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Localized Corrosion Initiation and Propagation Tests

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NWTRB Workshop on Localized Corrosion
of Alloy 22 in Yucca Mt. Environments
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Outline

- Introduction
  - Key Points
  - NRC/CNWRA Model for Alloy 22 Localized Corrosion
- Test Methods and Test Results
  - Localized Corrosion Initiation
  - Localized Corrosion Propagation
- Conclusions

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Key Points

- Localized corrosion susceptibility of Alloy 22 was affected by several factors
  - Temperature
  - pH
  - Ratio of chloride concentration to concentration of inhibitors (NO_3^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-)
  - Fabrication processes

- Strong tendency toward stifling and repassivation of localized corrosion was observed
  - 5 M NaCl solution at 95 °C
  - Uncertainties remain in elevated temperature and more aggressive chemical conditions

NRC/CNWRA Model for Alloy 22 Localized (Crevice) Corrosion

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- It is considered that localized corrosion initiates if $E_{corr} > E_{rcrev}$

E_{corr} — corrosion potential in an aerated environment

E_{rcrev} — repassivation potential for crevice corrosion, critical potential to initiate crevice corrosion

- Localized corrosion propagation typically conforms to

$$d = kt^n$$

d— penetration depth
t — time
n — time exponent, 0<n<1
k — coefficient

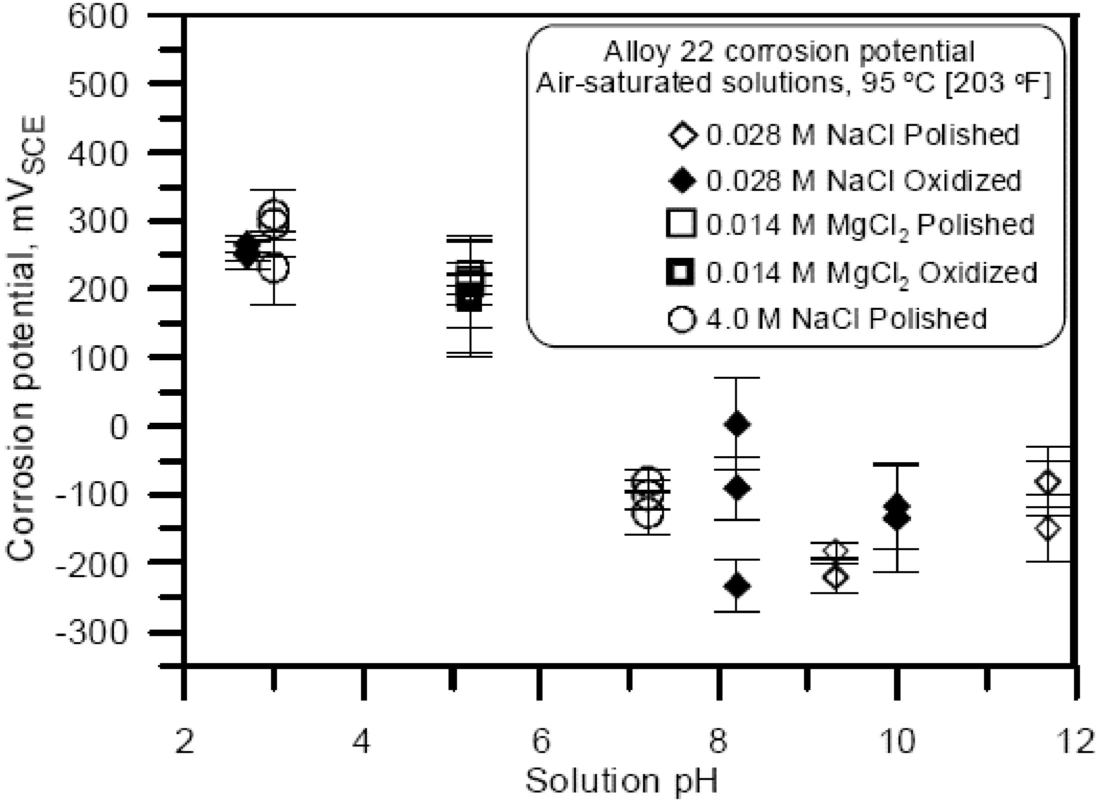
n = 0.5 for a diffusion controlled process

- Total-system Performance Assessment (TPA) code

$$d = kt^n$$

n = 1 and *K* = 0.25 mm/yr

Localized Corrosion Initiation —
Corrosion Potentials and pH



- E_{corr} in acidic condition was more than 300 mV greater than that in alkaline solutions

Corrosion Potentials and Temperature

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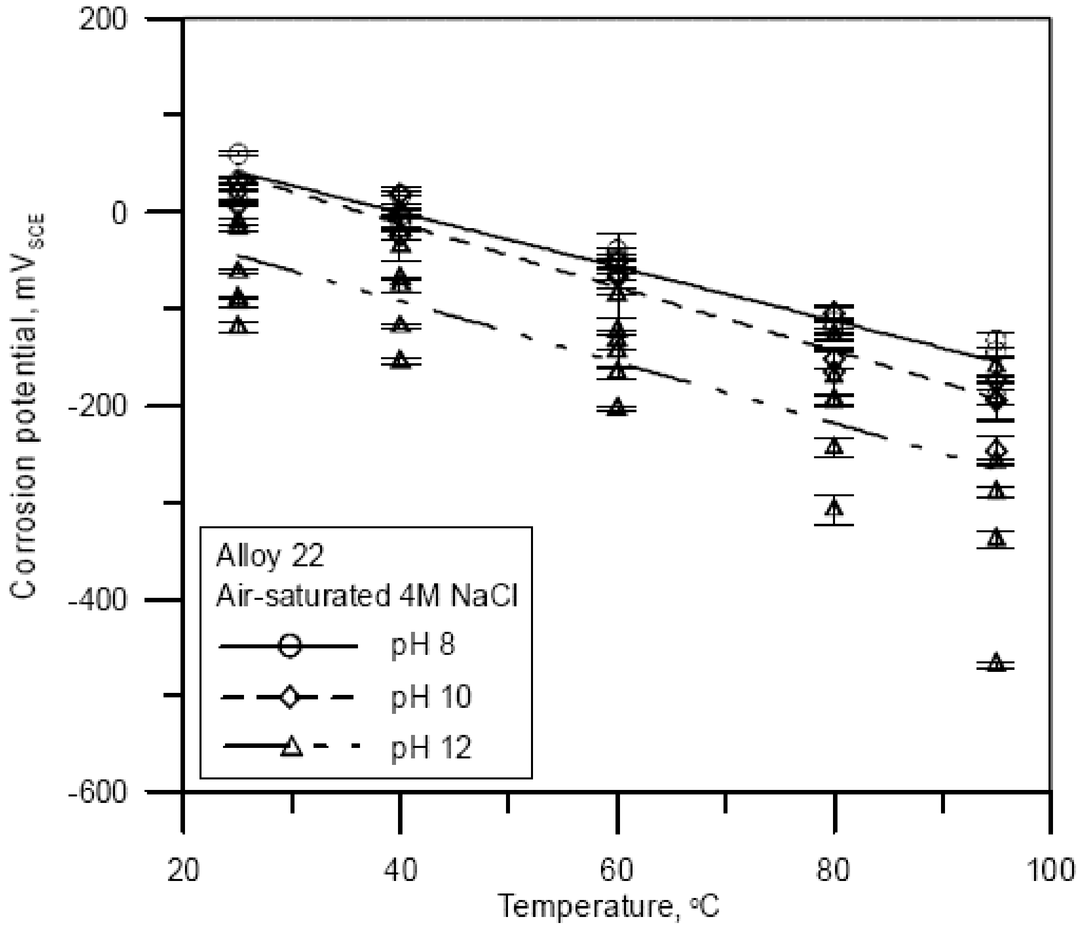

- E_{corr} decreased with increasing temperature
- E_{corr} values at 25 °C were approximately 150 to 200 mV greater than the values at 95 °C

Repassivation Potential Measurement Method

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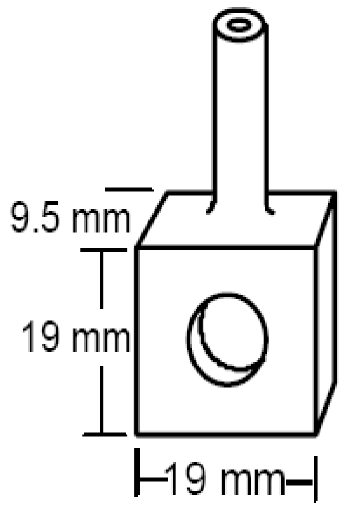
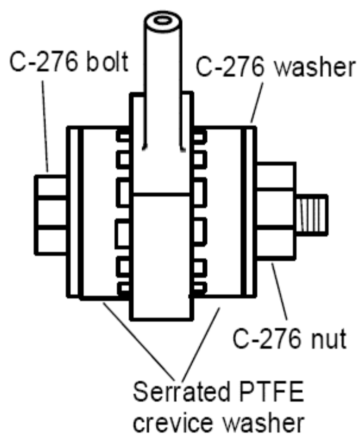
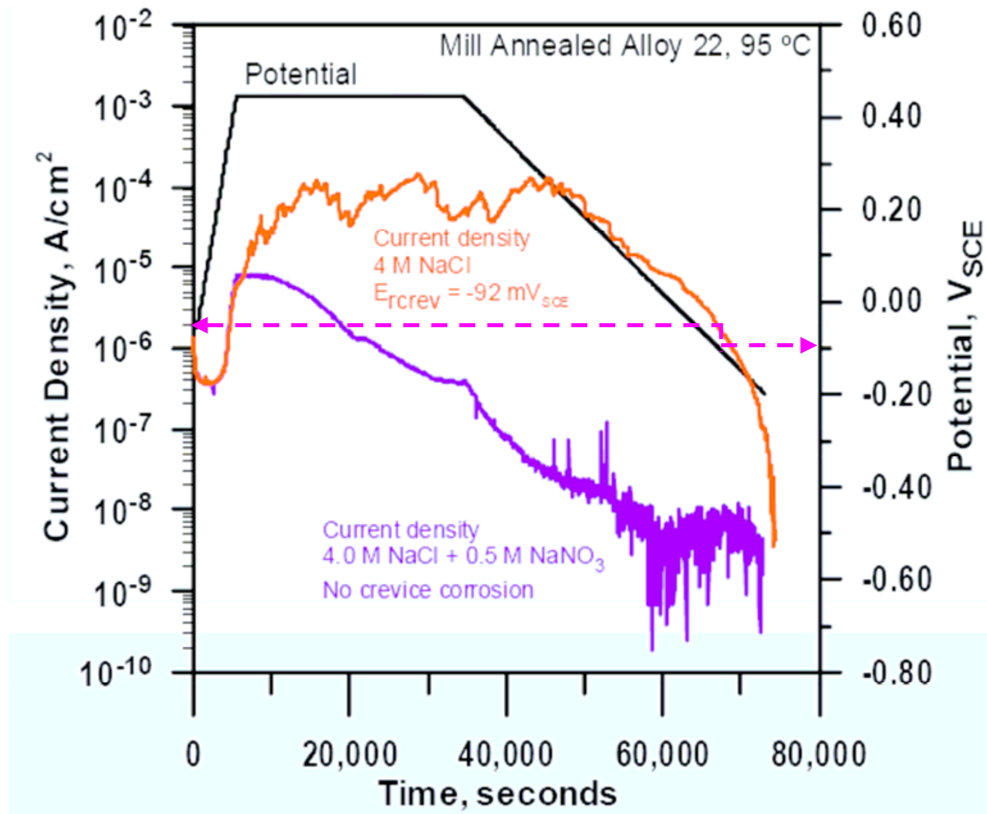
Multiple Crevice Assembly (ASTM G78)







- Electrochemical tests used to measure repassivation potential for assessing crevice corrosion

Repassivation Potentials and Effects of Fabrication Processes

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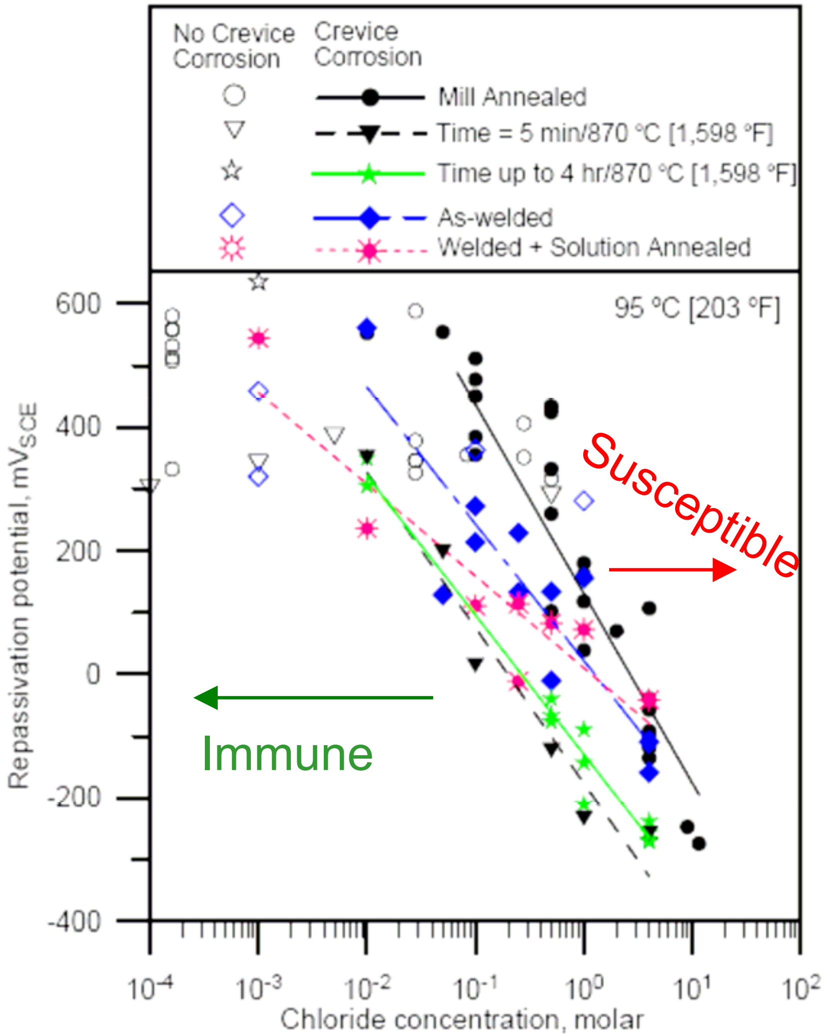
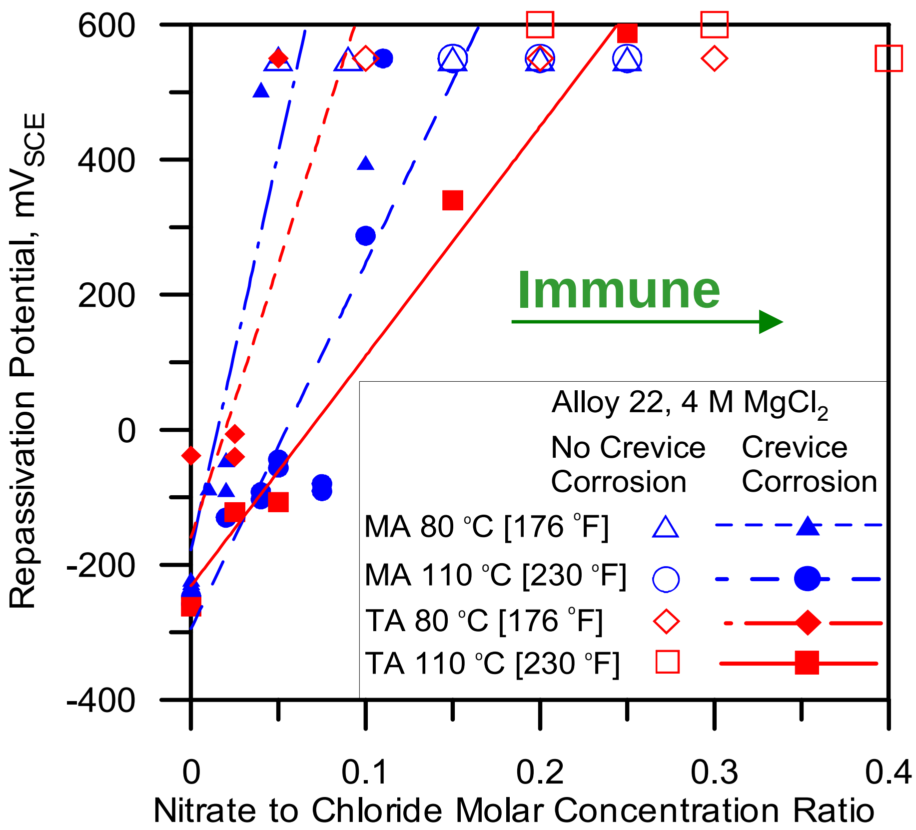


- Repassivation potential used as critical potential for the long-term initiation of localized corrosion
- Crevice corrosion susceptibility increases with increasing chloride concentration
- Fabrication processes such as welding, postweld heat treatments, and thermal-aging increase crevice corrosion susceptibility

Repassivation Potentials and Nitrate to Chloride Concentration Ratios



At 110 °C

- [Nitrate]/[Chloride] > 0.1 no localized corrosion for mill-annealed
- [Nitrate]/[Chloride] > 0.3 no localized corrosion for thermally aged

At 80 °C

- [Nitrate]/[Chloride] > 0.1 no localized corrosion for mill-annealed
- [Nitrate]/[Chloride] > 0.1 no localized corrosion for thermally aged

Dissimilar or Similar Metal Coupling

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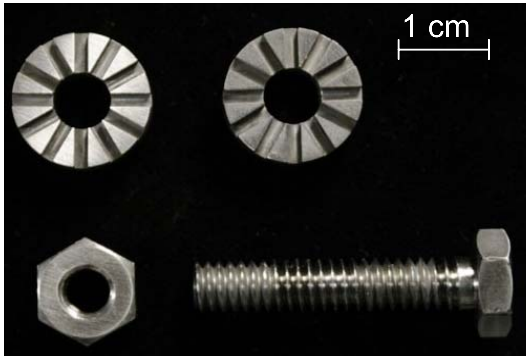
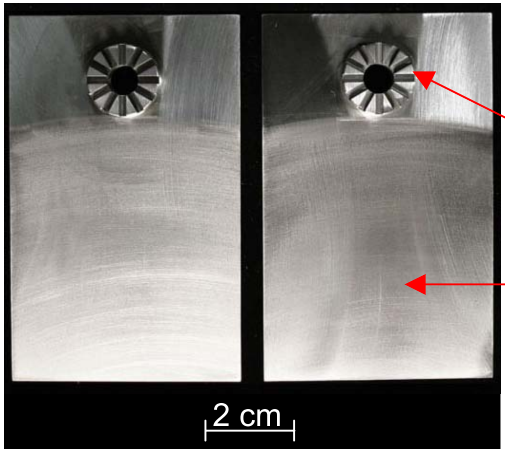
Crevice Specimen

Serrated Crevice Washer, Bolt, and Nut



Large Titanium Grade 7 Washer



Protruding serrated plateaus

Flange to increase surface area

Corrosion of Alloy 22, Ti Grade 7, and Alloy 22-to-Ti Grade 7 Crevice Couples

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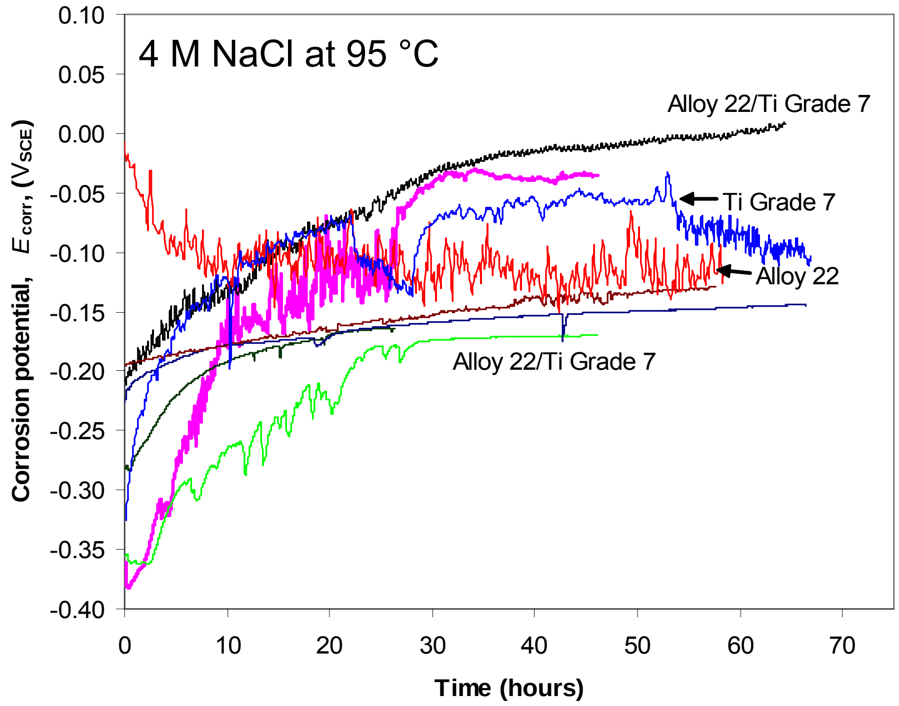

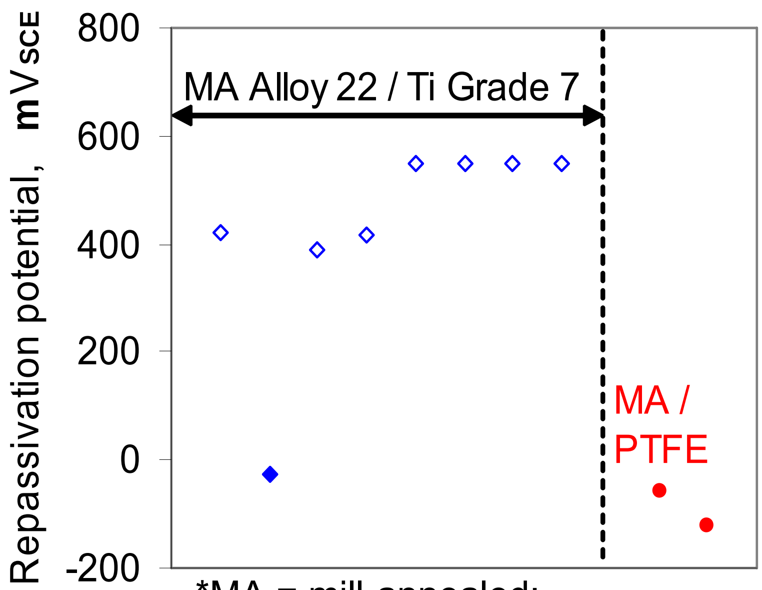

*MA = mill-annealed;

PTFE = polytetrafluoroethylene

- No effect of Alloy 22-to-Ti Grade 7 crevice couple on corrosion potential
- Alloy 22 crevice corrosion resistance was not degraded by forming crevices with Titanium Grade 7

Localized Corrosion Propagation — Experimental Setup

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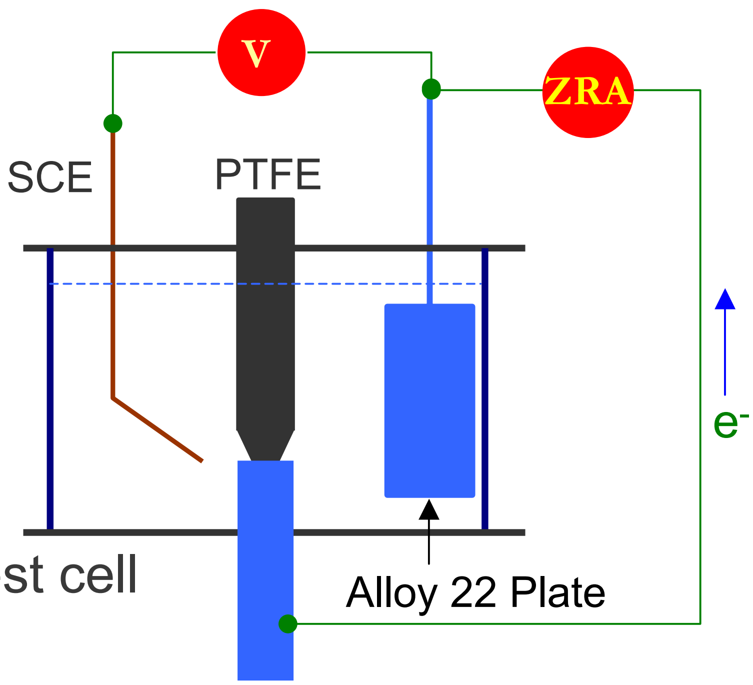
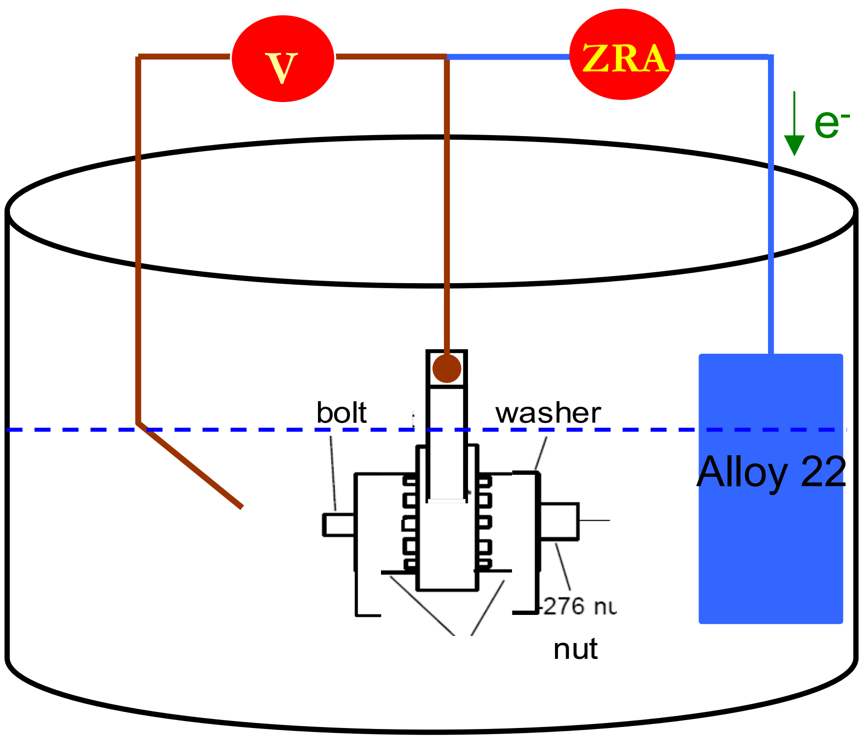
Single Crevice Assembly



Multiple Crevice Assembly



- Solution: 5 M NaCl + 2×10^{-4} M $CuCl_2$
- Temperature: 95 °C
- Test time: 0.5 – 90 days

Crevice Corrosion Propagation, Stifling, and Repassivation

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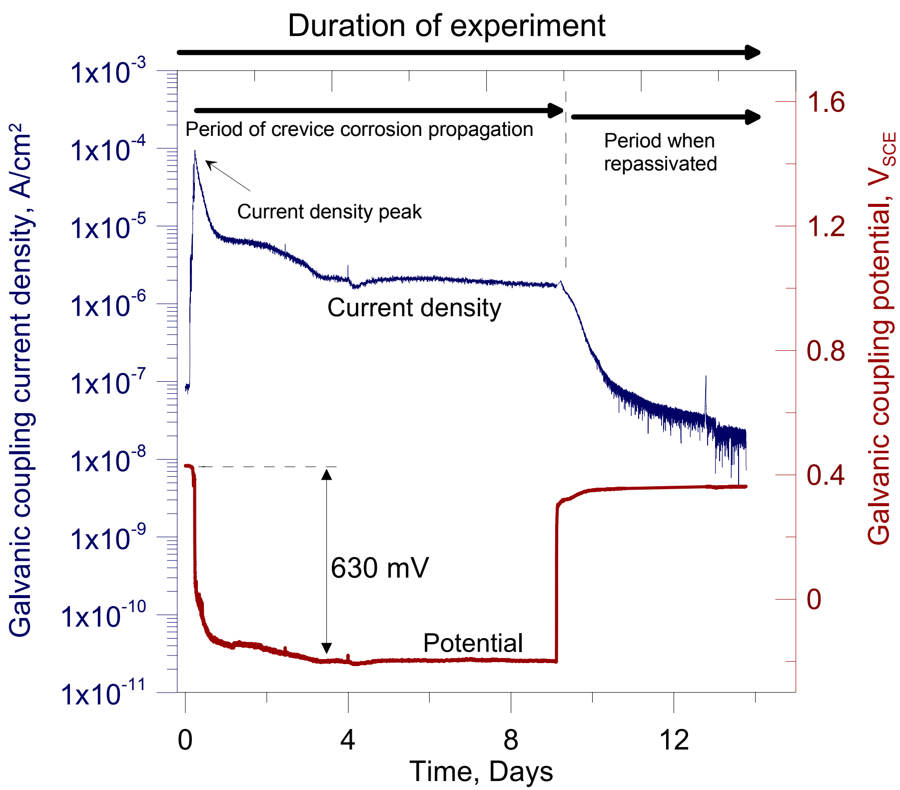
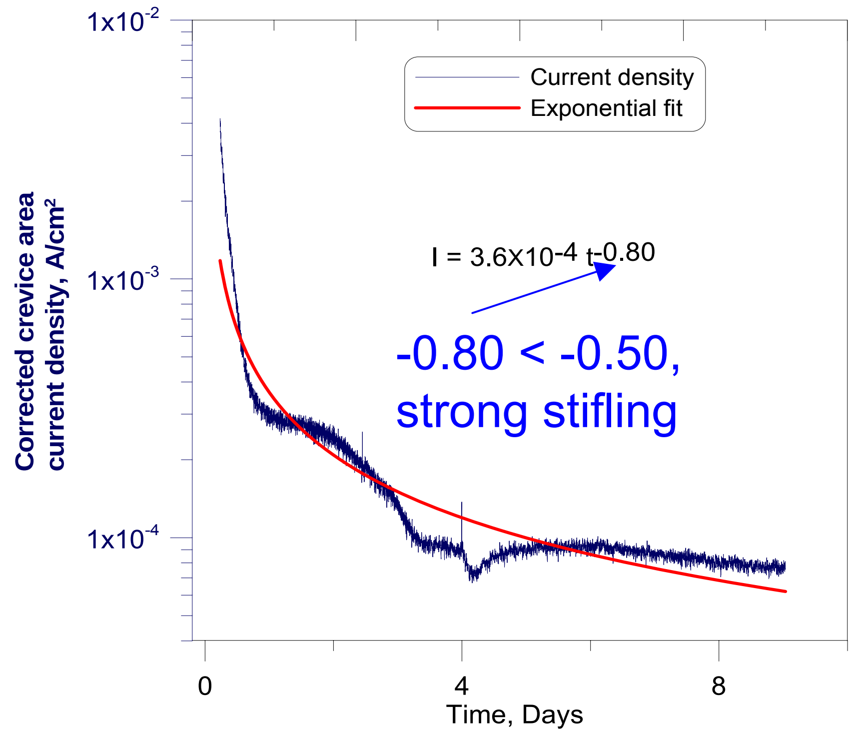
Initiation, propagation, and repassivation



Current density decay



- Strong stifling after initiation
- Arrest at 9 days and no re-initiation (Arrest refers to a stop in penetration, e.g. repassivation)

Crevice Corrosion Penetration Behavior

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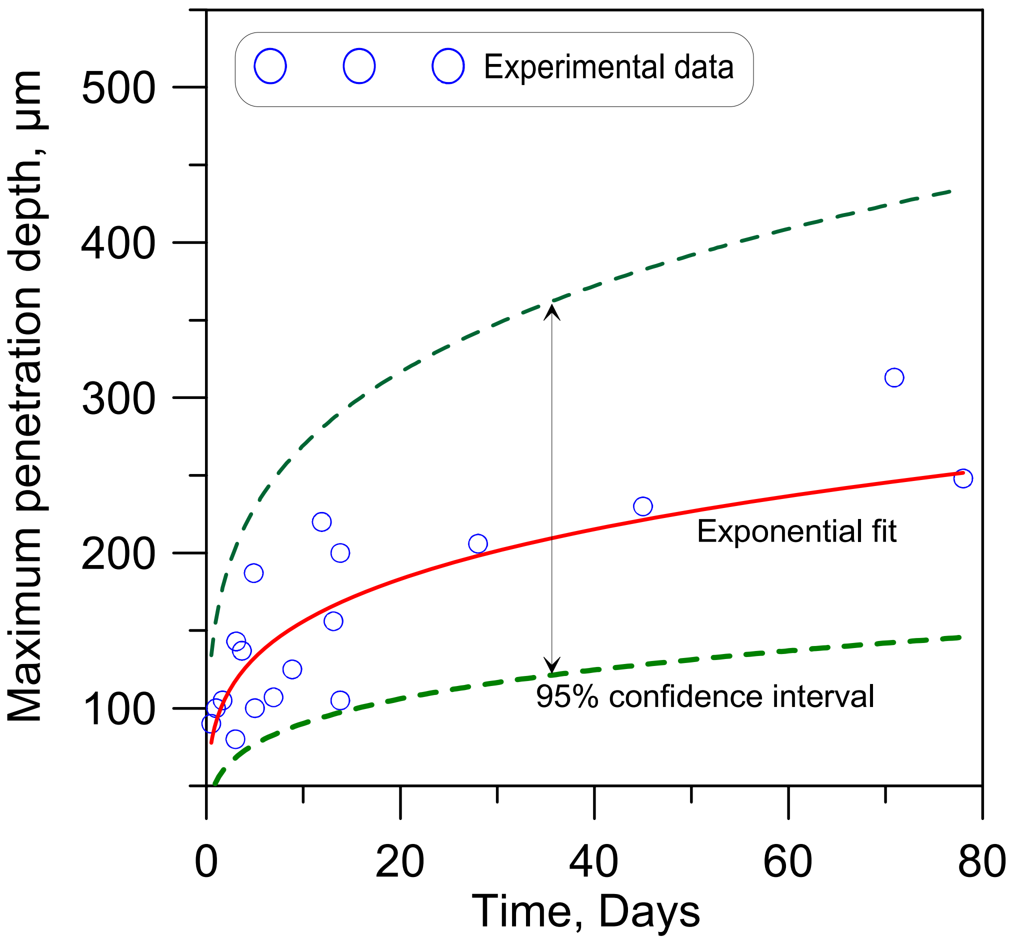

- Tests were conducted for specific time intervals
- Penetration depths were measured with an optical microscope
- Fitted equation

$$d_{max} = 0.0912\ t^{\,0.233}$$

d_{max} — Maximum penetration depth in mm

t — time in days

- 0.233 < 0.5, suggesting strong stifling tendency

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Conclusions

- Localized corrosion susceptibility of Alloy 22 was affected by several factors
  - Temperature
  - pH
  - Ratio of chloride concentration to concentration of inhibitors
  - Fabrication processes

- Strong tendency toward stifling and repassivation of localized corrosion was observed in 5 M NaCl solution at 95 °C

- The localized corrosion resistance of Alloy 22 was not degraded by similar or dissimilar metal crevices

Uncertainties Related to Localized Corrosion of Alloy 22

- Impact of dust deliquescence brines
- Tendency toward stifling and repassivation in elevated temperatures and more aggressive chemical conditions
- Applicability of data obtained from experiments in fully-immersed condition to limited-volume (e.g. water-film) systems

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  This presentation is an independent product of the CNWRA and does not necessarily reflect the view or regulatory position of the NRC.

BACKUP SLIDE

Crevice Corrosion Initiation of Dissimilar Metal Crevices

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Crevice Assembly		Coupling large plate	Did crevice corrosion initiate under open circuit condition?	Did crevice corrosion initiate with $CuCl_2$?
Crevice Specimen	Crevice washer			
Alloy 22	Ti Gr. 7	Ti Gr. 7	No	No
W+SA 22*	Alloy 22	Alloy 22	No	No
W+SA 22	Ti Gr. 7	Ti Gr. 7	No	No
W+SA 22	PTFE	Alloy 22	No	Yes, but it was arrested

* W+SA 22 = Welded-plus-solution-annealed Alloy 22

- Crevice corrosion resistance was not degraded by dissimilar metal crevices

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References

Mohanty, S., T.J. McCartin, and D. Esh. "Total-system Performance Assessment (TPA) Version 4.0 Code: Module Descriptions and User's Guide." San Antonio, Texas: CNWRA. 2002.

Dunn, D.S., O. Pensado, Y.-M. Pan, R.T. Pabalan, L. Yang, X. He, and K.T. Chiang. "Passive and Localized Corrosion of Alloy 22—Modeling and Experiments." CNWRA 2005-002. San Antonio, Texas: CNWRA. 2005.

He, X. and D.S. Dunn. "Alloy 22 Localized Corrosion Propagation in Chloride-Containing Waters." CNWRA 2006-001. San Antonio, Texas: CNWRA. 2005.

He, X. and D.S. Dunn. "Alloy 22 Localized Corrosion Propagation in Chloride-Containing Waters." Proceedings of the CORROSION '06 Conference. Paper No. 618. Houston, Texas: NACE International. 2006.

He, X., D.S. Dunn, and A.A. Csontos. "Corrosion of Similar and Dissimilar Metal Crevices in the Engineered Barrier System of a Potential Nuclear Waste Repository." *Electrochimica Acta* (in review). 2006.