REINHOLD ENVIRONMENTAL Ltd.

2010 APC Round Table
& Expo Presentation

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Considerations When Welding FGD Alloys

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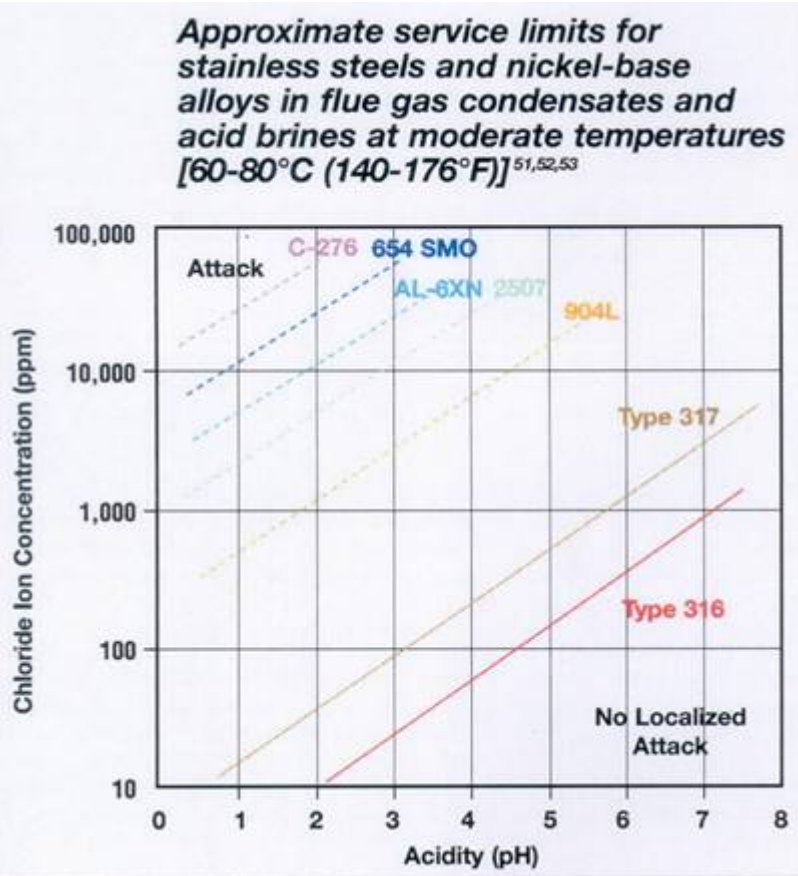
Before we can talk about welding, we need to discuss a few metallurgical concepts

In FGD service, the two primary factors that control corrosion of metals are chlorides and pH.

Cl – pH Relationship



GUIDELINE STAINLESS STEEL AND NICKEL ALLOY SELECTION FOR FGD EQUIPMENT

		MILD		MODERATE		SEVERE		VERY SEVERE		
	CHLORIDE ppm	100	500	1,000	5,000	10,000	30,000	50,000	100,000	200,000
MILD	pH 6.5	TYPE 316 L STAINLESS STEEL		TYPE 317 LMN					NICKEL ALLOY 625 ETC	
MODERATE	pH 4.5			STAINLESS STEEL		SUPER DUPLEX STAINLESS STEEL 25% Chromium Stainless Steels		SUPER AUSTENITIC STAINLESS STEEL 6% Molybdenum Stainless Steels		NICKEL ALLOY C276 ETC
SEVERE	pH 2.0	TYPE 317 LM STAINLESS STEEL			22% Cr DUPLEX STAINLESS STEEL					
VERY SEVERE	pH 1.0	TYPE 317 LMN STAINLESS STEEL		SUPER AUSTENITIC STAINLESS STEEL 6% Molybdenum Stainless Steels			NICKEL ALLOY 625 ETC			

Alloys Used in FGD Systems

Composition of Representative FGD Alloy Materials

Alloy Common Name	UNS Number	Nominal Composition, weight % Fe	Cr	Ni	Mo	Cu	N	Others
316L SS	S31603	Bal.	17	12	2.5	-	-	-
317L SS	S31703	Bal.	19	13	3.5	-	-	-
317LM SS	S31725	Bal.	19	16	4.5	-	-	-
317LMN SS	S31726	Bal.	19	16	4.5	-	0.15	-
317LN SS	S31753	Bal.	19	13	3.5	-	0.16	-
254 SMO	S31254	Bal.	20	18	6.3	0.8	0.2	-
2205 Duplex	S31803	Bal.	22	5.5	3.0	-	0.14	-
255 Duplex	S32550	Bal.	26	5.5	3.4	2.0	0.18	-
Zeron 100	S32760	Bal.	25	7	3.5	1.0	0.25	-
904L	N08904	Bal.	21	26	4.5	1.5	-	-
904hMo	N08925	Bal.	20	25	6.5	1.2	0.15	-
1925hMo	N08926	Bal.	21	25	6.4	0.9	0.22	-
AL-6X	N08366	Bal.	21	25	6.5	-	-	-
AL-6XN	N08367	Bal.	21	25	6.5	0.8	0.22	-
JS-700	N08700	Bal.	21	25	4.7	0.5	-	-
20	N08020	Bal.	20	35	2.5	3.5	-	0.5Cb + Ta
20 Mo-6	N08026	Bal.	24	35	5.9	3.0	-	-
825	N08825	Bal.	22	42	3.0	2.3	-	0.9Ti
G	N06007	20	22	Bal.	6.5	2.0	-	2.2Cb + Ta, 1.0W, 2.5Co
G-3	N06985	20	22	Bal.	7.0	2.0	-	0.5Cb + Ta, 1.5W, 5.0Co
H-9M	N06920	19	22	Bal.	9.0	-	-	2.0W, 5.0Co
Allcorr	N06110	-	31	Bal.	10.0	-	-	2.0W
625	N06625	5.0	22	Bal.	9.0	-	-	3.7Cb + Ta
C-276	N10276	5.5	15	Bal.	16.0	-	-	3.8W, 2.5Co
C-4	N06455	3.0	16	Bal.	16.0	-	-	0.7Ti, 2.0Co
C-22	N06022	3.0	22	Bal.	13.0	-	-	3.0W, 2.5Co
59	N06059	1.5	23	Bal.	16	-	-	-

After much laboratory testing, the metallurgists were able to predict the pitting resistance of an alloy based on the various components that are in that alloy. They called the result of their equation the Pitting Resistance Equivalent Number (PREN)

Pitting Resistance Equivalent Number

- Stainless Steel
  - PREN = Cr + 3.3Mo + 30N
- Nickel Alloys
  - PREN = Cr + 1.5(Mo + W + Nb)
- Duplex Alloys
  - PREN = Cr + 3.3Mo +1.65 W + 16N

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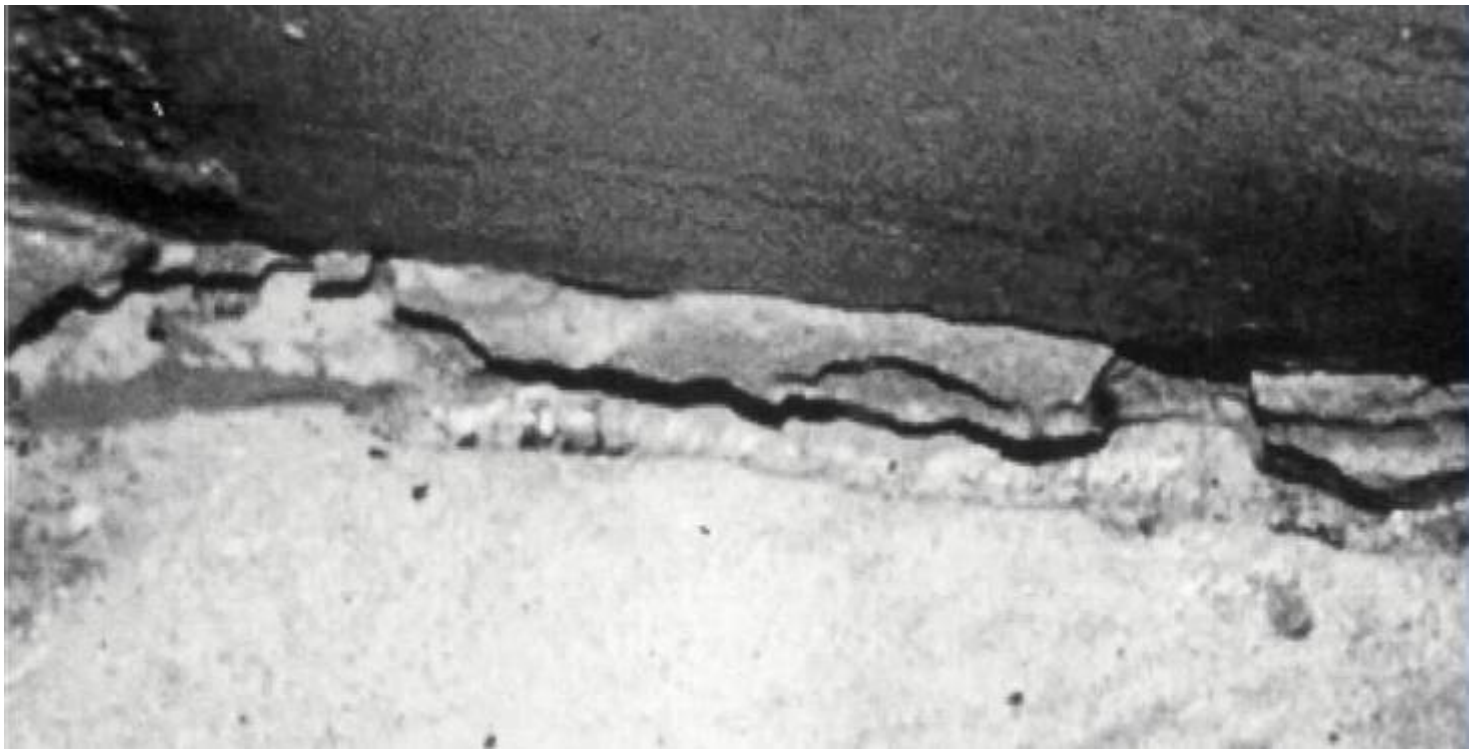
C-22	N06022	3.0	22	Bal.	13.0	-	-	3.0W, 2.5Co
59	N06059	1.5	23	Bal.	16	-	-	-

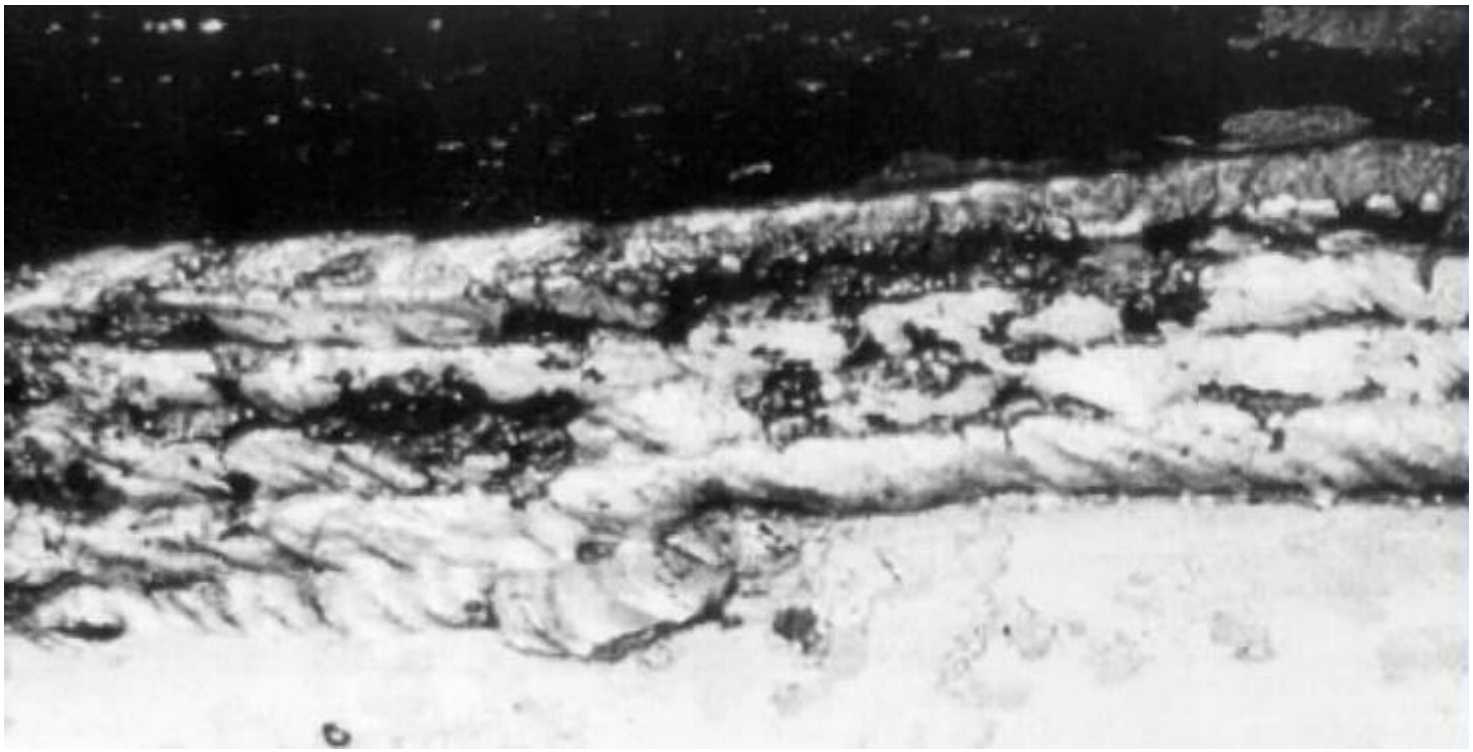
Welding Can Lower Pitting Resistance

- When welding with GTAW or TIG, the PREN can be reduced by:
  - PREN reduction = 335S + (700 – 1000)O
- The sulfur and oxygen form chromium bearing inclusions during weld cooling and deplete the surrounding metal of chromium.

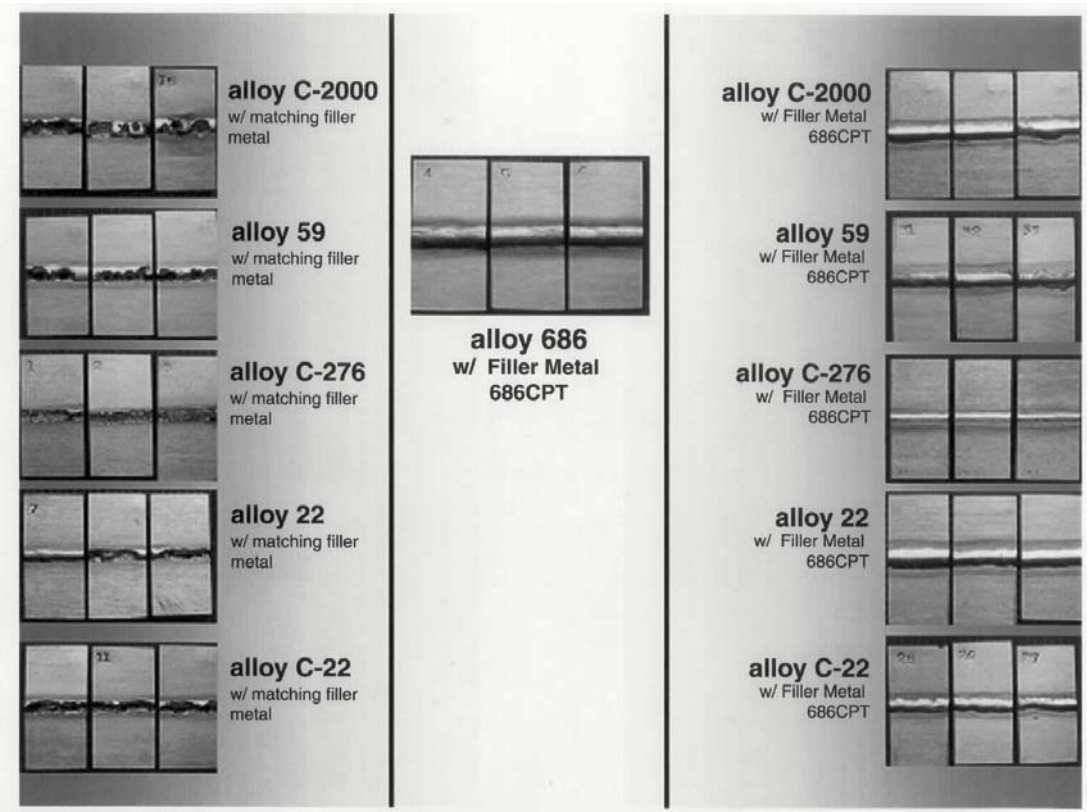
C-276 Metal with C-276 Filler



C-276 Metal with 686 Filler



Over Matching Filler Results ("Green Death" Test Solution)



Source: Huntington Alloys / Special Metals Corporation

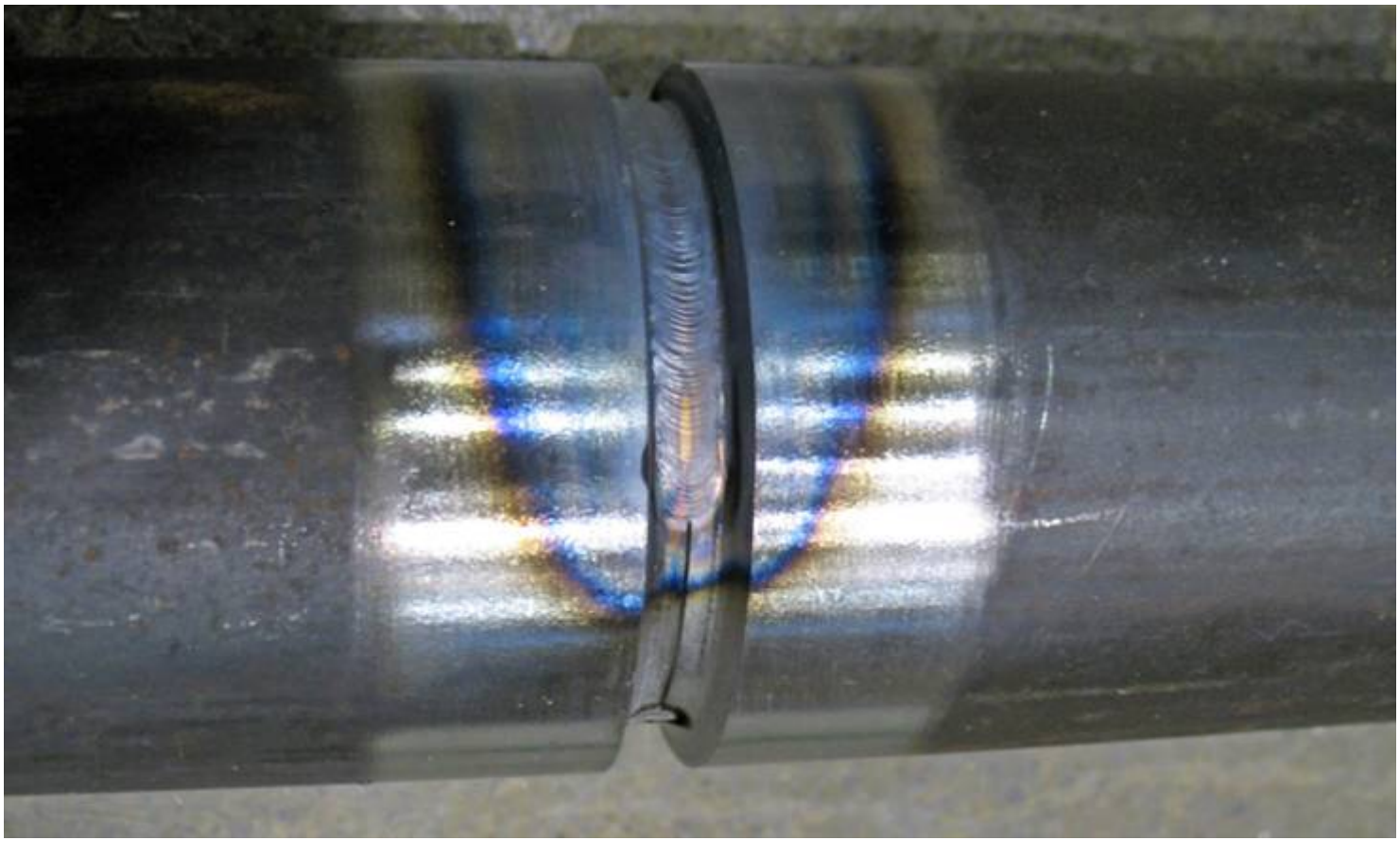
Some High Nickel Alloys

Alloy	UNS #	Fe	Ni	Cr	Mo	W	Nb	Cu	PREN
C-4	N06455	2	66	16	16				40
625	N06625	3	62	22	9		3.6		40.8
C-276	N10276	6	57	15.5	16	3.9			45.4
C-22	N06022	2.5	59	21.5	13.6	3.1			46.6
C-2000	N06200	1	57.4	23	16			1.6	47
59	N06059	1	59	23	16				47
686	N06686	1	58	20.5	16.3	3.9			50.8

Most metal suppliers are now recommending that one use a weld filler metal that is at least one position or more better in the corrosion resistance chart than the base metal. This is called using an overmatching weld filler metal.

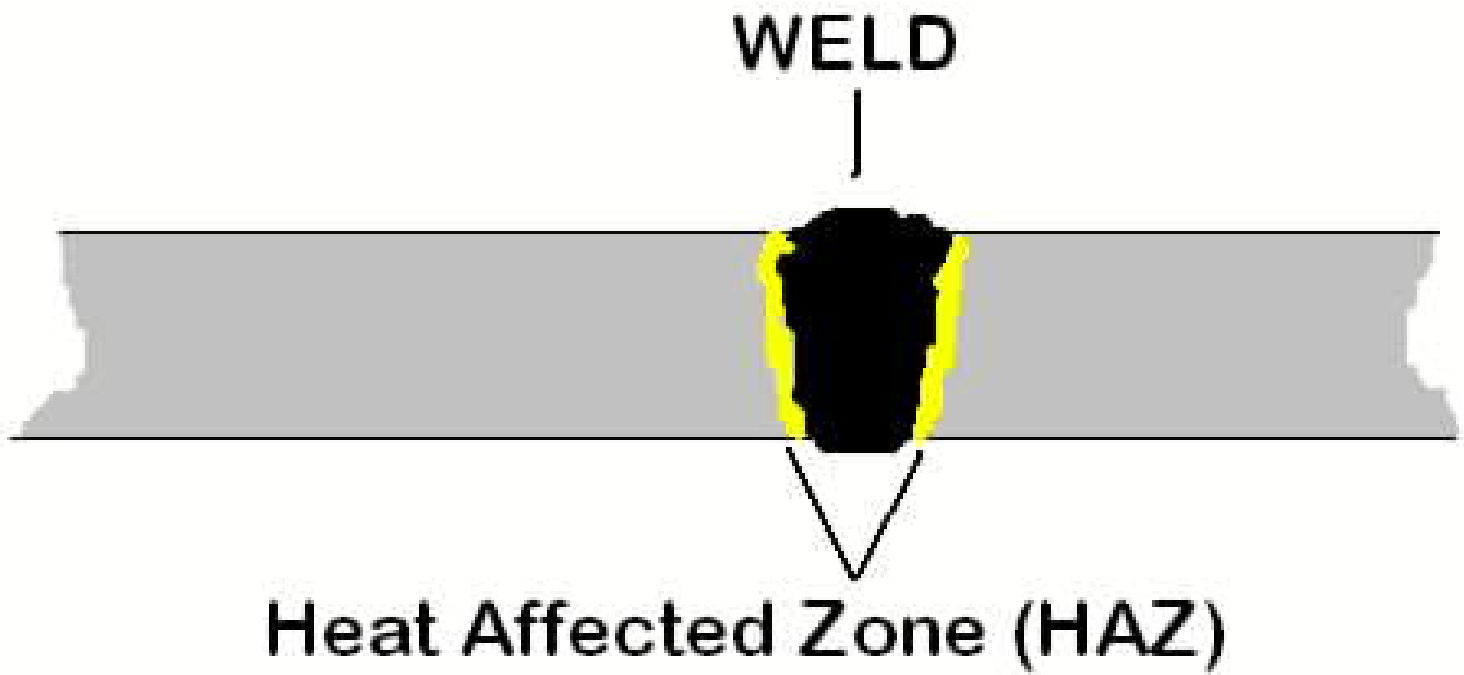
During the welding process, one is melting some of the base metal into the weld pool and heating some of the base metal to various sub-melting temperatures.

Heating Base Metal During Welding



The base metal adjacent to the weld that has not melted but has undergone a change in its microstructure is call the Heat Affected Zone (HAZ).

Heat Affected Zone (HAZ)



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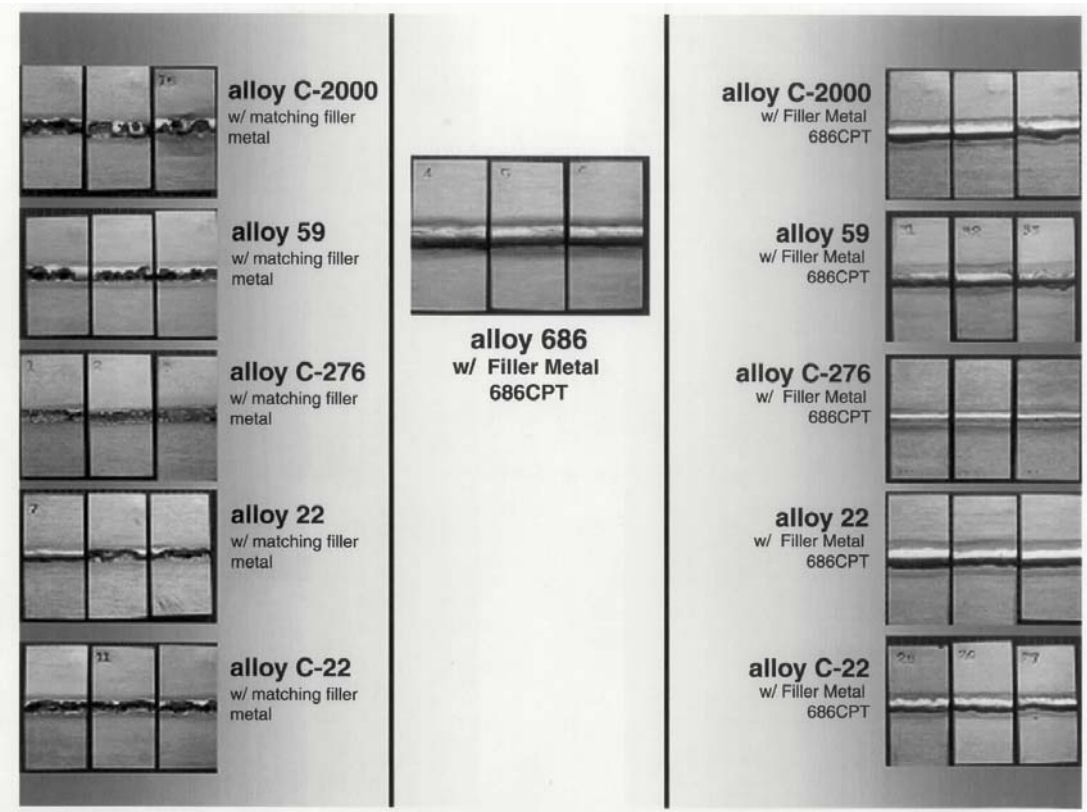
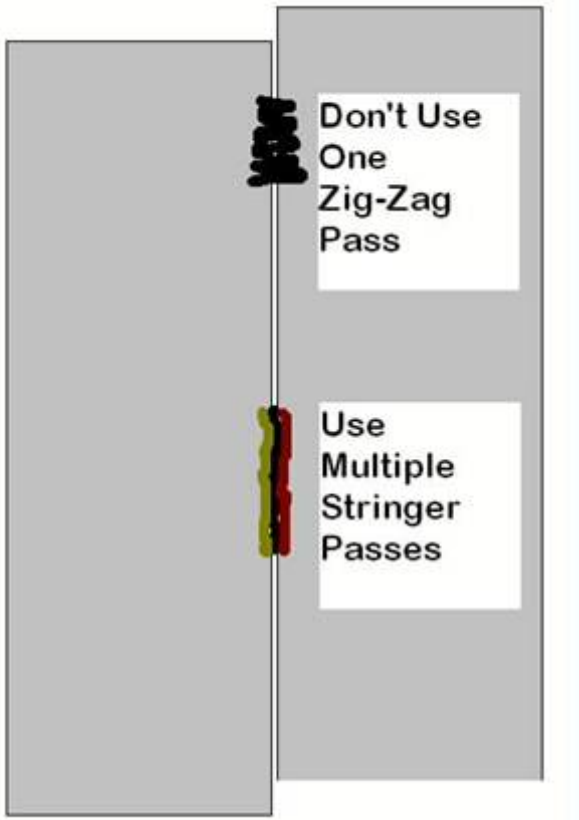


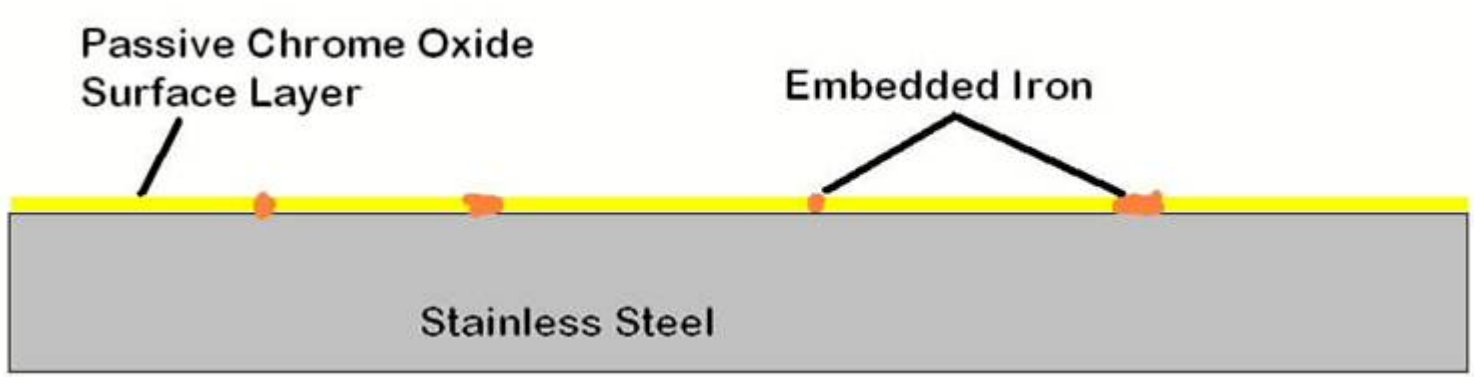
Source: Huntington Alloys / Special Metals Corporation

Heat Input During Welding is Critical



Iron Contamination

- Stainless steel is an active metal that gets its corrosion resistance from a thin adherent passive layer of chrome oxide on its surface.
- Iron contamination on the surface of stainless steel destroys its corrosion resistance by:
  - Disrupting the chrome oxide layer providing a path to the active metal
  - Setting up a galvanic cell between the iron and the stainless steel



Iron Contamination Occurs From Contact With Mild Steel

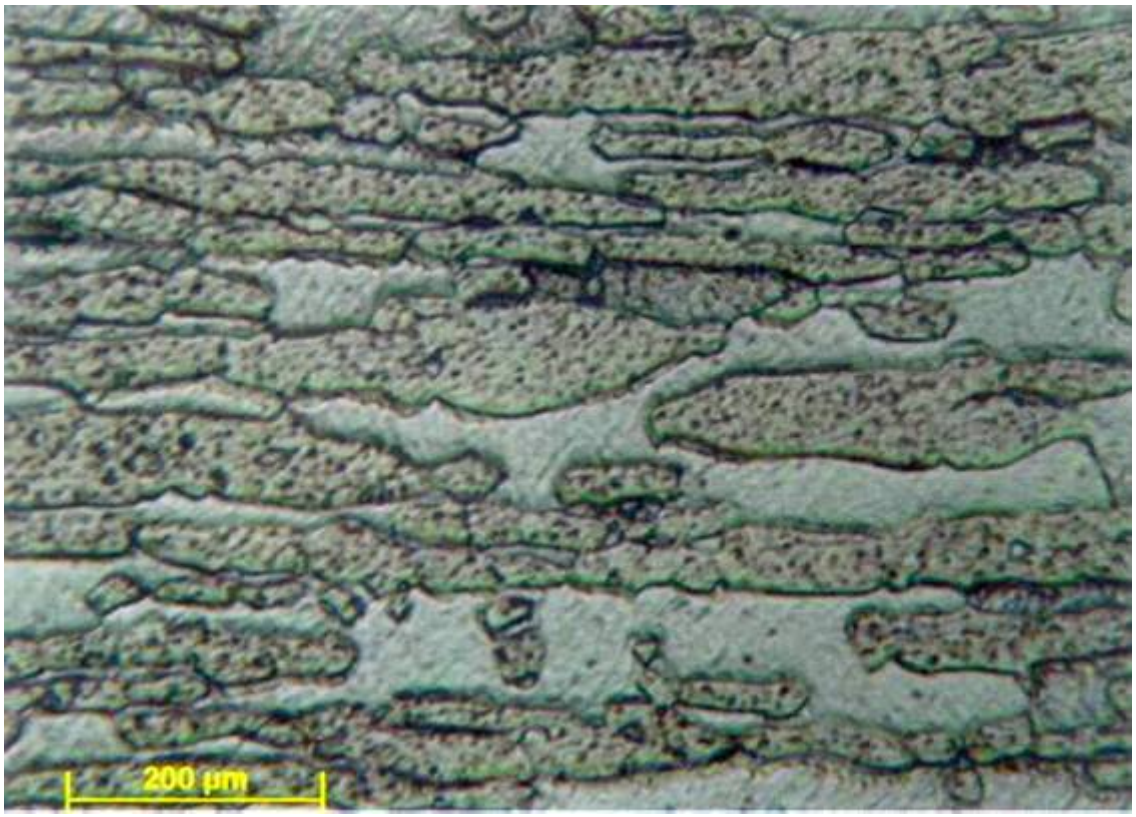
- Lifting hooks, chains, wire rope, lift forks or clamps
- Dragging over truck beds or rail cars
- Contact with metal shears or bending equipment
- Contamination from cutting, welding or grinding of mild steel overhead
- Contamination from tools previously used on mild steel i.e. grinding or polishing wheels, wire brushes, drills, files, screwdrivers

Removing Iron Contamination

- Trying to grind it out can make it worse
- One needs to dissolve the iron with a pickling solution (nitric or hydrofluoric acid) and then passivate the stainless steel with nitric acid.
  - There are pickling and passivating pastes and gels available for small areas
  - One can spray larger areas

Duplex stainless steels have a mixed microstructure of ferrite and austenite, the aim usually being to produce a 50/50 mix, although in commercial alloys the ratio may be 40/60. Duplex steels have improved strength over austenitic stainless steels and also improved resistance to localized corrosion, particularly pitting, crevice corrosion and stress corrosion cracking.

2205 Duplex Microstructure



Lighter Area = Ferrite Darker Area = Austenite

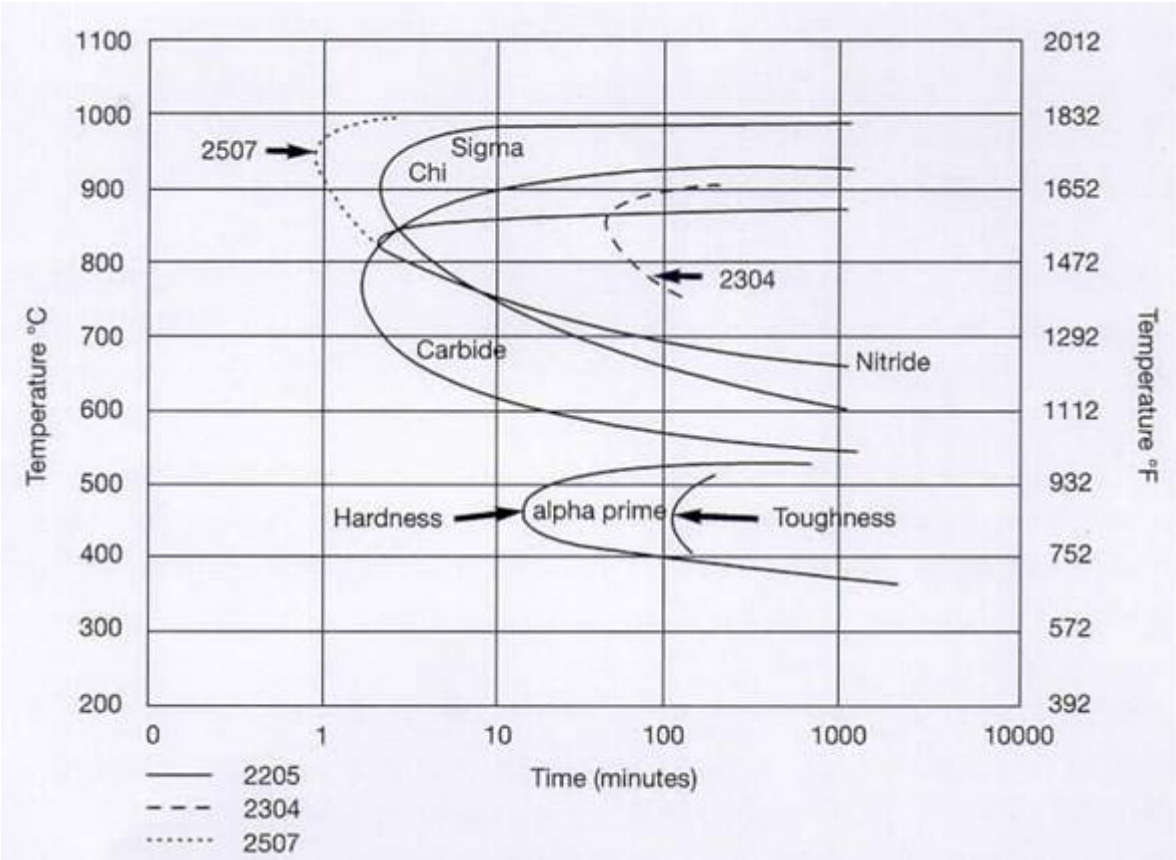
Heat Input and Cooling Rate are Critical During Welding

- At the welding temperature, most of the metal is ferrite, and as it cools, some of the ferrite converts to austenite.
- If the weld cools too fast, the high ferrite value will decrease toughness and corrosion resistance

Heat Input and Cooling Rate are Critical During Welding (Cont.)

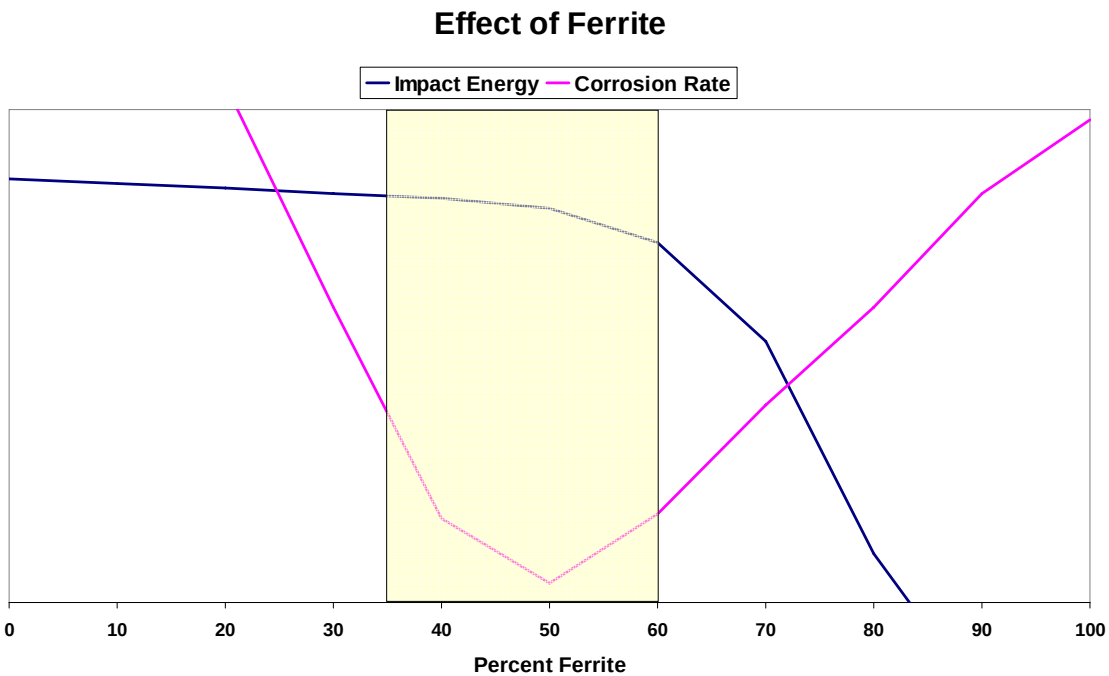
- If the weld area remains at a high temperature for too long, undesirable intermetallic phases can form.
- If the weld area has not cooled to the proper temperature before the next weld pass, the HAZ will be affected by staying at a high temperature too long.

2205 Phase Diagram

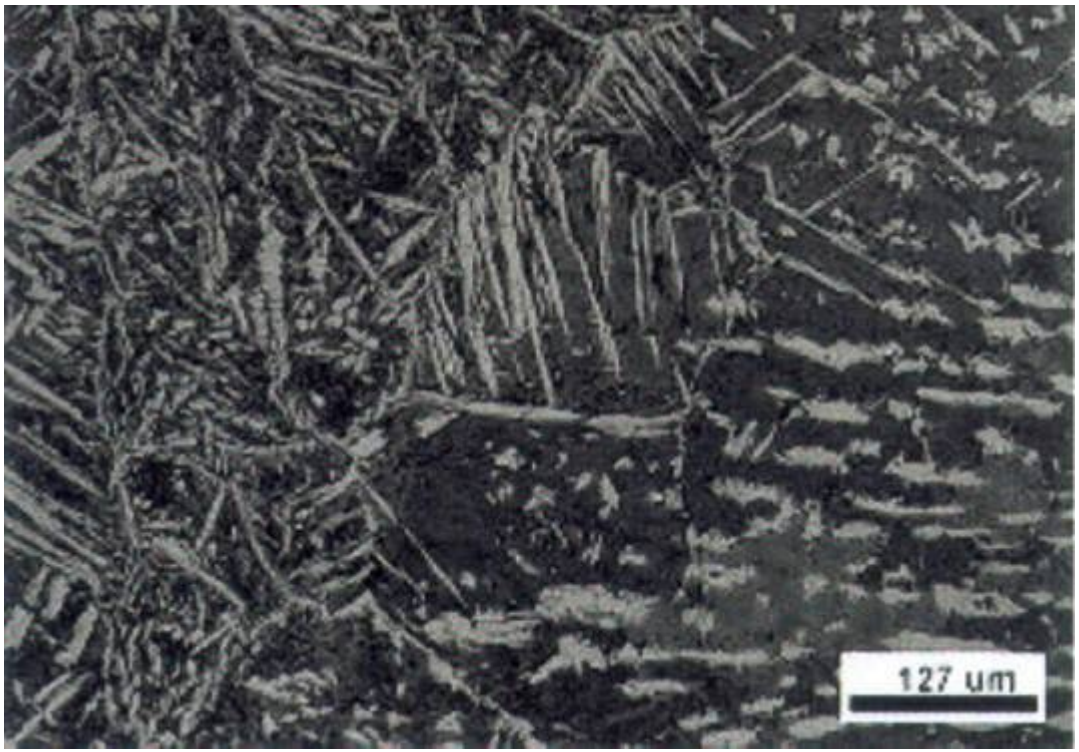


Heat Input and Cooling Rate are Critical During Welding (Cont.)

- The ferrite content in the HAZ will typically be higher than in the weld or in the base metal.



Duplex Microstructure in Weld Area



The weld is on the left side moving into the base metal on the right side

Dark Area = Ferrite Light Area = Austenite

Arc strikes outside of the weld joint will produce a localized area of rapid cooling which will leave a high ferrite area which may have a lower corrosion resistance. All arc strikes should occur in the weld joint.

Grinding or Polishing Duplex

- Flapper wheels are better than solid wheels
- Use only new unused wheels to prevent iron contamination
- If one works in one area too long, one can heat the surface of the duplex which can cause it to oxidize and hinder the formation of the protective passive layer

Questions??