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K.T. Chiang, O. Pensado, P.K. Shukla, and Y.-M. Pan

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ENVIRONMENTAL EFFECTS ON STRESS CORROSION CRACKING OF ALLOY 22

K.T. Chiang[2], O. Pensado[1], P.K. Shukla[1], Y.-M. Pan[1] and D.S. Dunn[2]
[1]Center for Nuclear Waste Regulatory Analyses
[2]Southwest Research Institute®
San Antonio, Texas, U.S.A.

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2007 TMS Annual Meeting
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Orlando, Florida
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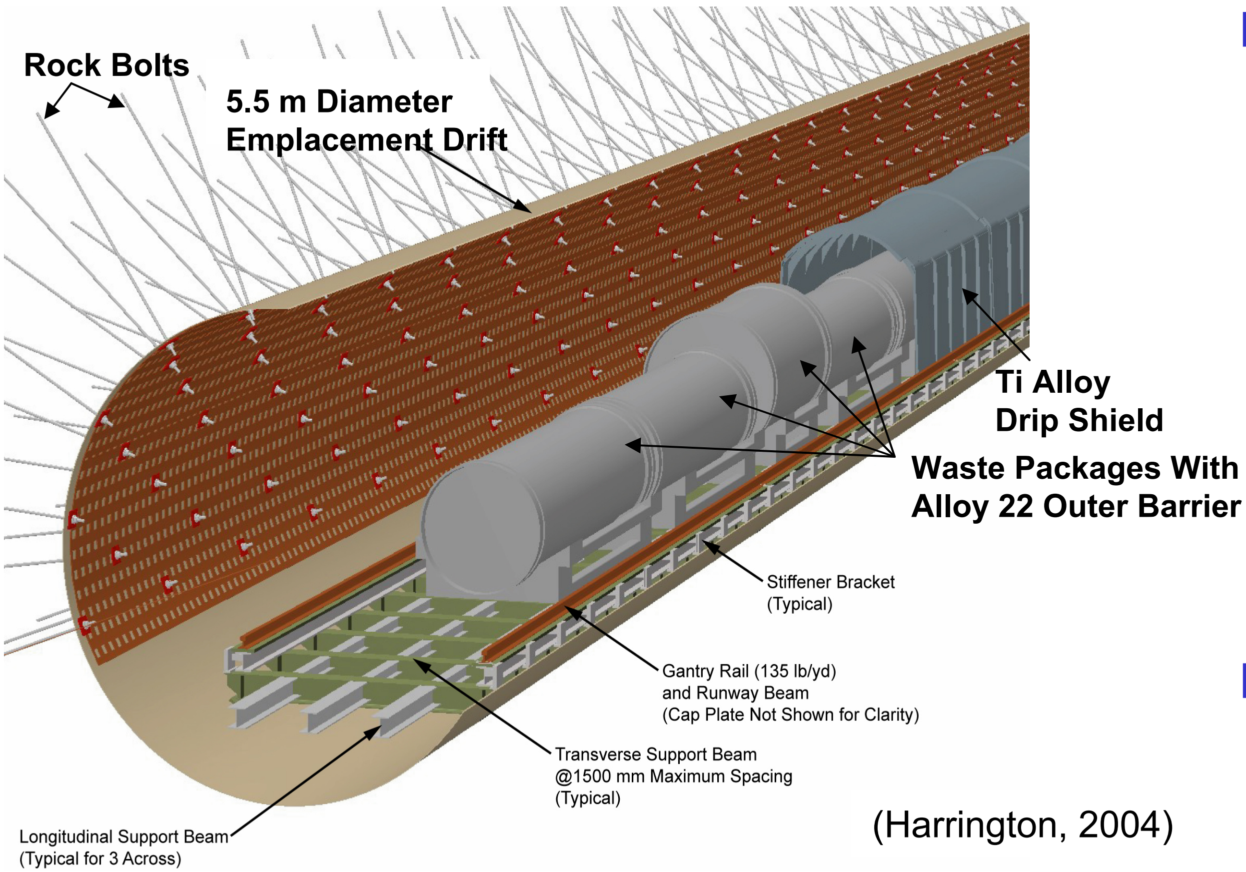
Outline

- Background
- Stress Corrosion Cracking (SCC) Testing of Alloy 22 in Solutions Containing Chloride and Bicarbonate Ions
- Preliminary Model Abstraction for SCC Initiation
- Performance Assessment of SCC Initiation in Yucca Mountain Environments
- Summary & Conclusions

Background: Potential Waste Package Design for High-Level Nuclear Waste Disposal



(Harrington, 2004)

- Long Lifetime of Waste Package Is a Key Attribute for Performance of Potential Yucca Mountain Repository
- SCC Analyses relevant to the thermal pulse period

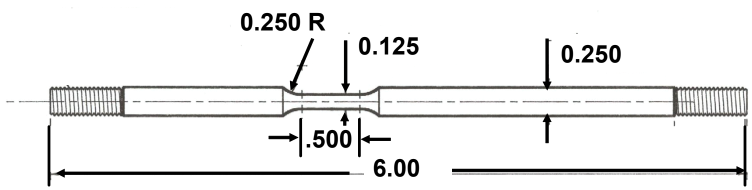
Reported SCC Testing of Alloy 22 in Simulated Concentrated Water (SCW)

Ion	K^+	Na^+	Mg^{2+}	Ca^{2+}	F^-	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-
mg/L	3,400	40,900	<1	<1	1,400	6,700	6,400	16,700	70,000
mM	87	1,780	<0.041	<0.025	74	189	103	174	1,148

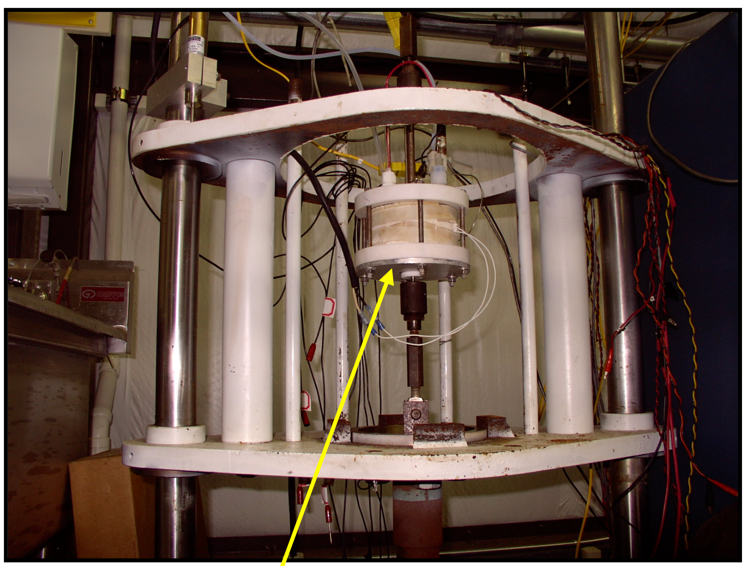
Reference: G.M. Gordon, "Corrosion Considerations Related to Permanent Disposal of High-Level Radioactive Waste", ***Corrosion***, 58(10), p. 811, 2002.

- Estill, et al. (*Corrosion 2002*) Reported SCC in Slow Strain Rate Tests (SSRTs) in SCW at 73 °C [163 °F] and 400 mV_{SSC} [356 mV_{SCE}]
- Chiang, et al. (*Corrosion 2005*) Reported Bicarbonate Ions Are the Predominant Constituent in SCW that Promoted SCC at 95 °C [203 °F] and 356 mV_{SCE}

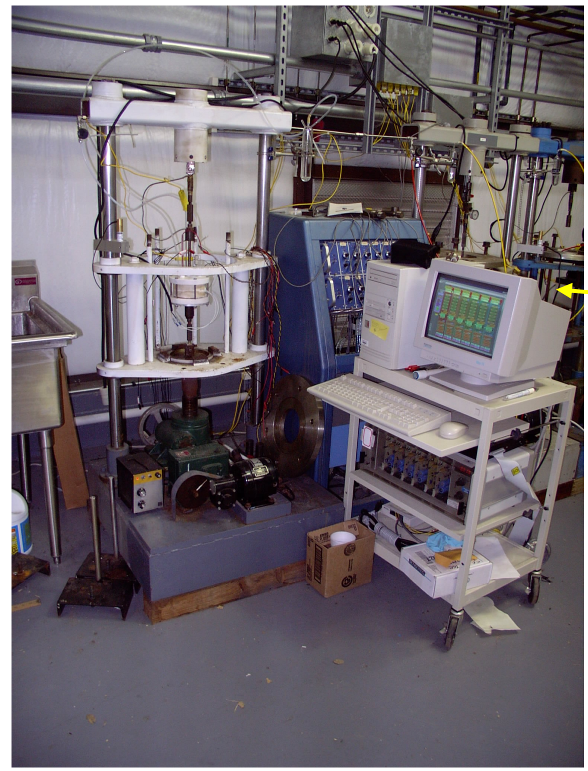
SSRT Experimental Setup



Specimen Dimensions (in)



Test Cell

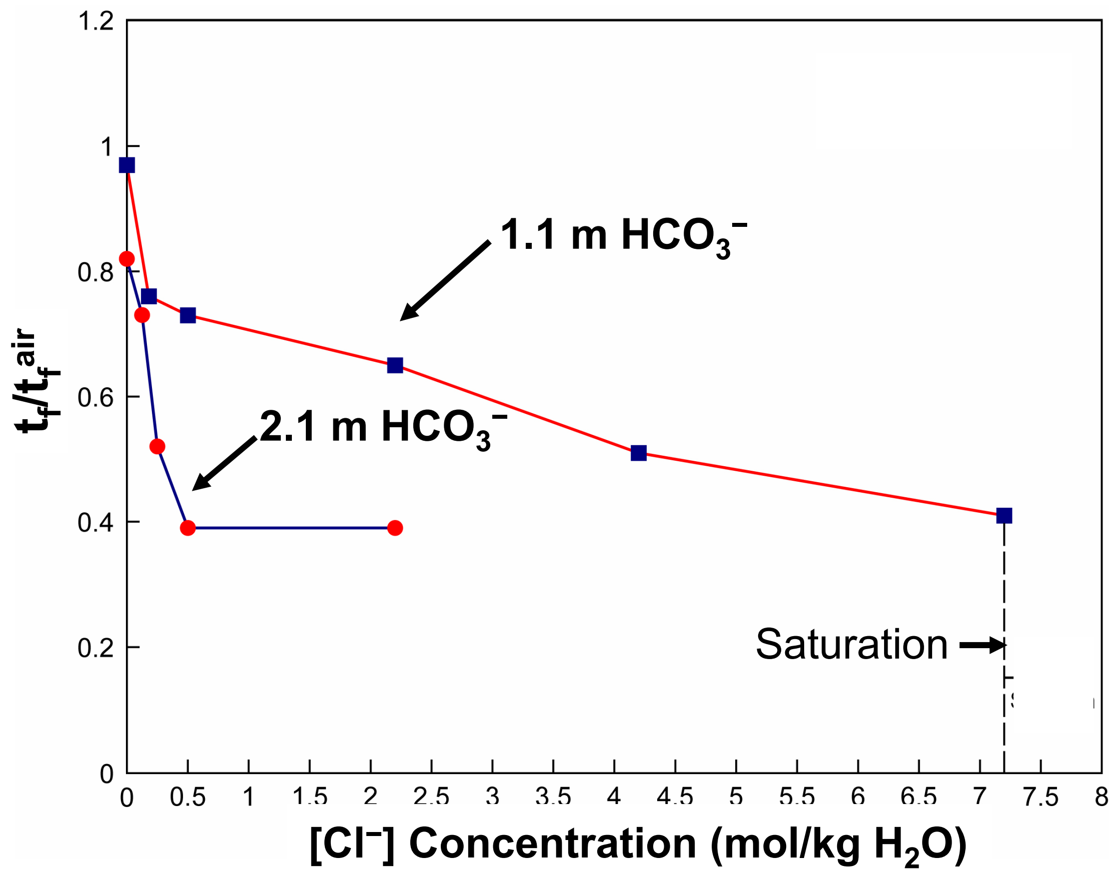


Data Acquisition System

Effect of [Cl⁻] and [HCO_3^-] on Time-to-Failure of Alloy 22 in SSRTs

Mill-Annealed Alloy 22 at 356 mV_{SCE} and 95°C [203 °F]

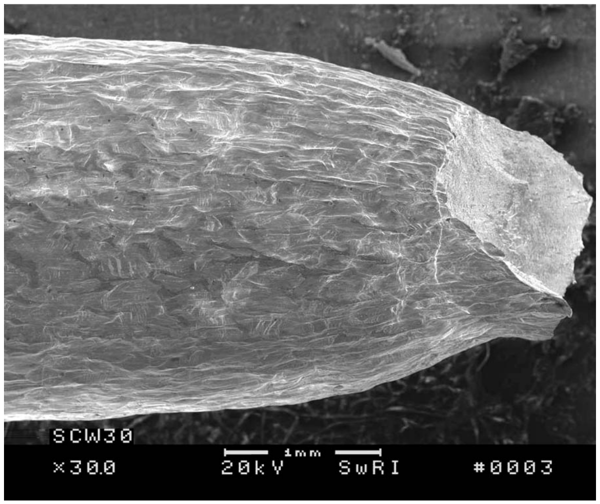
SSRTs at a Strain Rate of 3.2 × 10^{-6}/s

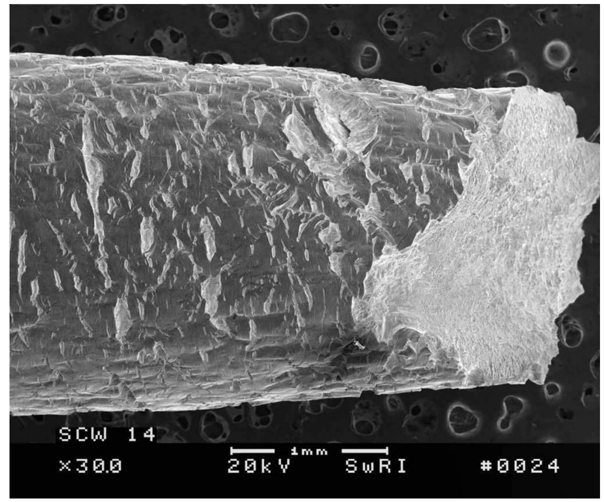


- t_f/t_f^{air} (Time-to-Failure Ratio in Solution versus Air) is an Index of Severity of SCC
- At Constant Bicarbonate Levels (1.1 m or 2.1 m), Susceptibility of Alloy 22 to SCC Increases With Increasing Chloride Ion Concentrations

Synergistic Effect of Cl^- and HCO_3^- in Causing SCC of Alloy 22 at 356 mV_{SCE}

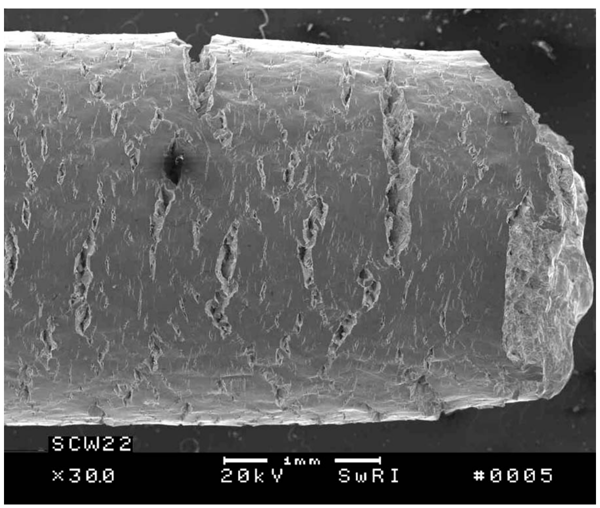
7.2 m Cl^- only

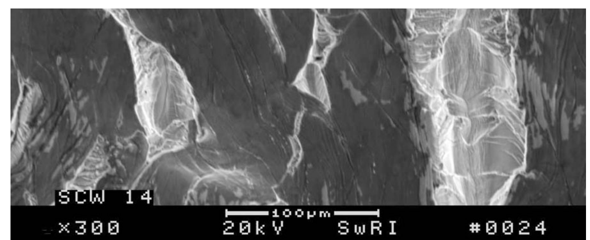




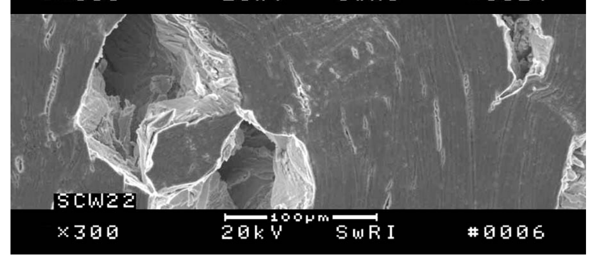
1.1 m HCO_3^- only

1.1 m HCO_3^- + 4.2 m Cl^-



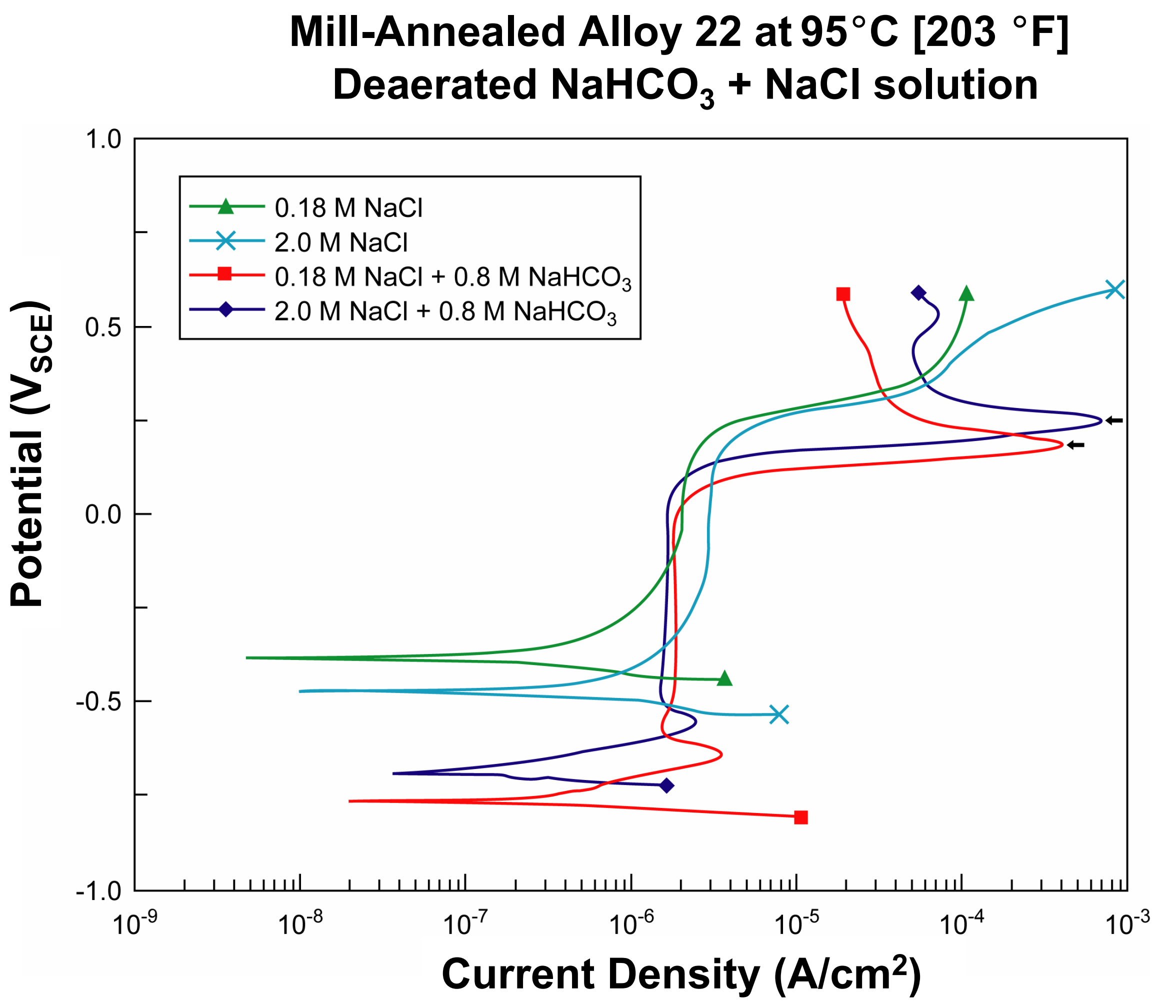


1.1 m HCO_3^- only



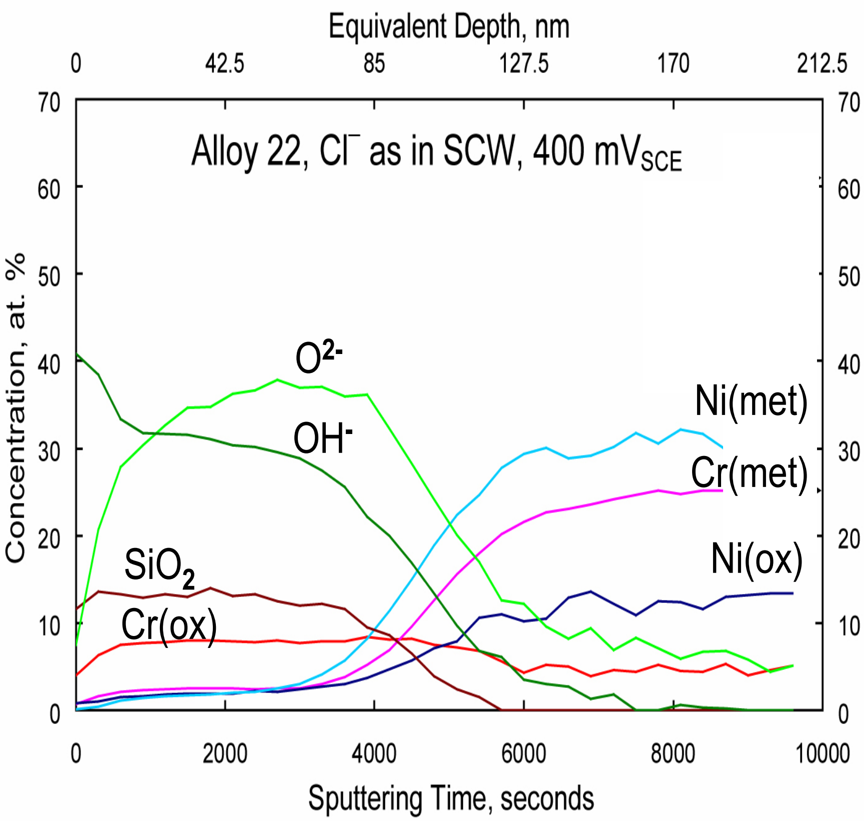
1.1 m HCO_3^- + 4.2 m Cl^-

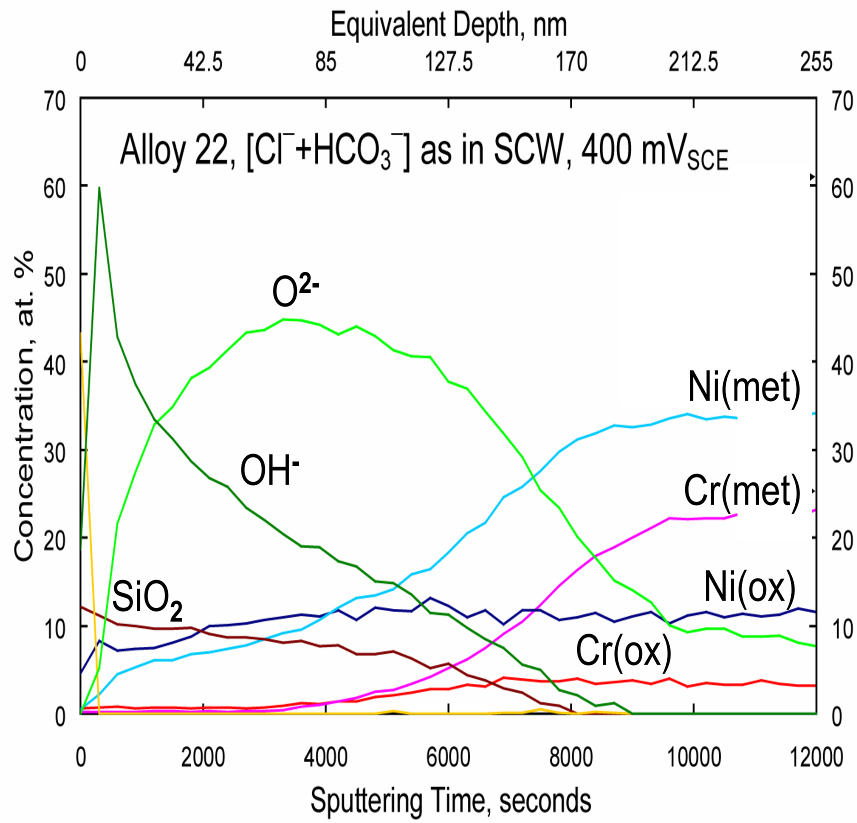
Anodic Polarization Behavior



- Anodic Peaks Were Observed in NaCl + $NaHCO_3$ Solutions
- No Anodic Peak in NaCl Only Solutions

Surface Analysis of Alloy 22 Using X-ray Photoelectron Spectroscopy





- In Cl^- Only Solutions, a Thin Cr-Rich Oxide Was Formed on Surface
- In [Cl^- + HCO_3^-] Solution, No Cr-Rich Oxide Was Formed on Surface Combination
- Cl^- and HCO_3^- Ions Disrupted Cr-Rich Oxide Passive Film Stability

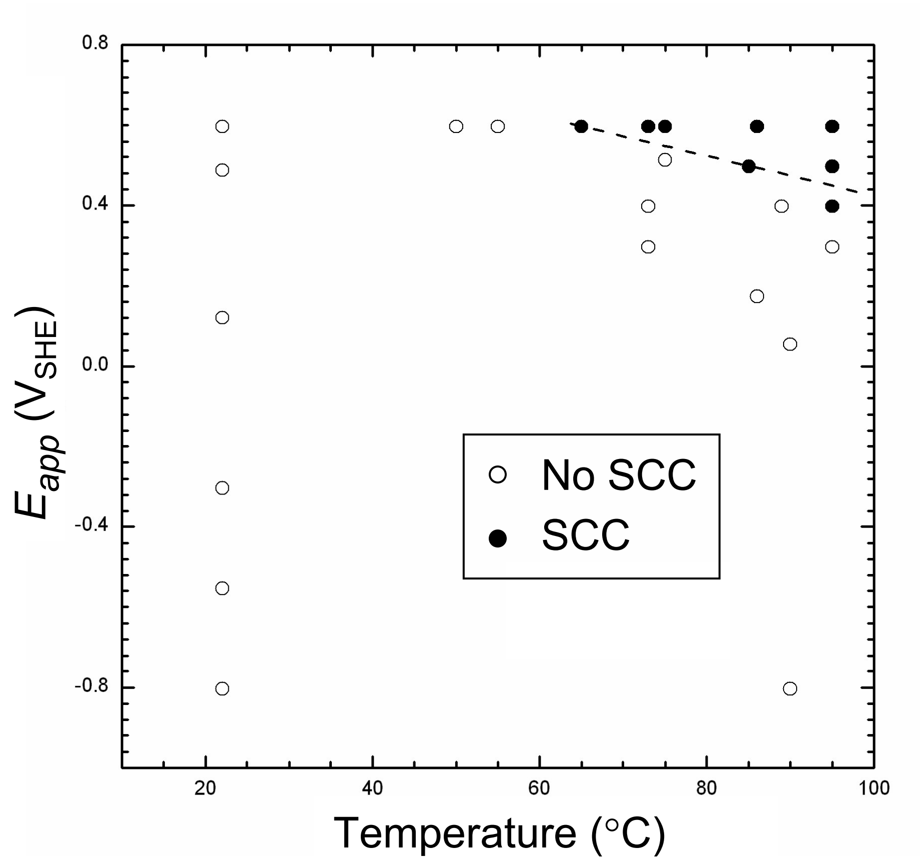
SSRT Conditions & Results for Alloy 22

(Strain Rate: 3.2×10^{-6}/s)

Environment	T(ºC) [ºF]	$E_{Applied}$ (mV_{SCE})	t_f/t_f^{air}	$E_{Applied}$ (V_{SHE})	SCC
Air	22 [72]	N/A	—	—	N
SCW	95 [203]	356	0.77	0.597	Y
SCW	95 [203]	156	1.0	0.397	N
7.2 m Cl^-	95 [203]	356	1.02	0.597	N
1.1 m HCO_3^- + 4.2 m Cl^-	95 [203]	356	0.51	0.597	Y
1.1 m HCO_3^- + 7.2 m Cl^-	95 [203]	356	0.41	0.597	Y
	95 [203]	256	0.62	0.497	Y
	95 [203]	156	0.91	0.397	Y
	95 [203]	56	1.03	0.297	N
1.1 m HCO_3^- + 2.2 m Cl^-	95 [203]	356	0.65	0.597	Y
	75 [167]	356	0.73	0.597	Y
	55 [131]	356	0.91	0.597	Y*
	22 [72]	356	0.92	0.597	N

* Minor transgranular cracking, mostly on side surfaces

Preliminary Model Abstraction for SCC Initiation Developed Based on Published SSRT Data



- SCC Requires Sufficient Chloride and Bicarbonate Concentrations, High Anodic Potentials and High Solution Temperatures
- Relationship Between E_{app} vs. temperature is obtained by fitting a straight line

  E_{app} (V_{SHE}) = [1 - 0.0084 (T - 65)]×0.597
- Critical Potential for SCC Initiation is proposed

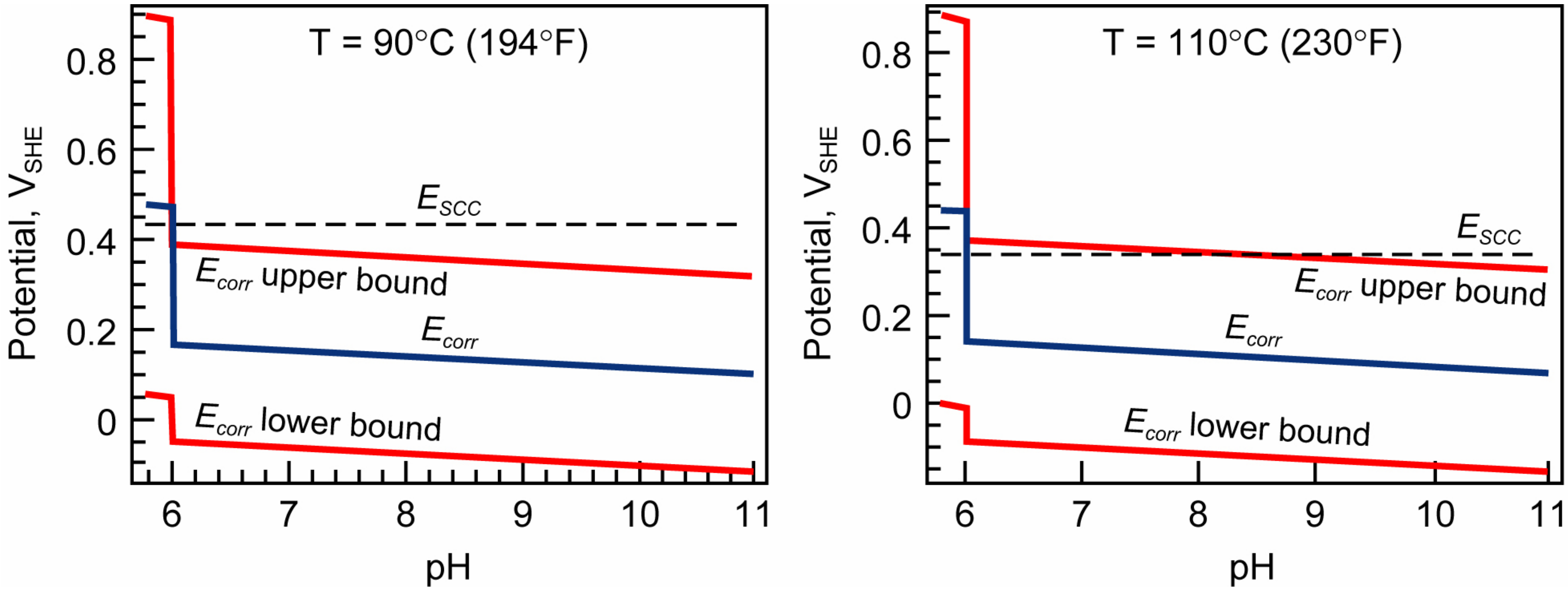
  E_{scc} (V_{SHE}) = [1 - 0.0084 (T - 65)]×0.55

E_{corr} and E_{scc} as Function of pH and Temperature

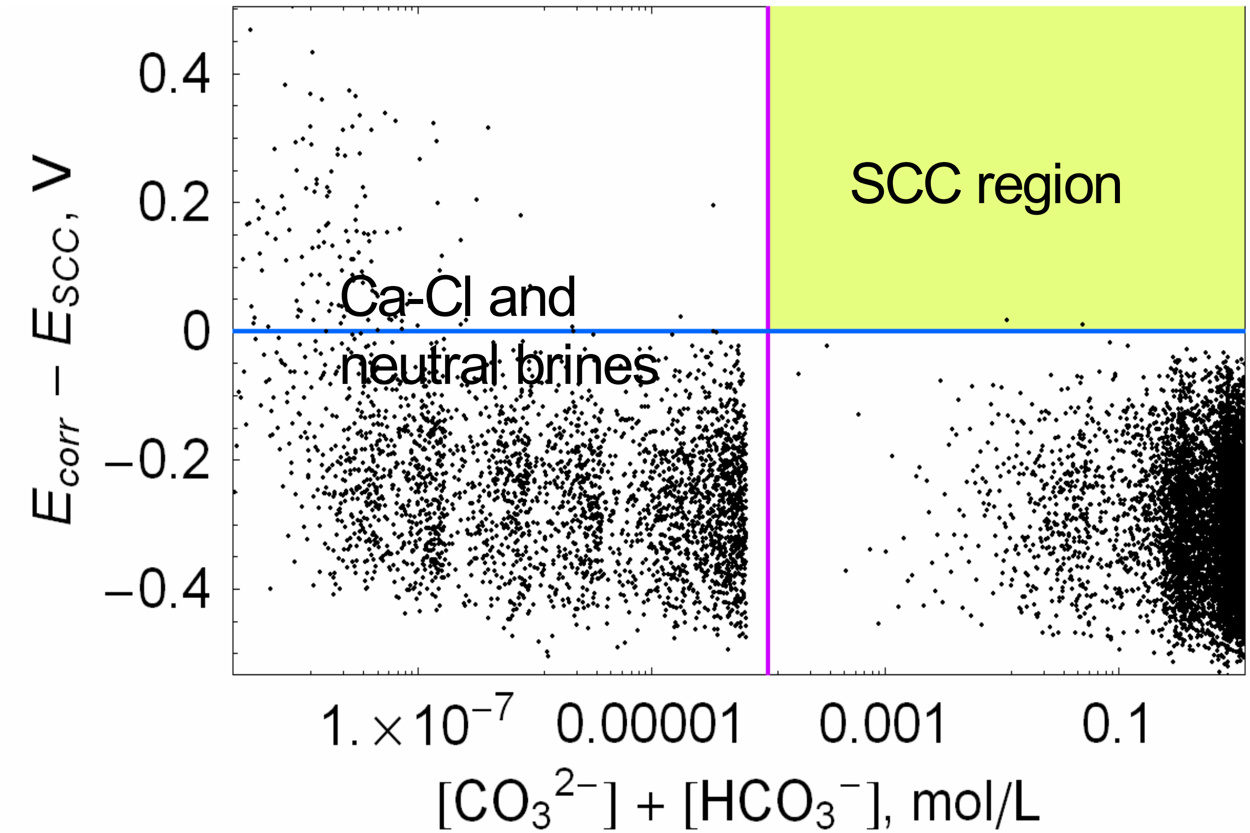
Criteria for SCC Initiation: $E_{corr} - E_{scc} \geq 0$

E_{corr} : Corrosion Potential (Solid Line)

E_{scc} : Critical Potential for SCC Initiation (Dash Line)



Scatter Plot of $E_{corr}-E_{scc}$ Versus $[CO_3^{2-}]+[HCO_3^{-}]$ Derived From Monte Carlo Analysis



- Monte Carlo Analysis Indicated Estimated Probability of 10^{-4} for (i) $E_{corr} > E_{SCC}$ and (ii) Chloride Solution With Sufficient Carbonate-Bicarbonate Ions Forms During Thermal Pulse.

Summary and Conclusions

- Slow Strain Rate Tests Showed That Two Major Anionic Constituents of Yucca Mountain Groundwater, HCO_3^- and Cl^- Ions Act Synergistically to Promote Transgranular SCC of Alloy 22 in SCW.
- Initiation of SCC in Alloy 22 Requires Sufficient Concentrations of Chloride and Bicarbonate Ions in Groundwaters, High Anodic Potentials and High Temperatures.
- A Preliminary SCC Initiation Model Was Developed Based on Slow Strain Rate Test Results.
- Monte Carlo Analyses Indicated a Low Probability ($\sim 10^{-4}$) to Attain Necessary Conditions Required for SCC Initiation During Thermal Pulse Period.

Acknowledgments

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