratories, Albuquerque, New Mexico, May 1970.
7. L. L. Stephenson, *A Survey of Factors Which Influence Stress Corrosion Crack Initiation in Several Uranium Base Alloys*, SC-DR-70-718, Sandia Laboratories, Albuquerque, New Mexico, October 1970.
8. N. J. Magnani, H. Romero, and C. J. Miglione, *The Effect of Chloride Ions on the Susceptibility to Stress Corrosion Cracking of U-7½ wt% Nb-2½ wt% Zr and U-4½ wt% Nb Alloys*, SC-RR-70-860, Sandia Laboratories, Albuquerque, New Mexico, December 1970.
9. G. A. Witlow, *Stress Corrosion of Uranium Alloys*, AWRE-0-49/66, Gt. Brit. Atomic Weapons Research Establishment, Aldermaston, Berks, England, July 1966.
10. L. J. Weirick (Sandia Laboratories, Livermore, California) and C. W. Schoenfelder, article submitted for publication in *Corrosion*.
11. E. D. Brandon, private communication with J. F. Boland July 31, 1972.