Corrosion and Corrosion Resistance of Stainless Steel Sanitary Equipment

Sponsor: Nickel Institute

Speaker: Dr. James D. Fritz

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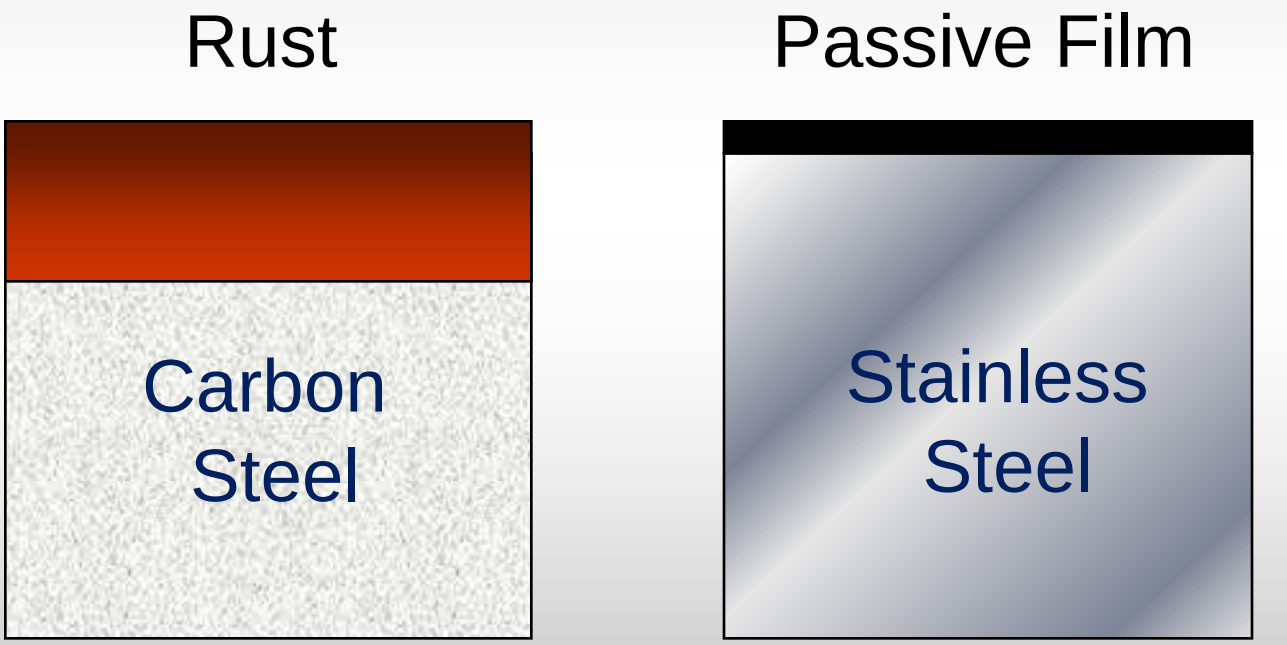
Presentation Topics

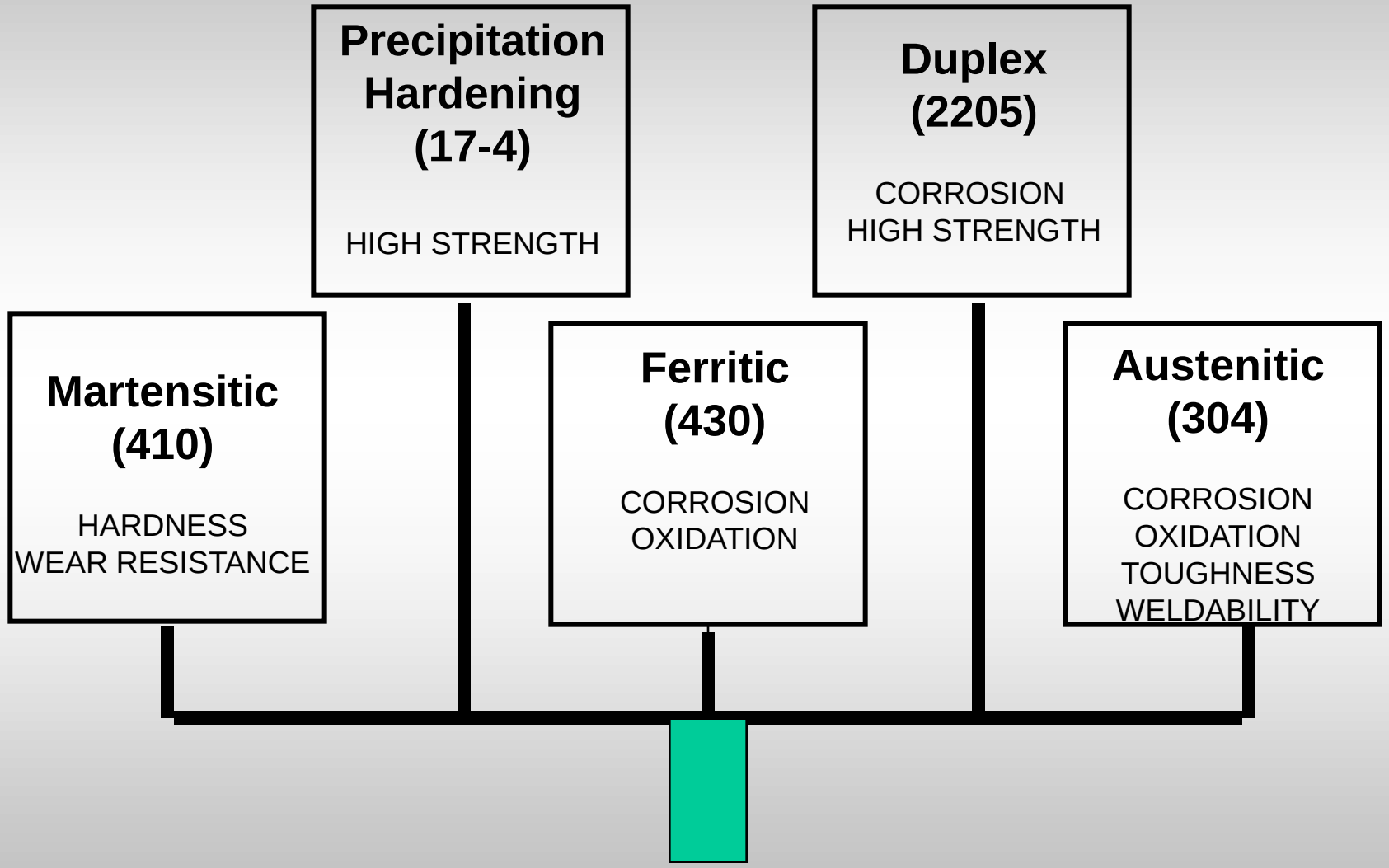
- What is a Stainless Steel
- Families of Stainless Steel
- Mode of corrosive attack
- Environmental Factors
- Metallurgical Factors
- Fabrication Issues

How Does A Stainless Steel Work?

Stainless steel is iron + at least 10.5% chromium



Stainless Steel Families

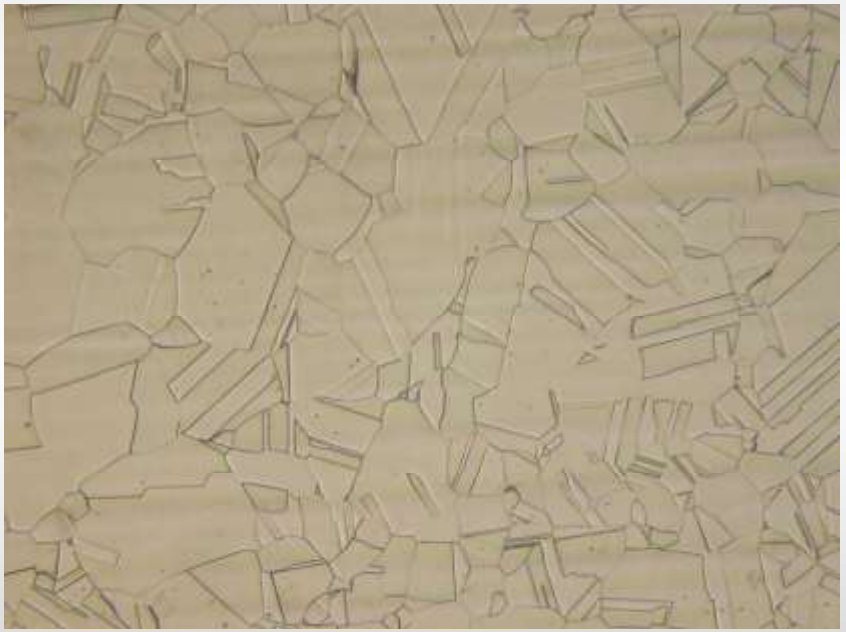


What Is an Austenitic Stainless Steel?

- Austenitic stainless steels are Fe-based alloys with a Cr content of at least 10.5% and microstructure composed primarily of austenite phase.
- Common examples – 304, 304L, 316, and 316L

Austenitic Stainless Steels

316L austenitic Stainless Steel – wrought plate



6% Mo austenitic Stainless Steel - wrought plate

Characteristics of Austenitic Stainless Steels

Moderately Strong

Excellent Ductility, Toughness, & Weldability

Corrosion Resistant

Susceptible to Stress Corrosion Cracking

Expensive (high in nickel)

High Thermal Expansion

Low Thermal Conductivity

ASTM A240 Compositional Ranges of Common Austenitic Stainless Steels

Name (UNS #)	C	Mn	P	S	Si	Cr	Ni	Mo	N	Cu
201L (S20103)	0.03	5.50 7.50	0.045	0.030	0.75	16.0 18.0	3.5 5.5	---	0.25	
304L (S30403)	0.03	2.0	0.045	0.030	0.75	17.5 19.5	8.0 12.0	---	0.10	---
316L (31603)	0.03	2.0	0.045	0.030	0.75	16.0 18.0	10.0 14.0	2.00 3.00	0.10	---
317L (S31703)	0.03	2.0	0.045	0.030	0.75	18.0 20.0	11.0 15.0	3.0 4.0	0.10	
6% Mo SST										
254 SMO® (S31254)	0.02	1.0	0.030	0.010	0.80	19.5 20.5	17.5 18.5	6.0 6.5	0.18 0.22	0.50 1.00
AL-6XN® (N08367)	0.03	2.0	0.040	0.030	1.00	20.0 22.0	23.5 25.5	6.0 7.0	0.18 0.25	0.75

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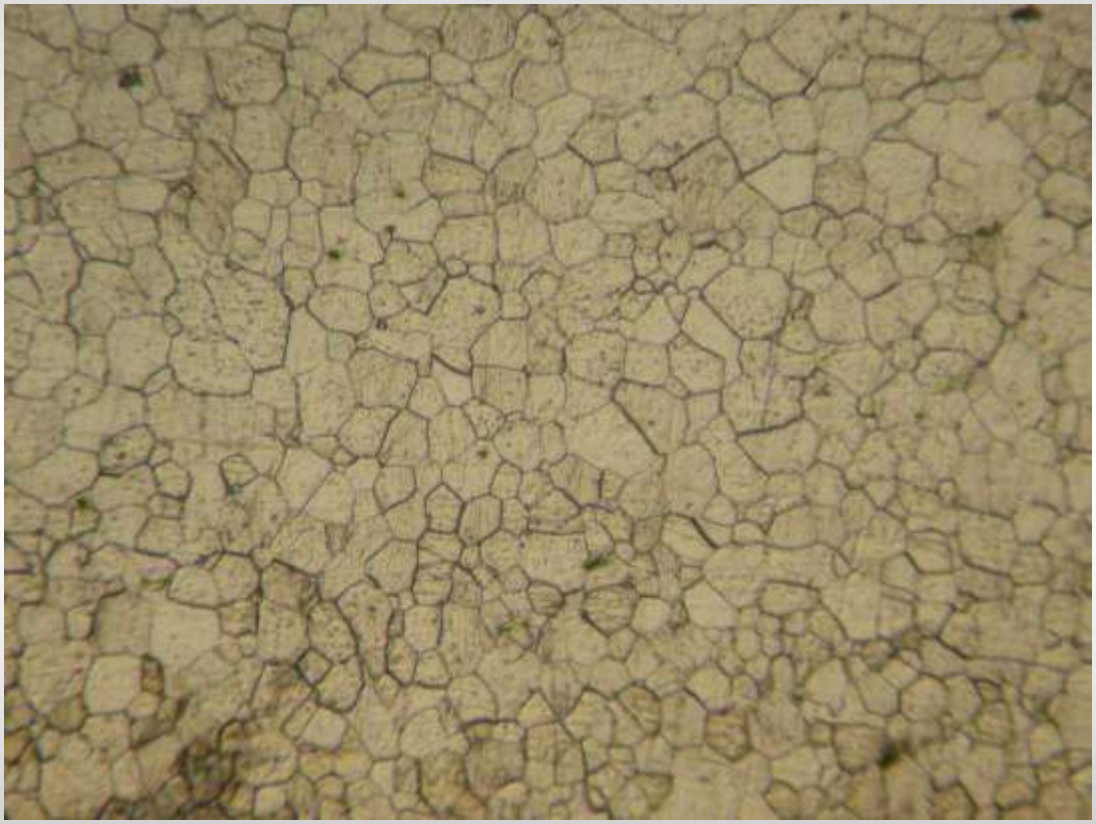
What Is a Ferritic Stainless Steel?

- Ferritic stainless steels are Fe-based alloys with a Cr content of at least 10.5% and a microstructure composed primarily of ferrite phase.
- Common examples – 409, 430, 436, 439, and 444

Ferritic Stainless Steels



439 Ferritic Stainless Steel

ASTM A240 Compositional Ranges of Common Ferritic Stainless Steels

Name (UNS #)	C	Mn	P	S	Si	Cr	Ni	Mo	N	other
430 (S43000)	0.12	1.00	0.040	0.030	1.00	16.0 18.0	0.75	---	---	
439 (S43035)	0.03	1.00	0.040	0.030	1.00	17.0 19.0	0.50	---	0.030	Ti [0.20+4(C+N)] 1.10 max
434 (S43400)	0.12	1.00	0.040	0.030	1.00	16.0 18.0	---	0.75 1.25	---	---
436 (43600)	0.12	1.00	0.040	0.030	1.00	16.0 18.0	---	0.75 1.25	---	Cb 5xC 0.80 max
444 (44400)	0.025	1.00	0.040	0.030	1.00	17.5 19.5	1.00	1.75 2.50	0.035	Ti + Cb [0.20+4(C+N)] 1.10 max
SEA-CURE® (S44660)	0.030	1.00	0.040	0.030	1.00	25.0 28.0	1.0 3.5	3.0 4.0	0.040	Ti + Cb 0.20-1.00, 6 X(C+N) min

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Characteristics of Ferritic Stainless Steels

Moderately Strong

Moderately Ductile, Limited Toughness (DBTT)

Limited Weldability

Corrosion Resistant

Virtually Immune to Stress Corrosion Cracking

Cost effective (low nickel)

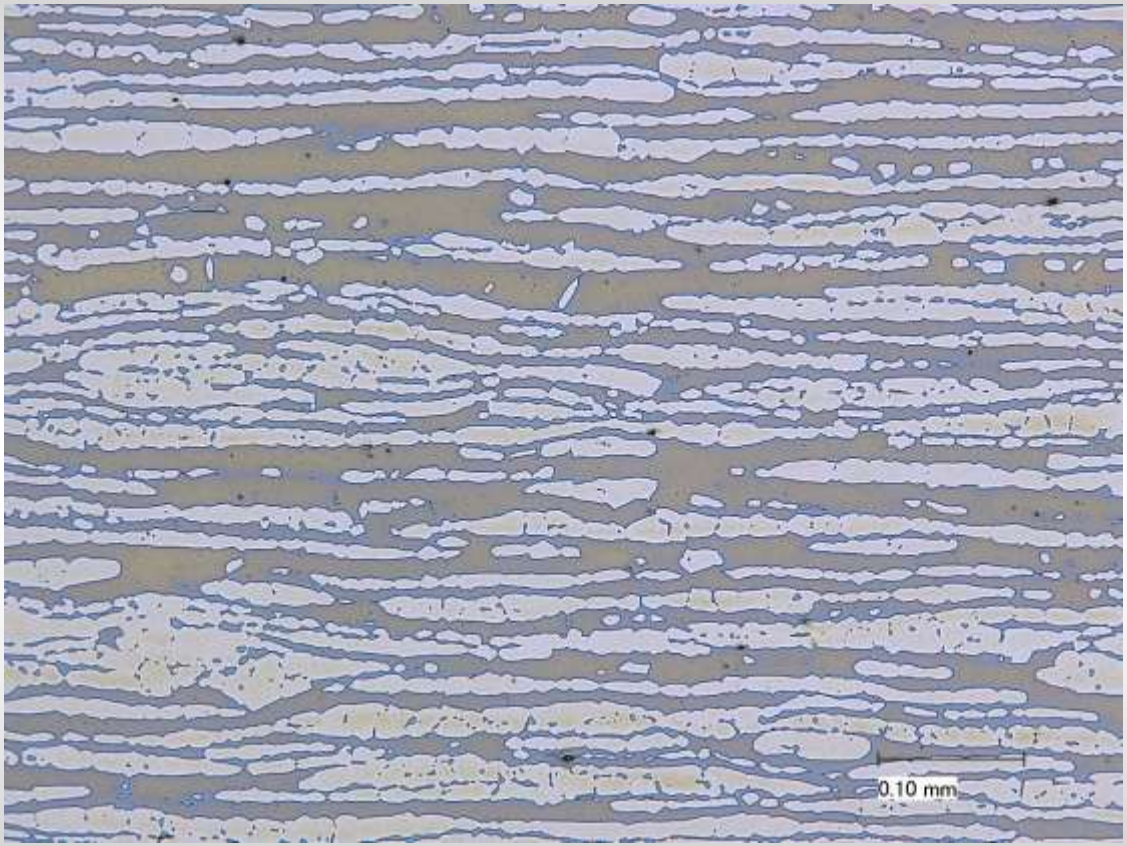
Lower Thermal Expansion

Higher Thermal Conductivity

What Is a Duplex Stainless Steel?

- Duplex stainless steels steels are Fe-based alloys with a minimum Cr content of 10.5% and a structure of about 50% austenite and 50% ferrite phase, but may range from 30 to 70%.
- Common example – Type 2205

Microstructure ≈ 50% Ferrite/50% Austenite



Type 2205 wrought plate structure

Characteristics of Second Generation Duplex Stainless Steels

Very Strong

Good Toughness, Ductility, & Weldability

Corrosion Resistant

Resistant to Stress Corrosion Cracking

Cost Effective (low nickel)

Intermediate Thermal Expansion and Thermal Conductivity

ASTM A240 Compositional Ranges of Common Duplex Stainless Steels

Name (UNS)	C	Mn	P	S	Si	Cr	Ni	Mo	N	Cu
LDX 2101® (S32101)	0.04	4.0 6.0	0.040	0.030	1.00	21.0 22.0	1.25 1.70	0.10 0.80	0.20 0.25	0.10 0.80
2304 (S32304)	0.03	2.50	0.040	0.030	1.00	21.5 24.5	3.0 5.5	0.05 0.60	0.05 0.20	0.05 0.60
2205 (S32205)	0.03	2.0	0.030	0.020	1.00	22.0 23.0	4.5 6.5	3.0 3.5	0.14 0.20	---
2507 (S32750)	0.03	1.20	0.035	0.020	0.80	24.0 26.0	6.0 8.0	3.0 5.0	0.24 0.32	0.50

ASTM A240 - Required Mechanical Properties

Grade	UNS #	Tensile St (KSI)	Yield St (KSI)	% Elg.	Hardness (max)
304L	S30403	70	25	40	201 HBW
316L	S31603	70	25	40	217 HBW
Al-6XN® (sheet)	N08367	100	45	30	100 RB
430	S43000	65	30	22	183 HBW
434	S43400	65	35	22	89 RB
444	S44400	60	40	20	217 HBW
2101 (t ≤ 0.187”) 2101 (t > 0.187”)	S32101	101 94	77 65	30 30	290 HBW 290 HBW
2304	S32304	87	58	25	290 HBW
2205	S32205	95	65	25	293 HBW
2507	S32750	116	80	15	310 HBW

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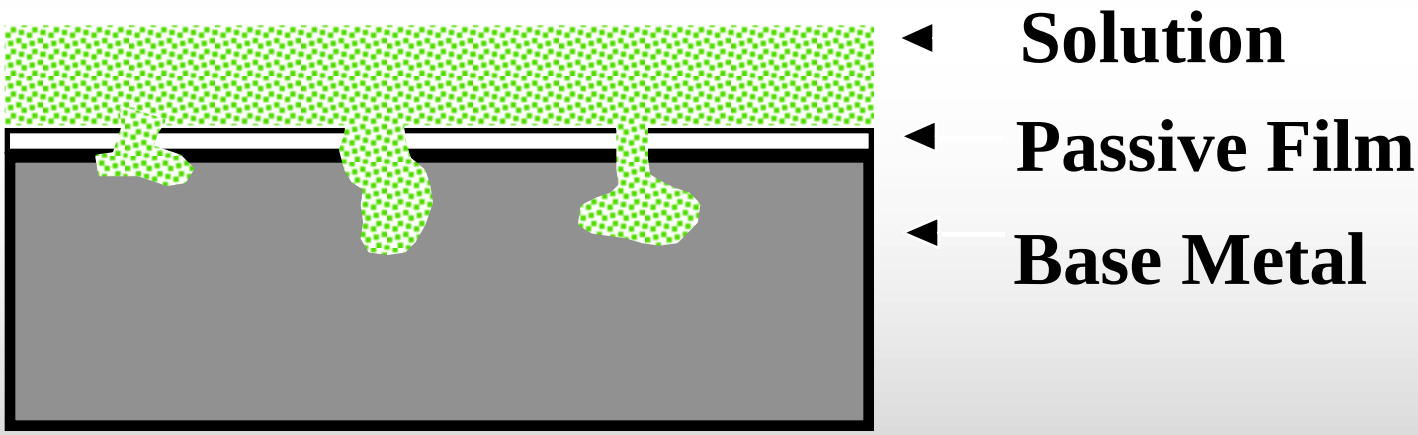
Common Modes of Corrosive Attack With Stainless Steels

- Uniform or General Corrosion
- Pitting Corrosion
- Crevice Corrosion
- Stress Corrosion Cracking (at temp > 50C)
- Intergranular Attack
- Galvanic Corrosion
- Microbiologically Influenced Corrosion (MIC)

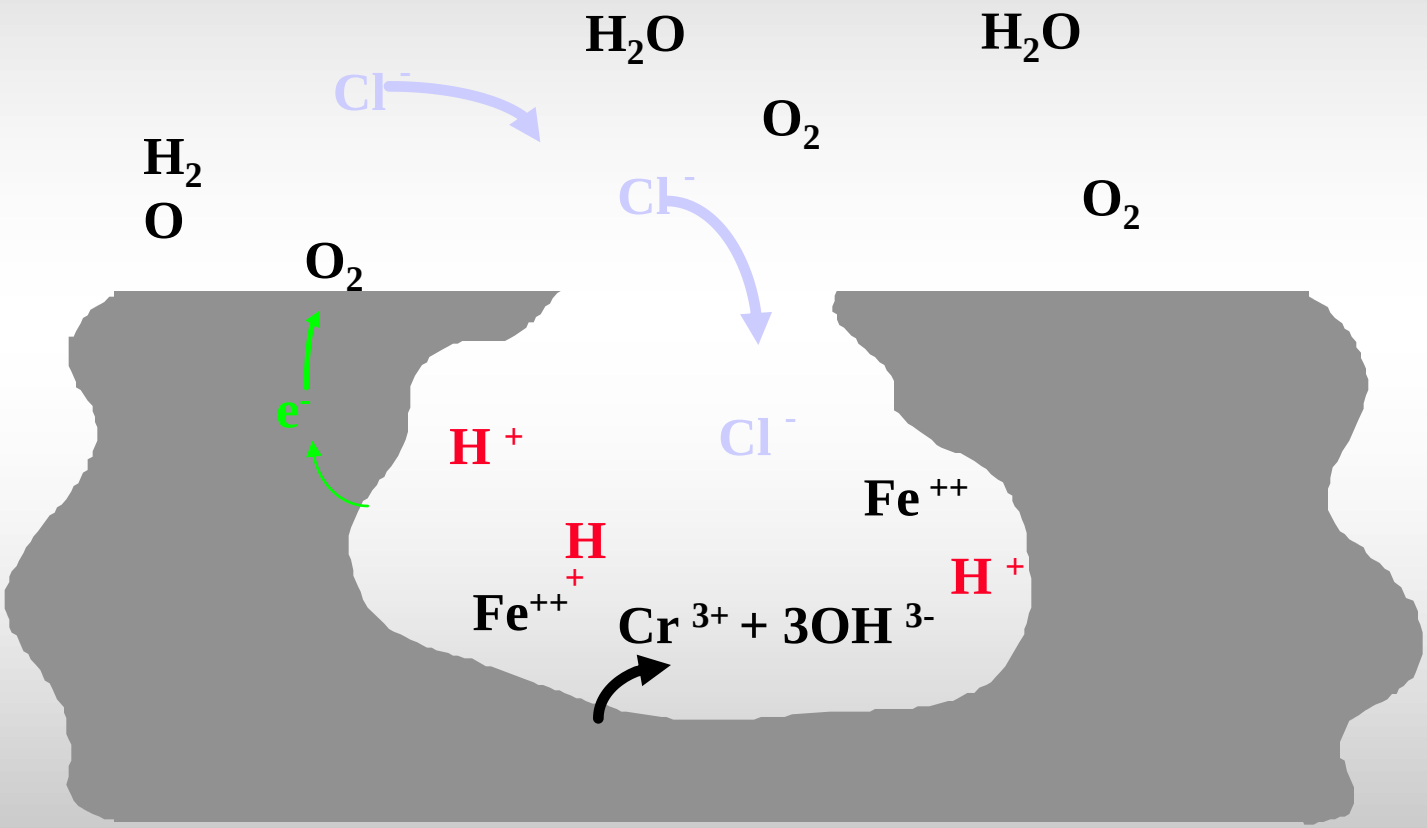
Pitting Corrosion



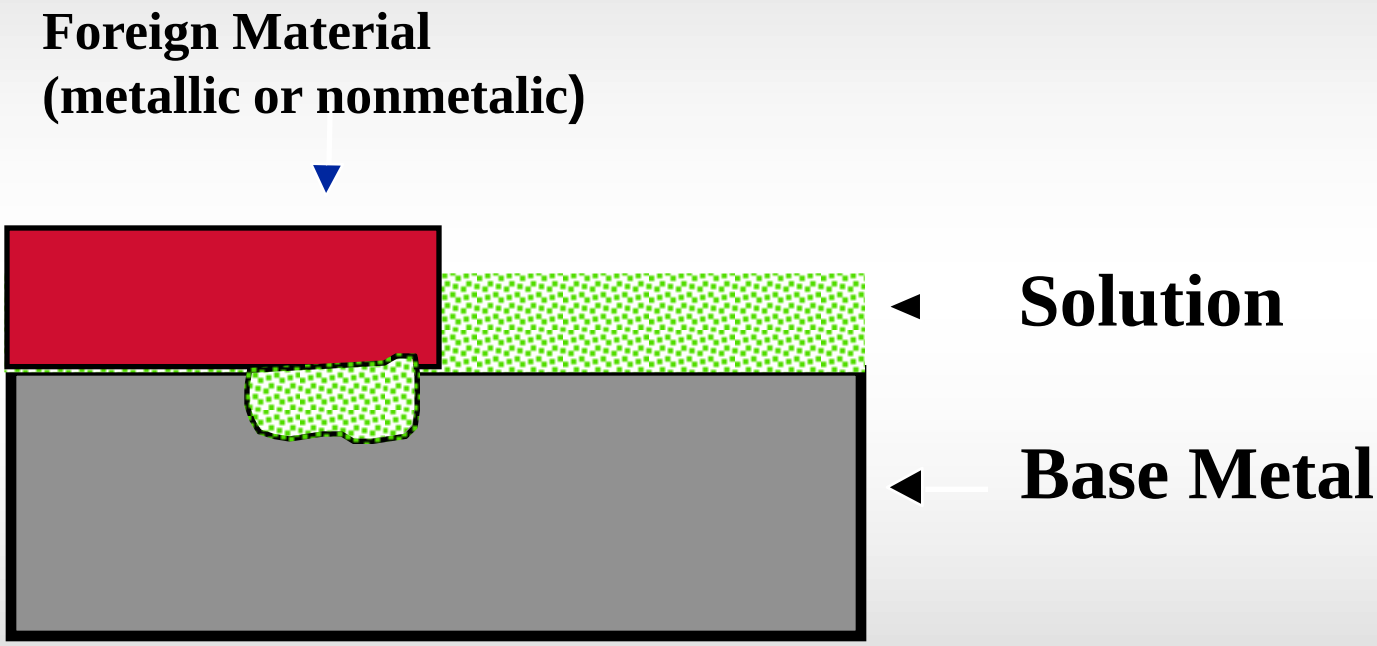
Pitting Corrosion

- Deep narrow attack which often results in through-wall penetration
- Occurs with passive metals in specific environments
- Initiates at weak links (inclusions, inferior surfaces, etc.)

Pitting of Stainless Steel



Crevice Corrosion



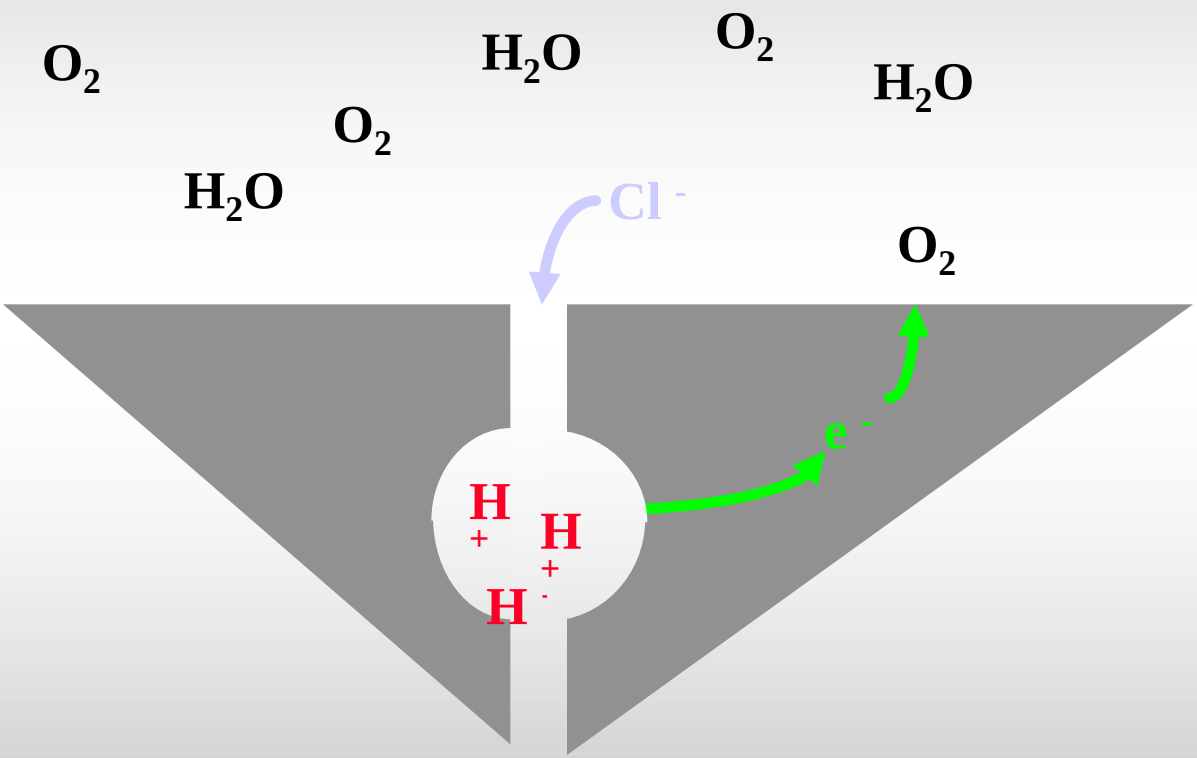
Crevice Corrosion

- Localized attack at locations where free access to the surrounding environment is restricted
- Very similar to a growing pit
- Crevices can be formed either by metal-to-metal or metal-to-nonmetal surfaces

Crevice Corrosion

- Occurs more readily than pitting
- Crevices can result from design
- Crevices can result from service (under deposits)
- Crevice geometry is critical (deep and tight crevices are more detrimental)

Crevice Corrosion



Common Crevice Formers

- Lap joints
- O-ring seals
- Gasket seals
- Connectors
- Rolled tube joints
- Dirt, oil, or grease
- Crayon marks
- Tape
- Fouling deposits
- Corrosion products

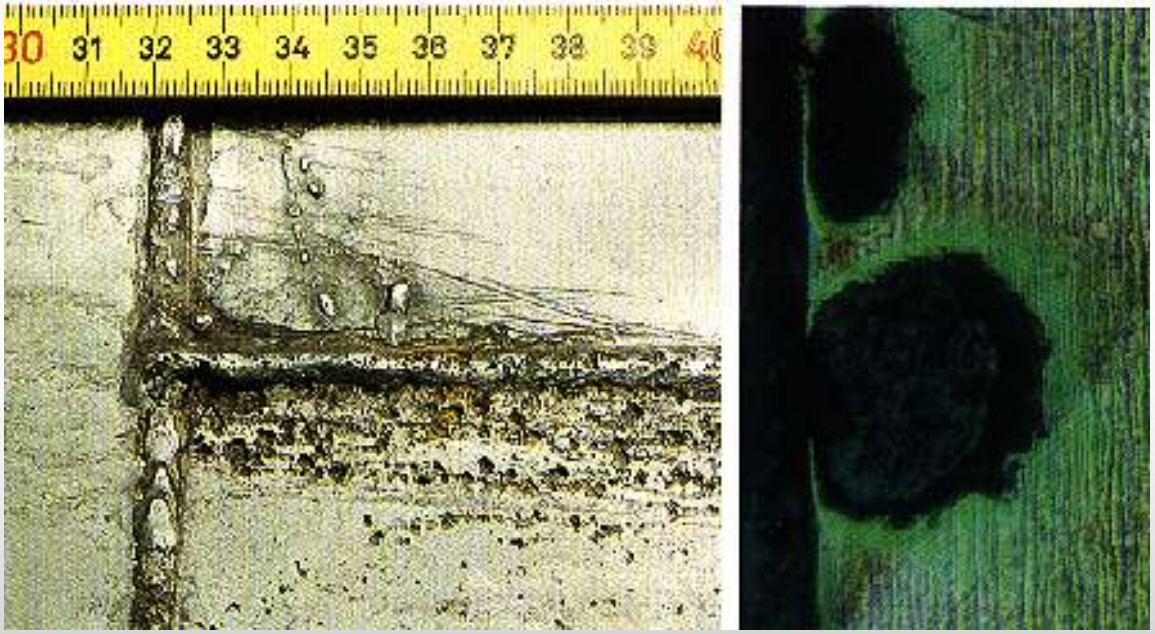
Very difficult to avoid crevices!!

Most Likely Modes of Attack

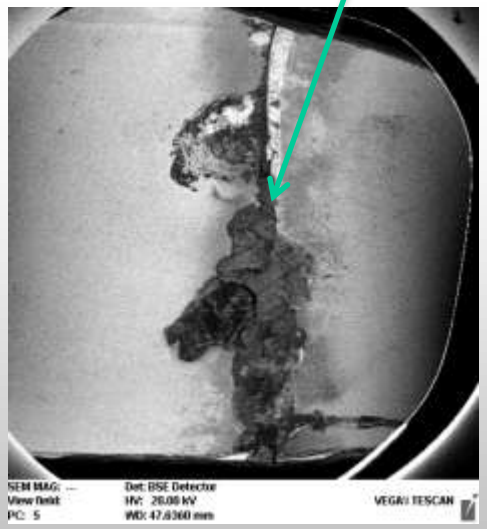
Pitting

Crevice Corrosion

Pitting Corrosion



Corrosion at the Crevice Created by the Lack of Full Penetration



304 stainless steel piping for a spa application

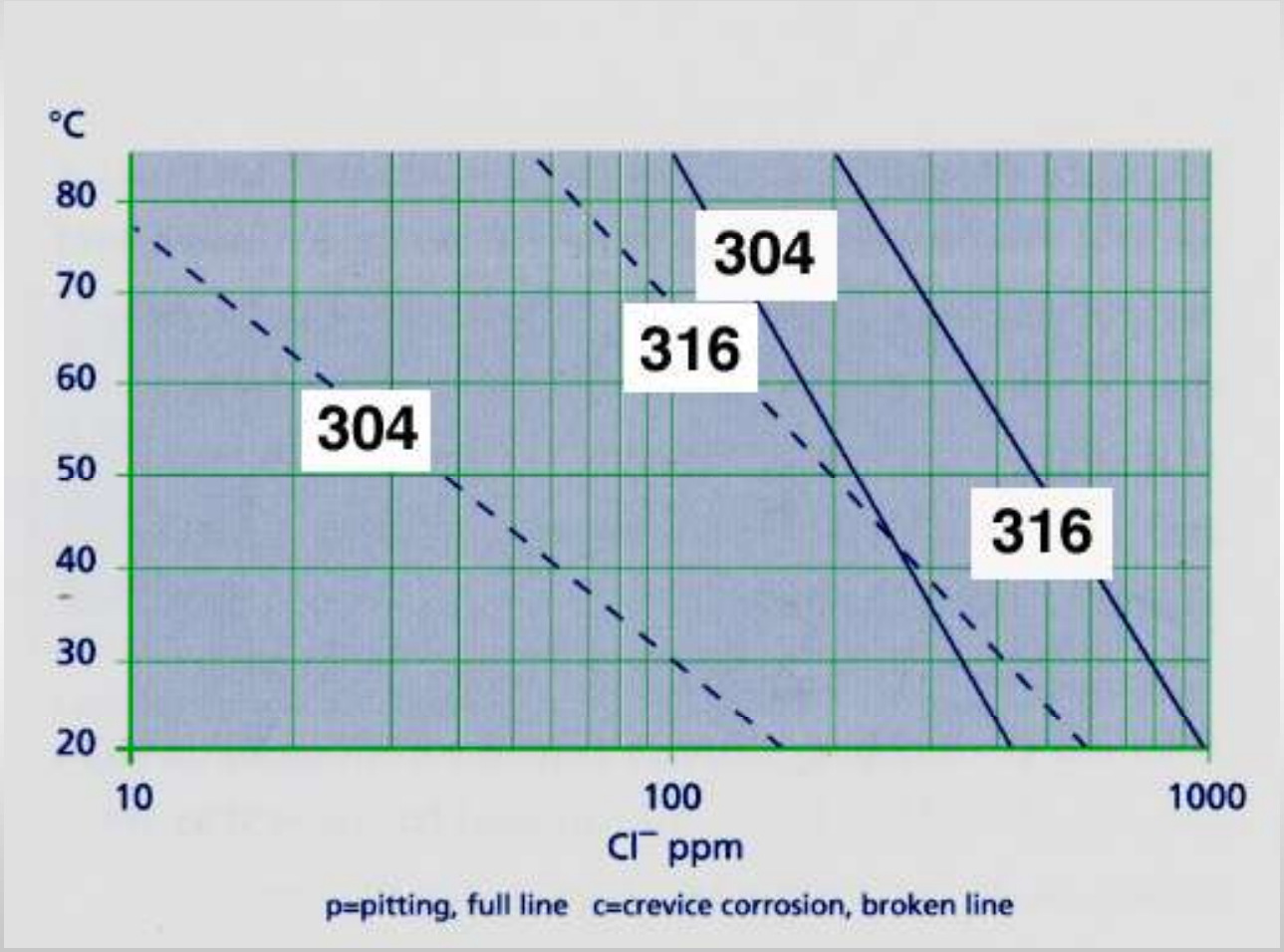
Environmental Factors that Promote Pitting and Crevice Corrosion

- Higher chloride content
- Higher temperature
- Lower pH
- Reduced sulfate levels
- More noble corrosion potentials
  - Increased addition of oxidizing species (increased levels of free chlorine)

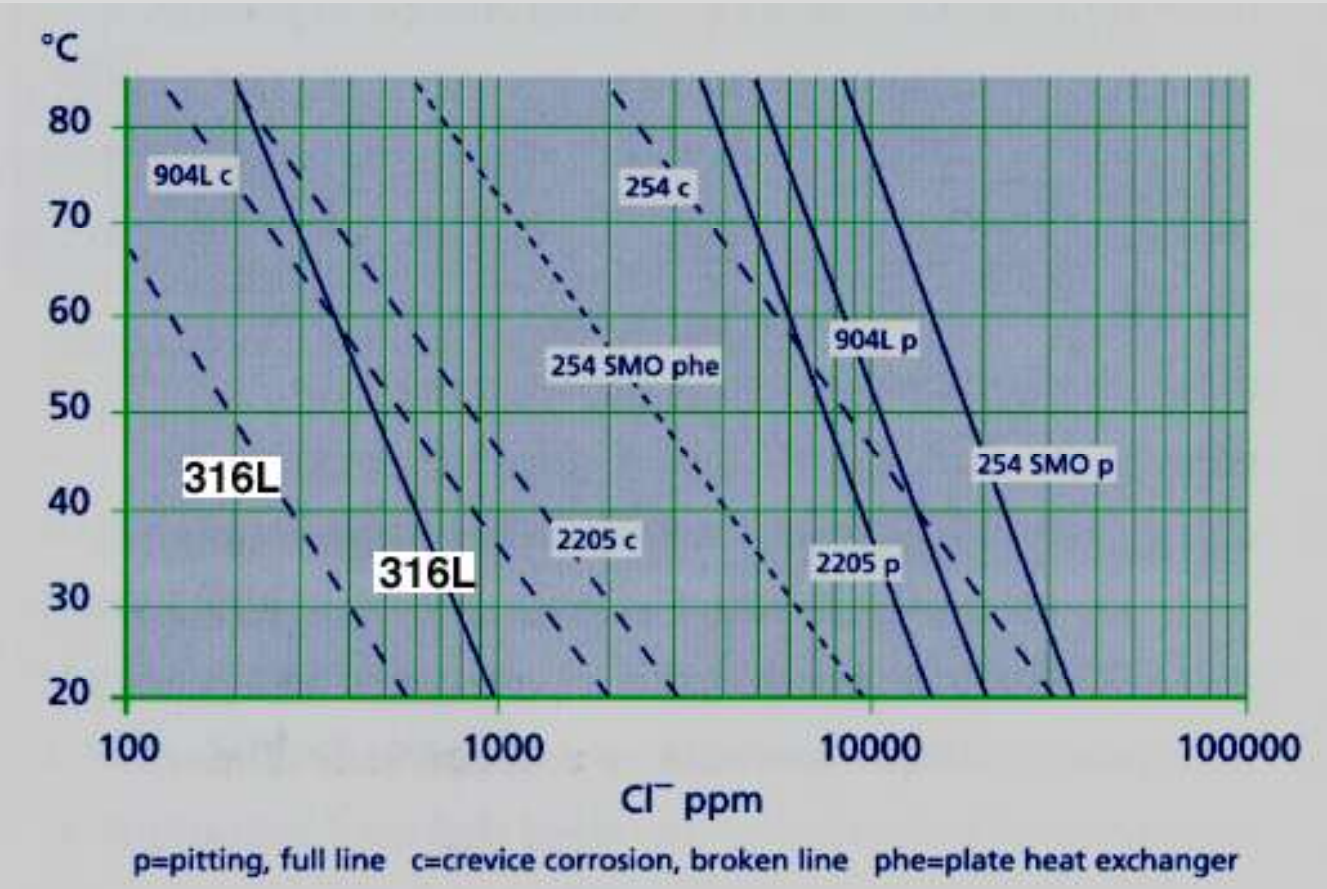
Factors that Promote Pitting and Crevice Corrosion

- Static conditions
- Tight crevice geometries
- Evaporative conditions
- Presence of aggressive bacteria (MIC)

Engineering Diagrams



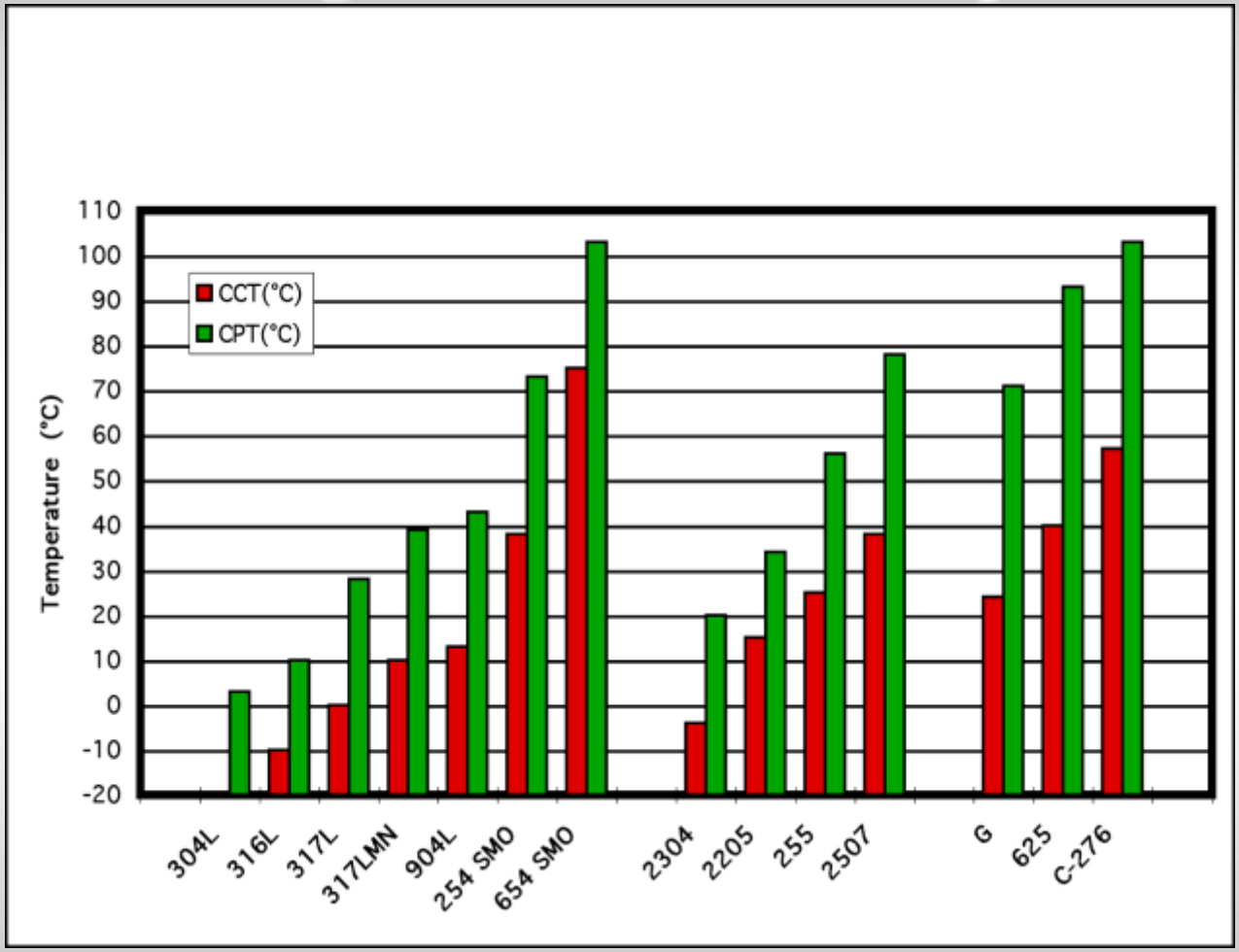
Engineering Diagrams



Metallurgical Variables

- Alloy composition
  - Primary alloying additions
  - Residual elements
- Undesirable secondary phases
  - Inclusions - sulfides, carbides, nitrides, etc.
  - Intermetallic compounds – sigma and chi
- Surface condition
- Phase balance (austenite/ferrite)
- Homogenized structure

Critical Pitting and Crevice Temperatures



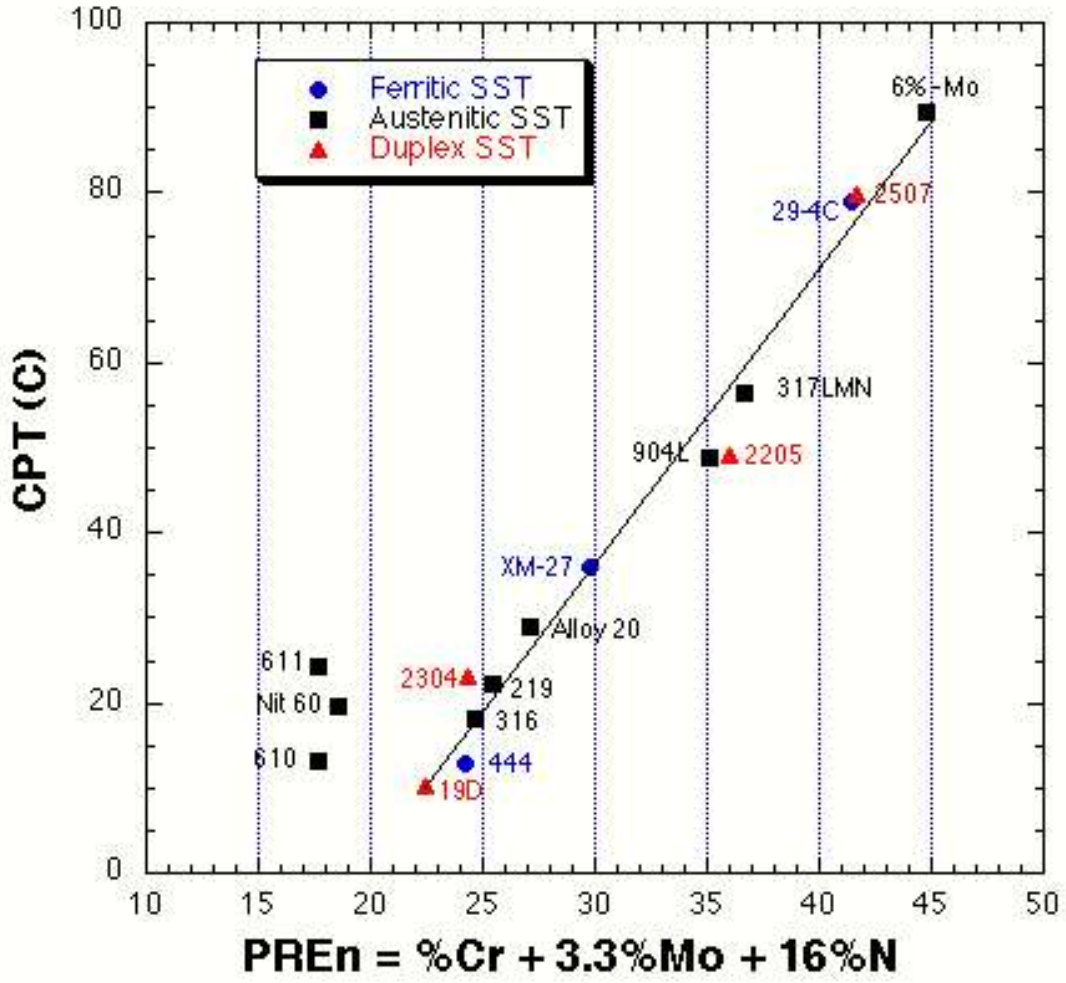
CPT & CCT Measured in 6% ferric chloride

Influence of Alloy Content

- **Alloying elements that improve crevice corrosion resistance - Cr, Mo, & N**
- **Relative resistance is proportional to the "Pitting Resistance Equivalent Number"**

(PREn) = %Cr + 3.3%Mo + 16%N

CPT (ASTM G 150) vs. PREn



Austenitic Grades

UNS Number	Common Name	PREn
S20103	201L	19
S30403	304L	20
S31603	316L	24
S31703	317L	28
S31254 N08367	6% Mo	41 - 43

Ferritic Grades

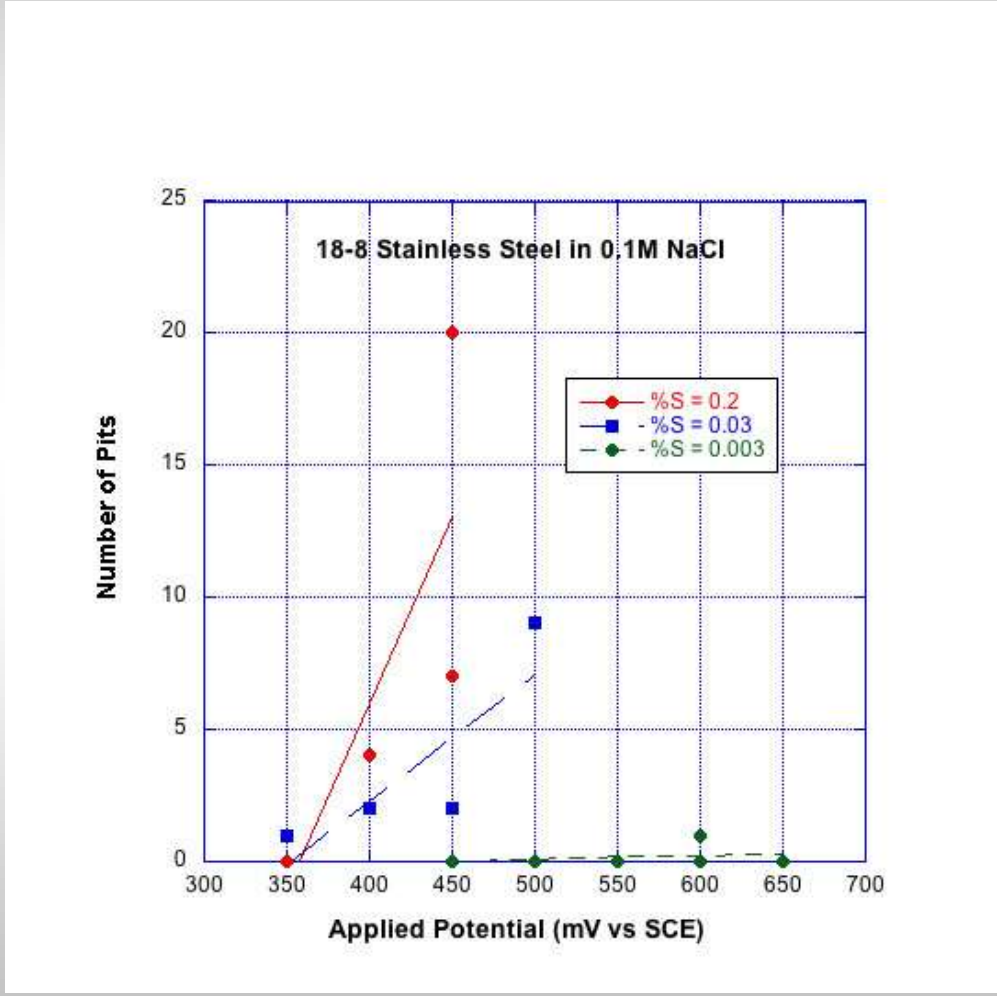
UNS Number	Common Name	PREn
S43000	430	17
S43035	439	18
S43400	434	19
S44400	444	24
S44660	SEA-CURE®	38

Duplex Grades

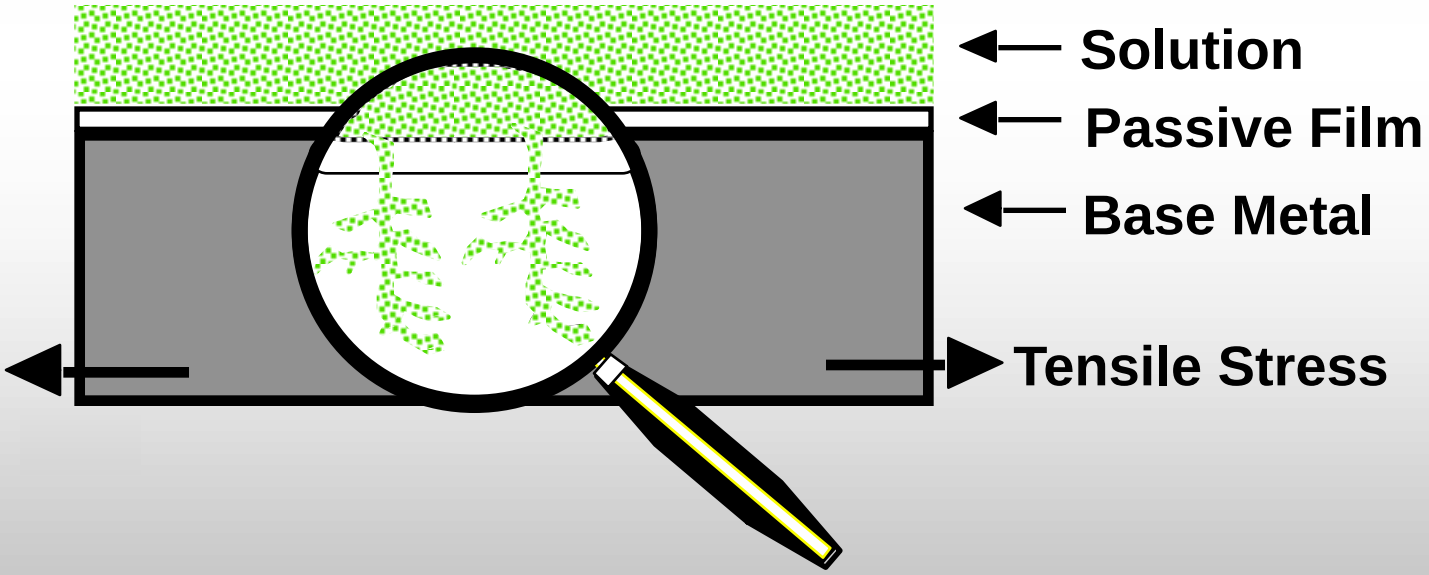
UNS Number	Common Name	PREn
S320103	LDX 2101®	23
S32304	2304	24
S32205	2205	35
S32750	2507	41

Effect of S Content on Pitting Resistance

Brennert & Eklund Scandinavian J. of Met. 5 (1976)

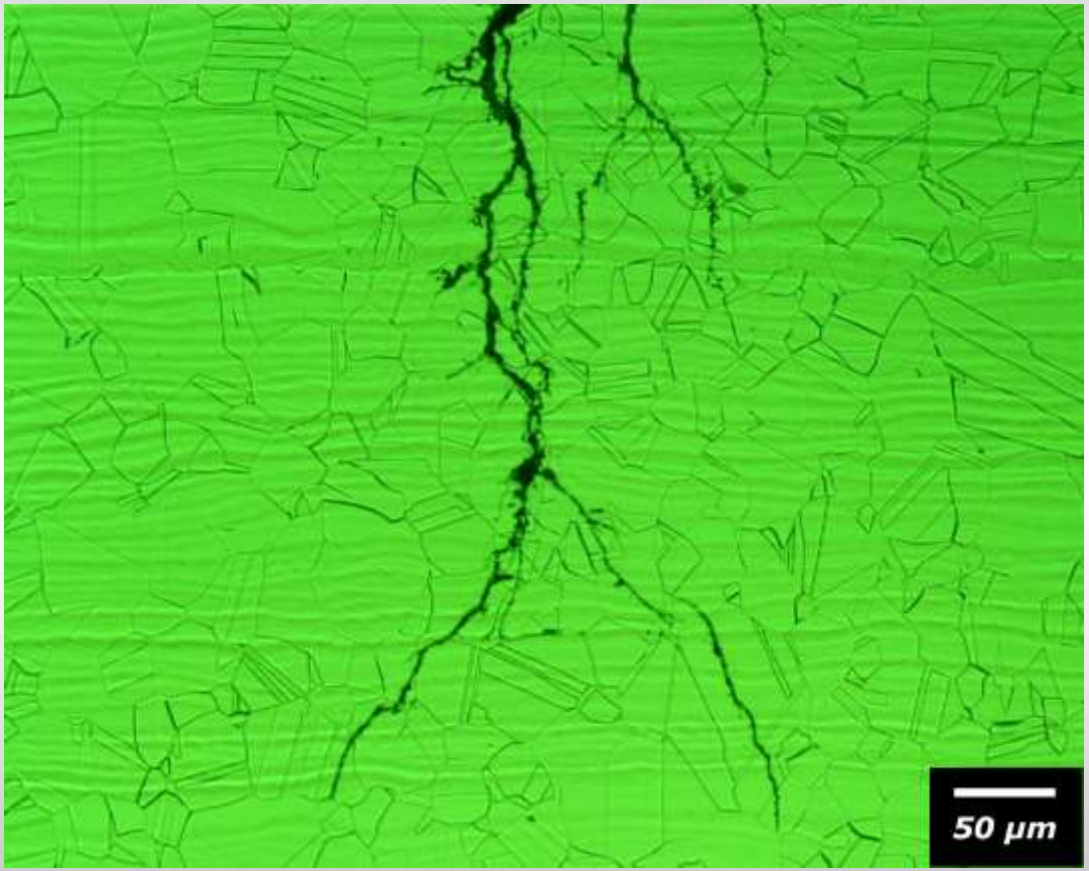


Chloride Stress Corrosion Cracking



Stress Corrosion Cracking

SCC - Austenitic Stainless Steel



Environmental Factors that Promote Chloride SCC

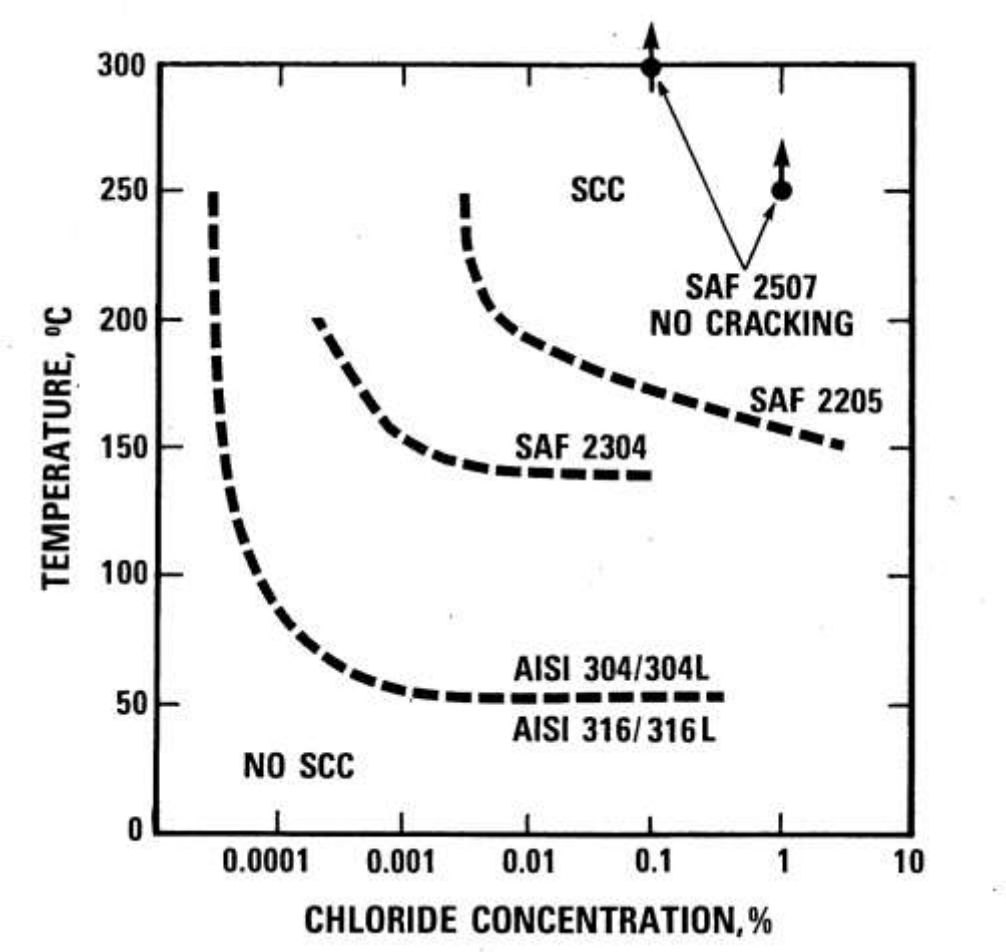
SCC is Promote by:

- Increased chlorides
- Increased tensile stress
- Higher temperature (rare below 50 ° C)
- Lower pH
- Evaporative conditions
- Longer exposure times

Metallurgical Variables

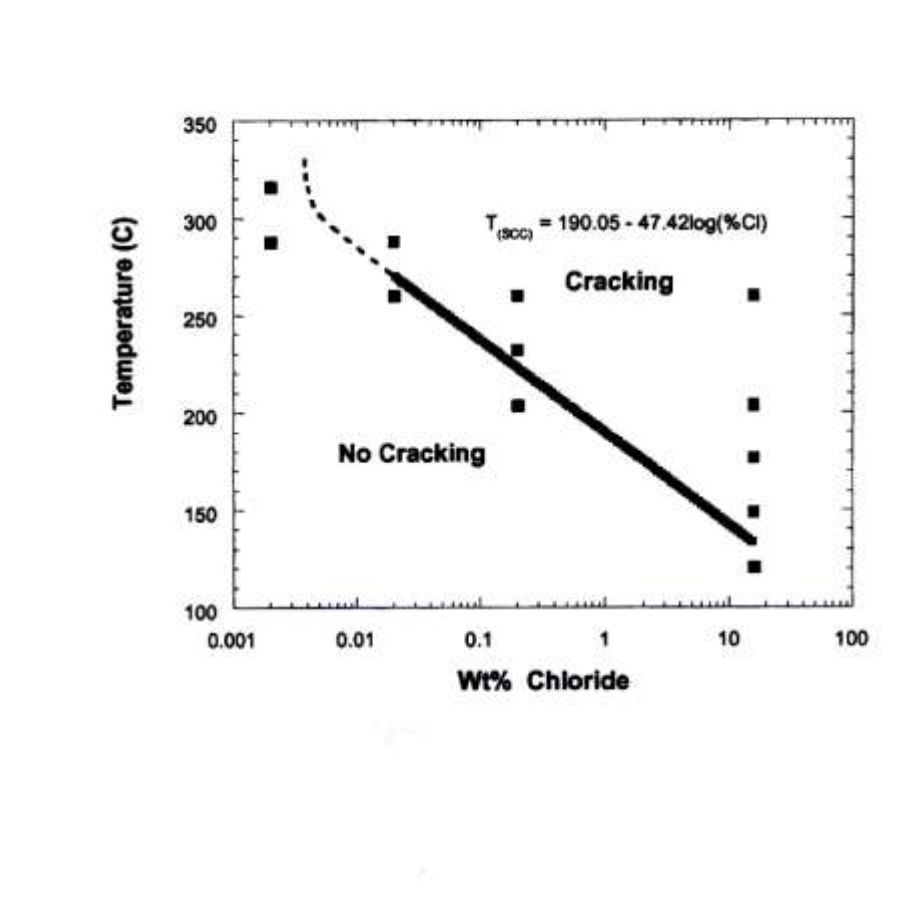
- Austenitic grades with 8 – 10 % Ni tend to be very susceptible
- Ferritic SST grades (400 series) tend to be very resistant
- Nickel alloys tend to be very resistant
- Duplex grades have good resistance

Chloride SCC of Duplex SST



Reference - Sandvik, *A High Performance Duplex Stainless Steel*

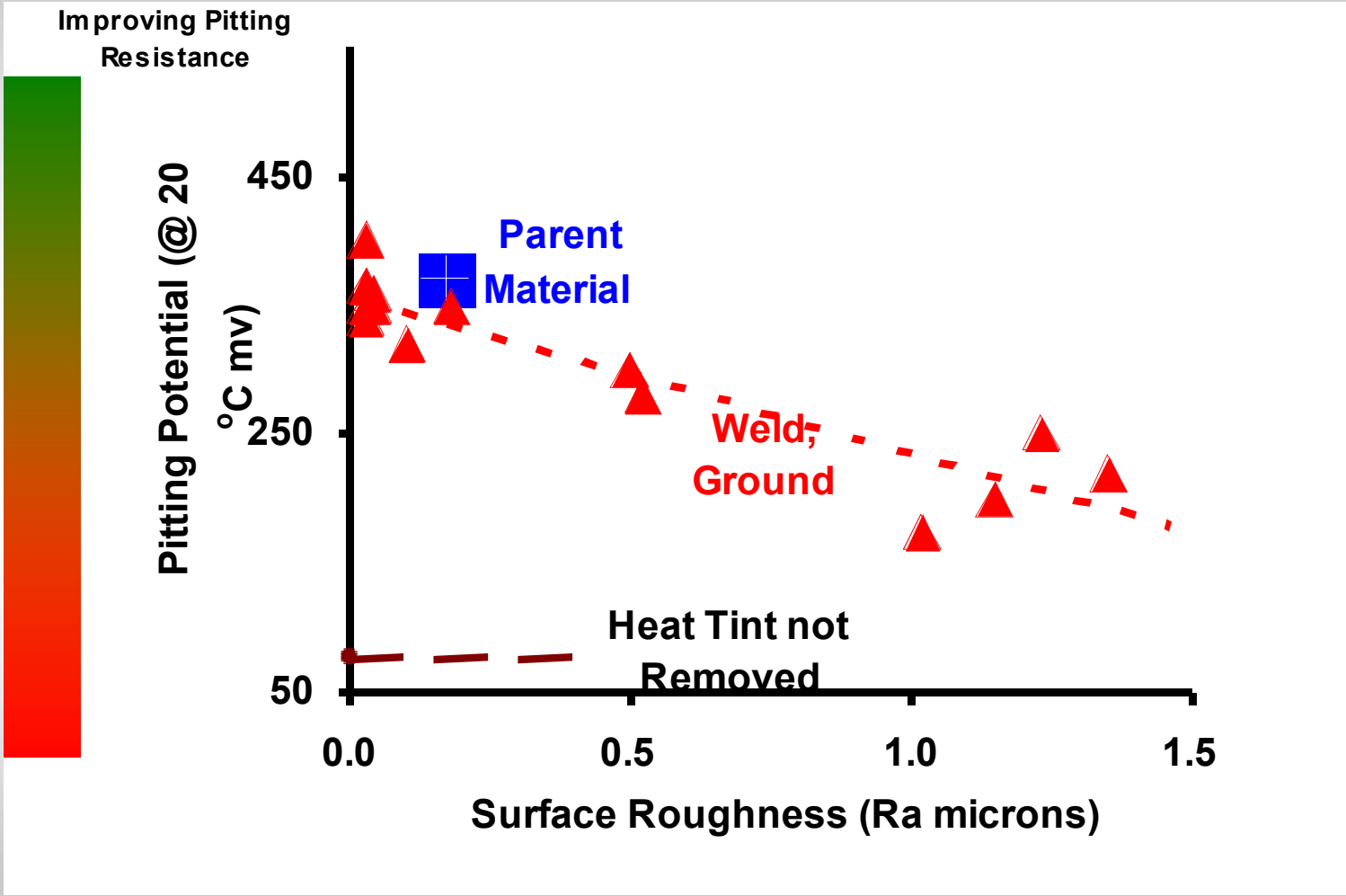
SCC Threshold for a 6% Mo SST (N08367)



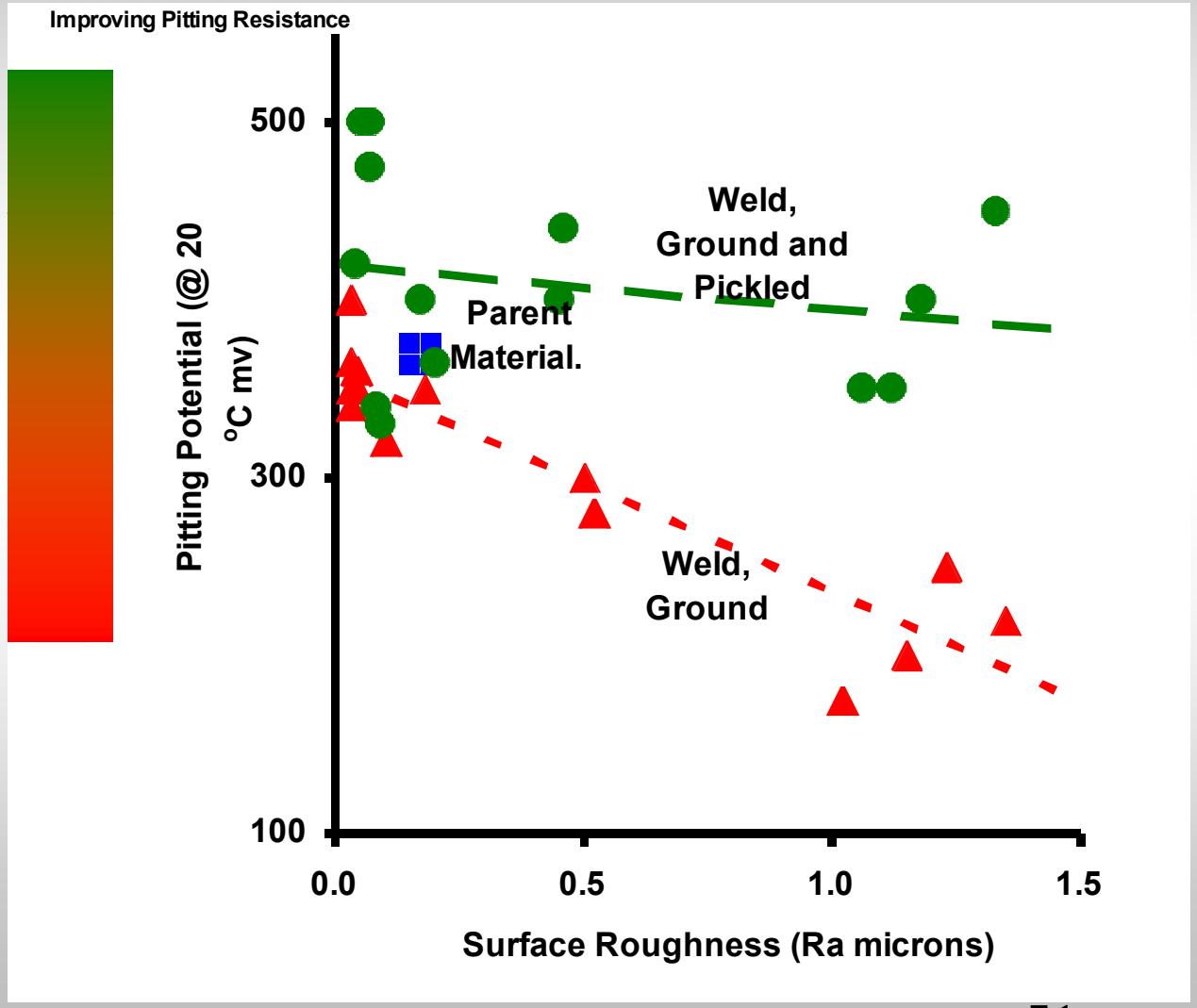
Ref. – R. Gerlock and J Fritz, NACE Corrosion 2002, Paper No 02423

Heat Tint

Weld Corrosion Resistance



Weld Corrosion Resistance



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