A Primer for DUPLEX Stainless Steel

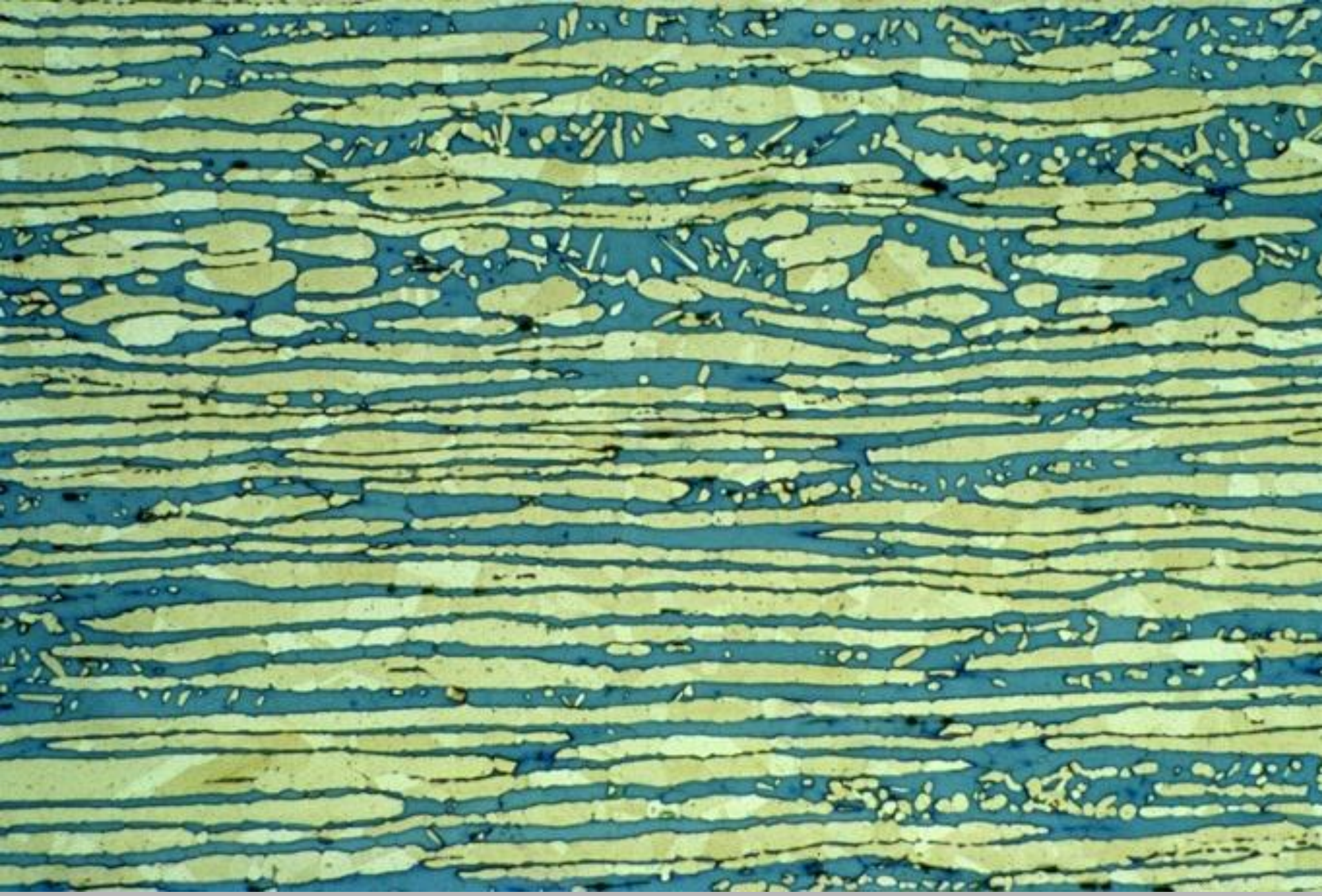
John Grocki

2012

ArcelorMittal

What are Duplex Stainless Steels ?

- **A *family* of stainless steels whose:**
- **structures are approximately *50/50* austenite and ferrite**
- **physical properties are a combination of the ferritic and the austenitic grades**



Duplex Microstructure

What is the “Family”

- **Lean Duplex SS** – lower nickel and no molybdenum – 2101, 2102, 2202, 2304
- **Duplex SS** – higher nickel and molybdenum **- 2205**, 2003, 2404
- **Super Duplex** – 25Chromium and higher nickel and molybdenum “plus” – 2507, 255 and Z100
- **Hyper Duplex** – More Cr, Ni, Mo and N - 2707

Chemistry of Lean Duplex SS

Name	UNS No.	C	Cr	Ni	Mo	N	Other
2101	**S32101**	**.04**	**21**	**1.5**	**0.5**	**.22**	**Mn=5**
2102	**S82011**	**.03**	**21.5**	**1.5**	**0.5**	**.21**	**Mn=2.5**
2202	**S32202**	**.03**	**22**	**2**	**0.5**	**.22**	
2304	**S32304**	**.03**	**23**	**4**	**0.5**	**.12**	

High Cr low Ni 0.2 N and no Mo

Chemistry of *Duplex* SS

Name	UNS No.	C	Cr	Ni	Mo	N	Other
2003	***S32003***	***.03***	***20***	***3.5***	***1.7***	***.16***	
2404	***S82441***	***.03***	***24***	***3.5***	***1.5***	***.22***	***Cu***
2205	***S31803***	***.03***	***21.8***	***5***	***2.8***	***.12***	
2205	***S32205***	***.03***	***22.5***	***5***	***3.2***	***.16***	

High Cr ***Moderate Ni and Mo*** ***and 0.16N***

Chemistry of Super Duplex SS

and Hyper Duplex

Name	UNS No.	C	Cr	Ni	Mo	N	Other
2507	**S32750**	**.03**	**25**	**7**	**4.0**	**.28**	**Cu=.5**
255	**S32550**	**.03**	**25.5**	**5.5**	**3.4**	**.20**	**Cu=2.0**
Z100	**S32760**	**.03**	**25**	**7**	**3.5**	**.25**	**Cu=.75W=.75**
2707	**S32707**	**.03**	**27**	**6.5**	**4.8**	**.40**	

Higher Cr **More Ni and Mo** **.25+N**

and “others”

General Corrosion

- Similar to relative austenitic alloys.

  (e.g. 2202 and 2304 are similar to 304 & 316)

- General corrosion resistance can vary greatly with changes in concentration, pH, temperature and impurities. *It is important to discuss these variables for any application!*

Digester – Pulp and Paper

Duplex vs. Austenitic

- Duplex Grades
- **2202 /2101/2102**
- **2304**
- ***2003 /2404***
-
- ***2205***
-
- **255 / 2507 / Z100**
-
- **2707**

Austenitic Grades

304L

316L

317L

317LMN

904L

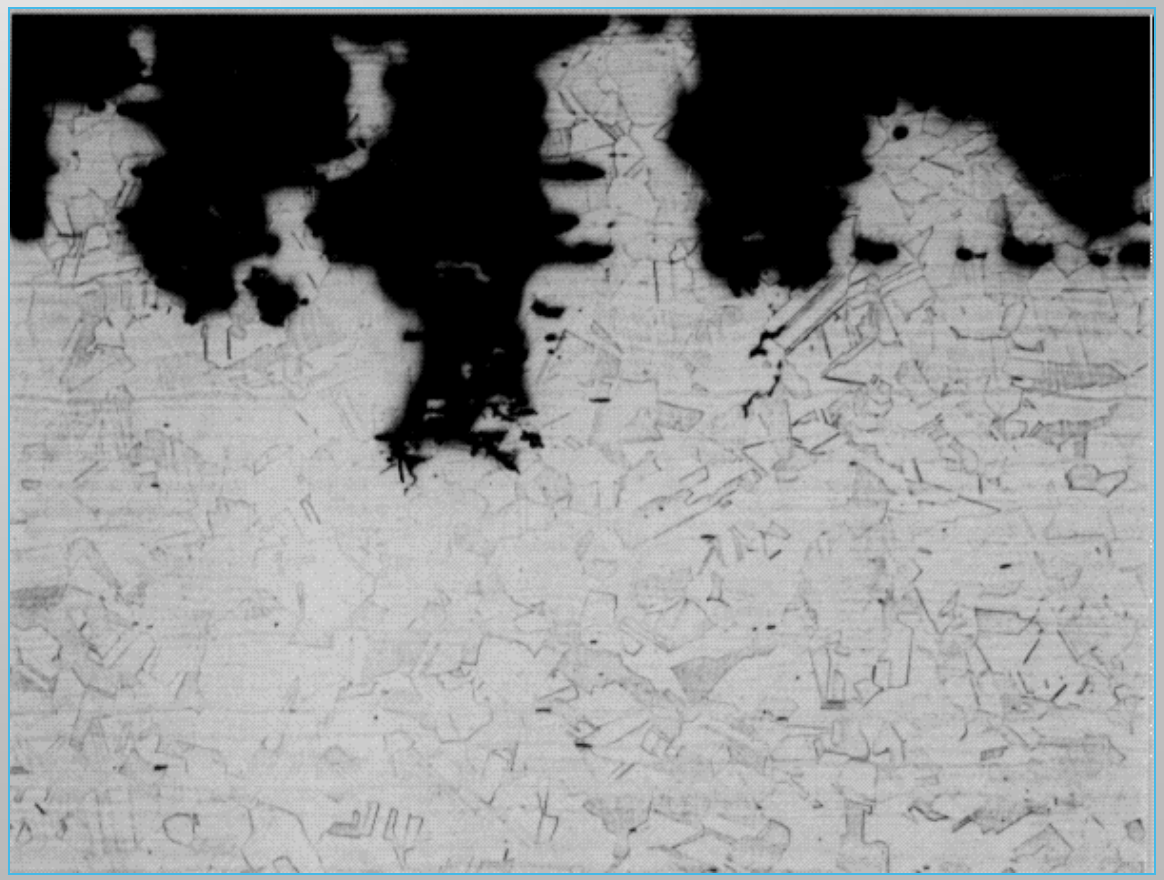
6Mo Grades

(increased resistance)

Localized Corrosion { PREN = Cr + 3.3Mo + 16N }

Grade	PREN
201LN	18
304L	19
316L	24
2202/2102/2101/2304	**26**
317L	30
2003	***30***
2404/317LMN	33
2205(S32205)	***35***
904L	35
Z100	**41**
255	**42**
2507	**43**
6Mo Grades	45
2707	**49**

316 LN TANKER
Transportation of H2SO4
Tank rinsed with … Sea Water !



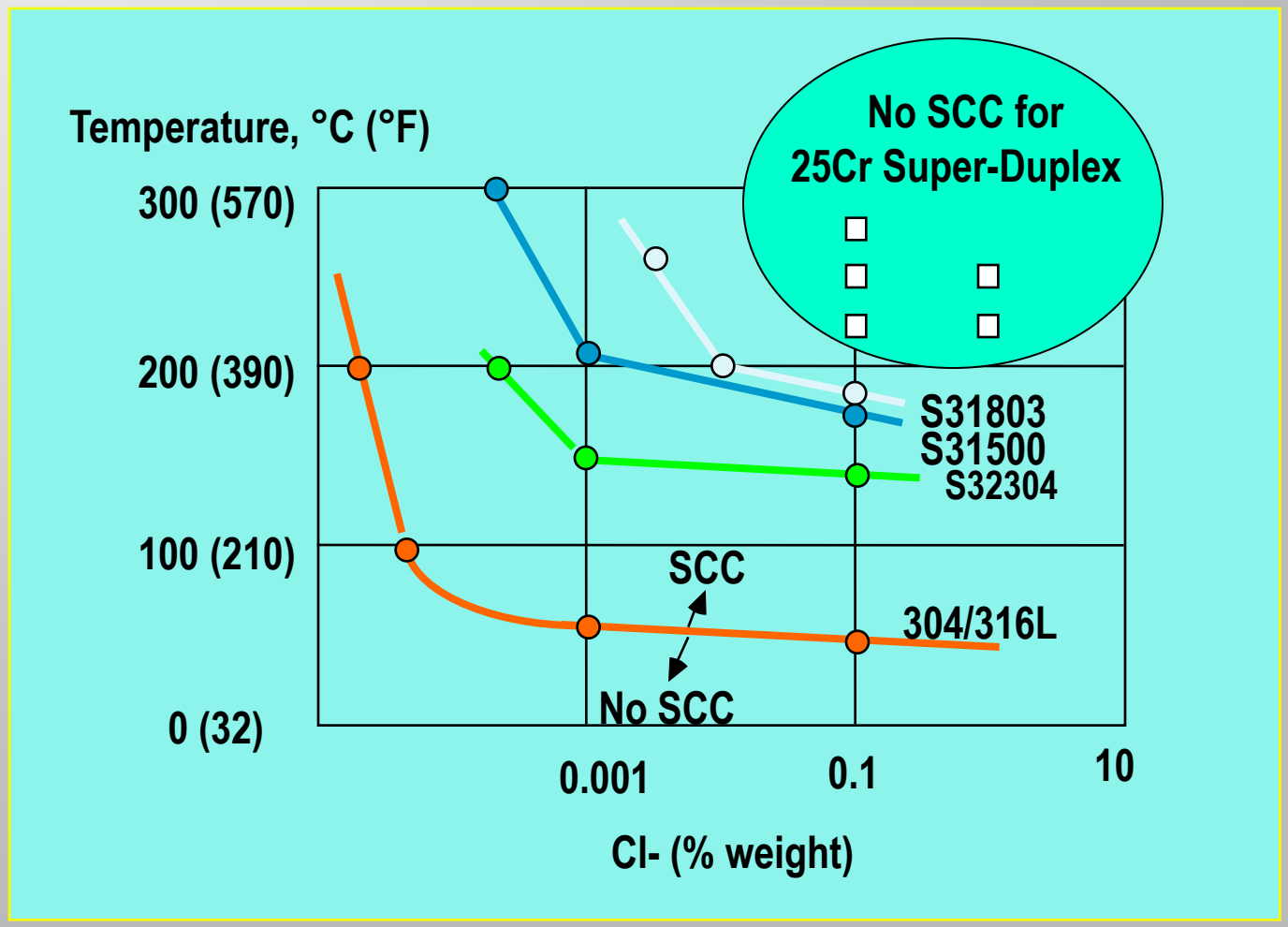
Chloride Stress Corrosion Cracking

- The greatest corrosion advantage for duplex stainless steels is their improved resistance to CSCC when compared to the austenitic grades.

- Only the 25% Nickel grades have similar CSCC resistance.

Stress Corrosion Cracking

STRESS CORROSION CRACKING RESISTANCE vs TEMPERATURE and Cl-



Mechanical Properties

- Duplex Stainless Steels have roughly twice the yield strength of their counterpart austenitic grades.

- This allows equipment designers to use thinner gauge material for vessel construction!

Room Temperature Strength

Grade	Min Tensile(KSI)	Min Yield(KSI)	%Elong.
2101/2102	**95**	**65**	**30**
2202	**94**	**65**	**30**
2304	**87**	**58**	**25**
2003	***90***	***65***	***25***
2404	***99***	***70***	***25***
2205	***95***	***65***	***25***
2507	**116**	**80**	**15**
255	**110**	**80**	**15**
Z100	**108**	**80**	**25**
2707	**133**	**101**	**15**
201LN	*95*	*45*	*45*
304(L)/316(L)	70	25	40
317LMN	80	35	40
6Mo	94	43	35

ASME (allowable stress in KSI)

Grade	@100F	200F	300F	400F	500F	600F
2202	**27.1**	**26.9**	**25.1**	**25.1**	**25.1**	**25.1**
2304	**24.9**	**24.0**	**22.5**	**21.7**	**21.3**	**21.0**
2205	***25.7***	***25.7***	***24.8***	***23.9***	***23.3***	***23.1***
2507	**33.1**	**33.0**	**31.2**	**30.1**	**29.6**	**29.4**
255	**31.4**	**31.3**	**29.5**	**28.6**	**28.2**	**--**
316/316L	20.0	17.3	15.6	14.3	13.3	12.6
316L	16.7	14.2	12.7	11.7	10.9	10.4
317LMN	20.5	18.9	16.7	15.6	15.1	--
6Mo	24.9	23.2	21.3	19.8	18.3	17.3

Tank

Hardness

- High hardness provides better wear resistance in abrasive environments.

Grade	Hardness (BHN)
201LN	*241*
304L	215
316L	217
317L	217
317LMN	223
904L	220
6Mo	240
2102/2101	**290**
2202/2304	**290**
2404	**290**
2003/2205	***293***
Z100	***270***
255	**302**
2507	**310**

S32550
Feed Screw Flight

Thermal Expansion (/ºFx10)

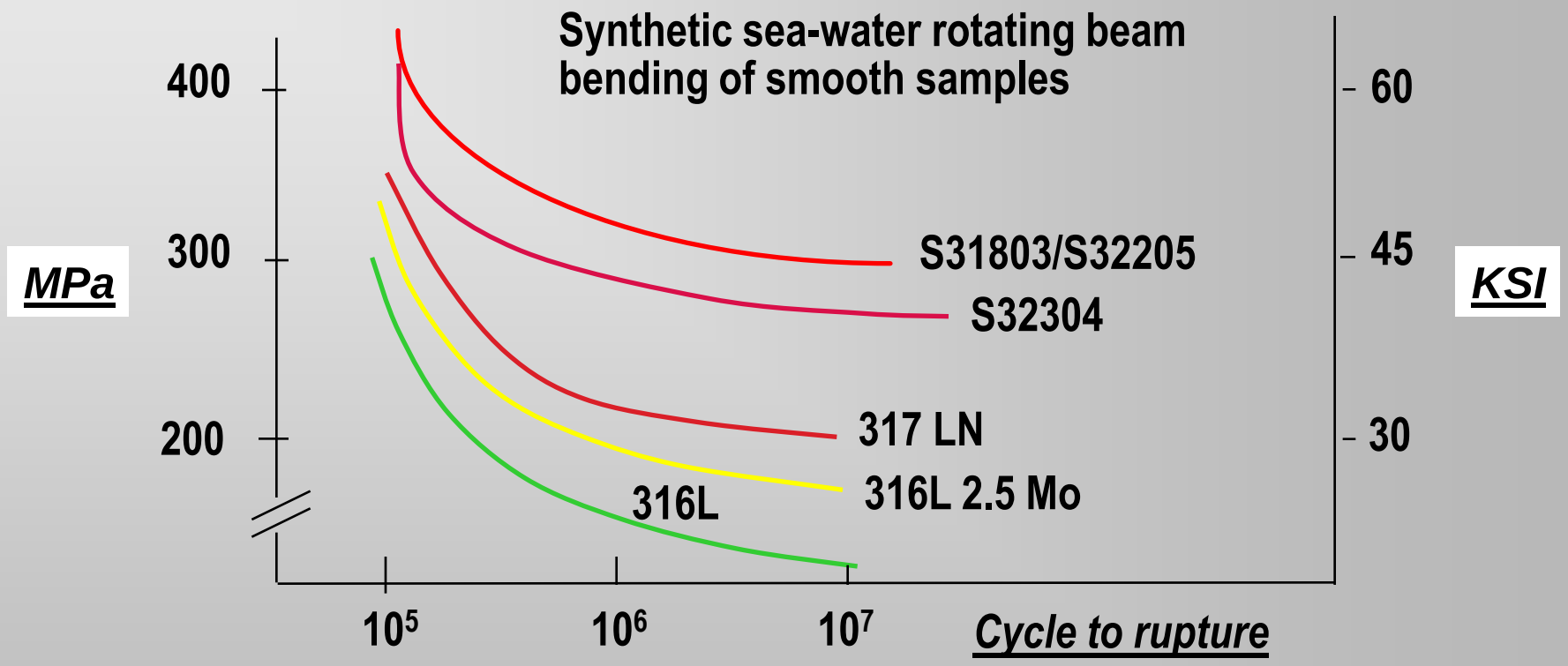
Grade	@212F	392F	572F	752F	932F
C- Steel	*6.66*	*7.22*	--	*7.77*	--
2102/2101	**7.16**	**7.50**	**7.77**	**8.05**	
2202	**7.05**	**7.50**	**8.00**	**--**	
2304	**7.22**	**7.50**	**8.00**	**8.05**	**8.33**
2205	***7.22***	***7.50***	***8.00***	***8.06***	***8.33***
2507 /255	**7.22**	**7.50**	**8.00**	**8.06**	**8.33**
Z100	**7.22**	**7.50**	**8.00**	**7.39**	**7.56**
2707	**7.00**	**7.22**	**7.50**	**7.77**	
304L	*9.11*	*9.40*	*9.60*	*9.77*	*10.00*

Fatigue Strength

- Higher strength means higher cyclic-stresses can be applied without fatigue failures.

- This holds true even in corrosion fatigue environments!

FATIGUE - CORROSION RESISTANCE



Fatigue and fatigue corrosion resistance of stainless steels are enhanced by the use of duplex grades (higher mechanical properties, chromium content and duplex microstructure

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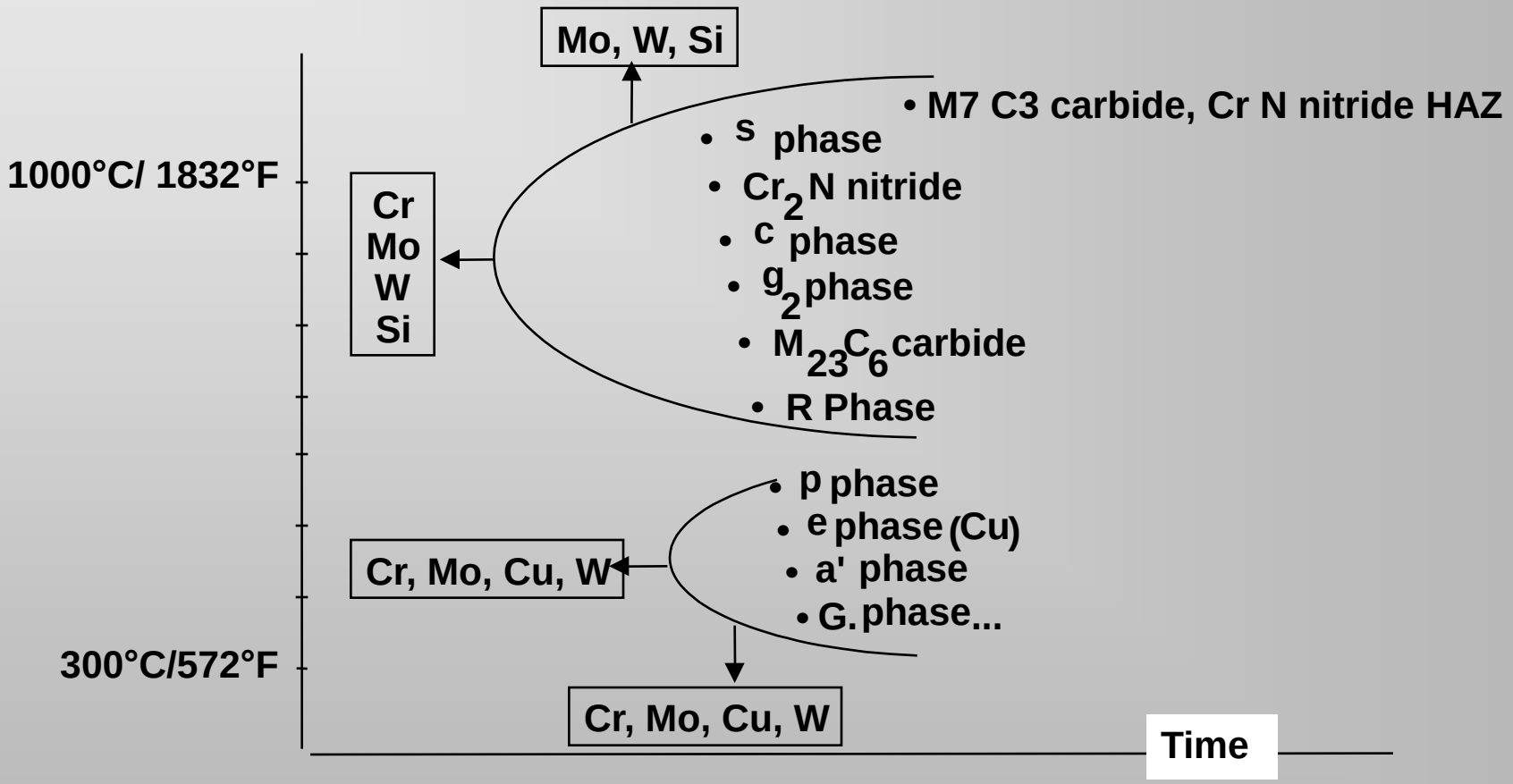
Fracture Toughness

- Due to the high ferrite content the Duplex SS have a ductile – brittle transition temperature of -50ºF.
- This restricts the minimum operating temperature to -50ºF.
- In certain circumstances the Duplex SS may be used down to -100ºF.



Possible precipitations in super duplex stainless steels within 25 – 40 minutes, while 2205 is ~1 hour and 2304 is ~8 hours for significant precipitations

Fabrication

Welding

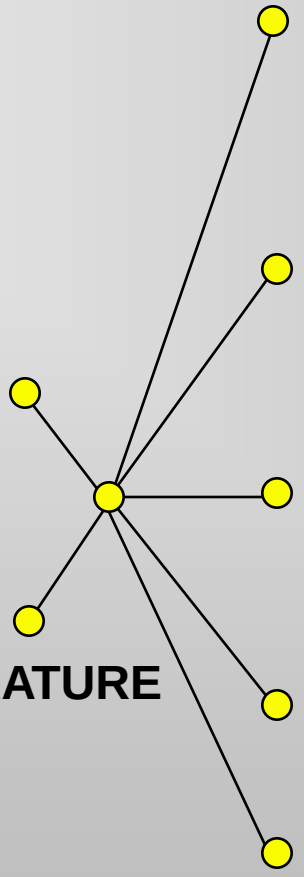
- Welding procedures must be developed to achieve acceptable corrosion resistance and mechanical properties/toughness in the weld zone.
- **Welding of Duplex SS is not difficult. It is just *different!***
- ***"lean duplex" = welder friendly!***

WHAT ABOUT WELDED STRUCTURES ?

Duplex filler metal

WE NEED

- **CORROSION RESISTANCE**
- **TOUGHNESS AT LOW TEMPERATURE**



CONTROL OF FERRITE
in HAZ < 70 %
in welds 20-40 % SAW, SMAW
25-60 % TIG, MIG, PLASMA

CONTROL OF OXYGEN CONTENT
SAW with appropriate basic flux

CONTROL OF HYDROGEN CONTENT
Degasing of welding consummables...
No hydrogen in shielding gas

CONTROL OF NITROGEN LEVEL
Add N2 to the shielding gas

CONTROL OF THERMAL CYCLE
Heat input adapted to plate thickness/weld geometry
Minimum and Maximum

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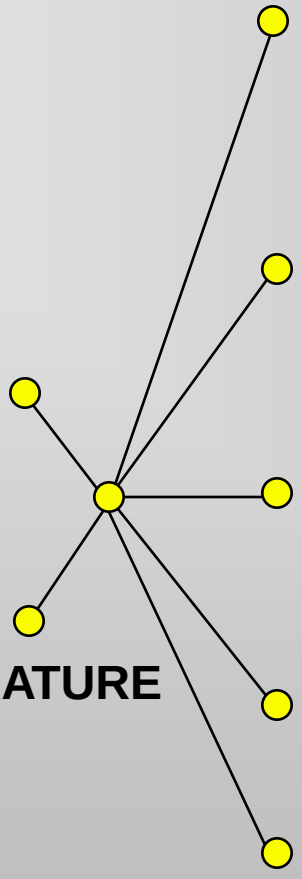
WHAT ABOUT WELDED STRUCTURES ?

Austenitic filler metal

WE NEED

- **CORROSION RESISTANCE**
- **TOUGHNESS AT LOW TEMPERATURE**



CONTROL OF FERRITE

Not required for when using fully austenitic filler metal

CONTROL OF OXYGEN CONTENT

SAW with appropriate flux basicity

CONTROL OF HYDROGEN CONTENT

Degasing of welding consummables...
No hydrogen in shielding gas

CONTROL OF NITROGEN LEVEL

Not required for when using austenitic filler metal

CONTROL OF THERMAL CYCLE

HAZ is the only concern when using a fully austenitic filler material

Formulinox

- Formulinox.xlsm

Standard Specifications

Grade	ASTM	ASME	(Sect VIII Div I)
2101*	**A240**	**--**	**code case 2418**
2202	**A240**	**--**	**Code Case 2669**
2304*	**A240**	**SA240**	**yes**
2003*	***A240***	**--**	***code case 2503***
2205(S31803)*	***A240***	***SA240***	***yes***
2205(S32205)*	***A240***	**--**	***no***
255* Z100*	**A240**	**SA240**	**yes**
2507*	**A240**	**SA789/790**	**tube/pipe**
2707	**A789/A790**	**--**	**code case**

Standard Specifications

Grade	Bar	W/S Pipe	W/S Tube	Fittings
2101	**X**	**X**	**X**	**X**
2202	**X**	*X*	*X*	**X**
2102	**-**	**-**	**-**	**-**
2304	**X**	**X**	**X**	*X*
2003	*X*	***X***	*X*	*X*
2205(dual)	***X***	***X***	***X***	***X***
255	**X**	**X**	**X**	**X**
2507	*X*	*X*	*X*	*X*
Z100	**X**	**X**	*X*	*X*
2707	**-**	**X(s)**	**X(s)**	*X*

Cost Comparison

Cost ratio based on 304L=1.0 (3/8 pattern mill plate)

Duplex		Austenitic	
• **2202 2101**	**= 0.83**	*201LN*	*= 0.86*
• **2102**	**= 0.83**	**304L**	**= 1.00**
• **2304**	**= 0.96**		
• **2003/2404**	**= 1.26**		
•		316L	= 1.25
• **2205**	**= 1.16**		
•		317L	= 1.66
• **255/2507**	**= 1.85**		
• **Z100**	**= 1.90**		
•		317LMN	= 2.04
•		904L	= 2.72
•		6Mo	= 2.83 – 3.46

- Ni = 8.46 Mo = 12.76 Cr = 1.32

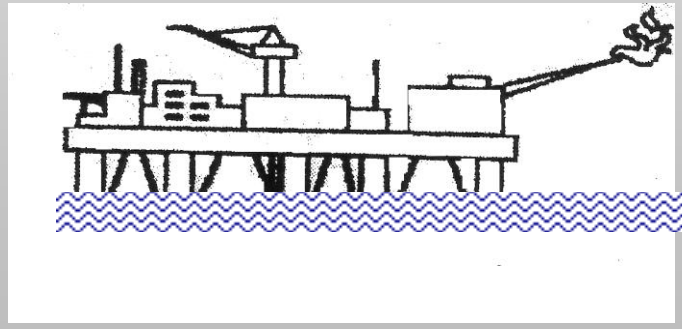
Cost Advantage

- If a vessel design uses the Duplex SS's additional strength to decrease wall thickness **savings of up to 25% may be achieved for the fabrication** vs. a comparable austenitic grade.
- Machining cost savings may be considerable.
- Physical property advantages must be evaluated for process and fabrication cost savings.

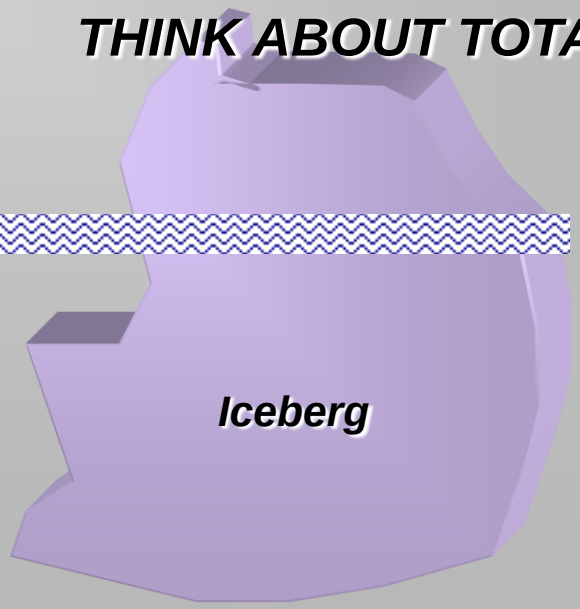
DUPLEX COST SAVINGS

If you save weight (wall thickness reductions) :

- **You reduce the amount of material needed for the project**
- **You reduce the labor costs (weldings of thinner plates)**
- **You reduce transportation costs**
- **You reduce erection costs**
- **You reduce structural costs (concrete…)**



THINK ABOUT TOTAL COSTS



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CALRES

- Corrosion Solutions Calres.xlsm

Some Duplex SS Precautions

- Thermal history control, to reduce the risk of forming secondary phases(sigma and alpha prime), is minimized for “lean duplex”.

- Good procedures must be developed for welding, forming, machining and heat treatment. Duplex SS are *not difficult* to work with but they are *different*! *And “lean duplex” are the easiest!*

- Duplex SS must be used for applications which **operate between -50ºF and +600ºF.**

What DUPLEX Means!

- **A family of *excellent* engineering materials!**
- **A family of *excellent* cost effective materials!**

- **Comparable to austenitics in corrosion resistance – with improved CSCC.**
- **Twice the strength of austenitics.**
- **Advantageous physical properties.**
- **Covered by standard and end user specifications.**
- **Advantages with both material cost and engineered fabrication cost.**

MARKET EVOLUTION OF DUPLEX QUARTO PLATES (2000/2008) in KT

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Chemical tankers Terminals	20	15	10	7	10	10	15	8	10
Offshore : Tubes, blast walls, topsides flow lines	5	5	5	6	6	7	10	12	13
New applications : hydrometallurgy, water, structures, other	0	0	0,5	1	1,5	2	2,5	5	9
Desalination	0	0	0,5	0,5	1,5	8	15	18	21
Pulp + Paper	7	7	7	8	8	9	10	10	10
Chemicals, Fertilizers, Petrochemicals	5	6	6	7	7	7	7	12	14
Pollution control	0	0,5	0,5	1	3	7	8	10	7
Distribution	5	5	5	7	9	10	12	15	16
TOTAL (KT)	42	39	35	38	46	63	80	90	100
Total SS production	660	700	720	680	760	800	850	900	950
% Duplex	6%	5.5 %	5%	5.5 %	6%	8%	9%	10%	10.5 %

DESALINATION: INDUSTEEL REFERENCES 2002-2006

LOCATION	GRADE	ENGINEERING
2000		
Jebel Ali K2 - Dubai	316LMo	FISIA
2002		
Shuweihat - Abu Dhabi	316L 317L	FISIA
Ras Laffan - Qatar	317L 316L 316L P355+316L	FISIA
2003		
Jebel Ali L1 - Dubai	316L	FISIA
Mobin - Bandar Assaluyeh - IRAN	316L 316L	SIDEM
Zuara 1 - Lybia	316L 31803 32304	SIDEM
Ras Al Khaimah 1 - 4 + Ajman	316L 316L 31803	SIDEM
2004		
Huanghua - China	316L	SIDEM
Abutaraba - Libya	31803 316L	SIDEM
2005		
Layyah 1 - 4 - Lybia	32304 31803 32750	SIDEM
Jebel Ali L - 2 - Dubai	32205 31803 31254	FISIA
Beckton, Portobello Fab - UK	32750 32205	PRIDESA/THAMES WATER
2006		
Al Taweelah B - Abu Dhabi	31803 31254	FISIA
Al Hidd 1 - 3 - Bahrein	32304 31803	SIDEM
Ras Abu Fontas - Qatar	32205	FISIA
Oman	32205 32750	AQUATECH
Mukaizhna	32205 32750	
Hasco	32205 31254	

Austenitic grades

Duplex grades

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Power Generation

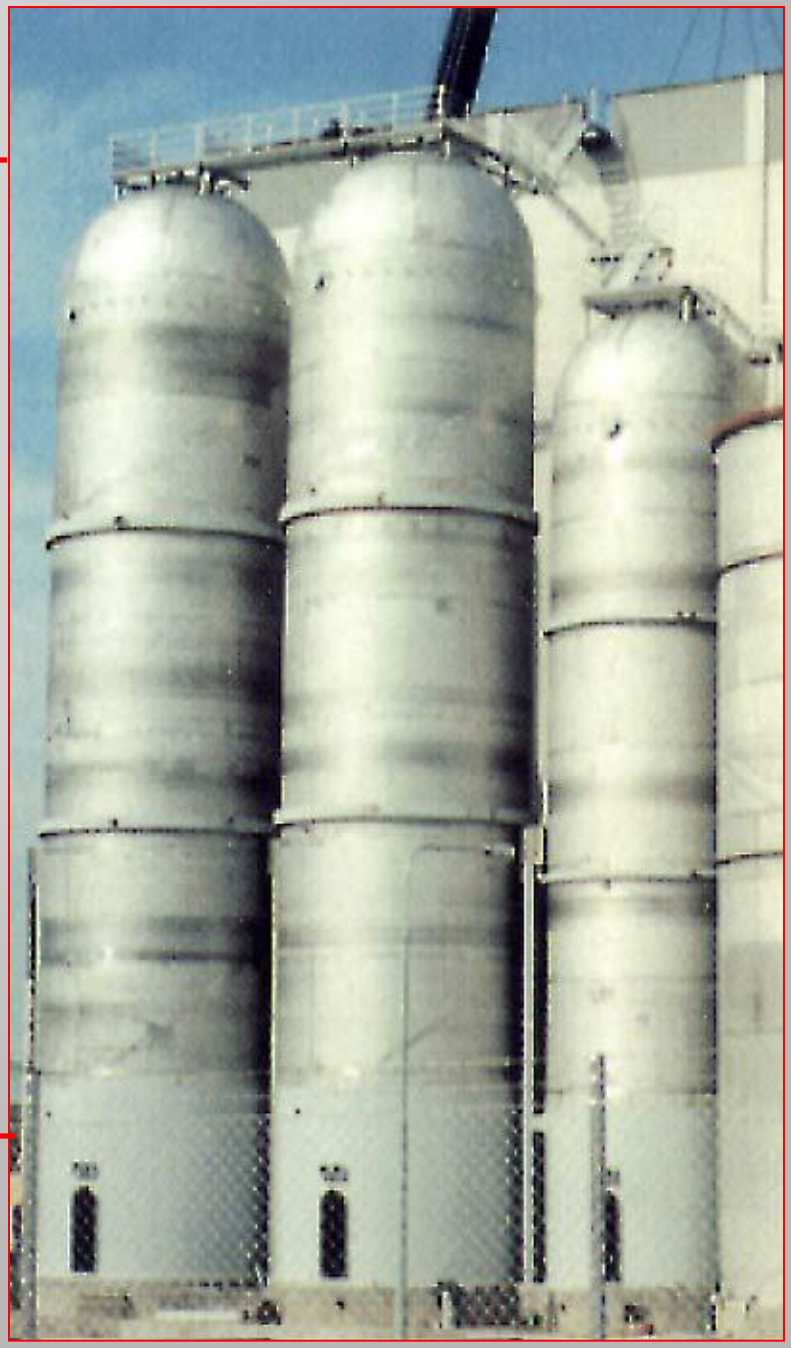
- Two shapes of scrubbers

- **Cylindrical/Rectangular type scrubbers**
- **Materials of Construction**
  - 2205, 255, 2507, 2304, 6Mo and Clad
  - thick plates in carbon steel lined with rubber
  - Fiberglass and Stebbins Tile

- **Rectangular type scrubber** using stiffeners and thin plates in :
  - ✓Stainless Steel
  - ✓Or carbon steel lined with rubber

Pulp and Paper Industry Duplex References

Black and White Liquor Vessels S31803, and S32304



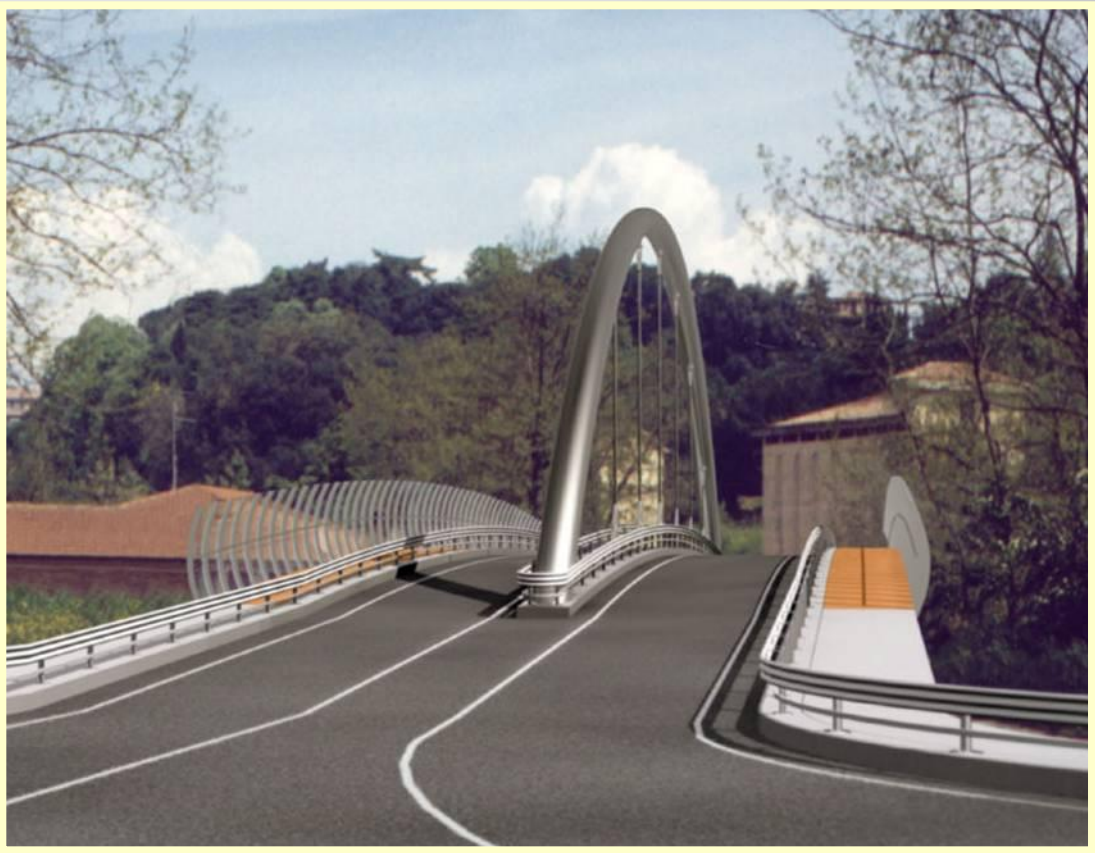
Digesters – S32205

Pulp and Paper Industry Duplex References

Batch digesters for Potlatch (USA) S31803

Duplex Bridges

MALIZIA BRIDGE IN SIENA (Italy)



BRIDGE DATA

- Total length : 51.5 m [169 ft]
- Deck width : 15.8 m [52 ft]
- Deck height : 1.2 m [4 ft]
- Arch height : 10.0 m [33 ft]
- Steel used for the deck :290 t
- Steel used for the arch : 50 t
- Contractor : COMUNE DI SIENA
- Project study :SETECO Ingegneria s.r.l.
- Project : Ing. Raffaello Fontani
- Architect : Arch. Paola D'Orsi

MALIZIA BRIDGE IN SIENA (Italy)

Final assembly

Duplex Stainless Structures

Location	Type of equipment	Grade	Tons	Constructor	Main constructor	Architect
1989						
Arche de la Défense - Paris (F)	Lift structure	S31803	50			
1993						
Bibliothèque nationale François Mitterrand Paris (F)	Wind bracing	302	500	CFEM/Rinaldi		Dominique Perrault
2000						
York Millenium Bridge (UK)	Bridge anchor plates	S31803		Cimolai		
2001						
The Spire of DUBLIN (IR)	Monument	316L	130	SIAC Radley	Dublin City council	Ian Ritchie
2004						
Arco Ponte Malizia - Siena (I)	Bridge structure	S32304		Cimolai		
Les Braves - Omaha Beach (F)	Sculpture	316L/S31803	30	CMN Cherbourg		Anilore Banon
2005						
Ministère de la culture "Les Bons enfants" - Paris (F)	Building	S32304	500	Lauboeuf	Ministry of Culture of Communication	Francis Soler
Tay Bridge (UK)	Bearing of bridge	S32304	30	PPC/Freyssinet		
2006						
Piove di Sacco - Padova (I)	Bridge structure	S32304	125	Castaldo Spa		
Sculptures Tallagh Town Centre in Dublin	Sculpture	S31803	30	Royceton Construction Design & Management		Eileen Mac Donagh
Mont Saint-Michel	Tide protection gates	S31803	36	CM Paimboeuf		Luc Weizmann

May 29th, 2007

Thank you for Your Attention
… You really deserve a DRINK now!

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