Modeling Corrosion Processes for Alloy 22 Waste Packages

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1. Introduction

- Waste packages for the potential repository at Yucca Mountain, Nevada will have an important contribution to waste isolation
- Waste packages for the disposal of high-level waste will be constructed of
  - An Alloy 22 (Ni-22Cr-13Mo-3W-4Fe) outer container
  - A Type 316 nuclear grade stainless steel (Fe-18Cr-8Ni-2Mo-high N-low C) inner container
- After loading, waste packages will be emplaced in mined drifts on pallets
- Titanium alloy drip shields, designed to protect waste packages from seepage water and rockfall, may be installed prior to permanent repository closure

2. Waste Package Corrosion Processes

- Performance assessment models used to evaluate overall system performance consider several possible waste package corrosion processes
- Uniform corrosion rates are low under environmental and material conditions where the passive oxide film is stable
- Crevice corrosion is possible in concentrated chloride solutions with low concentrations of inhibiting anions
- Stress corrosion cracking has been observed in solutions containing chloride and carbonate or bicarbonate at high anodic potentials

3. Objectives of this Study

- Improve models to evaluate crevice corrosion susceptibility of the Alloy 22 waste package outer container considering the effects of environmental variables and the concentrations of aggressive and inhibitor species
- Measure crevice corrosion propagation rates and assess possible damage to waste packages

4. Materials

Table 1. Composition of Alloy 22 test specimens

Material	Ni	Cr	Mo	W	Fe	Co	Si	Mn	V	P	S	C
Alloy 22 2277-8-3175	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 059902LL2	59.9	20.35	13.85	2.63	2.85	0.01	0.05	0.16	0.17	0.007	0.0002	0.005
Alloy 22 2277-3-3266	57.3	21.40	13.30	2.81	3.75	1.19	0.03	0.23	0.14	0.008	0.004	0.005

5. Test Results

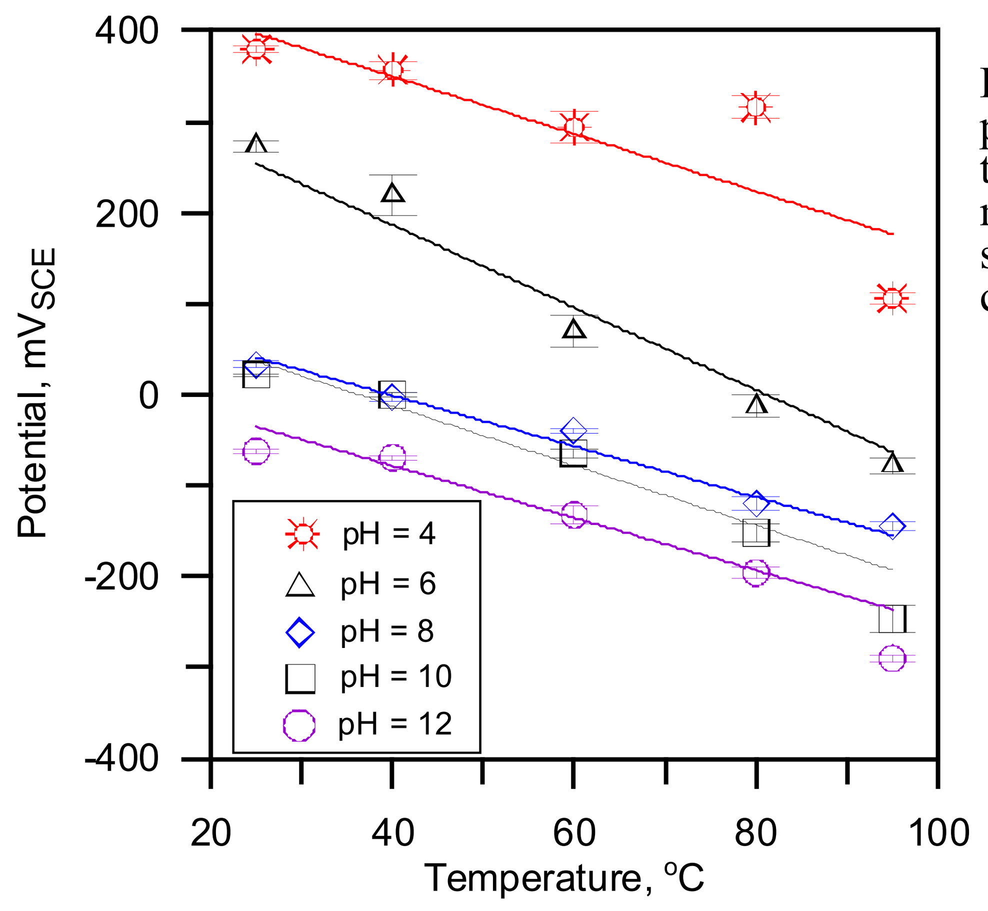


Figure 1. Alloy 22 corrosion potentials as a function of temperature. Potentials were measured in 4M NaCl solution maintained at constant pH values

- Corrosion potential depends on temperature and pH
- Previous investigations suggest corrosion potential is not strongly dependent on chloride concentration

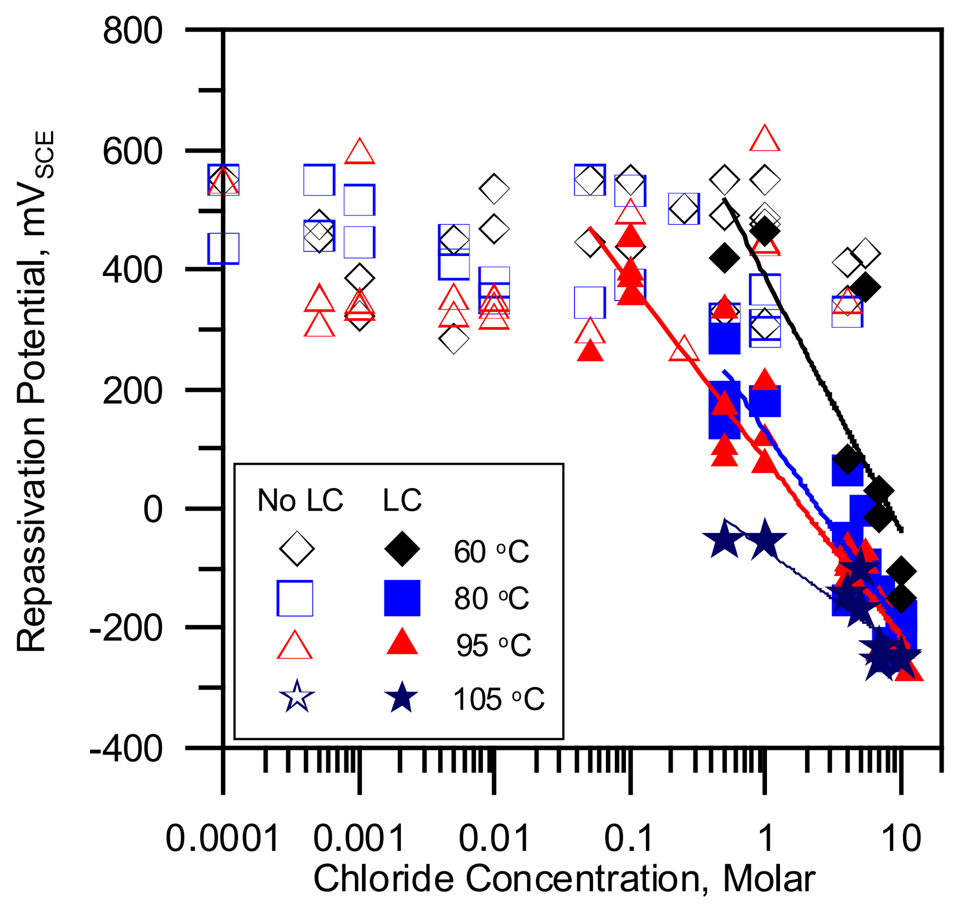


Figure 2. Crevice corrosion repassivation potentials for mill-annealed Alloy 22

- Repassivation potential depends on chloride concentration and temperature
- Previous investigations indicate nitrate, sulfate, carbonate, and bicarbonate inhibit localized corrosion even in concentrated chloride solutions.
- Fabrication processes increase susceptibility to crevice corrosion

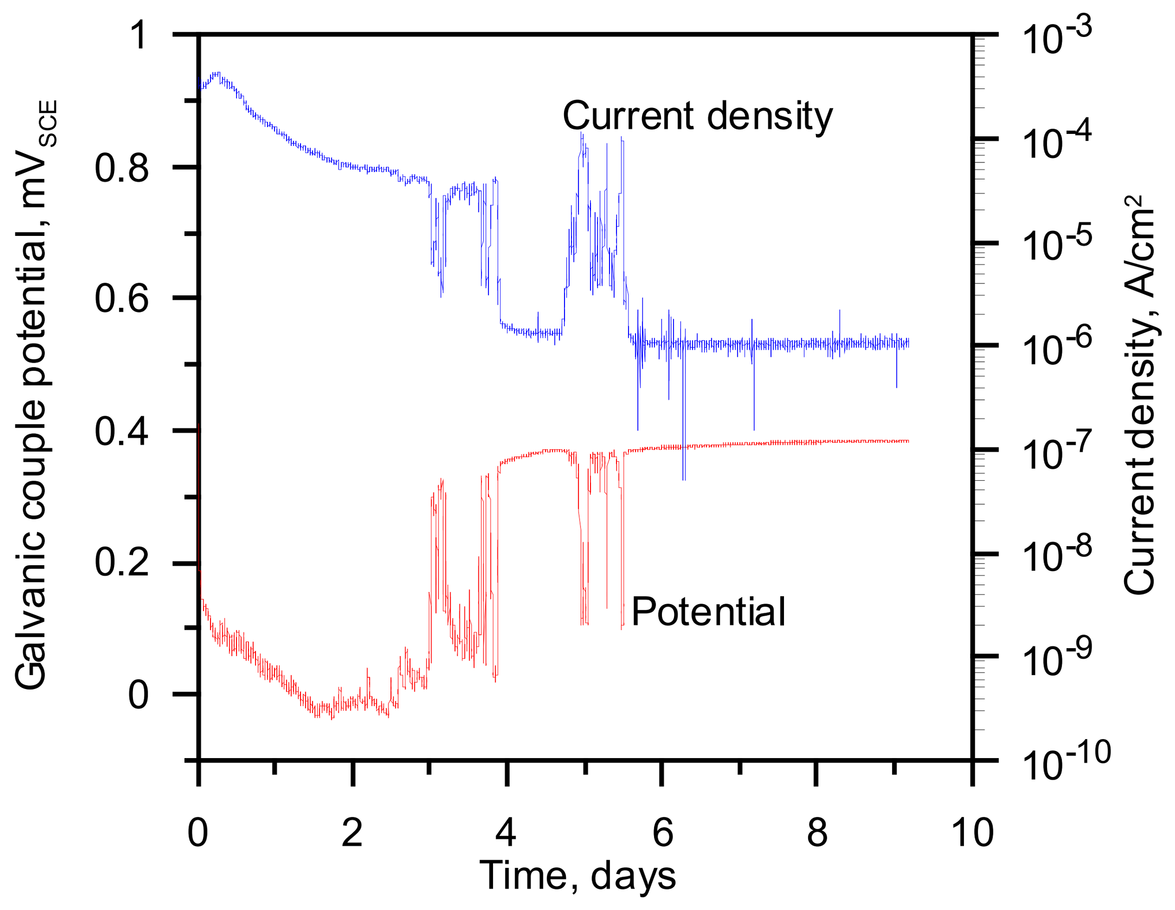
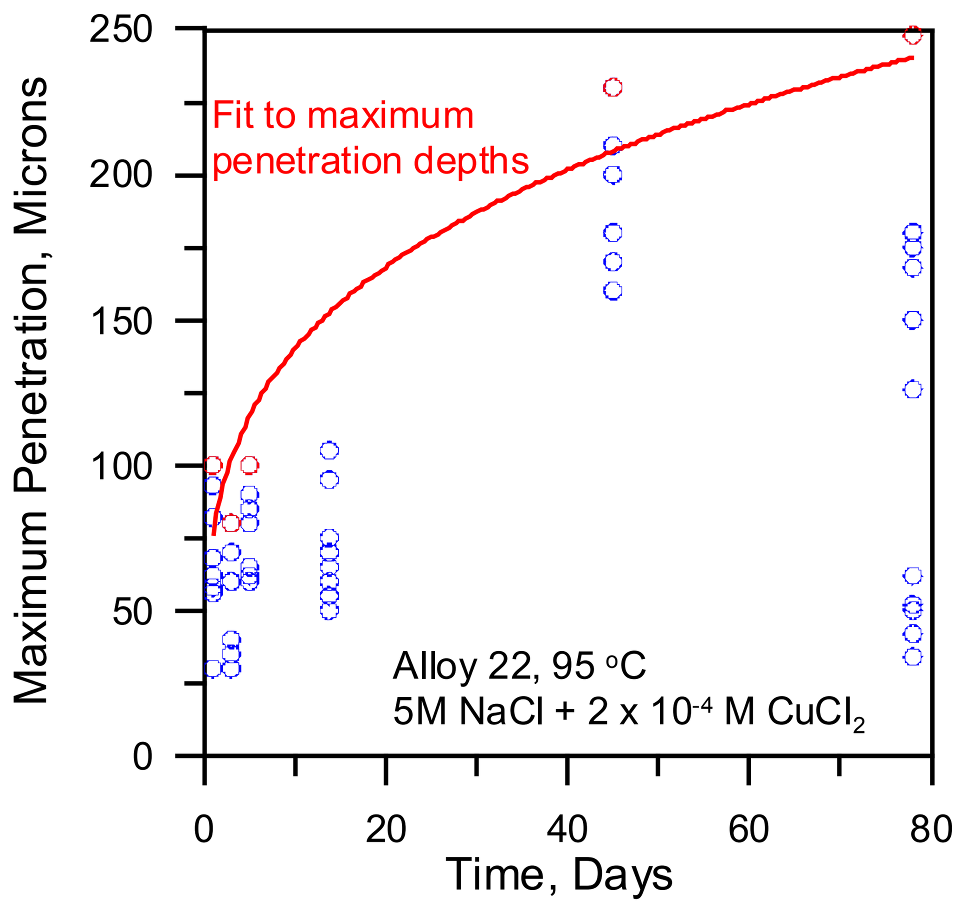


Figure 3. Potential and current transients for Alloy 22 crevice corrosion test in 5 M NaCl with $CuCl_2$ at 95 °C [203 °F]

- Rapid penetration rates when localized corrosion is active
- Stifling and arrest of localized corrosion are observed even in oxidizing solutions with high chloride concentrations
- Decrease in corrosion potential of 340 mV ±140 mV is observed when localized corrosion is active

Figure 4. Measured crevice corrosion penetration depths for Alloy 22

- Crevice corrosion penetration rate is diffusion controlled
- Electrochemical processes contributing to stifling and arrest also affect penetration rate and depth
- Maximum observed penetration depth was less than 300 µm in 80 days
- Based on measured values maximum crevice corrosion penetration of approximately 4 mm is expected in 10,000 years



6. Uniform Corrosion Model

- Under conditions where Alloy 22 is protected by a stable passive film, the corrosion rate is dependent only on temperature (E_a = 33.5 to 49.6 kJ/mol [8.0 to 11.9 kcal/mol])
- Long waste package lifetimes under environmental and material conditions where passivity is maintained

7. Localized Corrosion Model

Corrosion potential, E_{corr}

$E_{corr} = f(T, pH)$

Crevice Corrosion Repassivation Potential, E_{rcrev}

$$E_{rcrev}(T) = A_1 + A_2\,T + (B_1 + B_2\,T)\log_{10}[Cl^-] + \Delta E_{rcrev}$$

$$\Delta E_{rcrev} = \frac{\min(r, r_n)}{r_n}\,800\text{ mV}$$

$$r = \frac{[NO_3^-]}{[Cl^-]} + \frac{r_n}{r_s}\frac{[SO_4^{2-}]}{[Cl^-]} + \frac{r_n}{r_c}\frac{[CO_3^{2-}]+[HCO_3^-]}{[Cl^-]}$$

Table 2. Regression Parameters for Mill-Annealed and Thermally Altered Alloy 22

Metallurgical Condition	A_1 mV_{SCE}	A_2 mV/°C	B_1 mV	B_2 mV/°C	r_n	r_s	r_c
Mill-annealed	940	- 9.4	- 752	5.2	0.1	0.5	0.2
Thermally Altered	800	- 10.0	- 584.2	3.7	0.3	0.5	0.2

Necessary Condition for Crevice Corrosion

$E_{corr} - E_{rcrev} > 0$

Penetration Rate for Crevice Corrosion

$P = 0.0765t^{0.263}$ (P in mm, t in days)

8. Localized Corrosion Susceptibility

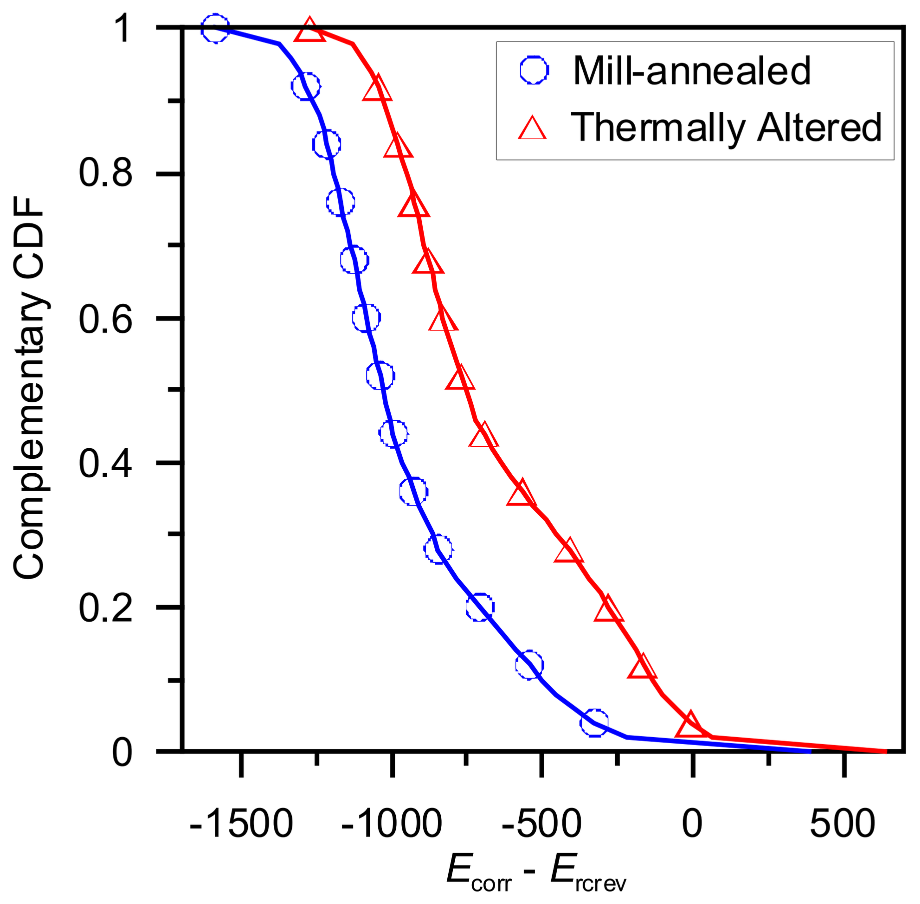


Figure 5. Complementary cumulative distribution function for the difference E_{corr}-E_{rcrev} at 110 °C [230 °F]

- A small percentage of waste packages that contact seepage water will be susceptible to crevice corrosion at 110 °C [230 °F]
- In order for the seepage water to contact the waste packages, the drip shields must be damaged by corrosion or mechanical loading
- Anionic inhibitors in the ground water can reduce the occurrence of crevice corrosion

9. Conclusions

- A revised model for the initiation, propagation, and repassivation of crevice corrosion of Alloy 22 was developed based on the results of laboratory tests
- The crevice corrosion repassivation potential is dependent on temperature, chloride concentration, the concentration of oxyanions that act as inhibitors, and the metallurgical condition of the alloy
- Initiation of localized corrosion on Alloy 22 requires aggressive environmental conditions that are not expected to prevail over a long period in the emplacement drifts
- If crevice corrosion is initiated, the damage to the Alloy 22 waste package outer container is likely to be limited to a small fraction of the container thickness due to the strong tendency for crevice corrosion to repassivate

10. Acknowledgments

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