Selection and Evaluation of Stainless Steel

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Type 304L and 316L Stainless Steel

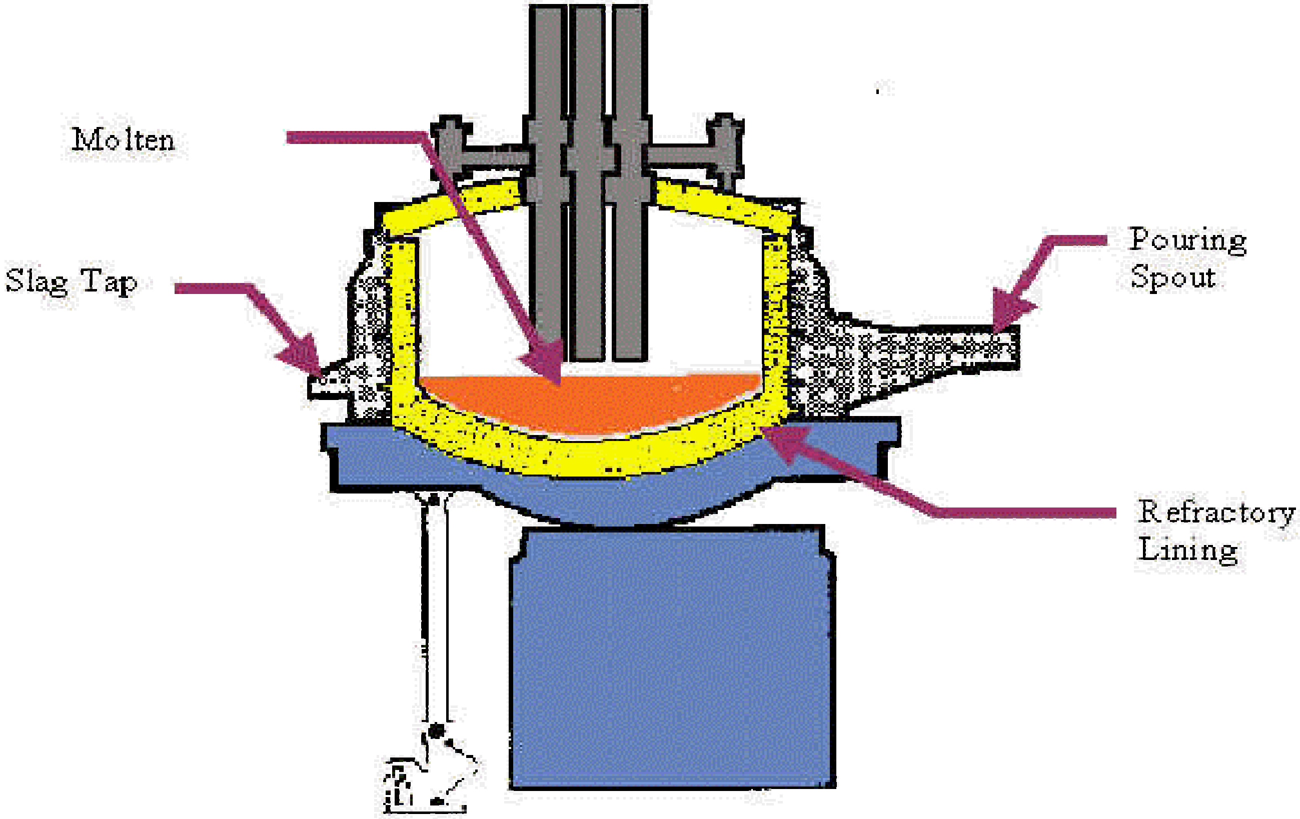
Grade	C	Mn	P	S	Si	Cr	Ni	Mo	N	Cu
304L	0.03	2.0	0.045	0.030	0.75	17.5 19.5	8.0 12.0	---	0.10	---
316L	0.03	2.0	0.045	0.030	0.75	16.0 18.0	10.0 14.0	2.00 3.00	0.10	---

Based on the ASTM A 24 requirements

Stainless Steel Production

- High cost of raw materials
  - Producers always want to reduce inventory costs
  - Reluctant to produce a new grade or variation of and existing grade
- Energy intensive process
  - Producers rely on economy of scale (large production facilities run at capacity)

Stainless Steel Production



Scrape and alloy additions are melted in an electric arc furnace

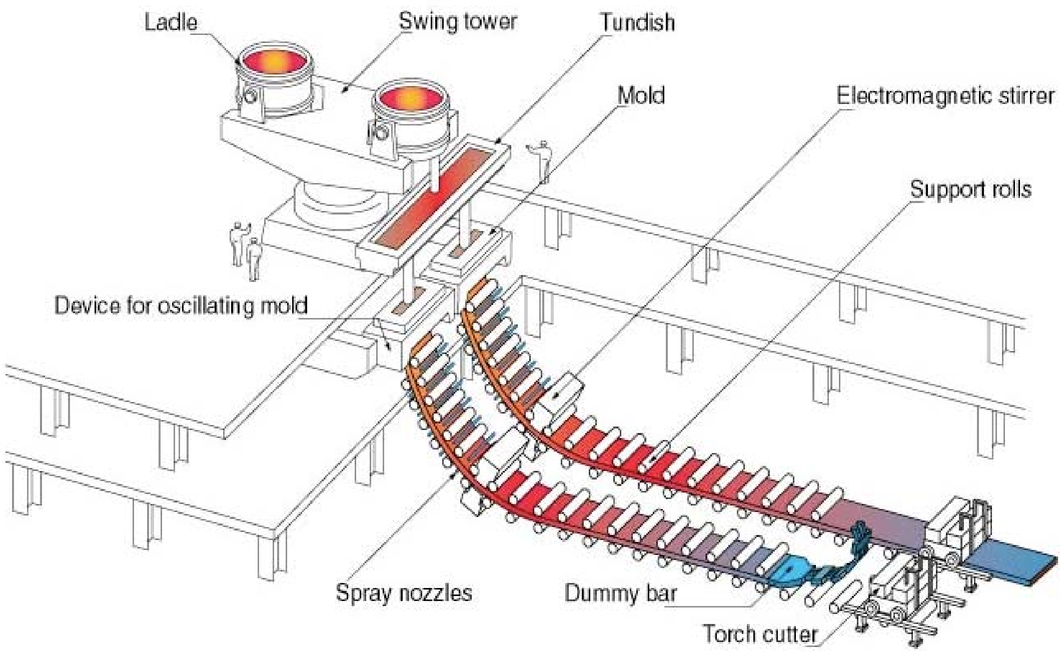
Stainless Steel Production

Molten metal is transferred to an AOD for subsequent processing

Stainless Steel Production

Typical AOD holds about 120 tons of stainless steel

Stainless Steel Production



After casting slabs are cut for processing into plate or coil product. Each slab weighs about 8 - 12 tons.

Important Process Parameters

- Typical size of an AOD heat ≈ 120 tons (240,000 lbs)
- Typical slab ≈ 8 - 12 tons
- An average sized mill will produce about 500,000 tons stainless steel per year

Who are the Larger Customers for Stainless Steel?

- Distributors
  - In North America about 60 - 70% of all stainless steel is sold through distributors
    - Distributor are very price sensitive and demand lowest possible price
- Large projects often purchase “mill direct”
    - Constrains on minimum size of an order and plate sizes
    - Typical mill order - 200 tons and up

Type 304L and 316L Stainless Steel

Grade	C	Mn	P	S	Si	Cr	Ni	Mo	N
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Based on the ASTM A 240 requirements

Special Order – Enhanced 304L or 316L Compositions for High Purity Applications

Is it practical?

Cost of “Special” 316L Composition

Example - Increase Mo% by 0.4%

- At the current price of Mo ($17.80/lb) the cost = $0.071 per pound of 316L or $17,088 per 120 ton heat

- The 0.4% increase in Mo will require an increase in Ni of approximately 0.5% to maintain the equivalent ferrite content

Cost of “Special” 316L Composition

Example - Increase Mo% by 0.4%

- – At the current price of Ni ($10.50/lb) cost = $0.052 per lb of 316L or $12,600 per 120 ton heat

- – **Total cost of the modification -** $29,688 per 120 ton heat

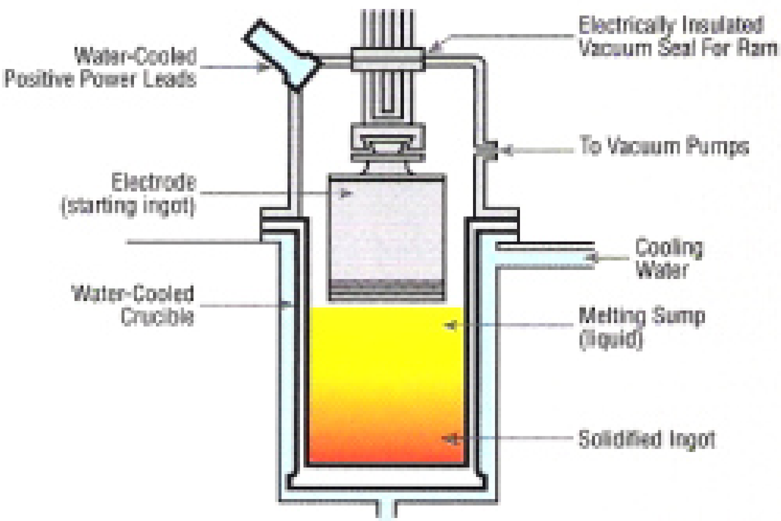
Example
Cost of “Special” 316L Composition

- For most applications it is more practical to select a higher grade of stainless steel such as 2205 duplex stainless steel
- Advantages of moving to a higher alloyed grade
  - Possible Lower costs
  - Higher strength
  - Better corrosion resistance
  - Shorter lead times

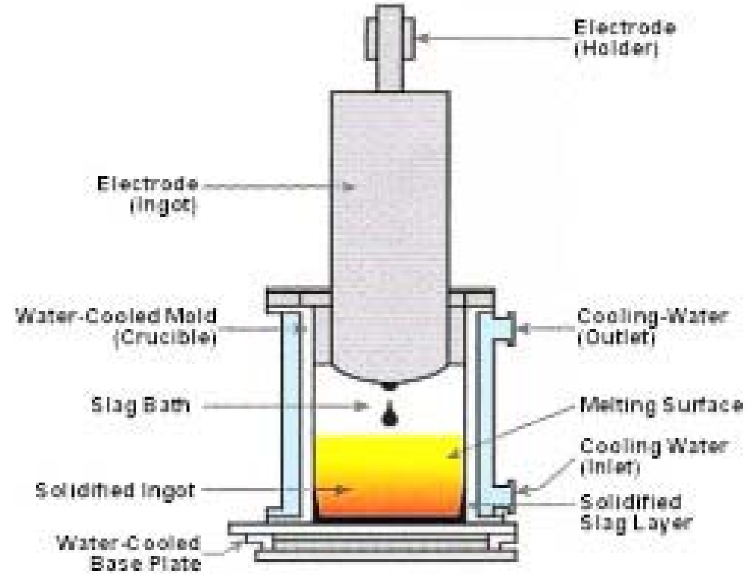
Special Processing

- Users often consider special processing requirements to enhance properties
  - Electroslag Remelting (ESR)
  - Vacuum Arc Remelting (VAR)

Remelting



VAR

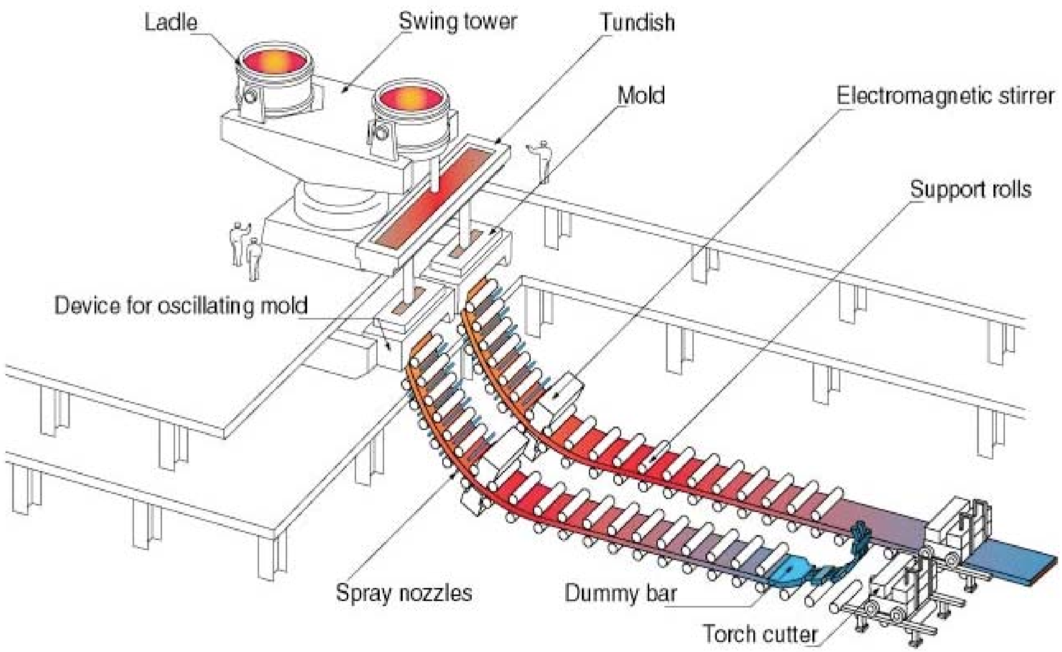


ESR

Electroslag Remelting (ESR)

- ESR is done on a per slab bases (8 -12 tons)
- Remelt capacity is typically fully utilized for processing higher alloys for aerospace applications
  - Long lead times and high costs

Stainless Steel Production



After casting slabs are cut for processing into plate or coil product. Each slab weighs about 8 - 12 tons.

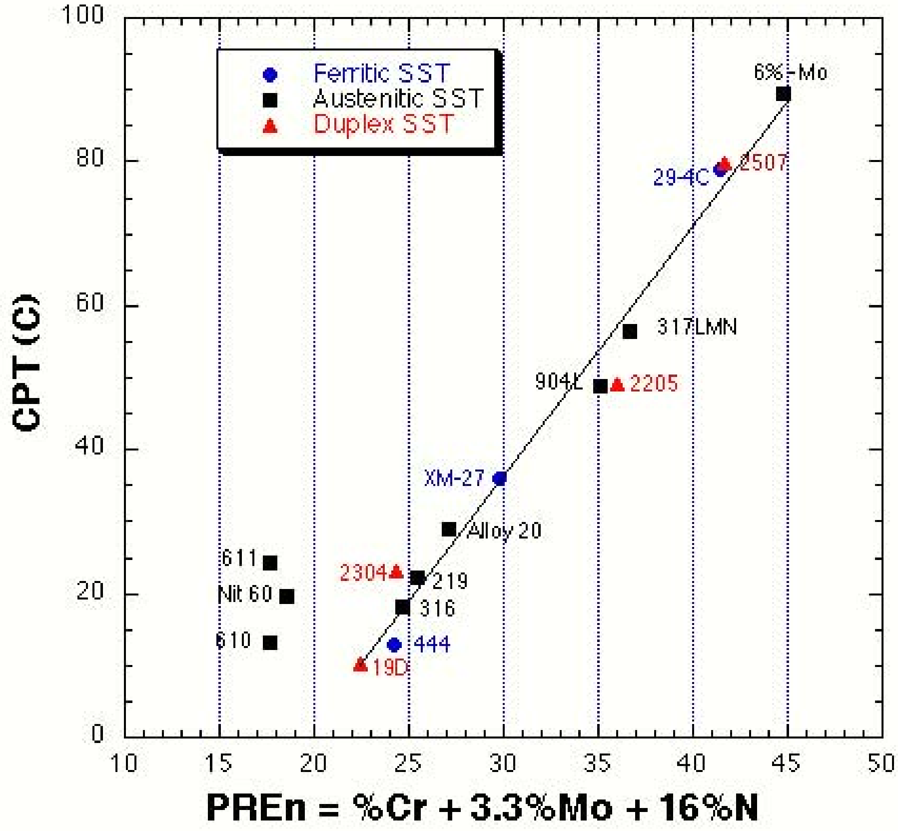
Electroslag Remelting (ESR)

- For types 304L and 316L, ESR typically not necessary
  - Most producers' continuous casters are very affective at reducing inclusions in stainless steels
  - Critical applications should avoid the first and last slab of the heat

Factors to Consider When Choosing a Stainless Steel

- Corrosion resistance
- Fabrication characteristics
  - Weldability, formability, machinablity electropolishing (EP) properties
- Mechanical properties
- Cost
- Availability

CPT (ASTM G 150) vs. PREn



PREn = Pitting Resistance Equivalent number

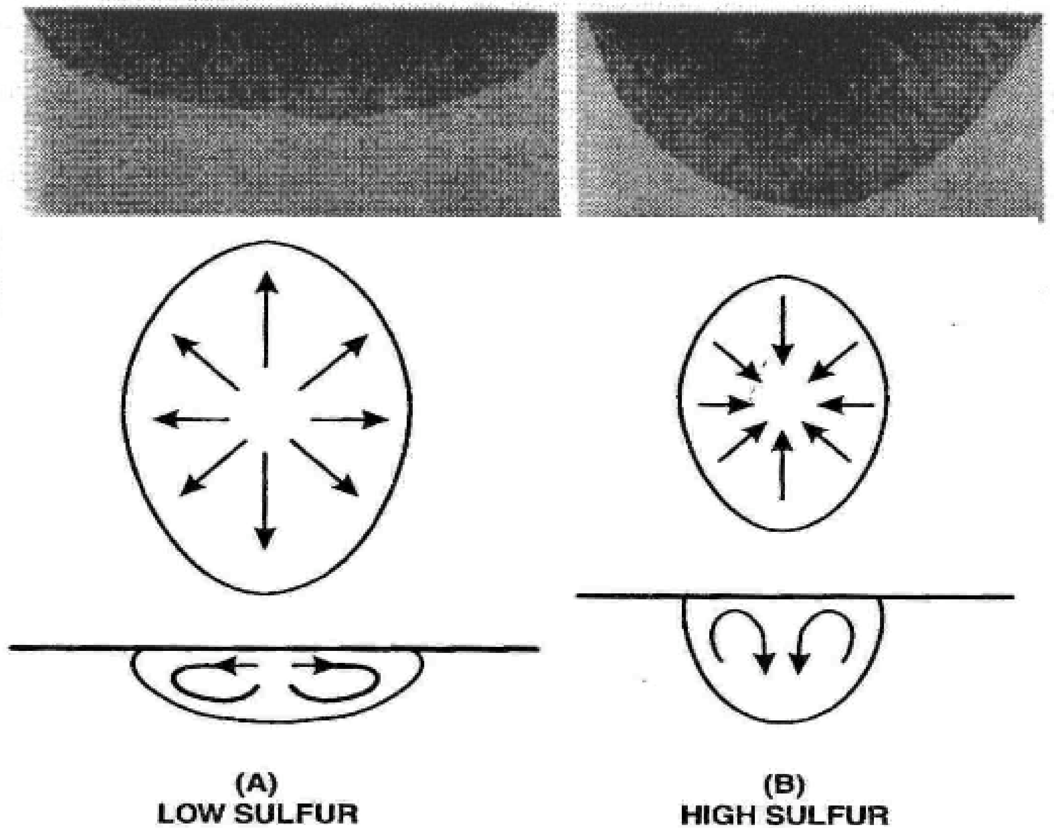
Other Factors

- Sulfur content
- Ferrite content
- Surface condition

Sulfur Content

- Detrimental to corrosion resistance
  - Sulfide inclusions serve as initiation sites for pits
- Detrimental to electropolishing
- Beneficial for autogenous welding
  - ASME BPE Standard requires 0.005 - 0.017% S for automatic welding
- Improves machinability
  - Type 304L and 316L bar products typically contains 0.020 - 0.030% S

What Effect Does Sulfur Have?

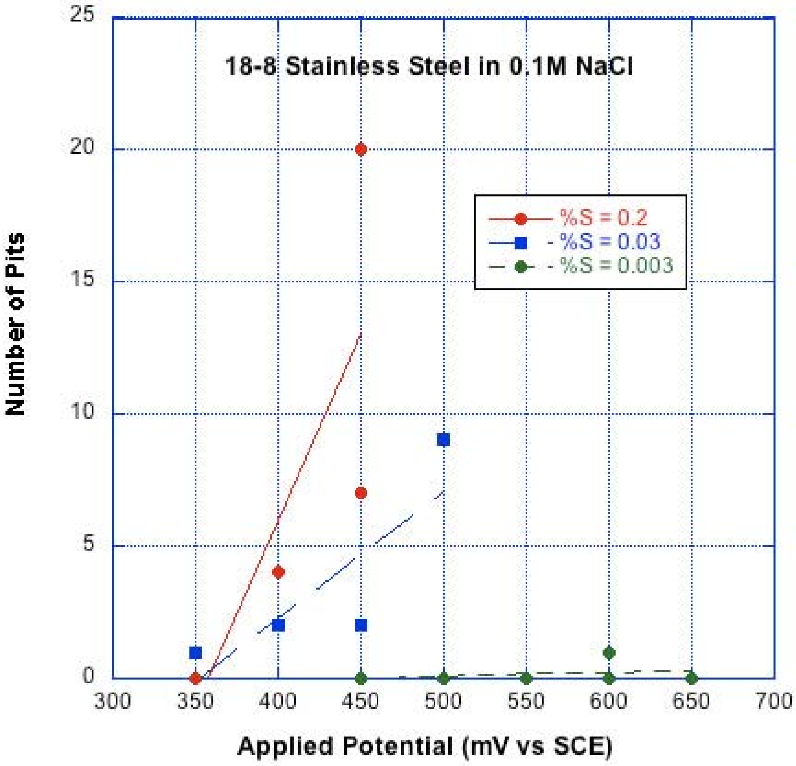


<0.001%S
Shallow Penetration

0.016% S
Deep Penetration

Effect of S Content on Pitting Resistance

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



Type 304L and 316L Stainless Steel

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316L	0.03	2.0	0.045	0.030	0.75	16.0 18.0	10.0 14.0	2.00 3.00	0.10
303	0.15	2.0	0.20	0.15 Min.	1.00	17.0 19.0	8.0 12.0	---	---

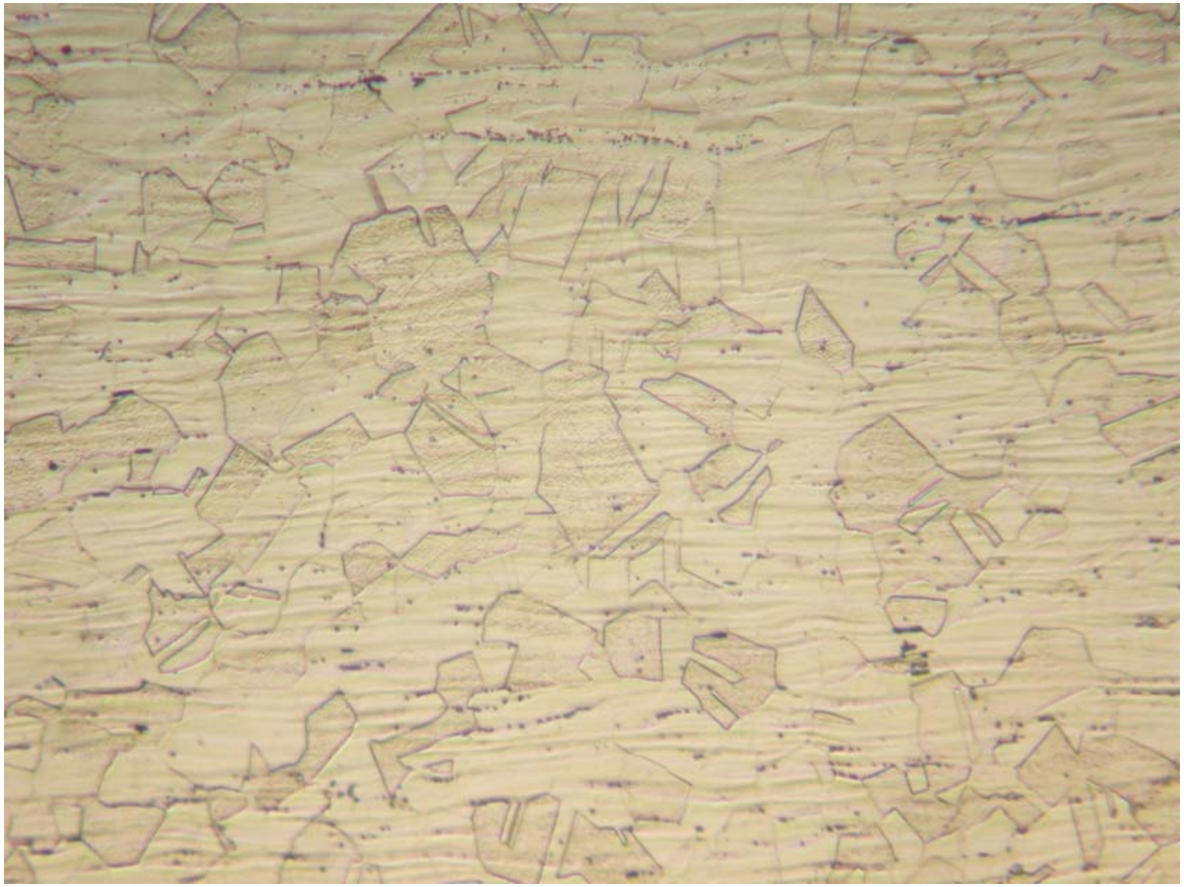
Based on the ASTM A 240/A 314 requirements

Type 303 Stainless Steel

Grade	C	Mn	P	S	Si	Cr	Ni	Mo	N
303	0.15	2.0	0.20	0.15 Min.	1.00	17.0 19.0	8.0 12.0	---	---
PRODEC® 304	0.03	2.0	0.045	0.030	0.75	18.0 19.5	8.0 12.0	---	0.10

Based on the ASTM A 240 requirements

Ferrite Content



Ferrite Content

- Presence of ferrite improves hot cracking resistance and hot workability
- Increased ferrite levels lower the pitting resistance and increase corrosion rates in strong acids
- Ferrite may reduce the EP properties on the end grain of bar product

Selecting Optimal 304L/316L for High Purity Applications

- Optimize selection requirements without seriously limiting availability
- Selection criterion should be based on product form
  - Plate/Sheet
  - Bar
  - Pipe/tubing

Selecting 304L/316L Plate and Sheet (no autogenous welding)

- Sulfur content - 0.003% maximum
- % Ferrite range - 3% maximum
- Electropolishing Applications
  - Procure product produced on a state of the art caster
  - Avoid first and last slabs of the melt sequence

Selecting Welded Pipe and Tubing

(welding applications)

- ASME BPE requires a sulfur content - 0.005 - 0.017%
  - For optimal corrosion and EP properties the sulfur level should be near the bottom of this range with a 0.010% max.
- % Ferrite range - 5% maximum
- Electropolishing Applications
  - Procure product produced in a state of the art melt shop
  - Avoid product from the first and last slabs of the melt sequence

Selecting Bar Product

- If possible, avoid type 303 stainless steel
  - Select a modern machining grade such as 304 PRODEC
- For maximum Corrosion Resistance
  - Sulfur content - 0.013% maximum
  - % Ferrite range - 5% maximum

Case Study - Type 304 Railings

Rail Station

Bus Station

Rail Station - Gate

Type 304/No.4 Polish

Bus Station - Handrail

Type 304/320 Grit Finish

Chemical Composition

Element	Rail Station Gate (wt%)	Bus Station Handrail (wt. %)	ASTM A 554, MT-304 Composition (wt. %)
Cr	18.00	18.18	18.0 – 20.0
Mn	1.74	1.77	2.00 (max.)
Ni	8.11	8.13	8.0 – 11.0
P	0.030	0.033	0.040 (max.)
S	0.014	0.013	0.030 (max.)
Si	0.42	0.46	1.00 (max.)
C	0.055	0.023	0.08 (max.)

Roughness

Rail Station - Gate

Location	R_a Readings (micro inches)	Average R_a (micro inches)
Top Horizontal Tube	52, 41, 40, 33	41.5
Vertical Tube (hinge side)	35, 32, 32	33.0
Vertical Tube (latch side)	52, 49, 52	51.0
Vertical Bar	19, 17, 19, 21, 19, 19	19.0
Latch Plate	52, 49, 52	51.0

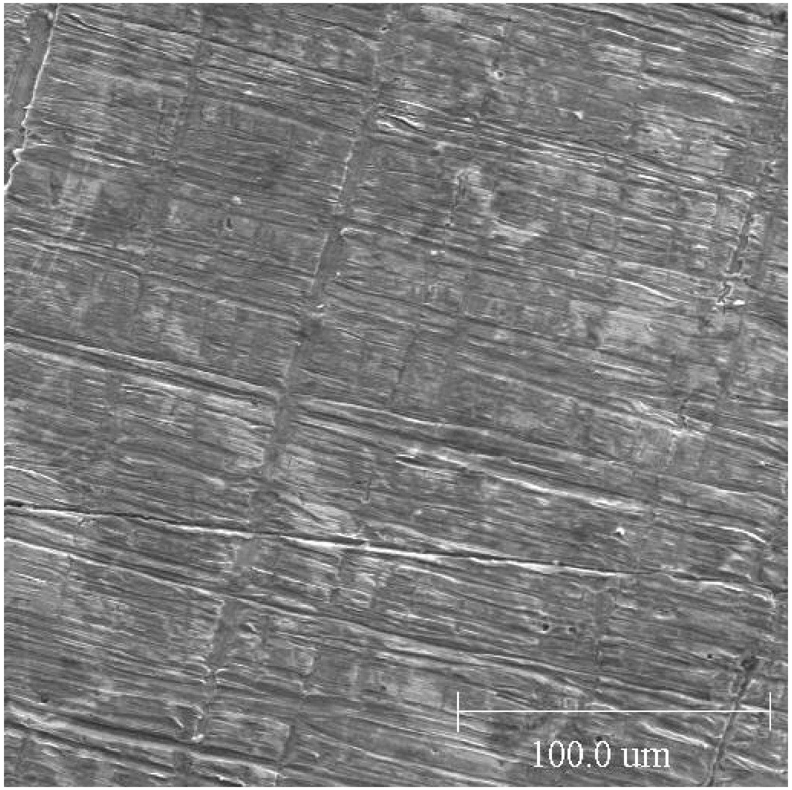
Bus Station - Railing

Location	R_a Readings (micro inches)	Average R_a value (micro inches)
Horizontal Tube	42, 40, 48, 52	45.5
Horizontal Tube	159, 98, 77, 97	112.7

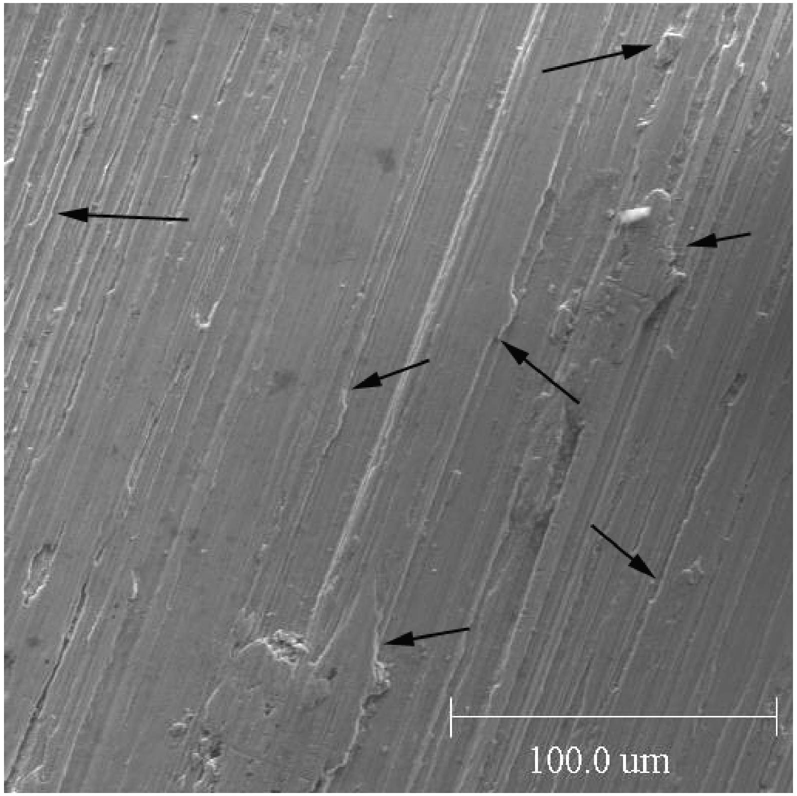
Surface Chloride - Chlor*Test™

Site - Test Area	Chloride Concentration ($\mu g/cm^2$)
Rail Station - Top tube on sheltered gate	40
Rail Station - Top tube on exposed railing	10
Rail Station - Top tube on exposed railing	12
Bus Station - Top tube on sheltered handrail	40
Bus Station - Top tube on exposed railing	55

Surface Morphology

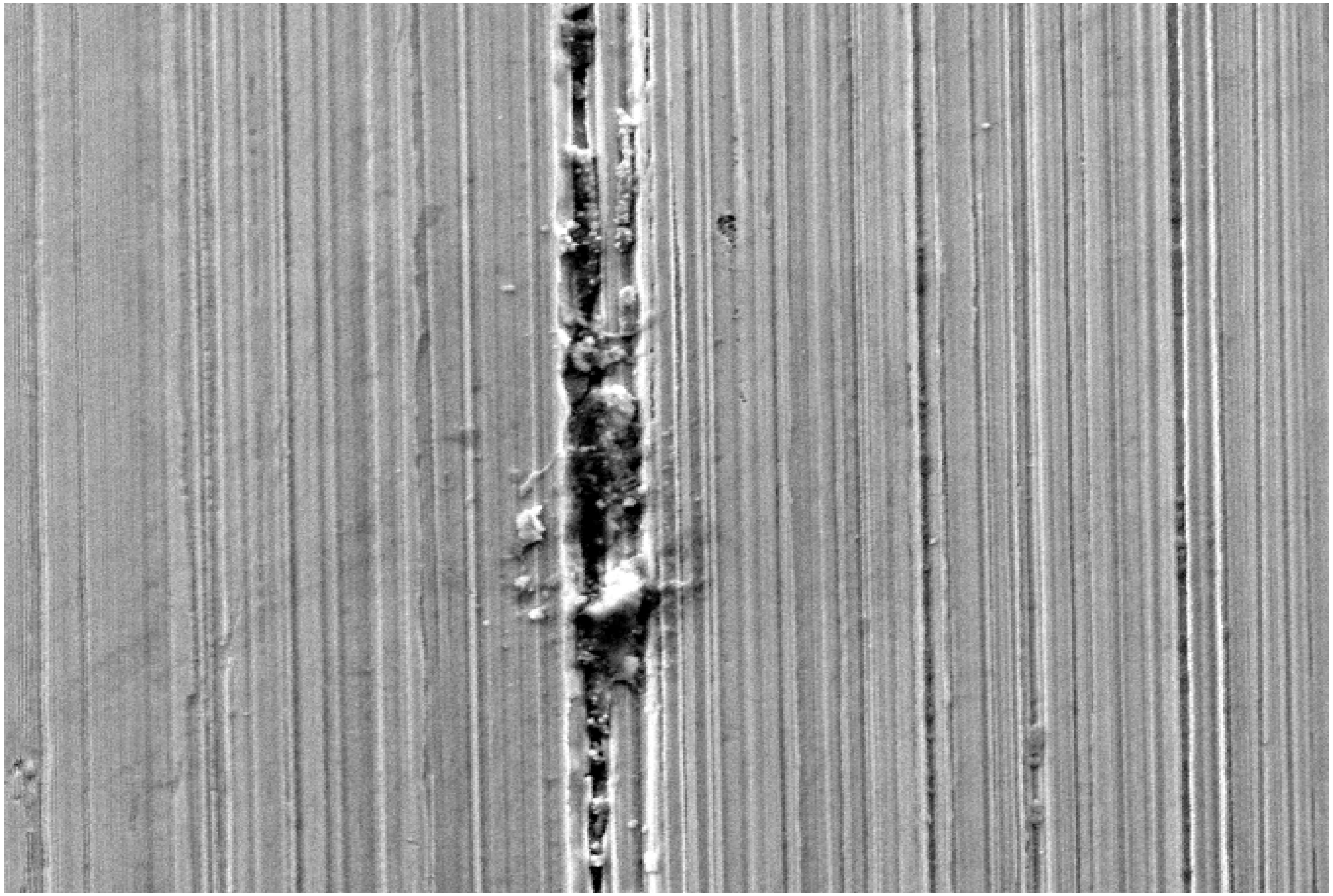


Bus Station



Rail Station

Corrosion Attack On a Mechanically Polished surface



What does Passivation Mean?

- Process by which stainless steel will spontaneously form a protective film
- Chemical treatment to remove free iron or other foreign matter that could interfere with the spontaneous formation of a protective film on a stainless steel
  - Typically an oxidant such as a nitric acid solution which enhances the spontaneous formation of a protective film

Methods for Characterizing the - Quality of a Passive Surface

- Measure the Cr/Fe ratio in on the passive surface using surface techniques such as Auger and XPS
- Electrochemical measurements that measure open circuit potentials or critical pitting potentials in a controlled test environment
  - Test.Clinox by Nitty Gritty
  - Passivation Tester 2026 by Koslow
  - Modified ASTM G 61 test

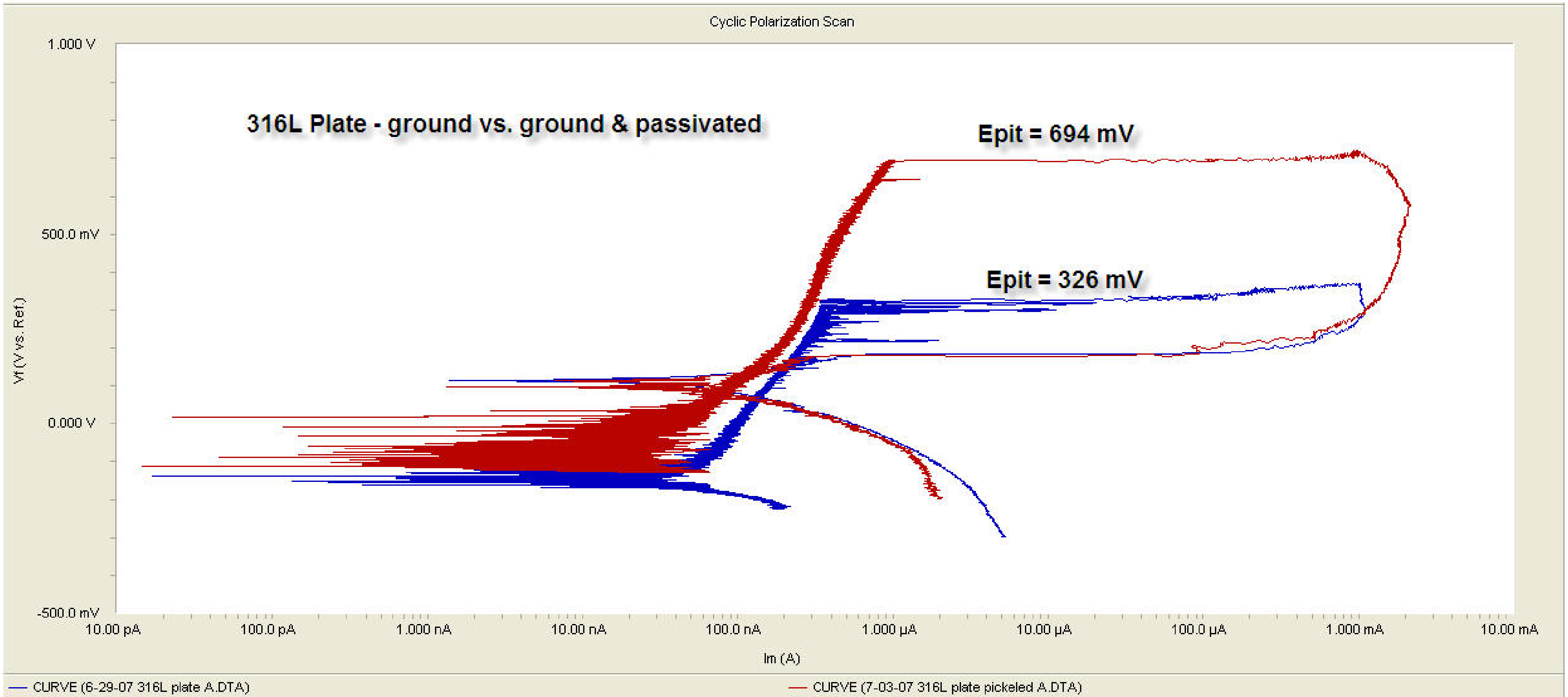
Test.Clinox


PASS
CAL
POWER ON
CAL
START TIMER
TEST.CLINOX
Patent Pending
nitty gritty
www.clinox.com

Passivation Study - Test methods

Cyclic Polarization (modified ASTM G 61)

- **Test Solution - 1000 ppm Cl^-/pH 5.0**
- **Electrode potential was scanned in the more noble direction from -25 mV below open circuit potential until the current reached a value of 500 µA/cm2**
- **Critical Pitting Potential was defined as the potential where the current reaches a level of 100 µA/cm2**


Cyclic Polarization Scan
316L Plate - ground vs. ground & passivated
Epit = 694 mV
Epit = 326 mV
1.000 V
500.0 mV
0.000 V
-500.0 mV
Vf (V vs. Ref.)
10.00 pA
100.0 pA
1.000 nA
10.00 nA
100.0 nA
1.000 µA
10.00 µA
100.0 µA
1.000 mA
10.00 mA
Im (A)
CURVE (6-29-07 316L plate A.DTA)
CURVE (7-03-07 316L plate pickeled A.DTA)

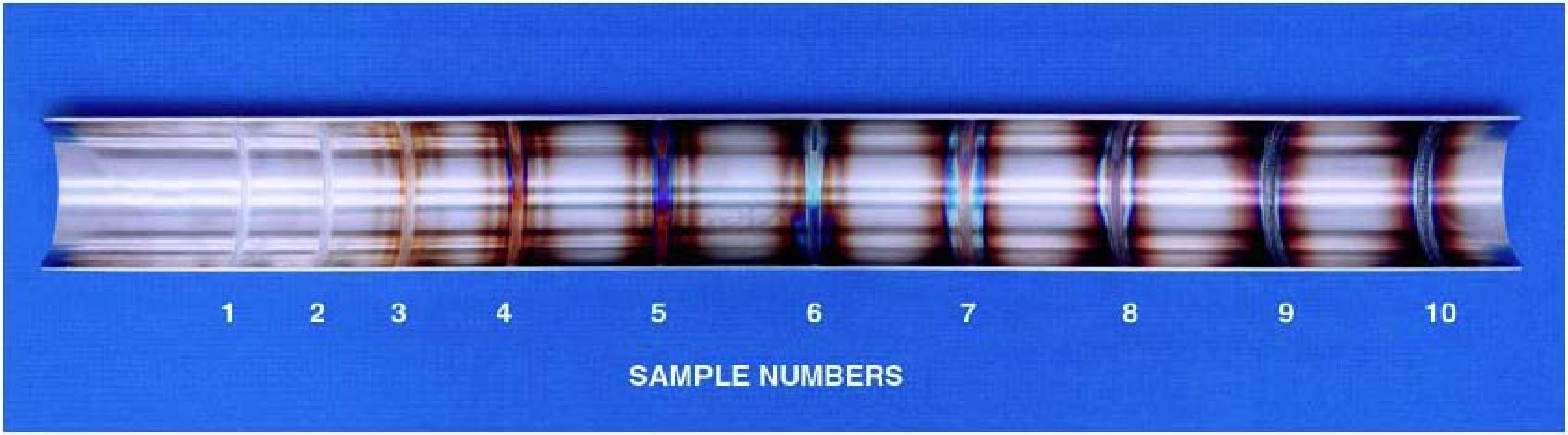
Passivation Study - Test Conditions

- **Type 316L stainless steel with sulfur in the range of 0.005 - 0.017%**

- **Welded (full penetration GTAW) by DCI - (AWS Weld Discoloration Level 2 - 3)**
  - **As-welded - no post-weld cleaning**
  - **Color Cleaned using a Scotch Bright pad**
  - **Ground to 120 Grit finish**

- **Passivation treatment - 30 minutes in 9.5% nitric acid at 55 ºC**

AWS D18.2 - Weld Discoloration



Summary of Test.Clinox

Sample	Unpassivated		Passivated	
	Run #1	Run #2	Run #1	Run #2
As Welded (HAZ)	Pass	Fail	Pass	Pass
Color Cleaned (HAZ)	Pass	Pass	Pass	Pass
Ground (HAZ)	Pass	Fail	Pass	Pass
Base Metal (2B Finish)	Pass	Pass	Pass	Pass

Summary of the Koslow Passivation Test

Sample	Unpassivated	Passivated
As Welded (HAZ)	-780 mV	-215 mV
Color Cleaned (HAZ)	-450 mV	-322 mV
Ground (HAZ)	-220 mV	-298 mV
Base Metal (2B Finish)	-221 mV	-258 mV

0 to -400 mV = Passive, -400 to -500 mV = Indeterminate, -500 to -1100 mV = Unpassivated

Summary Of The 316L CPP Measurements

Sample	Unpassivated	Passivated
As Welded (HAZ)	276 mV	525 mV
Color Cleaned (HAZ)	230 mV	475 mV
Ground (HAZ)	343 mV	495 mV
Base Metal (2B Finish)	506 mV	494 mV
Weld (ground)	---	603 mV

Mechanically Polished Surfaces

- Mechanically polished surfaces typically are not as corrosion resistant as a 2B mill surface
- The smoother the surface finish the better the corrosion resistance
- Avoid micro crevices
- For maximum Corrosion Resistance Passivate after mechanical polish

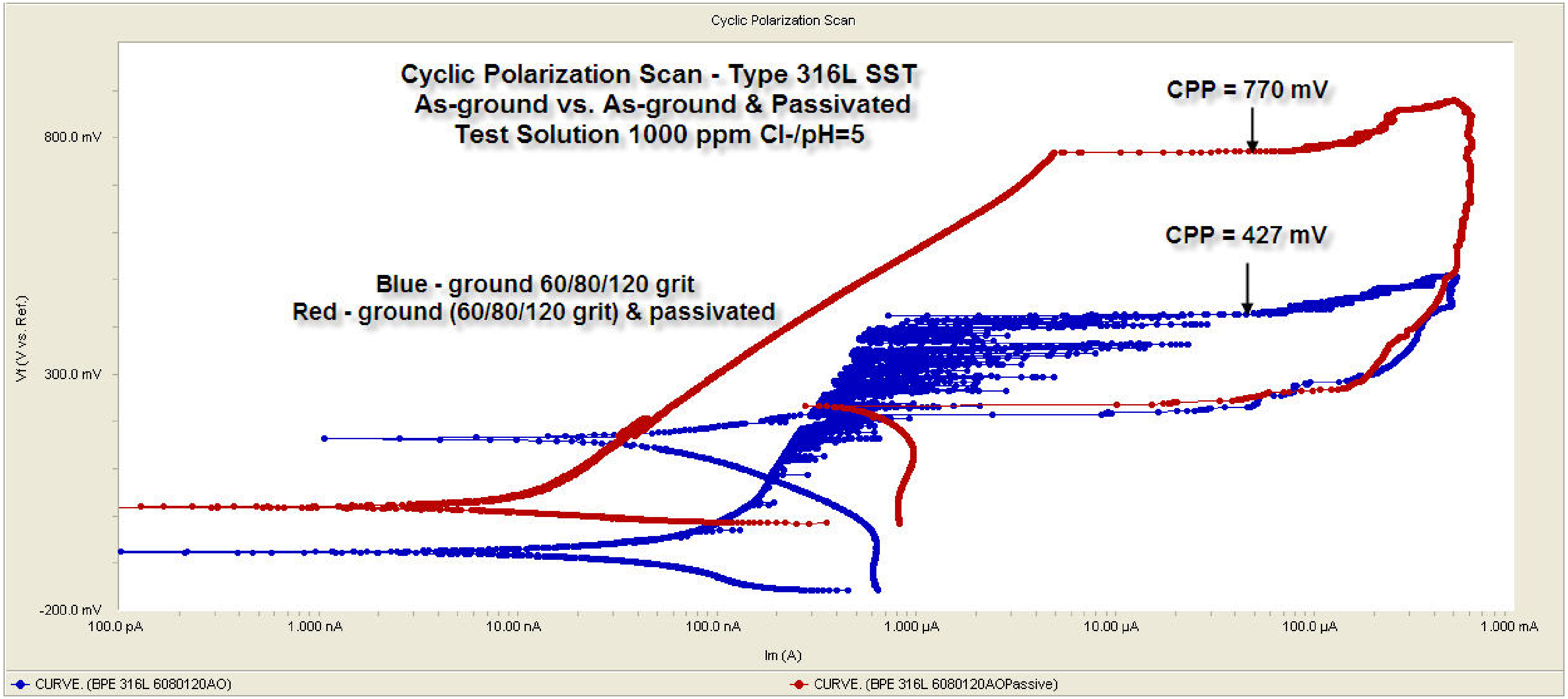
Passivation

- **Removes free iron, sulfides, and other foreign matter**
- **Does not affect the stainless steel**
- **Will not remove scale, heat tint, or chromium depleted areas**
- **Can assist in the formation of passive film with superior corrosion resistance**

Passivation Treatments

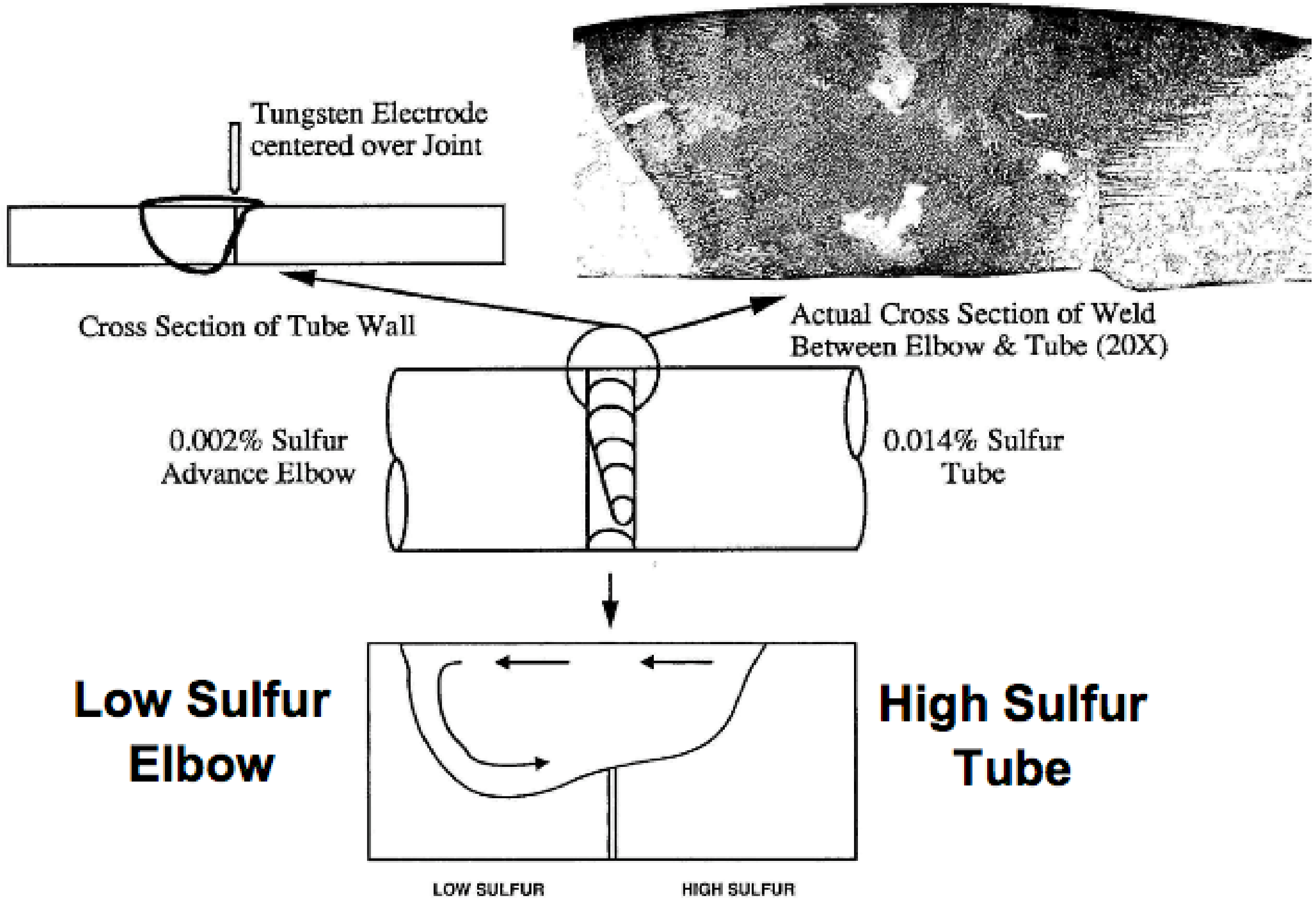
- **See ASTM A 380 and A 967 for details on commonly used passivation processes**
- **Nitric and citric acid solutions are the commonly used**

The Effects Of Passivation On A Mechanically Ground Surface



Thank You!

Missed Joint if Difference in Sulfur > 0.012%



Ferrite Content

$$\%Ferrite = 3.34(Cr_{equiv.}) - 2.46\ (Ni_{equiv.}) - 28.6$$

Where

$$(Cr_{equiv.}) = 1.5(\%Si) + \%\ Cr + \%Mo + 2(\%Ti) + 0.5(\%Nb)$$

$$(Ni_{equiv.}) = 30(\%C+\%N)) + \%Ni + 0.5(\%Mn+\%Cu+\%Co)$$

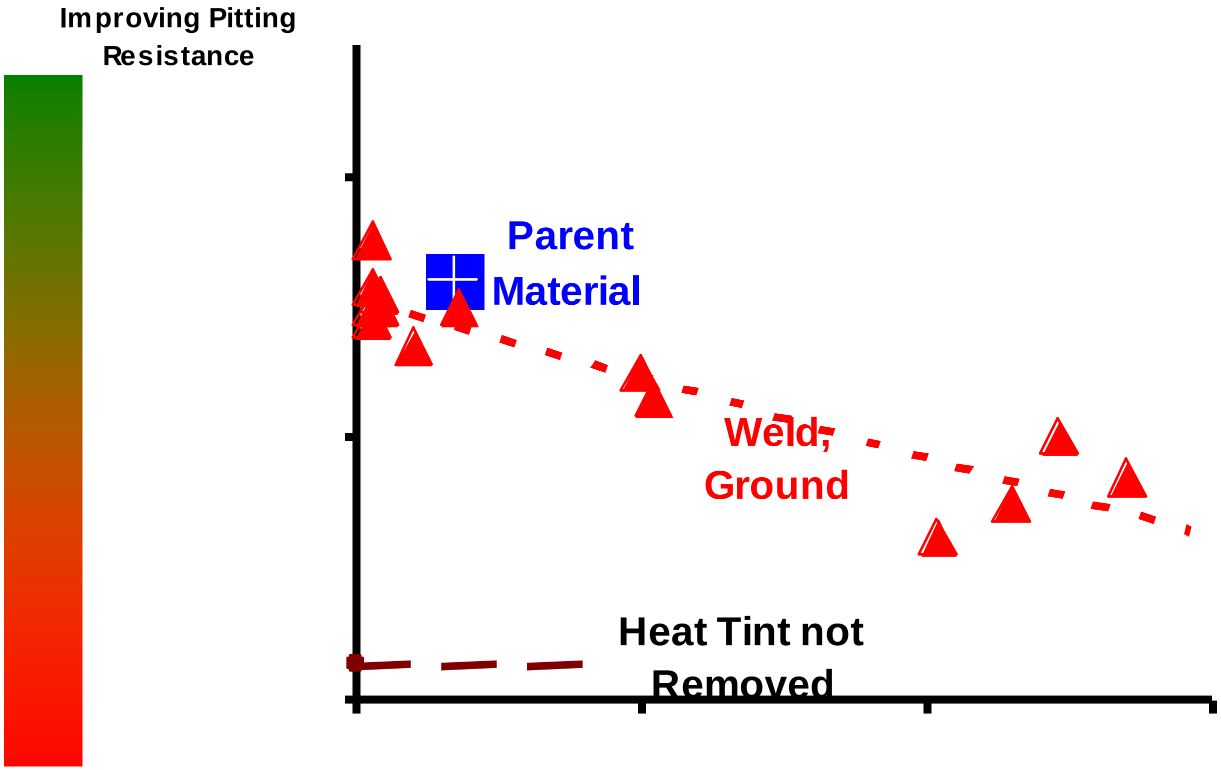
Why Clean Stainless Steels

- Restore corrosion properties after fabrication or repair procedures
- Meet the hygienic requirements of the application
- Meet the required aesthetic requirements

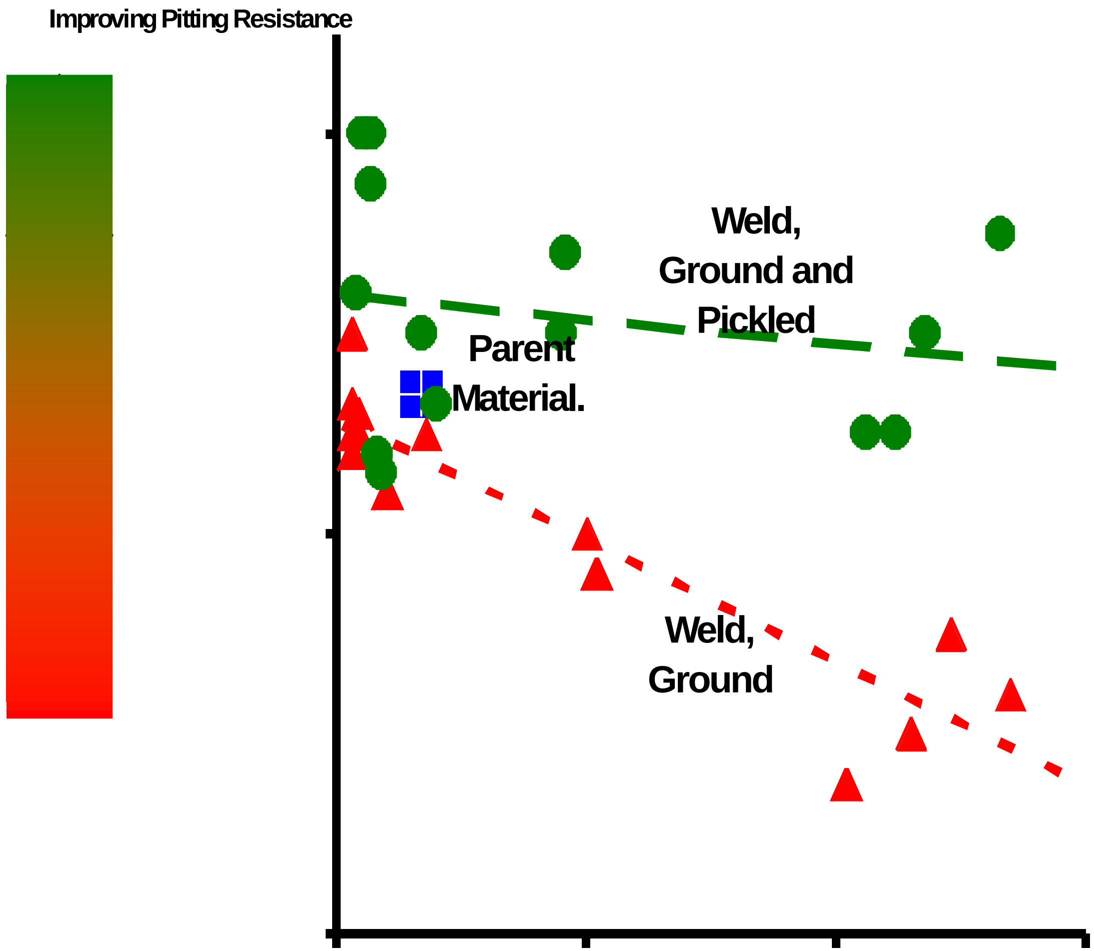
Typical Defects/Contaminants

- Weld defects - undercut, pores, slag, inclusions, weld spatter, arc strikes, heat tint, and chromium depletion fabrication
- Free iron contamination
- Rough surface
- Sulfides
- Organic contamination

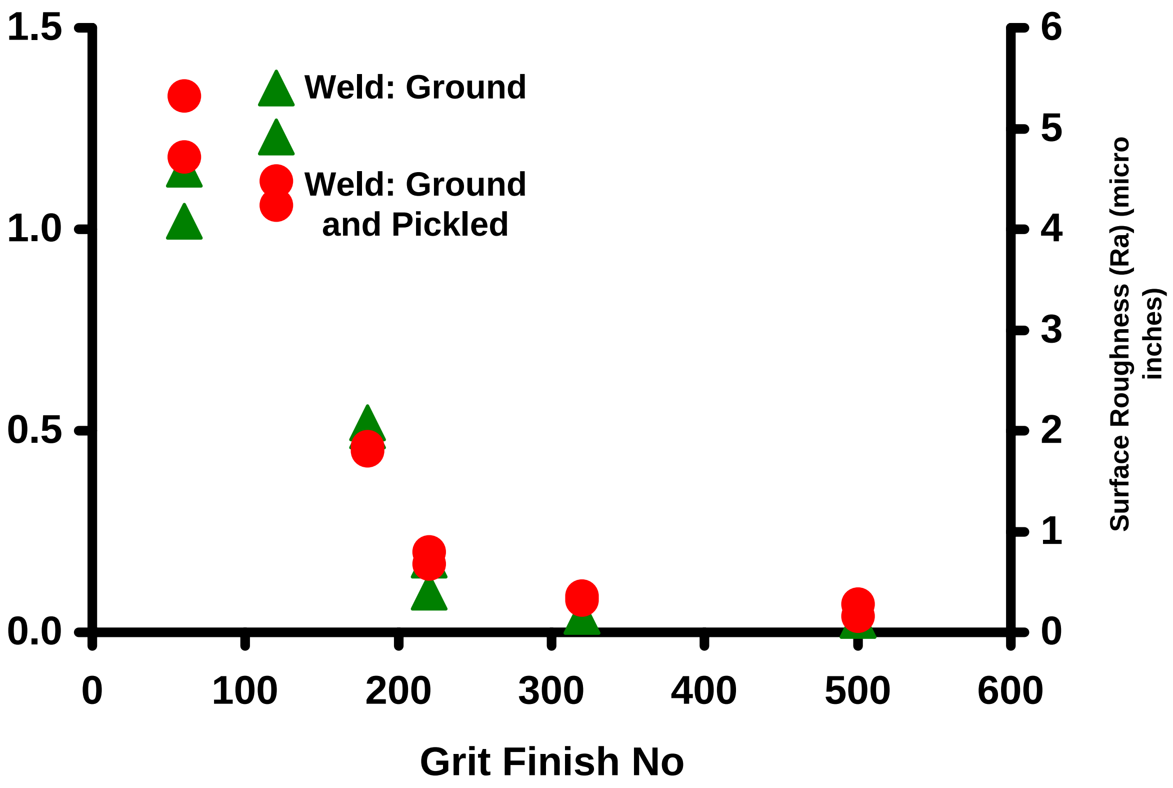
Pitting Potential vs. Roughness (Type 316L Stainless Steel)



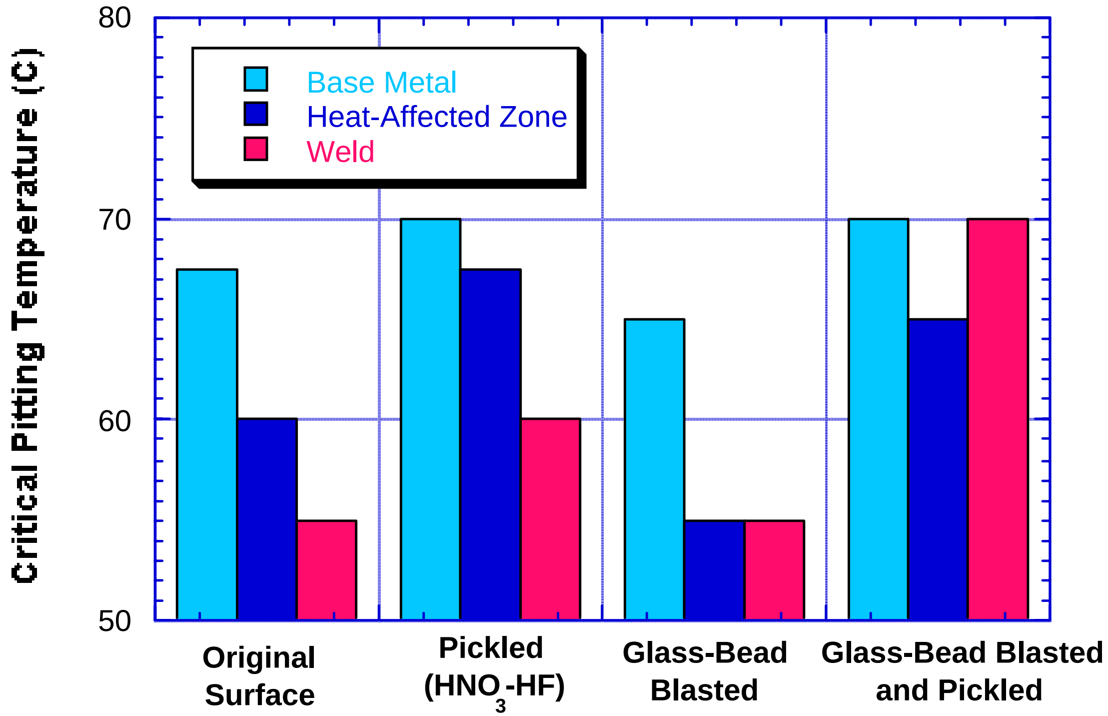
Weld Corrosion Resistance



Surface Roughness vs. Grit Finish

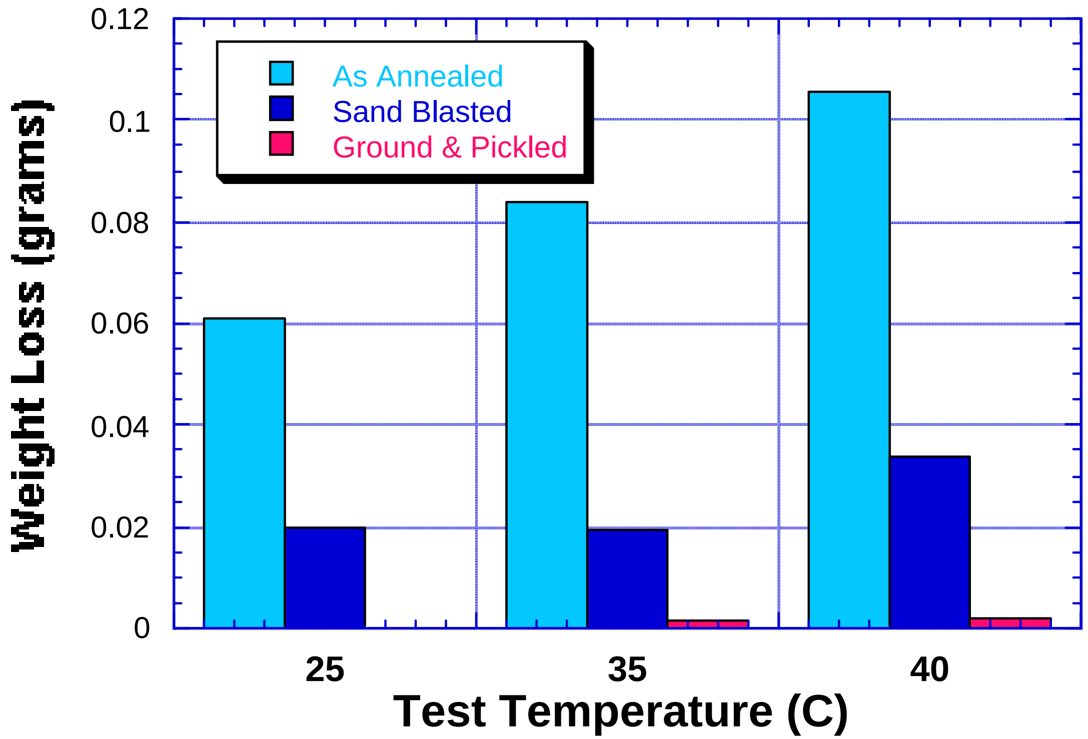


Influence of Pickling/Blasting On the Pitting Resistance of a Welded 6% Mo Stainless Steel



(A. H. Tuthill NiDI Tech Series No. 10 068)

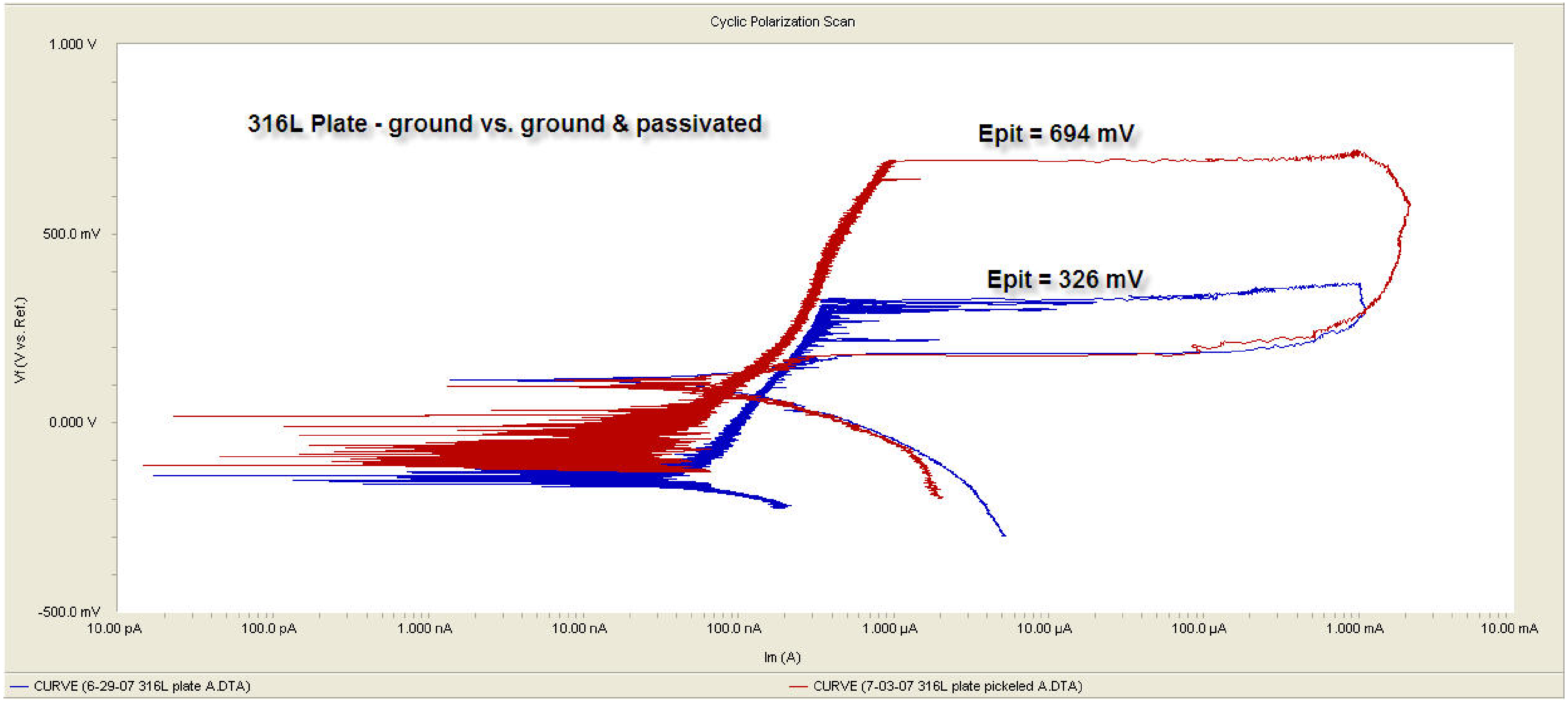
Influence of Mechanical Cleaning/Pickling



6% Mo SST tested in 6% $FeCl_3$

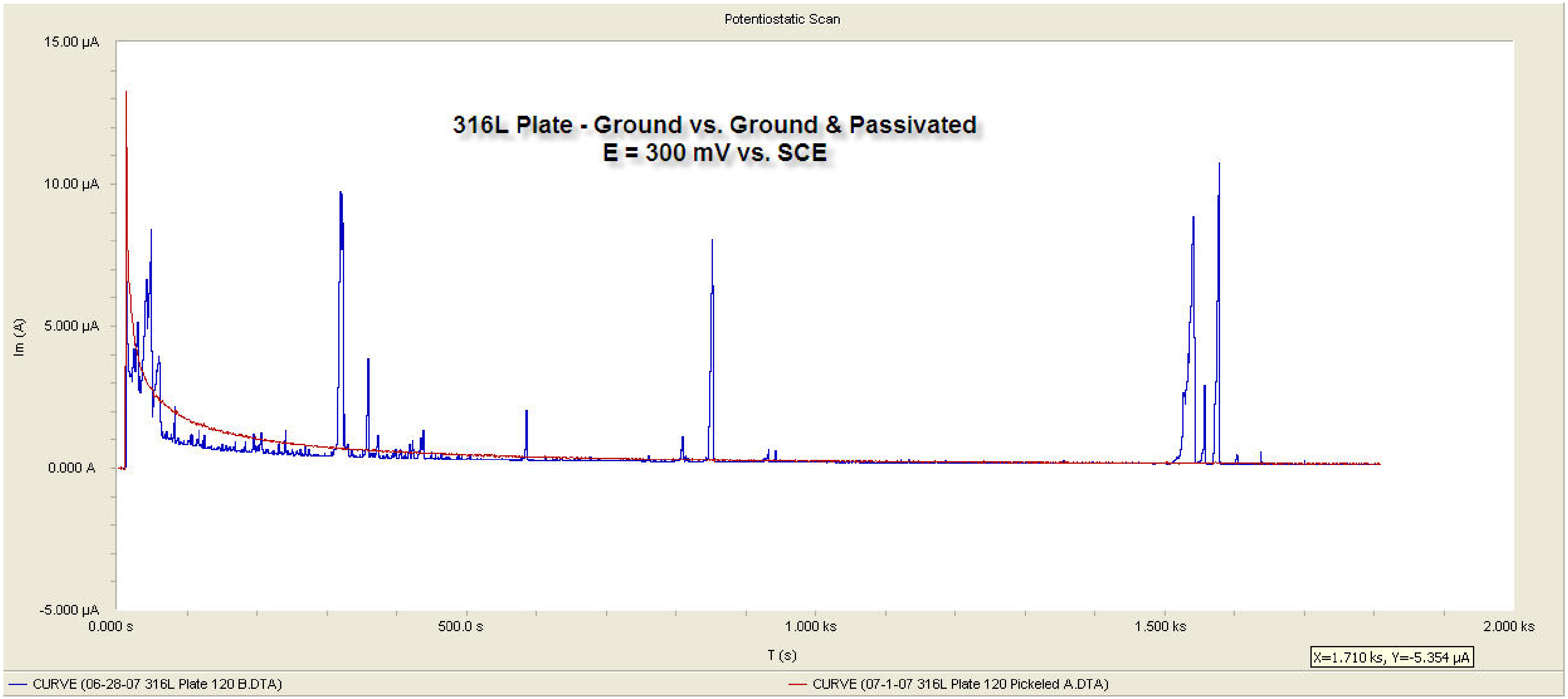
(JF Grubb, Int. Conf. On Stainless Steel 1991)

Passivation



Sample passivated in 9.5% HNO3 at 50 C

Passivation

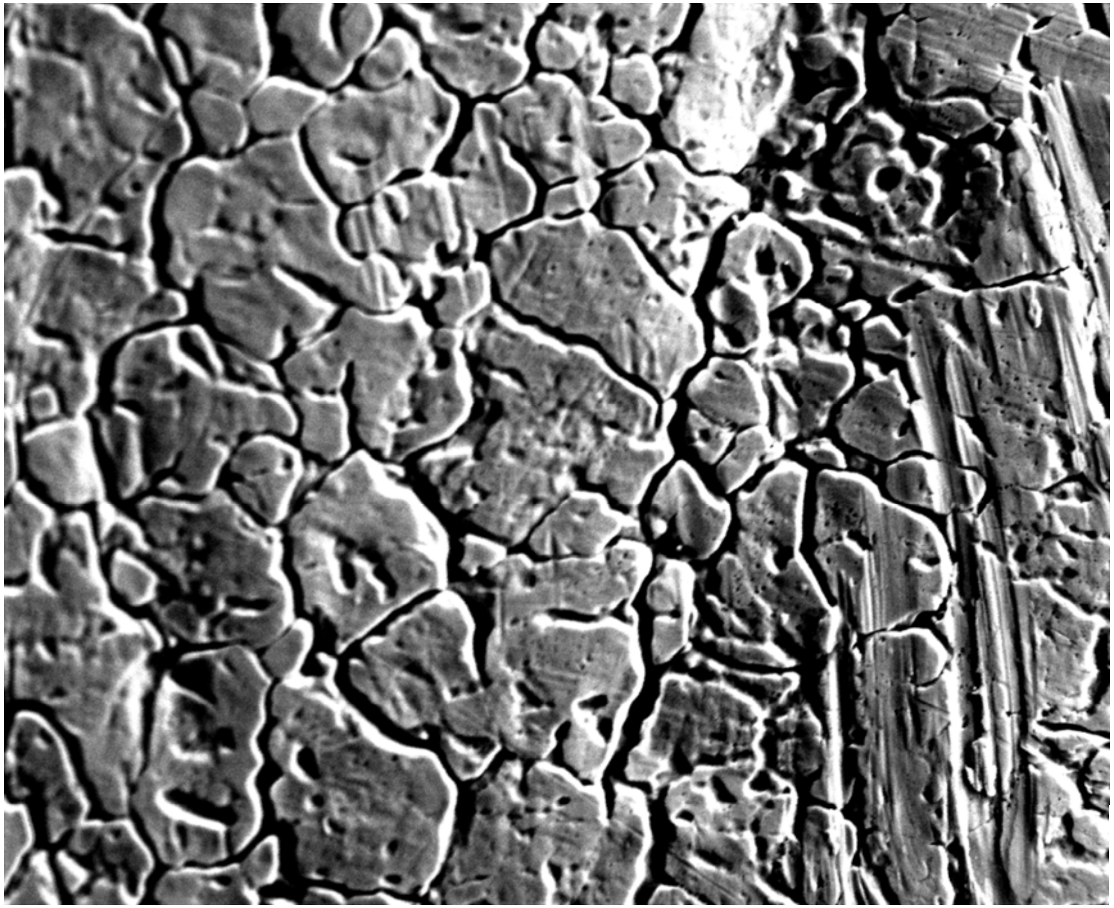


Sample passivated in 9.5% HNO3 at 50 C

Pickling

- Aggressive chemical method for removing oxides (descaling) and free iron contamination
- Removes chromium depleted areas and some of the stainless steel surface
- Nitric-hydrofluoric acid solutions are most widely used
  - See ASTM A 380 for recommendations on acid concentrations, temperatures, and dwell times

Pickled Surface



Magnification = 600X

Pickling Methods

- Dip pickling
  - Composition of the acid, temperature, and dwell time depends on stainless steel grade
- Spray methods
  - Used for large surfaces that can not be dipped
- Pickle Paste
  - HNO_3/HF solution with added binding agents
  - Not very affective at low temperatures (5 - 10 ºC)
  - Avoid drying the past - keep temperatures below 40 ºC

Electropolishing

- Controlled corrosion process
- Removes all free iron and the chromium depleted zone
- Smooth bright surface
- Typically provides the optimum corrosion resistance

Conclusions

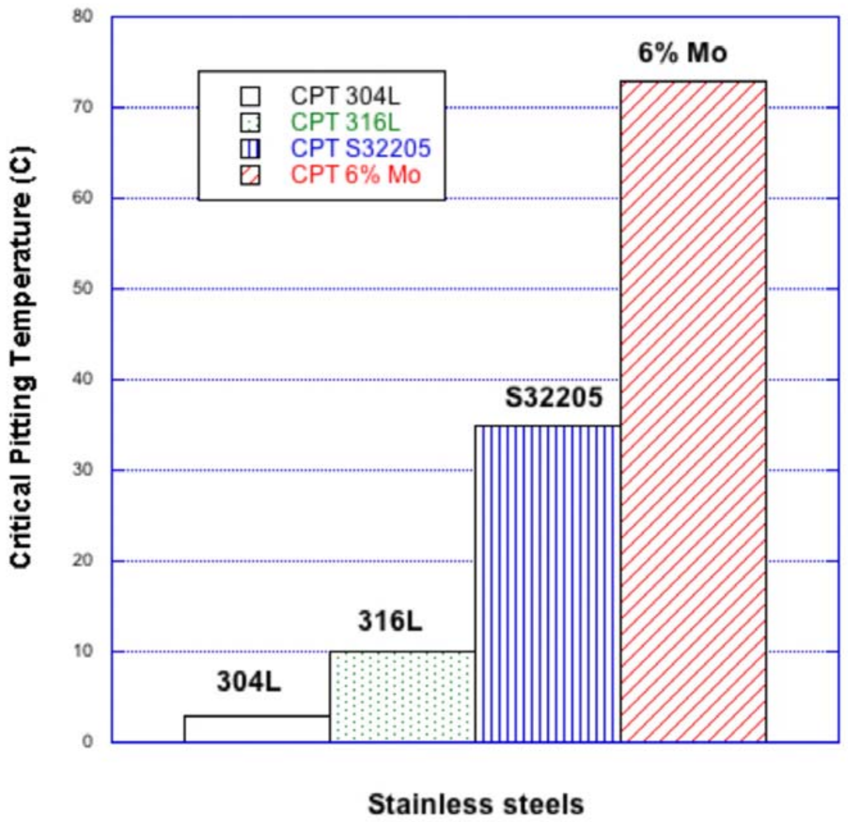
- Producers are very reluctant to produce new grades or new variations of an existing grade.
- The pharmaceutical industry is a relatively small market for stainless steels and producers probably will not make an alloy variation solely for this sector.
- Users can special order a modified 316L composition but this will increase lead times and this must be done on a per heat bases. (120 tons!!)

Conclusions

- Often it is more practical to specify a higher grade of stainless steel than special order a modified 316L heat.
- Improved EP properties can be achieved by selecting 316 SST that is produced on a state of the art caster and avoiding the first and last slabs of the melt sequence.
- Within any given product form users can maximize performance through careful section of sulfur and ferrite levels.

Thank You!

Relative Pitting resistance



Type 304L and 316L Stainless Steel

Element	Type 304L Composition (wt%)	Type 316L Composition (wt%)
C	0.030	0.030 max
Mn	2.00 max.	2.00 max.
P	0.045 max.	0.045 max.
S	0.030 max.	0.030 max.
Si	0.75 max.	0.75 max.
Cr	17.5 – 19.5	16.0 – 18.0
Ni	8.0 – 12.0	10.0 – 14.0
Mo	---	2.00 – 3.00
N	0.10	0.10

Based on the ASTM A 24 requirements

ASTM A 240 Compositional Ranges

Name	C	Mn	P	S	Si	Cr	Ni	Mo	N	Cu
304L	0.03	2.0	0.045	0.030	0.75	17.5 19.5	8.0 12.0	---	0.10	---
316L	0.03	2.0	0.045	0.030	0.75	16.0 18.0	10.0 14.0	2.00 3.00	0.10	---
2101	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
2205	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	---