Potentiodynamic Polarization and Galvanic Coupling to Evaluate Localized Corrosion of Alloy 22 in Chloride Solutions

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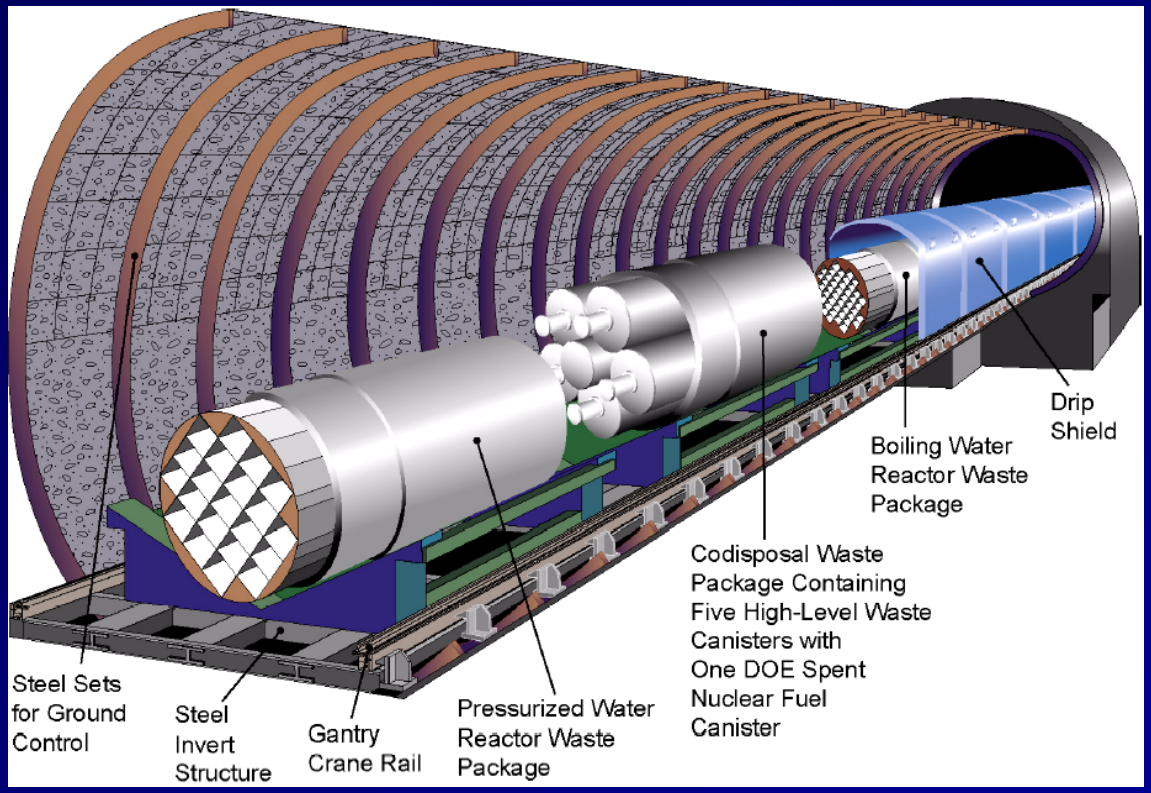
Outline

- Background
- Objectives
- Experimental Methods
  - Critical potential measurements
  - Crevice corrosion propagation
- Experimental Results on Alloy 22 Crevice Corrosion in Contact With Similar and Dissimilar Metals

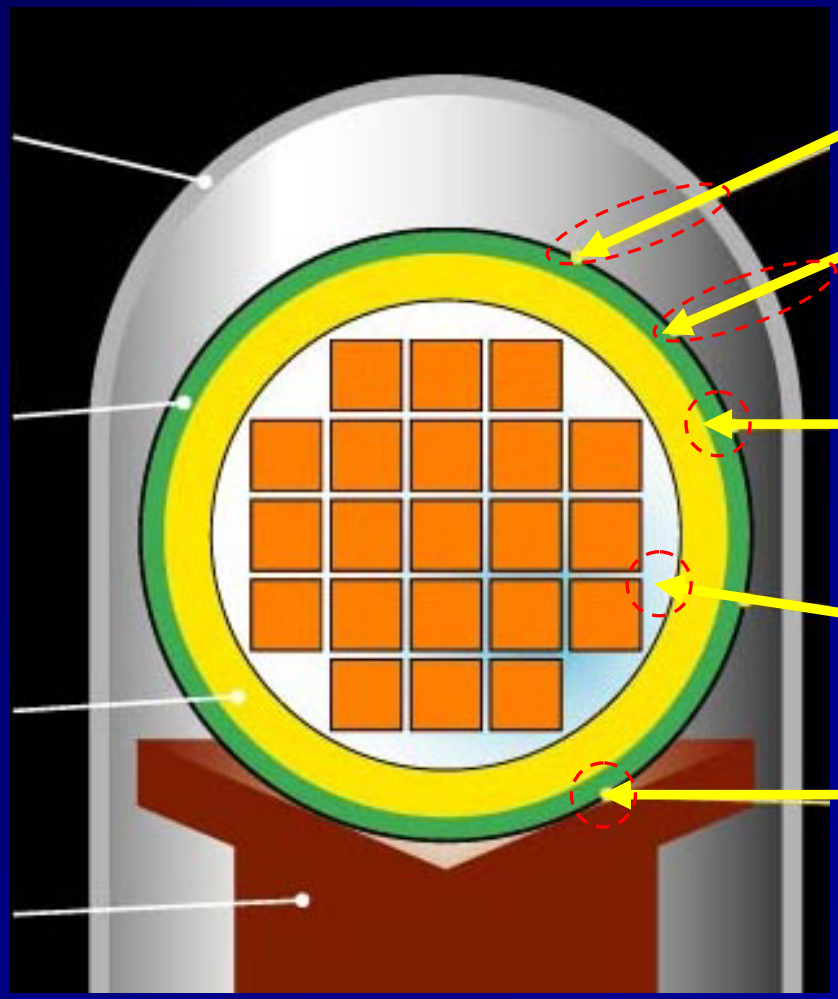
U.S Department of Energy Potential Engineered Barrier System for Yucca Mountain Repository



- Potential waste package
  - Alloy 22 outer container
  - 316L nuclear grade stainless steel (SS) inner vessel
- Potential drip shield
  - Titanium Grade 7
  - Titanium Grade 24/29

U.S. Department of Energy (2002)

Potential Similar and Dissimilar Metal Crevices



- Titanium Grade 7 to Alloy 22
- Titanium Grade 24/29 to Alloy 22
- Alloy 22 to 316L SS
- 316L SS to Carbon Steel
- Alloy 22 to Alloy 22
- Zircaloy to 316L SS

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

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

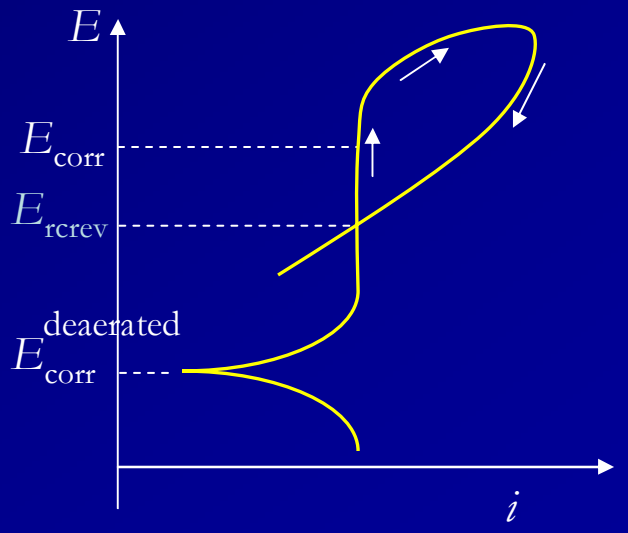
E_{corr} — corrosion potential in an aerated environment

$E_{corr} = f\,(T, pH, P_{O_2})$

E_{rcrev} — repassivation potential for crevice corrosion

$E_{rcrev} = f\,(T, [Cl^-], [Inhibitors])$

Typical Potentiodynamic Polarization Curve in Deaerated Solution



Inhibitors: NO_3^-, CO_3^{2-}, HCO_3^-, SO_4^{2-}

Objectives

- Evaluate the effect of realistic similar- and dissimilar-metal crevices on crevice corrosion of Alloy 22, including
  - Mill-annealed
  - Welded-plus-solution-annealed

  In contact with
  - 316L SS
  - Titanium Grade 7

- Compare with previous crevice corrosion data on Alloy 22-to-polytetrafluoroethylene (PTFE) crevice

Chemical Composition of Materials (Weight Percent)

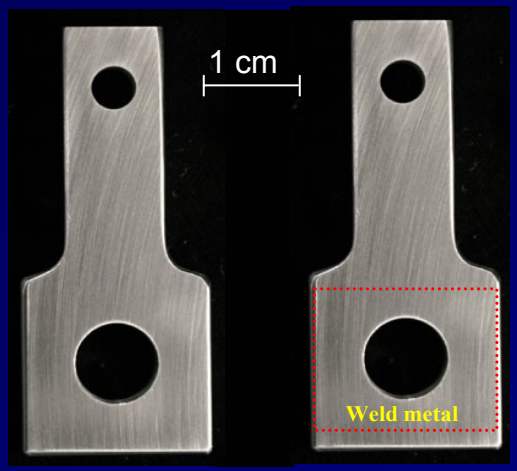
Material	Ni	Cr	Mo	W	Fe	Co	Si	Mn	V	P	S	C
Alloy 22 Heat 2277-3-3266	Bal	21.4	13.3	2.81	3.75	1.19	0.03	0.23	0.14	0.008	0.004	0.005
Alloy 22 Heat 2277-3-3292	Bal	21.2	13.6	2.96	3.69	1.32	0.02	0.23	0.13	0.005	0.003	0.005
Alloy 622 Weld Filler Wire WN813	Bal	22.2	13.7	3.13	2.37	0.41	0.02	0.34	0.01	0.003	0.001	0.003
316L Stainless Steel Heat P80746	10.0	16.3	2.07	NA	Bal	NA	0.49	1.58	NA	0.026	0.018	0.014

	Ti	Pd	Fe	C	N	O	H
Titanium Grade 7	Bal	0.16	0.08	0.01	0.01	0.13	0.001

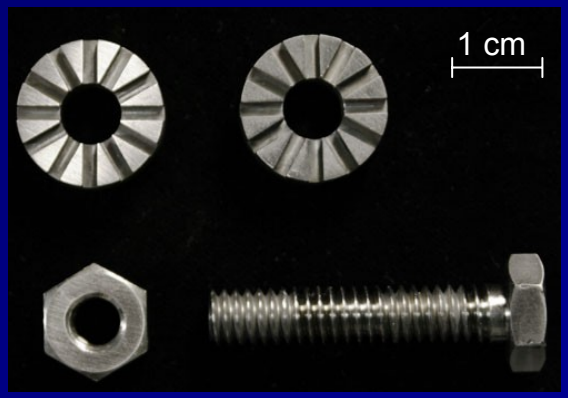
Part I. Critical Potential Measurements (E_{corr} and E_{rcrev})

Experimental Methods: Metal-to-Metal Crevice Assemblies for E_{corr} and E_{rcrev} Measurement

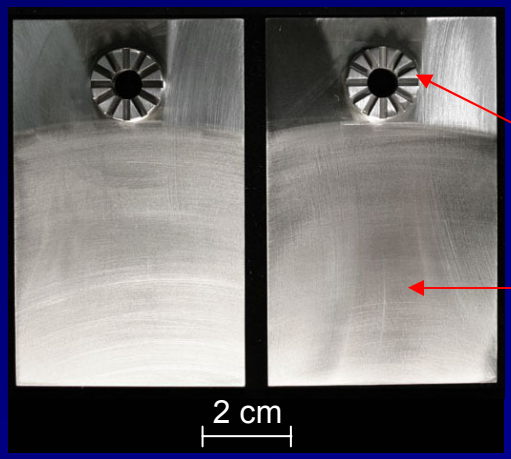
Crevice Specimen



Serrated Crevice Washer, Bolt, and Nut



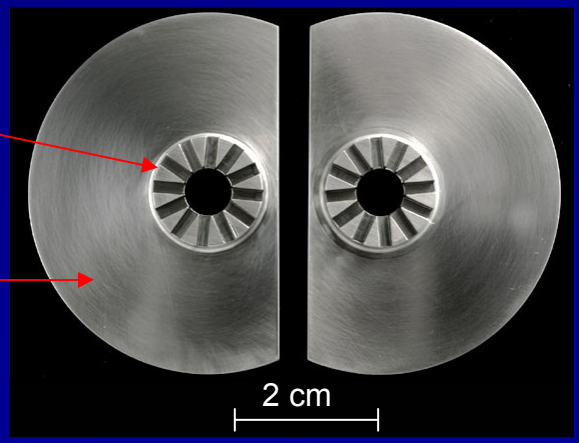
Large Titanium Grade 7 Washer



Protruding serrated plateaus

Flange to increase surface area

Large Alloy 22 Washer



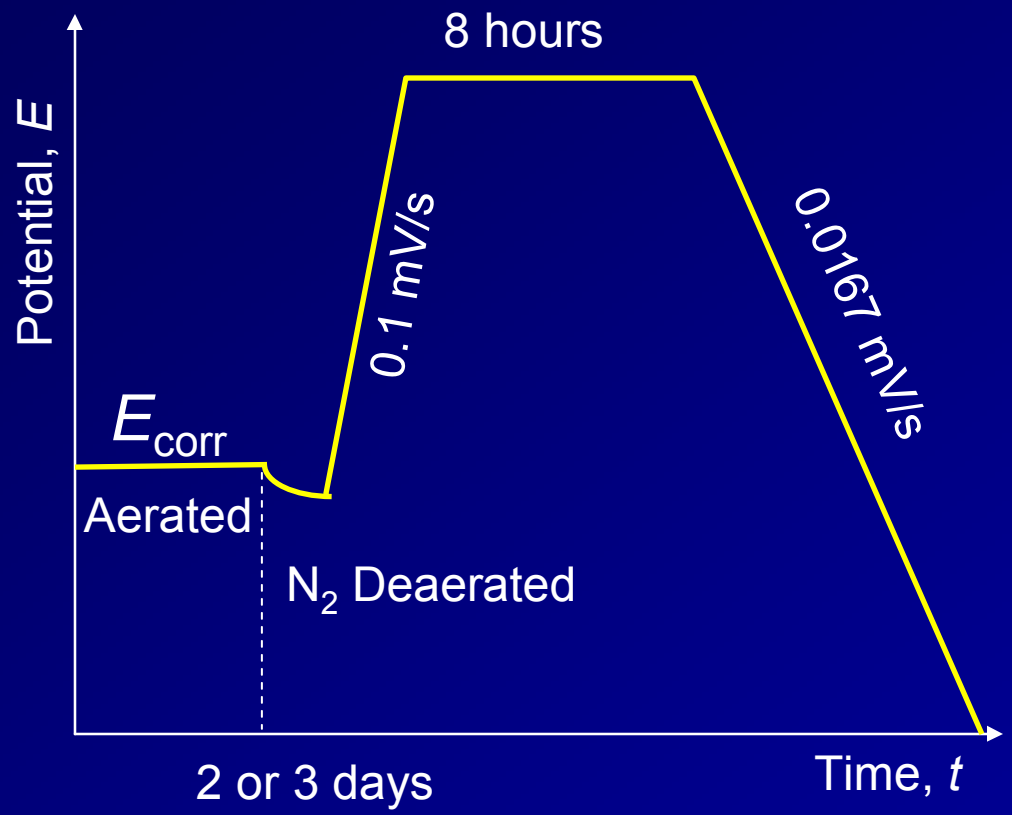
Experimental Methods: E_{corr} and E_{rcrev} Measurement

- Variables evaluated
  - Surface area ratios of crevice specimen-to-crevice washer: 1:3, 1:10, 1:18
  - Torque: 0.35 N·m [3.1 in·lb] vs. 8.4 N·m [75 in·lb] (ASTM 78*)
- Solution and temperature: 4 M NaCl solution at 95 °C [203 °F]
- Solution annealing of welded Alloy 22 at 1,125 °C [2,057 °F] for 20 minutes

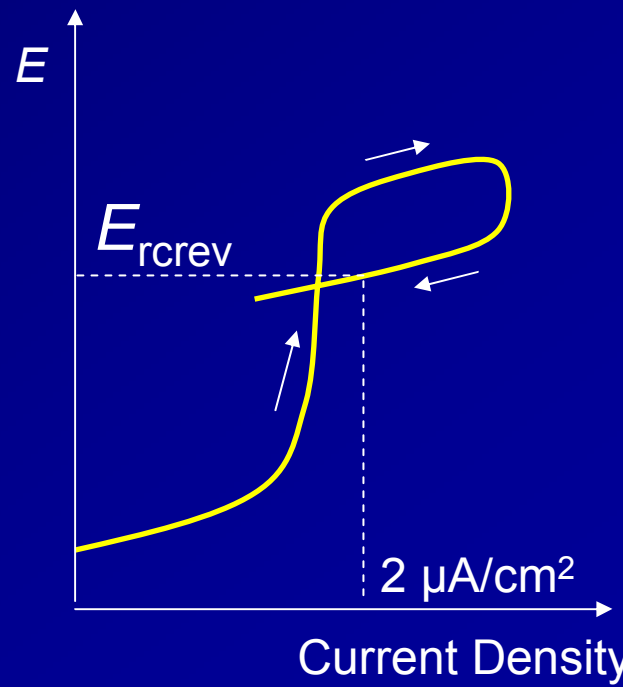
*Standard Guide for Crevice Corrosion Testing of Iron-Base and Nickel-Base Stainless Alloys in Seawater and Other Chloride-Containing Aqueous Environments

Experimental Methods: E_{corr} and E_{rcrev} Measurement (Continued)

Sequence of E_{corr} and E_{rcrev} measurement

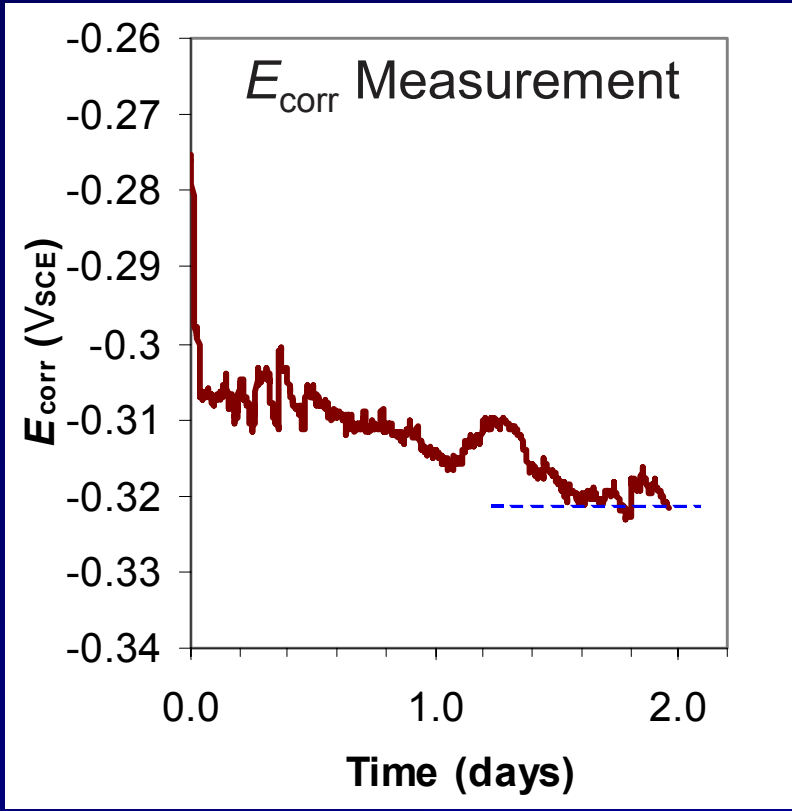


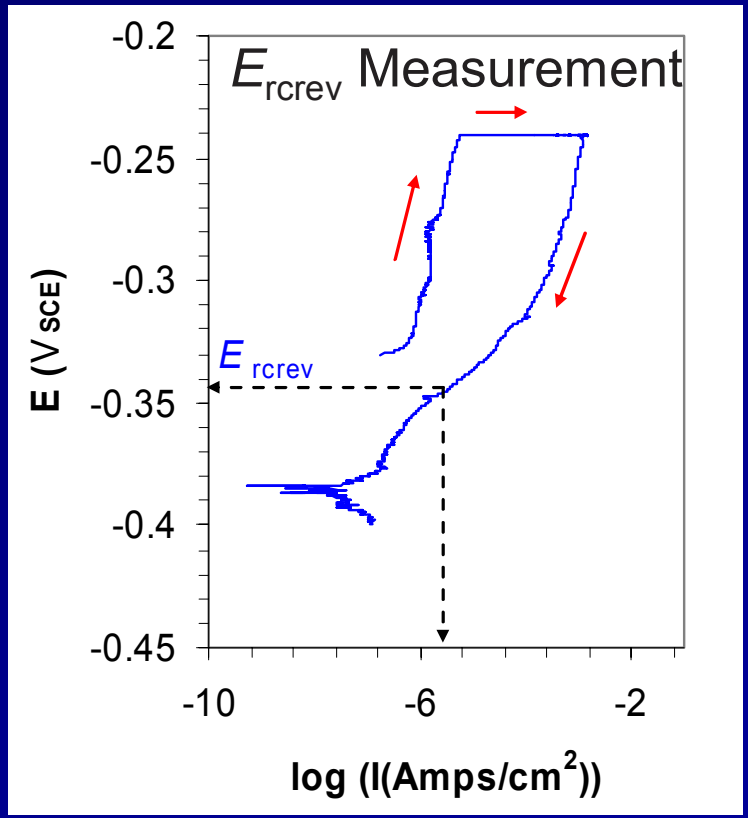
Determine E_{rcrev} from the potentiodynamic polarization curve



Experimental Results: 316L SS-to-Alloy 22 Crevice

$Area_{316L\ SS}$: $Area_{Alloy\ 22}$ = 3:1; Torque = 0.35 N·m [3.1 in·lb]

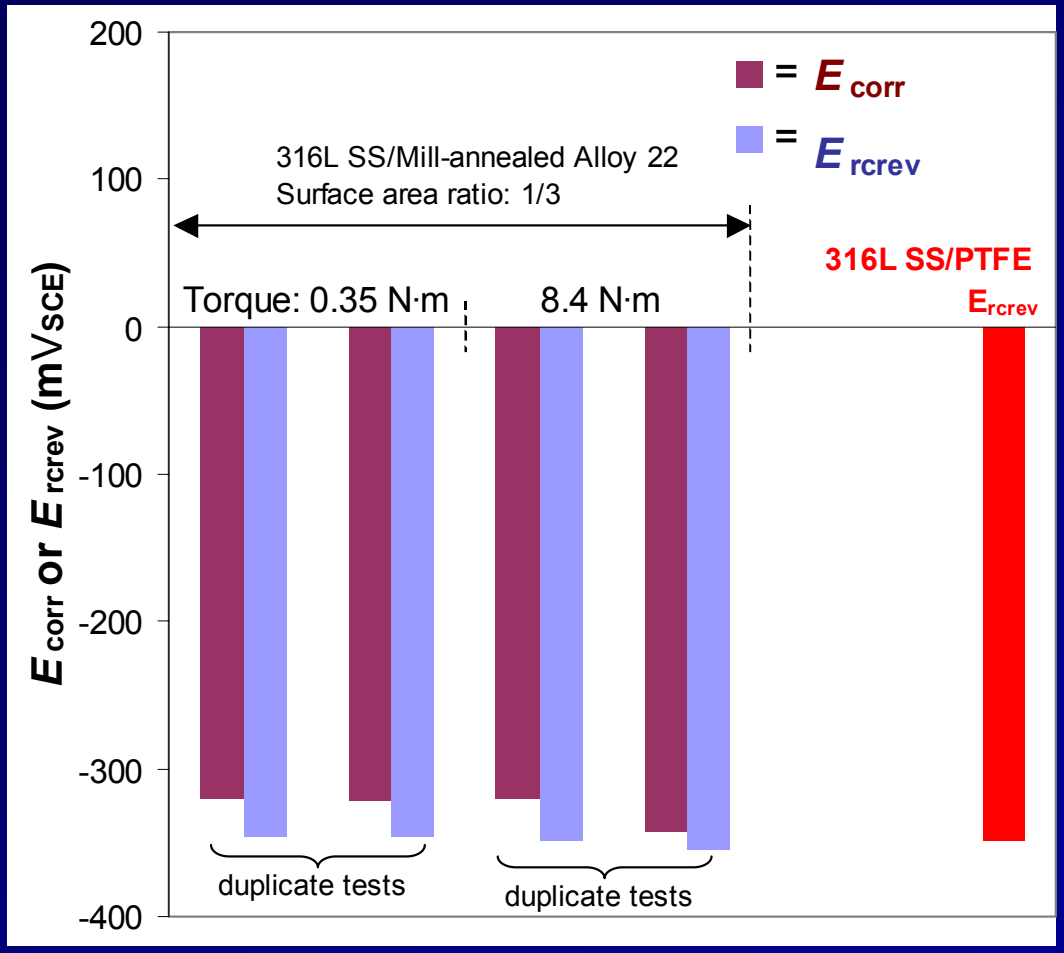




E_{corr} = -321 mV_{SCE}

E_{rcrev} = -346 mV_{SCE}

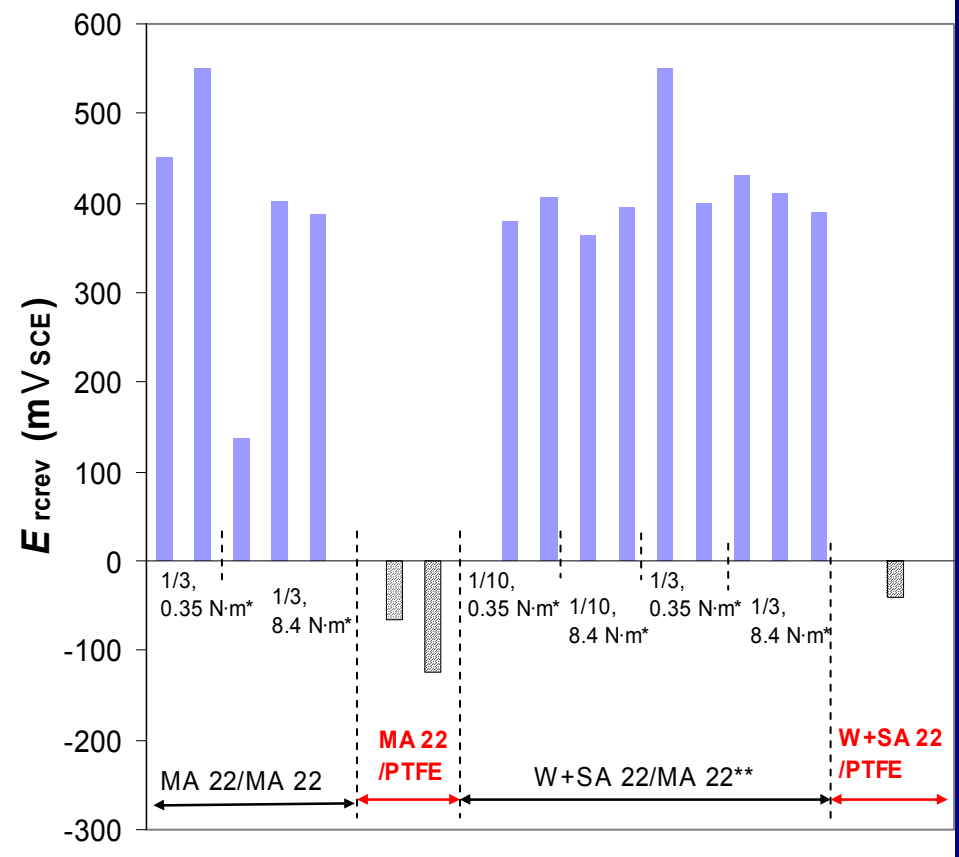
E_{corr} and E_{rcrev} of 316L SS-to-Alloy 22 Crevice



- E_{corr} > E_{rcrev} by 20 – 30 mV
- E_{rcrev} for 316L SS-to-Alloy 22 crevice ≈ E_{rcrev} for 316L SS-to-PTFE crevice
- Posttest examination
  - No corrosion on Alloy 22
  - Severe crevice corrosion on 316L SS

E_{corr} and E_{rcrev} of Alloy 22-to-Alloy 22 Crevice

E_{corr} : -200 – 0 mV_{SCE}

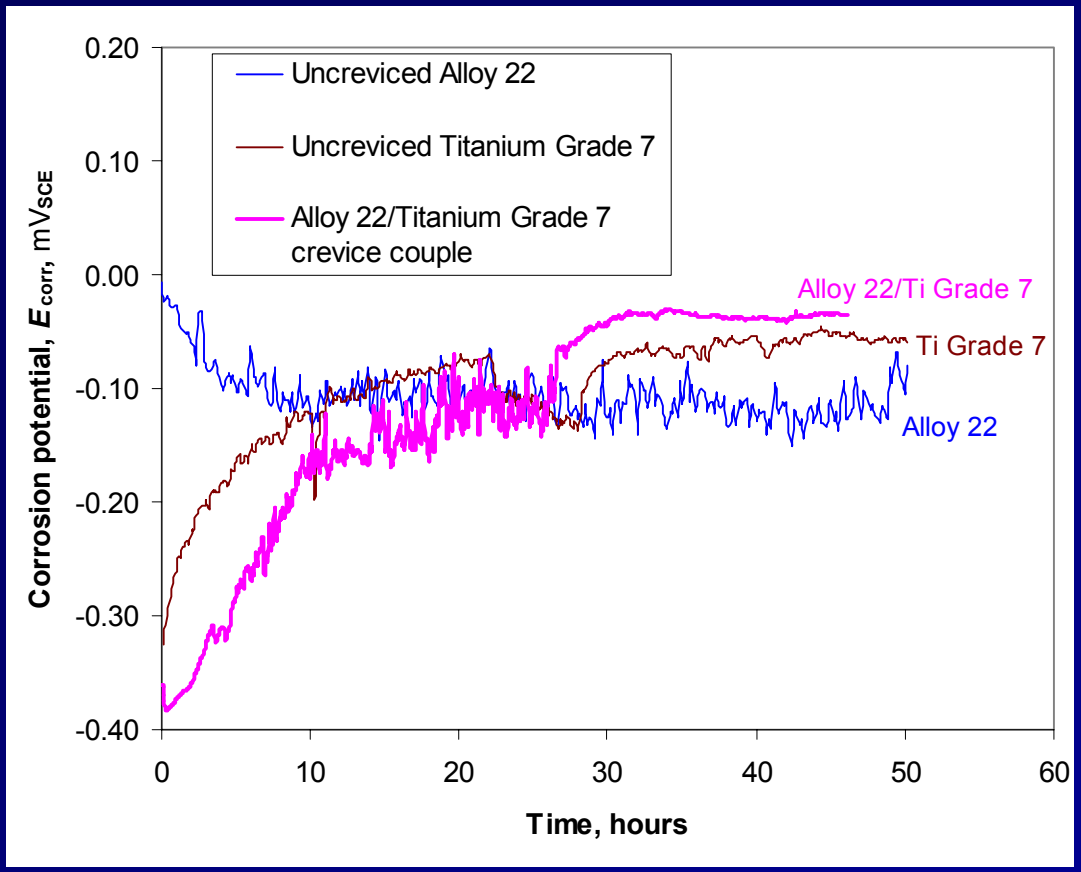


- E_{rcrev} > E_{corr}
- E_{rcrev} for metal-to-Alloy 22 > E_{rcrev} for metal-to-PTFE
- No observable difference between mill-annealed and welded-plus-solution-annealed Alloy 22
- No effect of surface area ratio and torque

*Surface area ratio and torque

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

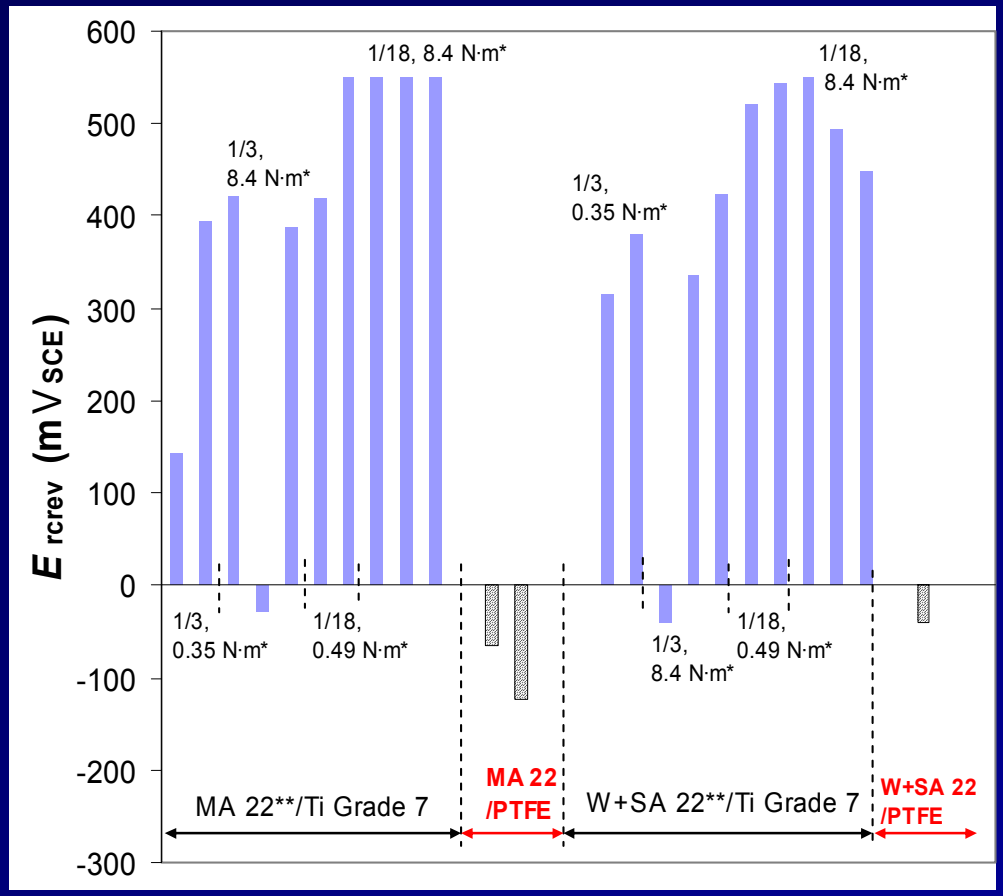
E_{corr} of Uncreviced Alloy 22, Ti Grade 7, and Alloy 22-to-Ti Grade 7 Crevice



- Corrosion potential of Alloy 22/Ti Grade 7 crevice couple shifted in noble direction
- No difference from uncreviced Alloy 22 and Ti Grade 7

E_{corr} and E_{rcrev} of Alloy 22-to-Ti Grade 7 Crevice

E_{corr} : -200 – 0 mV_{SCE}



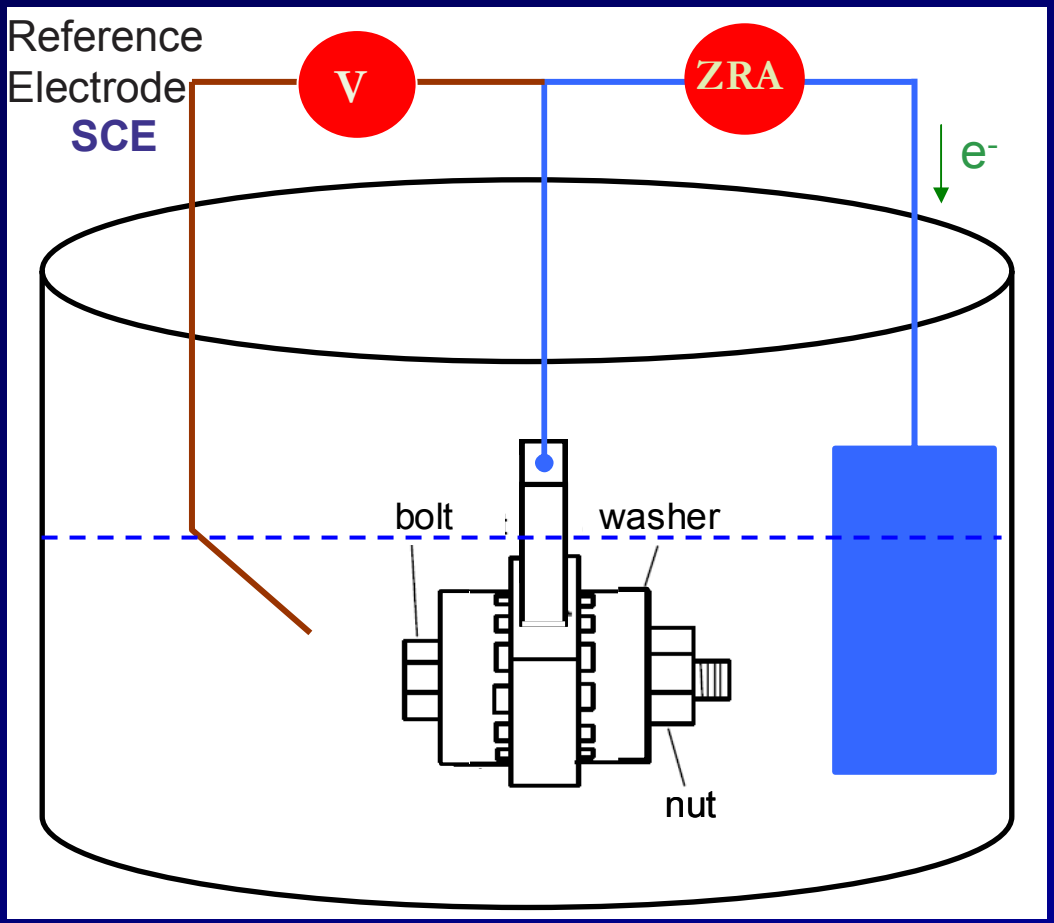
- $E_{rcrev} > E_{corr}$
- E_{rcrev} for metal-to-Ti Grade 7 > E_{rcrev} for metal-to-PTFE
- No observable difference between mill-annealed and welded-plus-solution-annealed Alloy 22
- No effect of surface area ratio and torque

*Surface area ratio and torque

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

Part II. Galvanic Coupling to Evaluate Alloy 22 Localized Corrosion Propagation

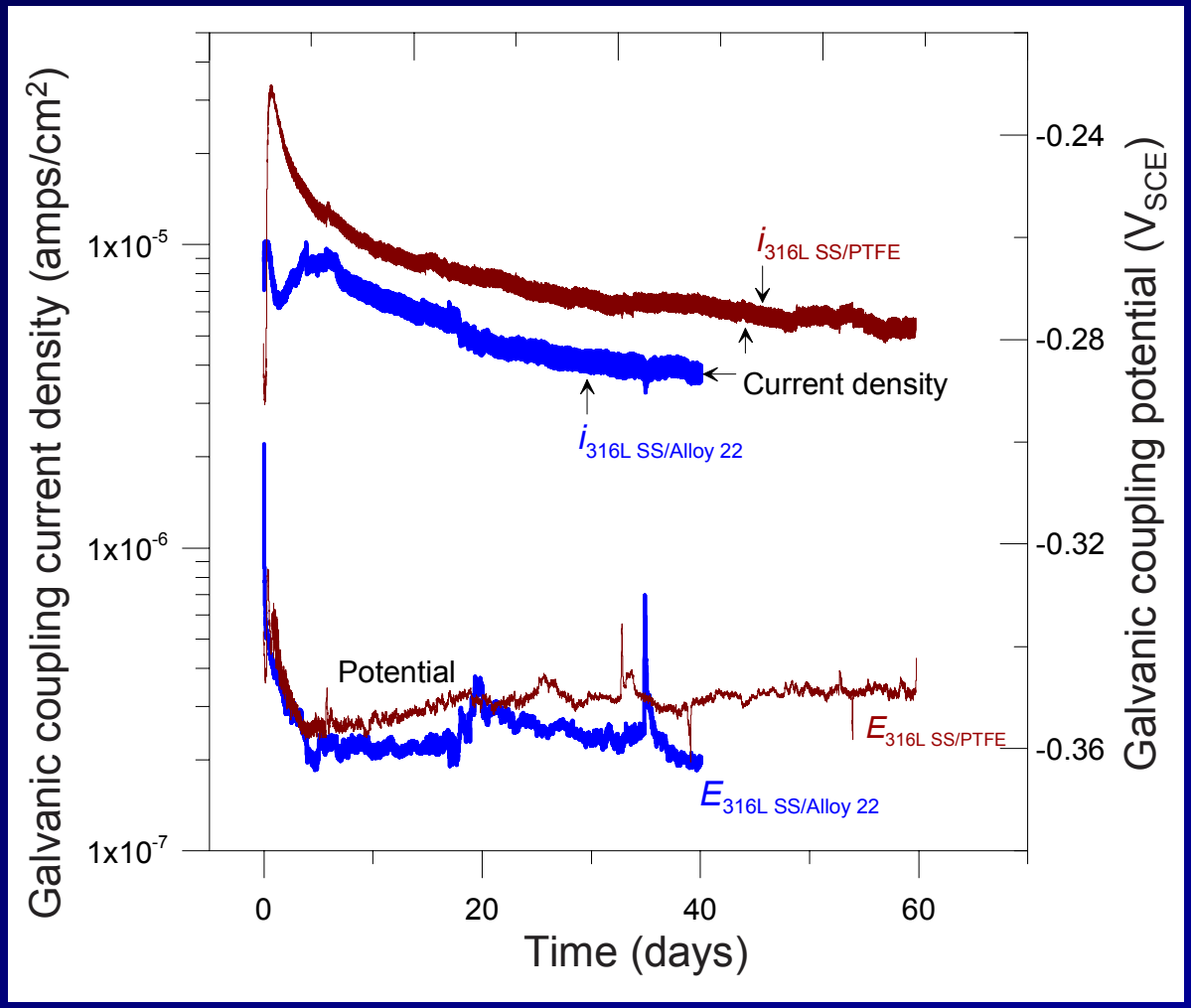
Experimental Method: Galvanic Coupling



- Solution and temperature: 5 M NaCl at 95 °C

- Potentiostat functions as a zero resistance ammeter (ZRA)
- Test metal: Alloy 22 or 316L SS
- Crevice washer: Alloy 22, Titanium Grade 7, or PTFE
- Large coupling plate: Alloy 22 or Titanium Grade 7

Galvanic Coupling Between Large Alloy 22 Plate and Creviced 316L SS Specimens

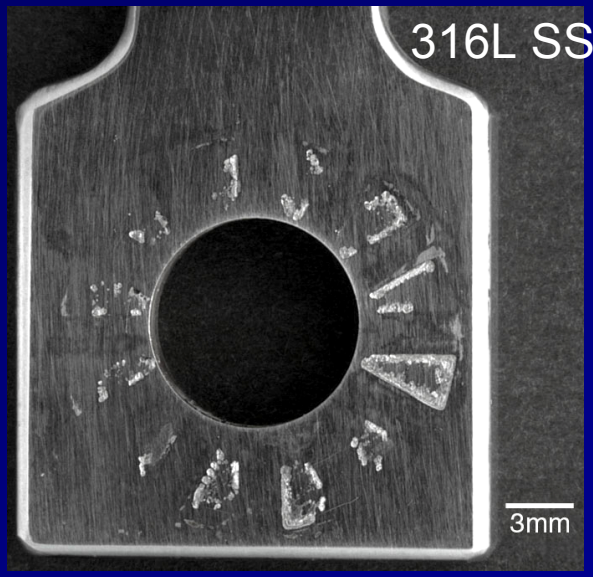


- Crevice corrosion initiated with Alloy 22 or PTFE as crevice washers
- No repassivation observed during testing period

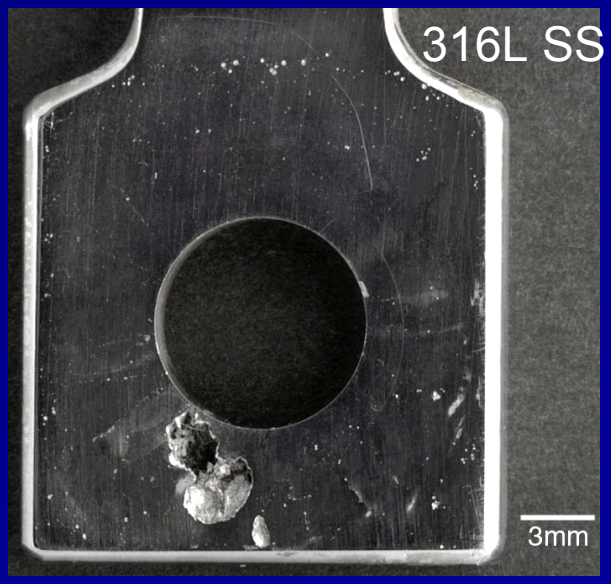
Posttest Observation of Galvanic Coupling Between Large Alloy 22 Plate and 316L SS

- No corrosion on Alloy 22
- Severe crevice corrosion on 316L SS

Torque: 8.4 N·m [75 in·lb]
Crevice washer: Alloy 22
Corrosion sites: 22/24
d_{max} = 258 μm



Torque: 0.70 N·m [6.2 in·lb]
Crevice washer: PTFE
Corrosion sites: 2/24
Penetration through specimen with thickness = 5 mm



Experimental Results: Galvanic Coupling

Crevice Assembly		Coupling large plate	Did Crevice corrosion initiate under open circuit condition?	Did crevice corrosion initiate with $CuCl_2$?	Penetration depth, μm
Crevice Specimen	Crevice washer				
Alloy 22	Ti Gr. 7	Ti Gr. 7	No No	No No	Not available
W+SA 22*	Alloy 22	Alloy 22	No No	No No	Not available
W+SA 22	Ti Gr. 7	Ti Gr. 7	No No	No No	Not available
Alloy 22	PTFE	Ti Gr. 7	No	Yes	181, 164
W+SA 22	PTFE	Alloy 22	No	Yes, but it arrested in < 5 days	284, 265

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

Summary

- 316L SS was susceptible to crevice corrosion
  - Coupling to Alloy 22
  - In chloride solutions at 95 °C [203 °F]

- Alloy 22-to-metal (Alloy 22 or Titanium Grade 7) crevices were not detrimental to Alloy 22 localized corrosion
  - Susceptibility
  - Propagation

  Regardless of
  - Metallurgical conditions (mill-annealed or welded-plus-solution-annealed)
  - Torque
  - Surface area ratio

Summary (Continued)

- E_{rcrev} for Alloy 22-to-metal crevice > E_{rcrev} for metal-to-PTFE
  - Alloy 22-to-metal crevices were less susceptible to crevice corrosion than Alloy 22-to-PTFE crevices
  - Alloy 22-to-PTFE crevices conservatively bound the Alloy 22 localized corrosion resistance

Acknowledgement and Disclaimer

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