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U.S. Nuclear Regulatory Commission
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Subject: Programmatic review of paper titled "Localized Corrosion Susceptibility of Alloy 22"
for presentation at the NACE 2003 Corrosion Conference

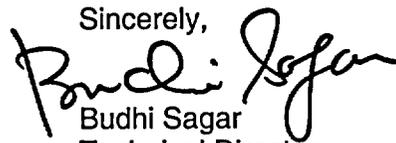
Dear Mrs. DeMarco:

The enclosed paper and the NRC Form 390A are being submitted for NRC programmatic review. This paper will be presented at the NACE 2003 Corrosion Conference in San Diego, California from March 16-20, 2003.

The paper provides a brief summary of the CNWRA studies related to the effects of fabrication processes such as welding on the localized corrosion susceptibility of the high-level waste outer container material. The results of this study indicate that fabrication processes could result in a higher susceptibility to localized corrosion compared to as-received Alloy 22 container material.

Please advise me of the results of your programmatic review. Your cooperation in this matter is appreciated.

Sincerely,



Budhi Sagar
Technical Director

Enclosure

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D S. Dunn, L. Yang, Y.-M Pan, and G A. Cragnolino

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Localized Corrosion Susceptibility of Alloy 22

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ABSTRACT

The localized corrosion susceptibility of Alloy 22, a candidate container material for the disposal of high-level nuclear waste in the proposed repository at Yucca Mountain, Nevada, was assessed in chloride containing solutions at temperatures ranging from 60 to 150 °C. Tests were conducted using the as-received material in the mill-annealed condition. In addition, the effects of fabrication processes were examined using both as-welded and thermally aged specimens. A comparison of the crevice corrosion repassivation potential and corrosion potential measured in separate tests suggests that fabrication processes and environmental conditions such as temperature and chemical composition of water contacting the waste packages (WPs) may influence the localized corrosion susceptibility of the Alloy 22 containers.

Keywords: Alloy 22, high-level waste, localized corrosion, welding

INTRODUCTION

The U.S. Department of Energy (DOE) is investigating Yucca Mountain, Nevada as the site for the permanent disposal of the nation's high-level nuclear waste (HLW) including spent nuclear fuel (SNF) from boiling water reactors (BWR) and pressurized water reactors (PWR), DOE-owned SNF, and high-level waste (HLW) glass. The DOE safety strategy¹ is focused on providing containment of the HLW within an engineered barrier subsystem (EBS) limiting the dose to the reasonably maximally exposed individual for the 10,000-year regulatory period. The U.S Code Of Federal Regulations (10 CFR Part 63) describes the regulatory requirements for the disposal of HLW in the proposed repository at Yucca Mountain, Nevada.

The proposed repository design and the EBS have several attributes that the DOE has suggested would contribute to the isolation of the HLW.¹ The proposed repository horizon at Yucca Mountain will be located in the unsaturated zone that has a low water infiltration rate. Selection of the repository horizon in the unsaturated zone is based on a strategy of keeping the WP dry for an extended period after repository closure. The prolonged dry period and unsaturated zone location

would also retard the migration of radionuclides in the event of WP failure. The current WP design is intended to provide containment of the radionuclides for thousands of years and consists of an Alloy 22 (56Ni-22Cr-13.5Mo-3W-3Fe) outer container surrounding a Type 316 nuclear grade (NG) stainless steel (SS) inner container to provide structural integrity.^{2,3} Descriptions of the fabrication sequence and nondestructive evaluation methods to be used to inspect the disposal container (DC) are provided in DOE documents.^{4,5}

In order to reduce residual stresses in Alloy 22 final closure welds, laser peening will be used for the inner Alloy 22 lid weld. For the outer closure lid, local induction annealing of the extended outer shell is proposed as a method to eliminate residual tensile stresses in the Alloy 22 outer closure weld. The induction annealing process will heat the end of the Alloy 22 disposal container with the completed closure weld to a temperature of 1,150 °C. Forced air or water will be used to rapidly reduce the temperature of the closure weld region.⁴ Elevated temperature exposures during welding and annealing processes can result in the precipitation of topologically close packed (TCP) phases.^{6,7,8} Formation of TCP phases has been shown to increase susceptibility of Alloy 22 to localized corrosion⁹ and reduce both its ductility and impact strength particularly in weld material and weld heat affected zones.^{10,11}

The objective of this investigation was to determine the localized corrosion susceptibility of Alloy 22 as a function of temperature, and solution chemistry. The effects of fabrication processes on the localized corrosion susceptibility of Alloy 22 were examined by testing welded material as well as material that was thermally aged. Results obtained in these investigations were compared to the results obtained for the as-received material and will be used to assess long-term WP performance.

EXPERIMENTAL APPROACH

The localized corrosion susceptibility was evaluated by measuring the repassivation potential for crevice corrosion.¹² Chemical compositions of the Alloy 22 heats and weld filler metals used in this study are provided in Table 1. Flat specimens fitted with two polytetrafluoroethylene (PTFE) crevice forming washers, shown in Figure 1, were used to measure the repassivation potential for crevice corrosion (E_{rcrev}). The crevice forming washers were held using an insulated Alloy C-276 hardware torqued to 0.35 N·m (50 in oz). Tests were carried out in autoclaves at temperatures of 80 to 175 °C, and in glass cells at temperatures of 60 to 95 °C. Both the autoclaves and the glass cells contained platinum counter electrodes. Tests conducted in autoclaves used a pressure balanced Ag/AgCl reference electrode filled with 0.01 M KCl. Potentials were converted to the saturated calomel electrode scale at 25 °C. Tests conducted in glass cells used a standard SCE as a reference electrode in a water cooled Luggin probe. A water-cooled condenser was used to prevent solution evaporation from the glass cells.

Cyclic potentiodynamic polarization (CPP) was used for tests conducted in autoclaves to measure the E_{rcrev} of the as-received material (heat 2277-8-3175). Test solutions contained 0.5 to 4.0 M chloride (Cl^-), 1.24 mM bicarbonate (HCO_3^-), 0.20 mM sulfate (SO_4^{2-}), 0.16 mM nitrate (NO_3^-), and 0.10 mM fluoride (F^-), added as sodium salts. High purity nitrogen gas was used to deaerate the solutions throughout the duration of the test. The CPP scans were initiated 100 mV below the corrosion potential (E_{corr}). The potential of the specimens was increased at a rate of 0.167 mV/s and a current density of 5 mA/cm², the scans were reversed. The CPP scans were terminated at 200 mV below the initial E_{corr} . For test conditions where crevice corrosion was observed, the E_{rcrev} was determined by the potential where the current density remained below 2×10^{-6} A/cm² as previously described by Cragnolino et al.¹³

Repassivation tests conducted in glass test cells were used to compare the crevice corrosion resistance of as-received and thermally aged material (heat 2277-8-3175) at temperatures less than 100 °C. The effect of fabrication processes were determined using two welded samples of Alloy 22 listed in Table 1. The weld on these specimens was produced using gas tungsten arc welding (GTAW) with either a double V-groove (12.7-mm thick material, heat 2277-8-3235, filler metal heat

XX2048BG) joint geometry. Potentiodynamic scans were used to obtain the E_{rcrev} . Scan were initiated at $-100 \text{ mV}_{\text{SCE}}$ and the potential of the specimens were increased to a present value in the range of 400 to $700 \text{ mV}_{\text{SCE}}$ at a rate of 0.1 mV/s . Upon reaching the preset maximum potential, the specimen was held potentiostatically to allow localized corrosion propagation. After a period of 5 to 8 hours the potential was decreased at a rate of either 0.0167 or 0.167 mV/s to a potential of $-500 \text{ mV}_{\text{SCE}}$ where the test was terminated. The faster scan rates were used in the initial tests conducted in the glass test cells. Although differences in the values of E_{rcrev} measured with the different scan rates were not observed, slower scan rates were adopted as a precaution against overly conservative E_{rcrev} measurements. The criteria for determination of the E_{rcrev} was identical to the tests conducted in the autoclaves and defined as the potential where the current density remained below $2 \times 10^{-6} \text{ A/cm}^2$.

The E_{corr} of Alloy 22 was also measured in air saturated chloride solutions. Long-term corrosion potentials were measured in solutions containing 4.0 M Cl^- , 1.24 mM HCO_3^- , $0.20 \text{ mM SO}_4^{2-}$, 0.16 mM NO_3^- , and 0.10 mM F^- using creviced test specimens shown in Figure 1. The specimen was periodically removed from the test cell and examined for signs of localized corrosion. Additional corrosion potential measurements were conducted with smooth cylindrical specimens measuring 48.6 mm long and 6.2 mm in diameter.¹⁴ Initial tests with the cylindrical specimens were carried out using 600 grit polished surfaces in air-saturated chloride containing solutions. The pH of the solutions was varied from 2.7 to 11.7 using additions of HCl or predetermined ratios of HCO_3^- to carbonate (CO_3^{2-}). Subsequent tests were conducted in similar solutions using specimens that were thermally oxidized at $200 \text{ }^\circ\text{C}$ for 30 days.

RESULTS

In the CPP tests conducted in autoclaves, localized corrosion was initiated by progressively increasing the potential of the test specimen until breakdown of the passive film occurred which was marked by a significant increase in the anodic current density. A representative CPP scan conducted in 4.0 molar Cl⁻ at $95 \text{ }^\circ\text{C}$ is shown in Figure 2. A small anodic peak was observed at around $400 \text{ mV}_{\text{SCE}}$ followed by the breakdown of the passive film at $700 \text{ mV}_{\text{SCE}}$. Based on a current density value of $2 \times 10^{-6} \text{ A/cm}^2$ as the criterion for repassivation, the E_{rcrev} measured in this test was $-57 \text{ mV}_{\text{SCE}}$. The E_{rcrev} versus Cl⁻ concentration plots for all as received Alloy 22 test specimens measured at temperatures ranging from 80 to $150 \text{ }^\circ\text{C}$ is shown in Figure 3. No localized corrosion was observed on tests conducted at either 80 or $95 \text{ }^\circ\text{C}$ in 0.5 molar Cl⁻. The results in Figure 3 show that temperature has a strong influence on the E_{rcrev} . It is also apparent that the E_{rcrev} at a given temperature decreases with chloride concentration. The largest decrease in E_{rcrev} occurs as the temperature increases from 80 to $125 \text{ }^\circ\text{C}$. For example, in a 1 molar Cl⁻ solution the E_{rcrev} decreased by 400 mV from $250 \text{ mV}_{\text{SCE}}$ to $-150 \text{ mV}_{\text{SCE}}$.

Figure 4 shows an example of the E_{rcrev} measurements conducted in glass cells using a potentiodynamic scan. The scan was initiated at $0 \text{ mV}_{\text{SCE}}$ and the potential of the specimen was increased to a value of $700 \text{ mV}_{\text{SCE}}$. After holding the specimen at this potential for 5 hr , the potential was decreased at a rate of 0.167 mV/s . The potential of the specimen was held constant for two periods when the current reached values of 1×10^{-5} and $2 \times 10^{-6} \text{ A/cm}^2$. During both short potentiostatic holds, the current density increased with time indicating continued localized corrosion propagation. The measured current density decreased and remained below $2 \times 10^{-6} \text{ A/cm}^2$ at a potential of $-98 \text{ mV}_{\text{SCE}}$. At lower potentials the current density rapidly decreased suggesting repassivation of localized corrosion. This value of the E_{rcrev} is close to the value of $-57 \text{ mV}_{\text{SCE}}$ measured using the CPP test method in an autoclave under equivalent environmental conditions. Using a slower scan rate of 0.0167 mV/s , the measured E_{rcrev} with the same $2 \times 10^{-6} \text{ A/cm}^2$ criterion was $-92 \text{ mV}_{\text{SCE}}$ indicating that the slower scan rate did not significantly alter the E_{rcrev} value. Crevice corrosion was confirmed by post-test optical examination of the specimens.

For all of the as received specimens where localized corrosion was observed, the attack was characterized by deep penetrations under the crevice formers with a smooth, electropolished

appearance. The attack did not follow metallurgical features such as grain or twin boundaries. When localized corrosion was not observed the specimen surface had typically a bright gold color and often exhibited a light etching of grain boundaries that was attributed to transpassive dissolution. Pitting on the open surfaces was never observed.

The E_{rcrev} for welded Alloy 22 and thermally aged Alloy 22 (using specimens from the 12.7-mm plate) as a function of chloride concentration at 95 °C is shown in Figure 5. The measured values of the E_{rcrev} for the thermally aged material were similar to those measured for the welded specimens. It is also apparent that the welded material has a lower E_{rcrev} in concentrated chloride solutions compared to the as-received material in the mill-annealed condition (Figure 3). For example in 4 M chloride at 95 °C, the E_{rcrev} for the as received material was in the range from -57 to -98 mV_{SCE}, whereas the welded material had a E_{rcrev} of -159 mV_{SCE}. A greater difference in the localized corrosion susceptibility was observed at lower chloride concentrations. Although crevice corrosion was not observed in the CPP tests conducted in autoclaves at chloride concentrations less than 1 M, crevice corrosion was observed with welded specimens in solutions containing 0.005 M Cl⁻. The morphology of the localized corrosion regions was also different from that of the as received material. Whereas the as received material had penetrations consistent with an electropolished appearance, localized attack on the welded material exhibited preferential attack in the weld filler metal exposing the cast microstructure and intergranular attack in the adjacent heat affected zone. Attack on the thermally aged specimens was also characterized by intergranular corrosion that resulted in deep penetrations along grain boundaries.

Figure 6 shows the effect of thermal aging (5 minutes at 870 °C) on the E_{rcrev} as a function of chloride concentration and temperatures ranging from 60 to 95 °C. Also included are E_{rcrev} measurements for welded material using specimens from 38.1-mm thick plate at temperatures of 60 and 95 °C. Regression lines for the thermally aged specimens are plotted and the results show that the E_{rcrev} decreases with temperature and chloride concentration. It is also apparent that the critical chloride concentration for localized corrosion on the thermally aged specimens is dependent on temperature. At 60 °C the critical chloride concentration was 0.25 M and decreased to 0.05 M at 80 °C, and to 0.01 M at 95 °C. Compared to the results for the thermally aged material, the E_{rcrev} measurements suggest that welded material was more susceptible to localized corrosion at low chloride concentrations at 60 °C. However, based on the limited number of tests, it appears that the E_{rcrev} for welded material is not as strongly dependent on temperature.

An empirical relationship for the E_{rcrev} as a function of chloride concentration and temperature is shown as Eq. (1)

$$E_{rcrev} = E_{rcrev}^0(T) + B(T)\log[Cl^-] \quad (1)$$

where

$$E_{rcrev}^0(T) = A_1 + A_2T(^{\circ}C)$$

and

$$B(T) = B_1 + B_2T(^{\circ}C)$$

where the coefficients for Alloy 22 in the as-received condition and in the thermally aged condition are provided in Table 2. Comparison of the coefficients in Table 2 reveals the strong dependence of E_{rcrev} on both chloride concentration and temperature. It is apparent that the thermally aged material is much more susceptible to localized corrosion. In addition, the thermally aged material exhibited a stronger dependence on Cl⁻ concentration.

The value of the E_{corr} for Alloy 22 in air saturated 4 M Cl⁻ is shown in Figure 7. Values of the corrosion potential were generally in the range of -300 to -100 mV_{SCE}. The discontinuous appearance of the data

plotted in Figure 7 is a result of the testing method because the specimen was periodically removed from the test cell for optical examination. The crevice forming washers were removed and the specimen was examined for signs of localized corrosion. It is important to note that no surface grinding or other abrasive methods were used to clean the specimen. Cleaning consisted of ultrasonic agitation in deionized water. After more than 750 days of testing, no localized corrosion was observed. The value of the E_{corr} , and the time dependent changes in the E_{corr} during each test segment has evolved with time. During the early test periods, the initial values of the E_{corr} were greatest at the start of the test period and the E_{corr} decreased with time. Over the last 200 days of testing however the E_{corr} has increased from the initial value measured at the start of each test period to a maximum value near $-100 \text{ mV}_{\text{SCE}}$.

Short-term E_{corr} tests conducted on replicate Alloy 22 specimens are shown in Figures 8 and 9. The E_{corr} values in alkaline 0.028 M Cl⁻ for both polished and oxidized specimens are shown in Figure 8. For polished specimen, the E_{corr} was as low as $-340 \text{ mV}_{\text{SCE}}$ at the start of the test and subsequently increased and stabilized at values in the range of $-200 \text{ mV}_{\text{SCE}}$ to $0 \text{ mV}_{\text{SCE}}$. For the oxidized specimens the E_{corr} was found to have much greater variability compared to the polished specimens. Initial values of the E_{corr} were as high as $65 \text{ mV}_{\text{SCE}}$ and unlike the polished specimens, decreased with time. The E_{corr} values for oxidized specimens at acidic and slightly alkaline conditions are shown in Figure 9. The results obtained under slightly alkaline conditions were also characterized by large specimen to specimen variations however the E_{corr} tended to increase with time. In acidic conditions as shown in Figure 9, the E_{corr} of the oxidized specimens increased from initial values in the range of -40 to $60 \text{ mV}_{\text{SCE}}$ and stabilized near $250 \text{ mV}_{\text{SCE}}$. The specimen to specimen variation under acidic conditions was typically less than 50 mV .

DISCUSSION

In the proposed Yucca Mountain HLW repository, WP lifetime may be determined by the resistance of the container materials to localized corrosion. If the prevailing environmental conditions are such that no localized corrosion is initiated, WP lifetime may be determined by passive corrosion rates which are orders of magnitude slower than localized corrosion propagation rates. The selection of Alloy 22 as the WP outer container material is based on the resistance of this Ni-Cr-Mo-W alloy to localized corrosion and stress corrosion cracking.^{15,16} However, localized corrosion resistance may be altered by fabrication processes. The combination of cold work used in forming and machining operations and elevated temperature exposures as a result of welding and annealing processes may result in the precipitation of topologically close packed phases in the Alloy 22 WPs. During the solidification of the weld metal, molybdenum and tungsten segregate to the interdendritic regions leaving the dendrite core rich in nickel.^{6,7} The enrichment of molybdenum (and tungsten) in the interdendritic regions coupled with depletion of nickel promotes the precipitation of topologically close packed phases. The composition of all the topologically close packed phases, including σ , μ , and P phases can contain more than 30 percent molybdenum.⁸ The high concentration of molybdenum in these phases results in a depletion of molybdenum adjacent to the precipitates that reduces the resistance of the alloy to localized corrosion. Because the formation of the precipitates preferentially occurs in the weld regions and in the intergranular regions of the heat affected zone adjacent to the welds, localized corrosion in the form of interdendritic and intergranular corrosion may occur in environments that are much less aggressive than those required for localized corrosion of the alloy in the as-received condition.

The thermal stability of nickel-chromium-molybdenum alloys has been evaluated using several criteria including microstructural examination for the presence of secondary phase precipitates at the grain boundaries or in the interdendritic regions of welds, intergranular corrosion susceptibility in aggressive solutions containing boiling hydrochloric acid (HCl), and mechanical properties such as ductility, yield strength, or impact toughness. In this study, repassivation potential tests were conducted to determine the behavior of as-received, welded, and thermally aged Alloy 22 in environments that are plausible under disposal conditions. Results of this study confirm that fabrication processes can significantly

reduce the localized corrosion resistance of Alloy 22. The combination of Alloy 22 thermal instability and environmental variations may have a significant effect on HLW container lifetimes. Localized corrosion of Alloy 22 in the as-received condition was observed in chloride solutions. As a result of the localized corrosion resistance of mill-annealed Alloy 22 and the strong dependence of E_{crev} on Cl^- concentration and temperature, aggressive conditions are required to initiate localized corrosion. In low Cl^- concentration solutions or temperatures below 80 °C, the localized corrosion susceptibility of as-received Alloy 22 in the mill-annealed condition is limited to high potentials that would be difficult to attain under natural conditions without the presence of oxidants other than oxygen. Compared to mill-annealed material, localized corrosion of the as welded material was observed at lower temperatures in solutions with lower Cl^- concentrations. Similarly the thermally aged material also had greater susceptibility to localized corrosion compared to the as-received material as indicated by a comparison of the E_{crev} values shown in Figures 3 and 6 and the abstracted parameters for Eq. (1) listed in Table 2.

The localized corrosion susceptibility of the Alloy 22 WP outer container may also be affected by compositional variations. Microstructural examinations reported by Heubner et al.⁹ after isothermal exposures revealed the precipitation of topologically close packed phases in 15 minutes (the shortest time investigated) and complete coverage of the grain boundaries after 1 hour at temperatures in the range of 800 to 900 °C. A significant increase in the intergranular corrosion rate was observed after 1 hour at 800 °C based on the results of standardized tests.¹⁷ Bulk precipitation of topologically close packed phases was reported to occur after 10 hours at 800 °C and after 3 hours at 900 °C. In contrast, Rebak et al.¹⁸ using a different heat of Alloy 22 reported complete grain boundary precipitation after 10 hours at 800 °C and bulk precipitation within the grains after 100 hours at 800 °C.

Solution annealing at temperature of 1,125 °C may dissolve any secondary phase precipitates such as topologically close packed phases formed as a consequence of the welding processes. Solution annealing followed by water quenching at an adequate cooling rate is proposed for the Alloy 22 disposal container prior to loading with HLW in order to mitigate the residual stresses arising as a consequence of fabrication. Solution annealing of the final closure weld may relieve residual stresses from welding and redissolve topologically close packed phases in the interdendritic regions of welds and weld heat affected zones. Because the entire WP cannot be elevated to the solution annealing temperature, intergranular precipitation of topologically close packed phases may occur in areas adjacent to the final closure weld where the temperature is in the range of 800 to 900 °C. The results of this study as well as the previous results of Heubner et al.⁹ suggest that short term exposures in this temperature range are quite detrimental to localized corrosion resistance.

Measurements conducted with Alloy 22 specimens indicate the composition of the environment was shown to have a significant effect on the E_{corr} . It is apparent from the data shown in Figures 8 and 9 that the E_{corr} is strongly dependent on pH. After approximately 60 days, the maximum E_{corr} of thermally oxidized specimens in alkaline solutions (pH 10.6 to 11.7) was 0 mV_{SCE} but increased to 100 mV_{SCE} for solutions with an average pH of 8.7, and was greater than 250 mV_{SCE} in acidic solutions. Groundwater pH at the proposed Yucca Mountain repository will be determined by the presence of soluble species. Water with dissolved bicarbonate may have a near neutral or slightly alkaline pH whereas the addition of carbonate tends to increase the pH closer to 11. As shown in Figure 9, the corrosion potential in near neutral or slightly alkaline solutions for oxidized Alloy 22 was between -300 and 100 mV_{SCE} with a general trend to higher values and greater variation with time. From the data in Figure 3 for the as-received material specimens, it is apparent that the E_{crev} is close to the maximum value of the E_{corr} in Figure 9 under near neutral or slightly alkaline conditions. Initiation and propagation of crevice corrosion is possible when the E_{corr} is greater than the E_{crev} . For the as-received material alloy, the initiation of localized corrosion may not occur without either another oxidizing species or a continuously present thin water layer that would allow enhanced oxygen reduction kinetics. In contrast, the welded or thermally aged specimens have much lower E_{crev} . The combined anodic dissolution kinetics may determine the E_{corr} of the WPs because the welded or thermally aged material will be in contact with Alloy 22 in the solution annealed condition. By comparing the E_{corr} of as-received material in the

solution annealed condition with the E_{crev} for the thermally aged material, it may be concluded that localized corrosion of the thermally aged material is possible in near neutral solutions containing 0.1 M Cl^- .

For acidic solutions, which may be expected in occluded regions as a result of the hydrolysis of corrosion products, the E_{corr} was well above the E_{crev} for both the as-received, as-welded, or thermally aged material. Under such conditions, initiation of localized corrosion can be expected. As reported by Dunn et al.,¹⁹ the presence of other oxidizing species such as Fe(III) as a consequence of corrosion of carbon steel structures in the proposed repository drifts may further increase the E_{corr} and extend the susceptibility to localized corrosion to lower temperatures. Mitigation of localized corrosion for both as-received and welded Alloy 22 has been shown in solutions containing sufficient concentrations of inhibiting species such as nitrate. Because nitrate has been shown to both inhibit the initiation of crevice corrosion as well as increase the E_{crev} , the composition of the water contacting the WP may have a strong influence on the lifetime of the WPs.

CONCLUSIONS

Localized corrosion of mill-annealed Alloy 22 in the as-received condition in chloride containing solutions was limited to aggressive conditions characterized by highly oxidizing potentials and temperatures near boiling. Fabrication processes were shown to extend the environmental conditions for localized corrosion of Alloy 22 to less concentrated chloride solutions, lower temperatures and lower potentials. Corrosion potentials for Alloy 22 were strongly dependent on pH and in acidic solutions the corrosion potentials were significantly greater than the crevice corrosion repassivation potentials. These results suggest that the effects of fabrication processes combined with variations or evolution of the aqueous environment in the vicinity of the WPs may influence WP lifetimes.

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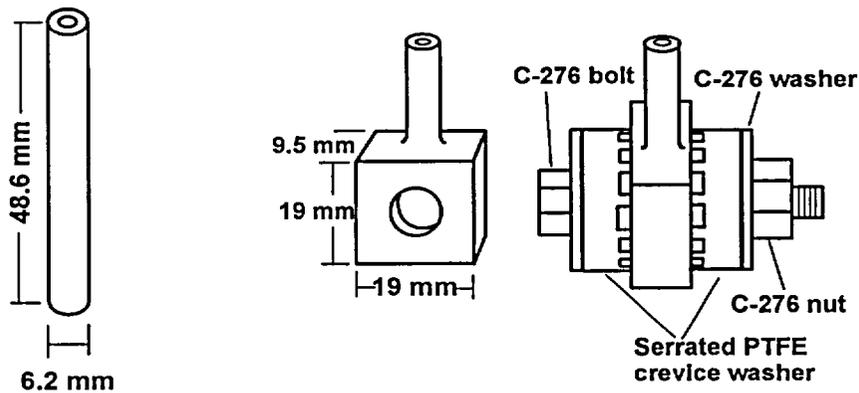
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TABLE 1
ANALYZED COMPOSITION OF ALLOY 22 HEATS AND ALLOY 622 FILLER METAL

Material	Ni	Cr	Mo	W	Fe	Co	Si	Mn	V	P	S	C
Alloy 22 Heat 2277-8-3175 12.7-mm thick	57.8	21.40	13.60	3.00	3.80	0.09	0.030	0.12	0.15	0.008	0.002	0.004
Alloy 22 Heat 2277-8-3235 12.7-mm thick	56.5	21.40	13.47	2.87	3.94	1.31	0.023	0.24	0.17	0.008	0.001	0.003
622 Filler Heat XX1045BG11	58.5	20.73	14.13	3.15	3.05	0.09	0.060	0.24	0.01	0.007	0.001	0.006
Alloy 22 Heat 059902LL2 38.1-mm thick	59.6	20.35	13.85	2.63	2.85	0.01	0.05	0.16	0.17	0.007	0.0002	0.005
622 Filler Heat XX2048BG	59.4	20.48	14.21	3.02	2.53	0.02	0.07	0.20	0.02	0.009	<0.001	0.001

TABLE 2
COEFFICIENTS OF THE CREVICE CORROSION REPASSIVATION POTENTIAL EXPRESSIONS

Alloy	T (°C)	[Cl ⁻] _{crit} (M)	A ₁ (mV _{SCE})	A ₂ (mV/°C)	B ₁ (mV)	B ₂ (mV/°C)
Alloy 22 Heat 2277-8-3175 As received/Mill annealed	80 to 125 °C	0.5	1,300	-13.1	-362.7	2.3
Alloy 22 Heat 2277-8-3175 Thermally Aged 5 minutes at 870°C	60 to 95 °C	0.01 to 0.25	800	-10.0	-584.2	3.7



Cylindrical Specimen

Crevice Corrosion Specimen

FIGURE 1. Schematic illustration of cylindrical and crevice corrosion specimens

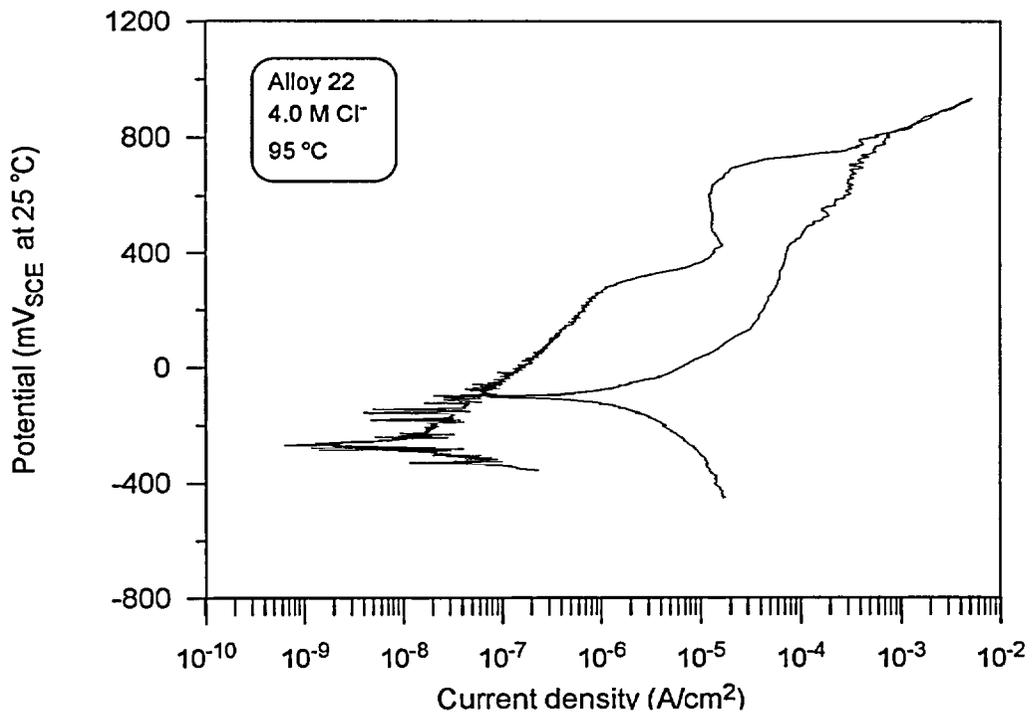


FIGURE 2. Cyclic potentiodynamic polarization curve for Alloy 22 in 4 M Cl⁻ at 95 °C. Test conducted in polytetrafluoroethylene lined Autoclave.

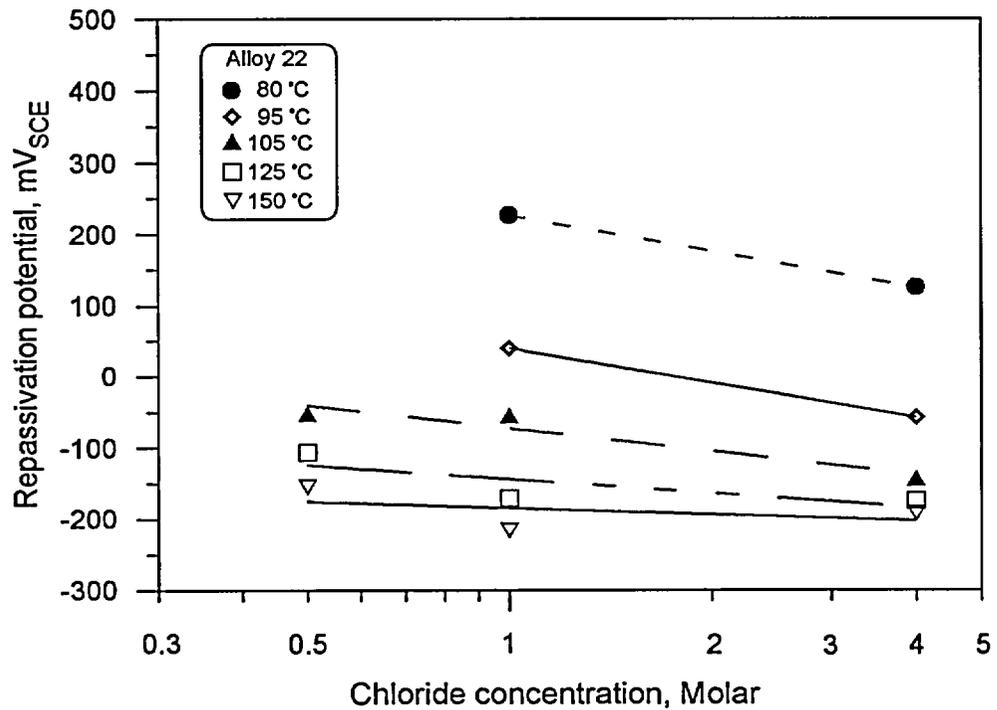


FIGURE 3. Crevice corrosion repassivation potential measurements for mill-annealed Alloy 22. Measurements obtained in autoclaves using cyclic potentiodynamic polarization.

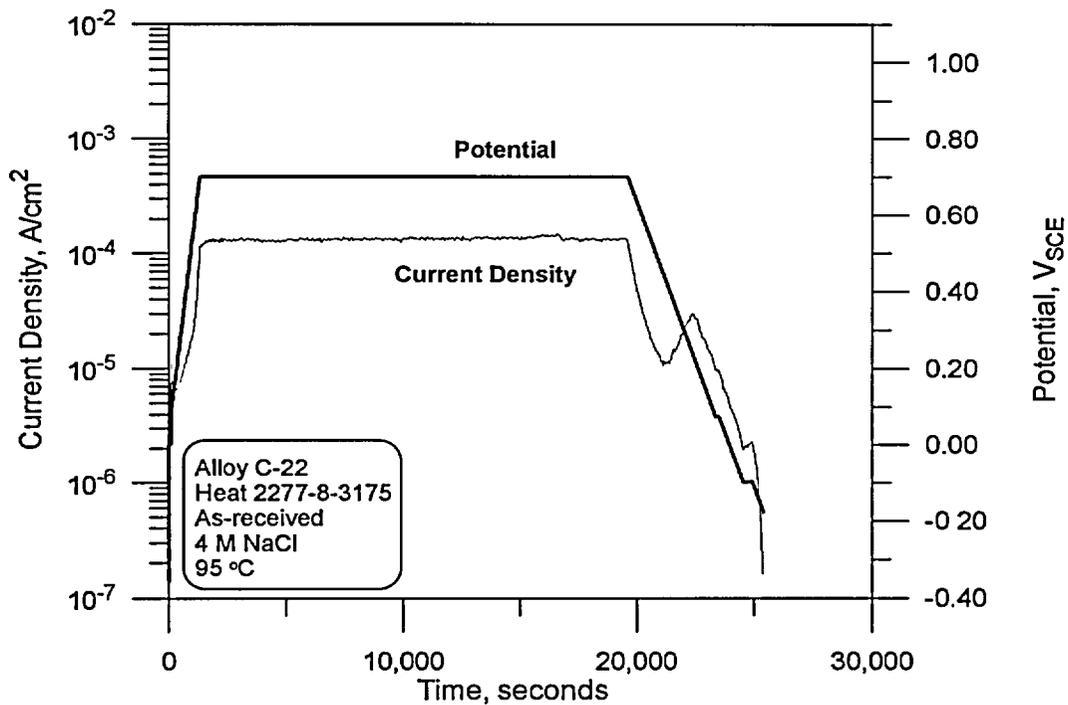


FIGURE 4. Example of crevice corrosion repassivation potential scan for Alloy 22 conducted in glass test cells

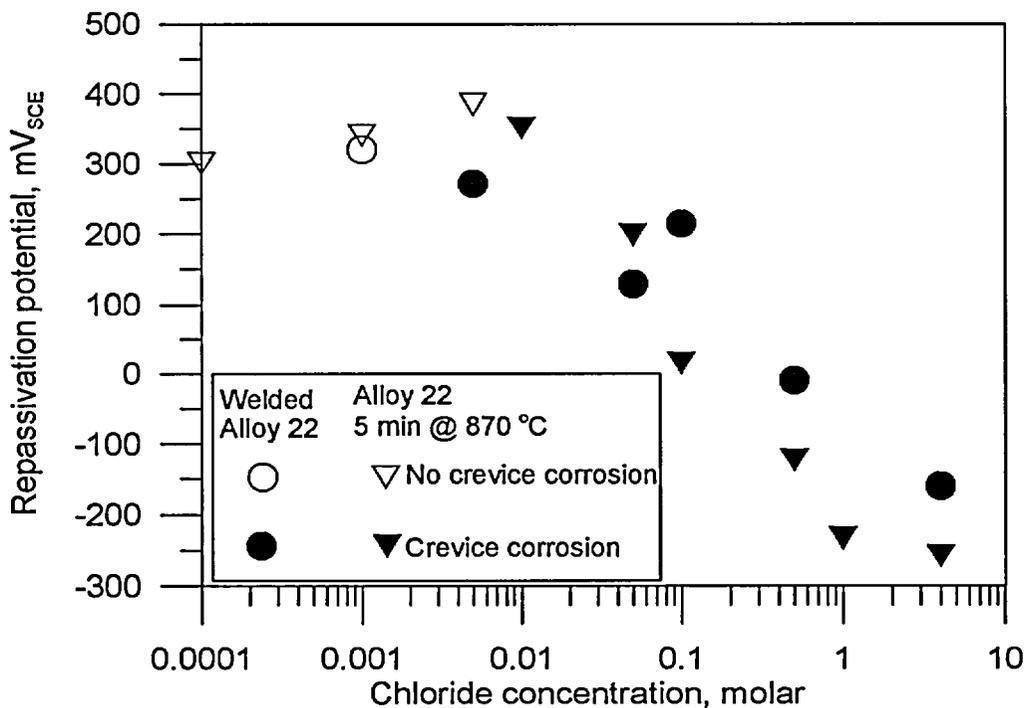


FIGURE 5. Crevice corrosion repassivation potential for 12.7-mm thick thermally aged and 12.7-mm thick welded Alloy 22 as a function of chloride concentration at 95 °C.

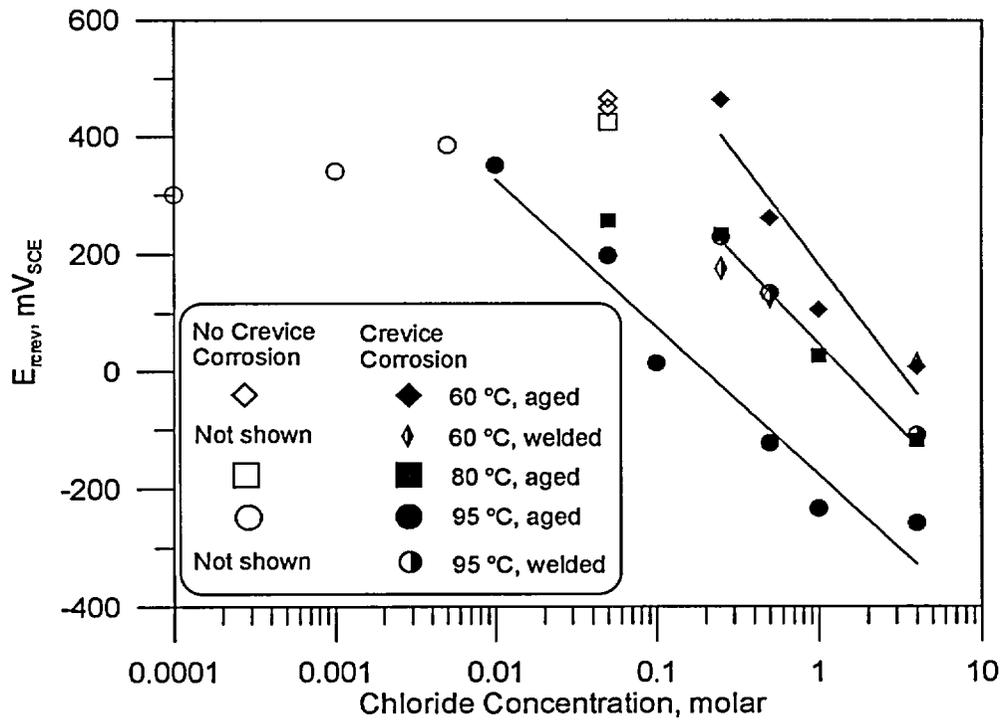


FIGURE 6. Crevice corrosion repassivation potential measured for 12.7-mm thick thermally aged and 38.1-mm thick welded Alloy 22 as a function of chloride concentration at various temperatures.

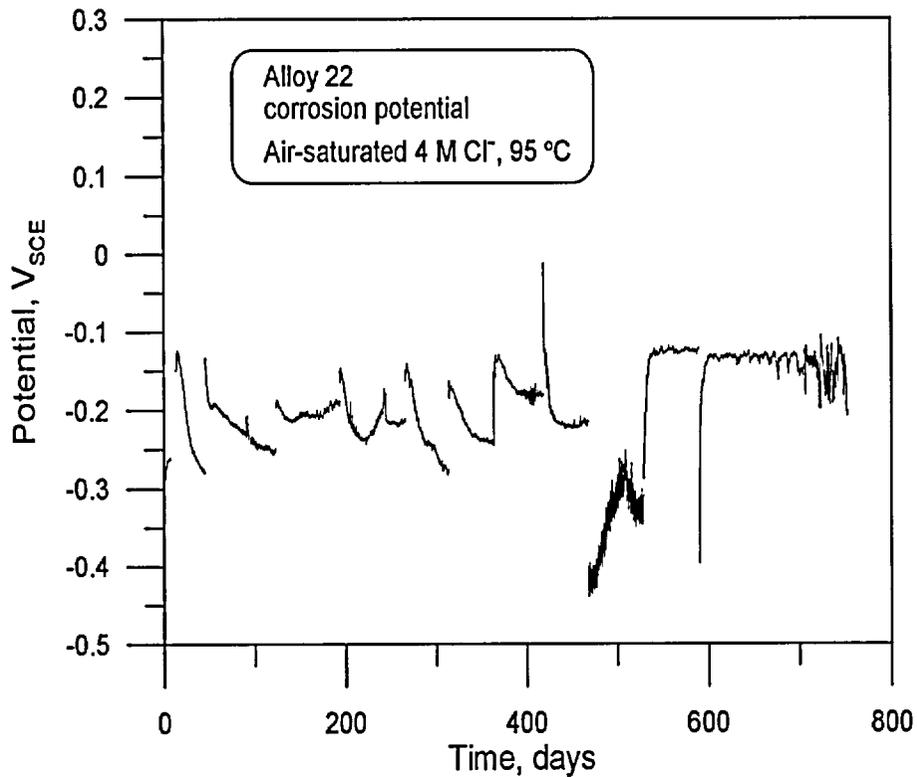


FIGURE 7. Open circuit corrosion potential for Alloy 22 in air saturated 4 molar NaCl

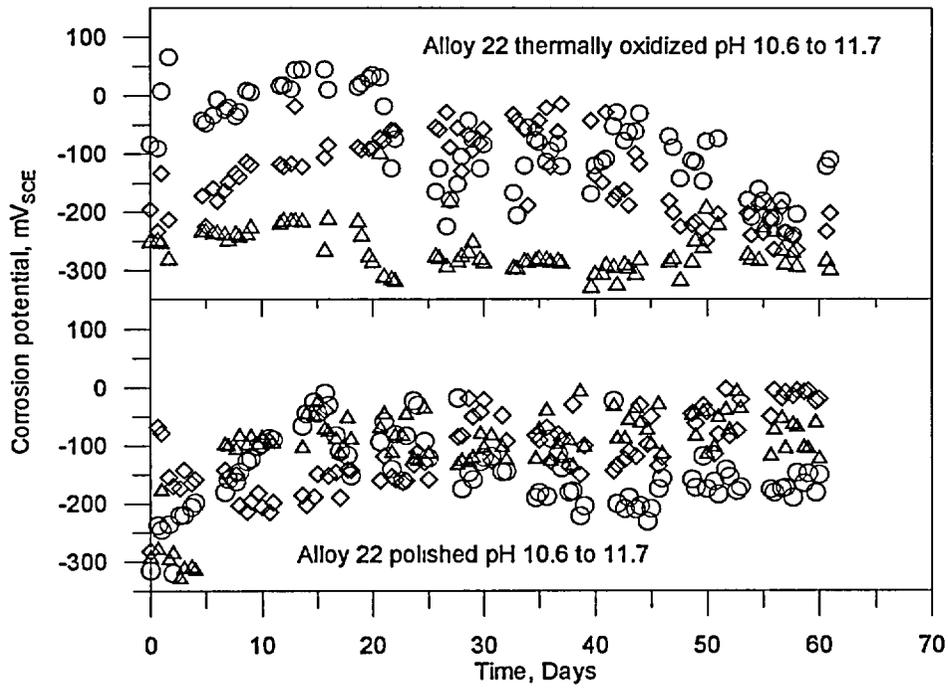


FIGURE 8. Alloy 22 corrosion potentials was a function of time in air saturated, alkaline 0.028 M NaCl at 95 °C. Tests conducted using freshly polished and oxidized (30 days at 200 °C) specimens. Three identical specimens used for each test condition.

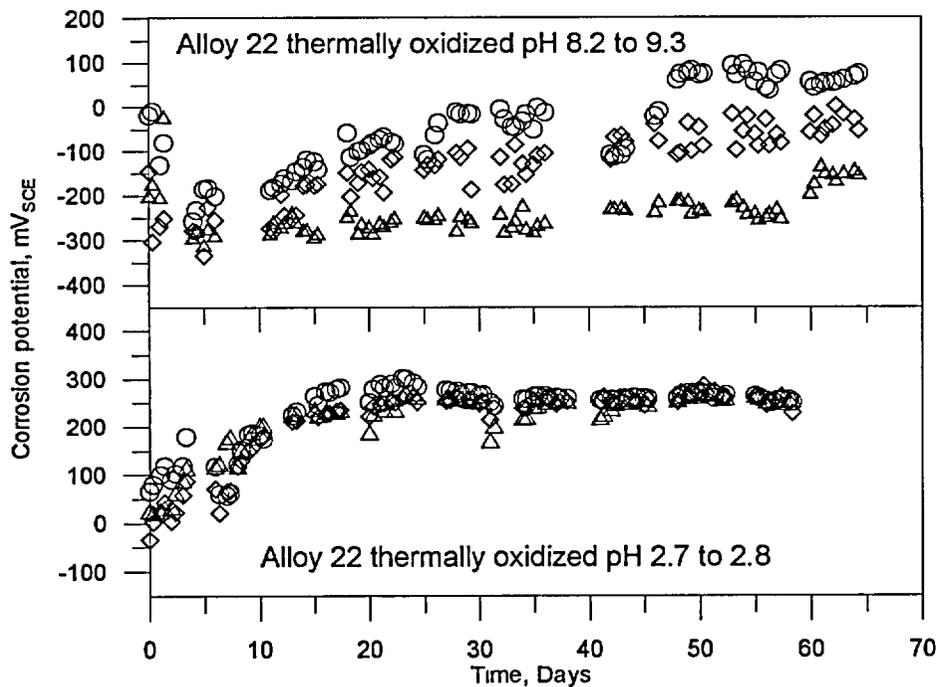


FIGURE 9. Alloy 22 corrosion potentials was a function of time in air saturated, acidic and neutral 0.028 M NaCl at 95 °C. Tests conducted using oxidized (30 days at 200 °C) specimens. Three identical specimens used for each test condition.

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