DUPLEX
Stainless Steel

STI SPFA

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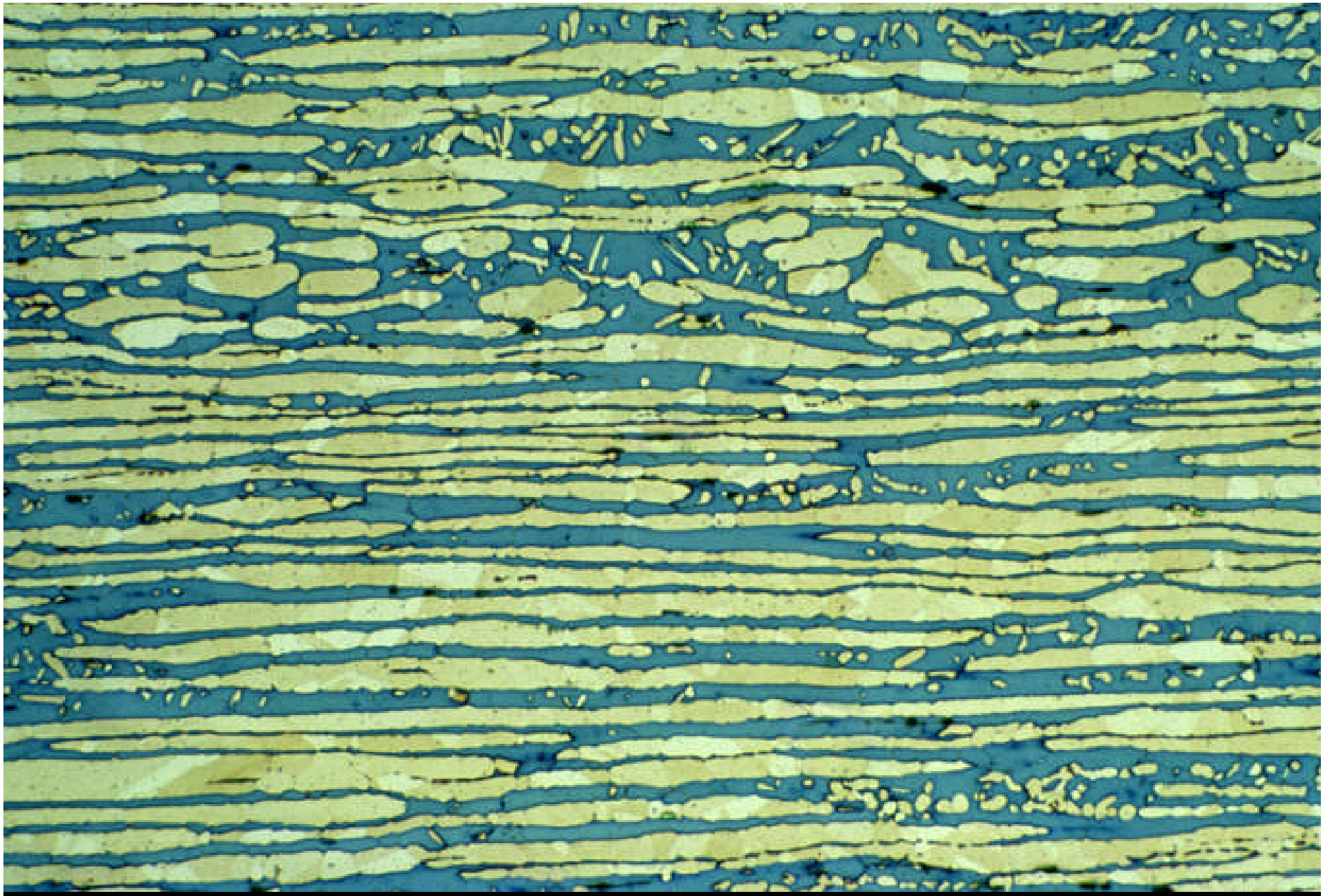
What are Duplex Stainless Steels ?

- 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

Chemistry of Duplex SS

Name	UNS No.	C	Cr	Ni	Mo	N	Other
201LN	S20153	.03	17	4.5	-	.20	Mn=7
2101	S32101	.04	21	1.5	0.5	.22	Mn=5
2202	S32202	.03	22	2	0.5	.22	
2304	S32304	.03	23	4	0.5	.12	
2003	S32003	.03	20	3.5	1.7	.16	
2205	S31803	.03	21.8	5	2.8	.12	
2205	S32205	.03	22.5	5	3.2	.16	
2507	S32750	.03	25	7	4.0	.28	Cu=.5
255	S32550	.03	25.5	5.5	3.4	.20	Cu=2.0

General Corrosion

- Similar to relative austenitic alloys.

  (2202 and2304 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!

Duplex vs. Austenitic

- Duplex Grades
- 2202 /2101
- 2304
- 2003
-
- 2205
-
- 255 / 2507
-

Austenitic Grades

304L

316L

317L

317LMN

904L

6Mo Grades

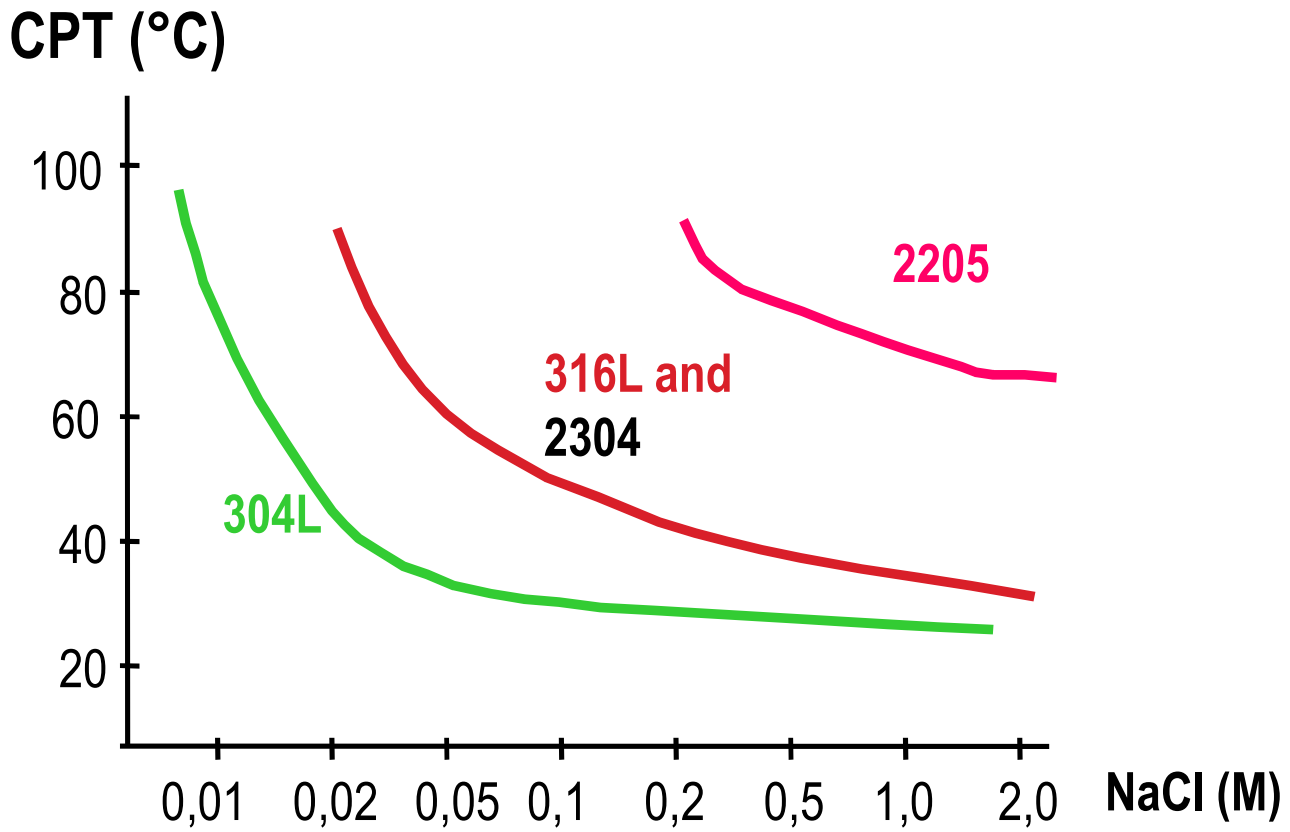
(increased resistance)

Localized Corrosion

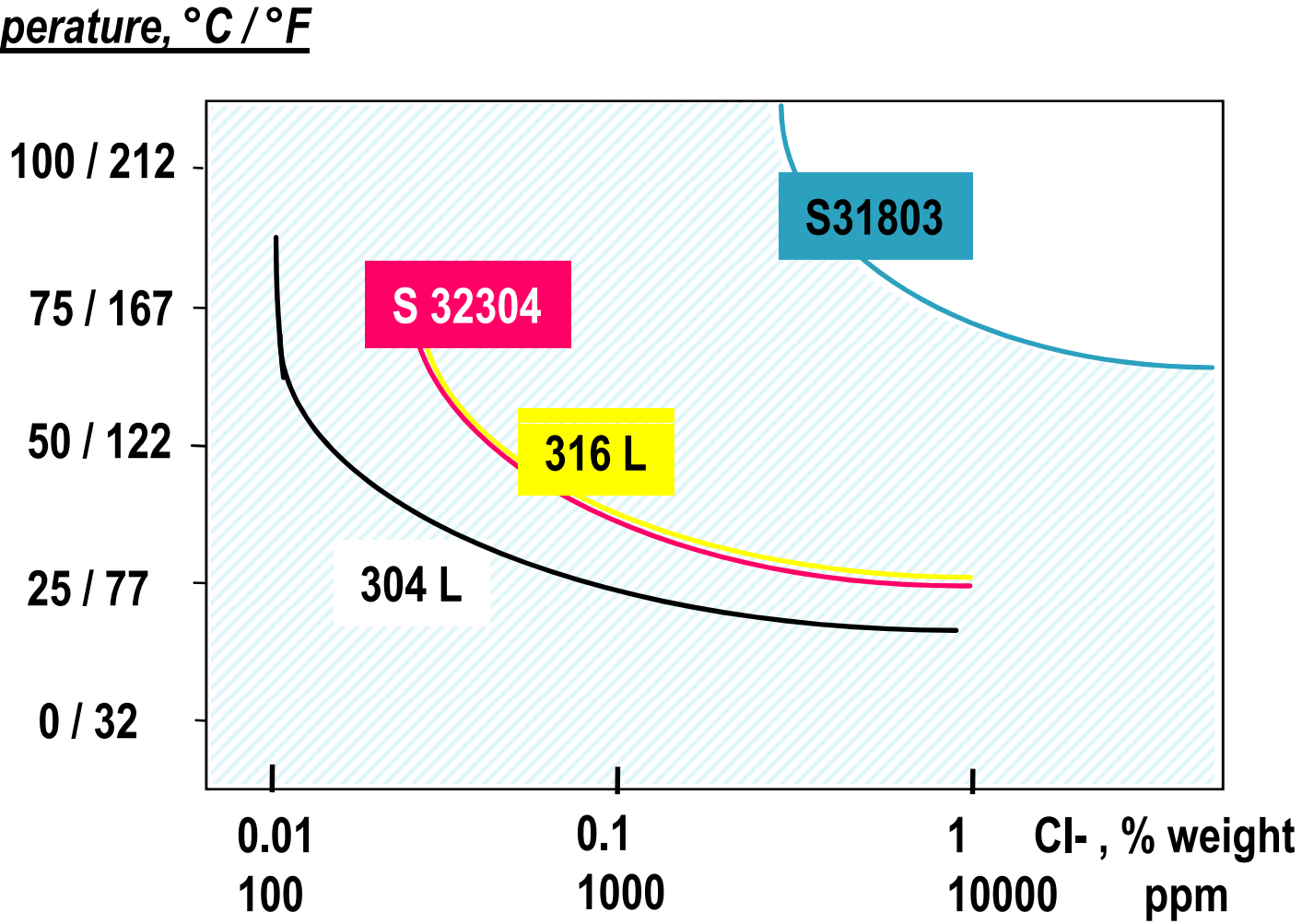
- { PREN = Cr + 3.3Mo + 16N }

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

CRITICAL PITTING TEMPERATURE IN CHLORIDE CONTAINING SOLUTIONS (E:+300mV/SCE)



THRESHOLD CHLORIDE vs TEMPERATURE FOR WHICH PITTING DOES NOT OCCUR

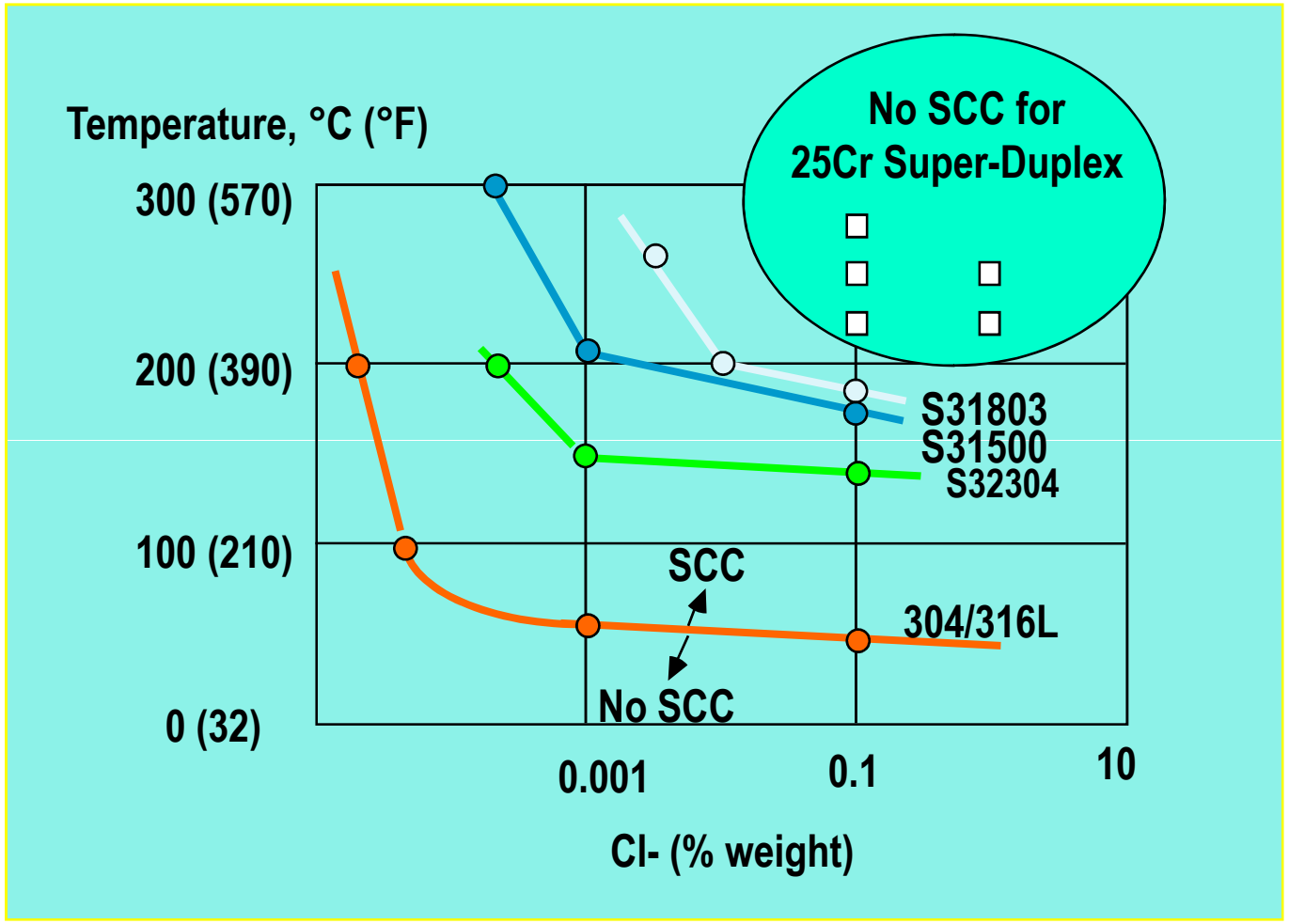


Chloride Stress Corrosion Cracking

- The greatest 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 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	95	65	30
2202	94	65	30
2304	87	58	25
2003	90	65	25
2205	95	65	25
2507	116	80	15
255	110	80	15
201LN	*95*	*45*	*45*
304	70	25	40
316L	70	25	40
317LMN	80	35	40
6Mo	94	43	35

ASME (allowable stress in KSI)

Grade	@100F	200F	300F	400F	500F	600F
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

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
2202/2101	290
2304	290
2003/2205	293
255	302
2507	310

Thermal Expansion (/ºFx10)

Grade	@212F	392F	572F	754F	932F
C- Steel	*6.70*	*7.22*	--	*7.78*	--
2202	7.00	7.50	8.00		
2304	7.22	7.50	7.78	8.06	8.33
2205	7.22	7.50	7.78	8.06	8.33
2507	7.22	7.50	7.78	8.06	8.33
255	6.72	7.00	7.22	7.39	7.56
304L	*9.10*	*9.40*	*9.60*	*9.80*	*10.00*

Heat Transfer

- Provides a 5% advantage compared to austenitic grades.

- This advantage is increased when design strength is used to decrease wall thickness!

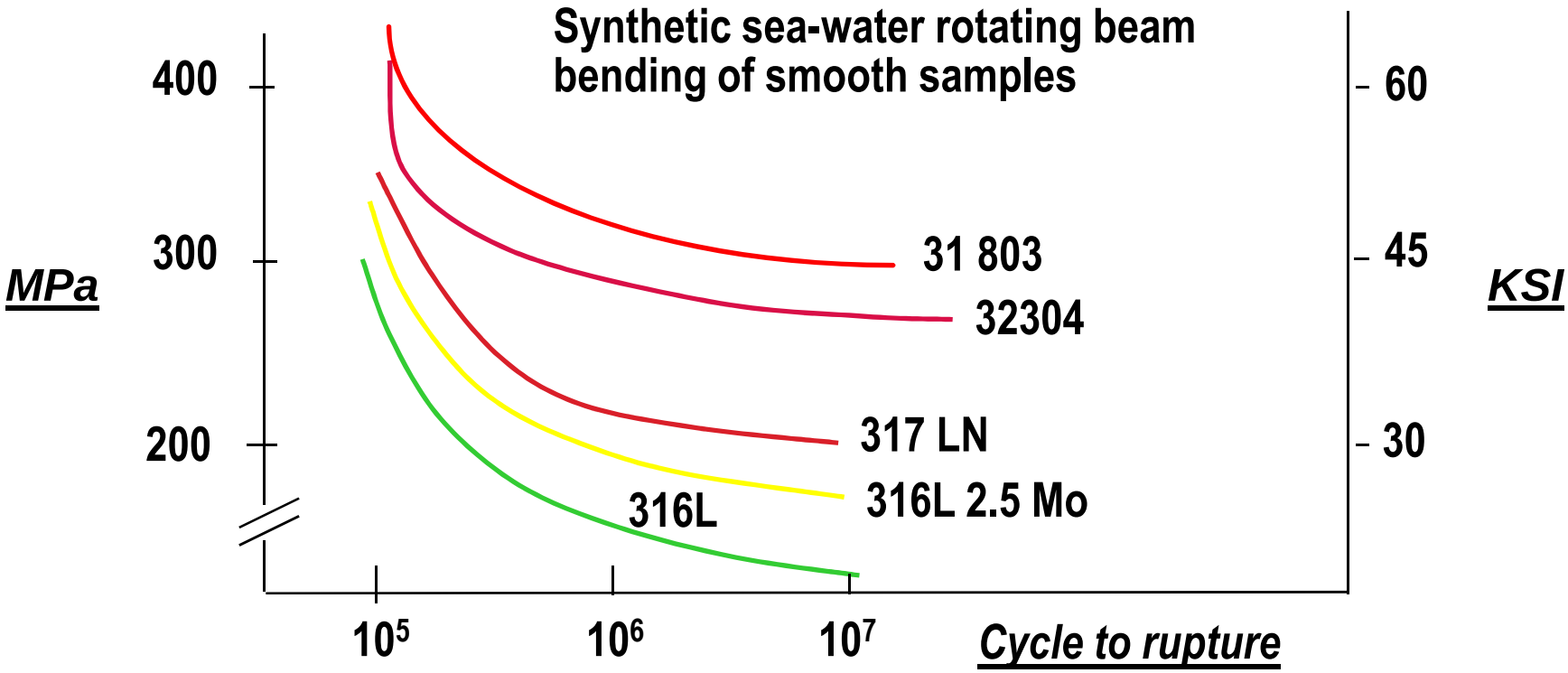
Fatigue Strength

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

- This holds true even in corrosion fatigue environments!

FATIGUE - CORROSION RESISTANCE

Corrosion resistance

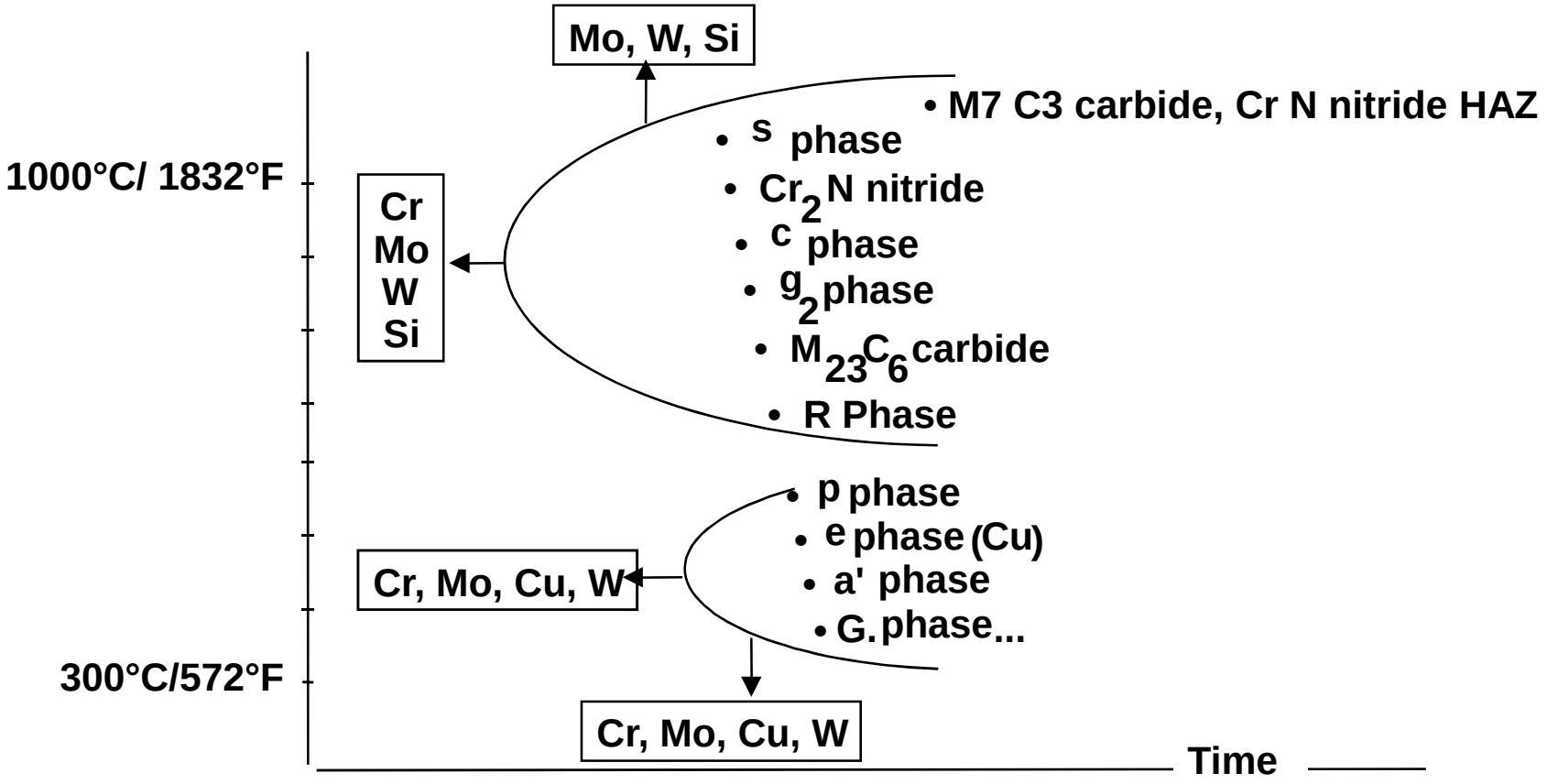


Fatigue and fatigue corrosion resistance of stainless steels are enhanced by the use of duplex grades (higher mechanical properties, chromium content and duplex microstructure

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.

TYPICAL PRECIPITATIONS



Possible precipitations in super duplex stainless steels

2304 `~8 hours for significant sigma vs. 2205 ~1 hour

Fabrication

Cutting

- Duplex SS may be cut by any of the standard methods.

- Sawing will be more difficult than carbon steel!
- Shearing is limited to thinner thickness when compared to 304L/316L. Maximum 85% for 2202/2304/2205 and 65% for 2507/255.
- Plasma and laser cutting can be done using parameters similar to 304L/316L.

Machining

- Machining will require higher cutting forces than 304L/316L.
- 2304 can be machined at higher rates than 304L/316L with similar tool wear.
- *The degree of machining difficulty increases with the more highly alloyed grades as does tool wear.*

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Hot Forming

- The temperature for hot forming must be well controlled.
- 1750 to 2050ºF for 2202/2304/2205.
- 1875 to 2175º for 2507/255.
- Too low a temperature will result in cracking of the ferrite phase!
- Too high a temperature will result in hot tearing of the ferrite phase!
- Parts must be annealed after forming.

Cold Forming

- Duplex SS can be formed to the same shapes as the austenitic grades.
- Additional equipment strength is required due to the higher strength of the Duplex SS.
- Springback is greater with the Duplex SS requiring greater over bending than the austenitic grades.
- Cold work will harden the Duplex SS requiring intermediate and/or final annealing depending on the amount of cross section reduction.

Bending Compared to Austenitics

- Bending radii should be more generous than for austenitic grades (3T or greater).
- When compared to a thickness of 304L/316L, Duplex SS maximum forming thickness are: 2304 = 65%, 2202/2205 = 50% and 2507/255 = 40%
- ***Springback*** will require over bending to 115º to achieve a 90º compared to 98º for 304L/316L

Annealing Requirements

- Final anneal is required if cold working exceeds 10 – 15%.
- For cold working exceeding 15% an intermediate anneal is required.

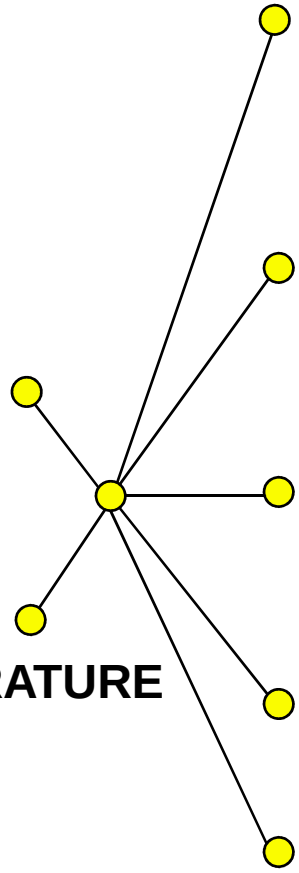
Welding

- 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!*
- *2304 is welder friendly!*

WHAT ABOUT WELDED STRUCTURES ?

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 flux basicity

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

CONTROL OF NITROGEN LEVEL

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

WHAT ABOUT WELDED STRUCTURES ?

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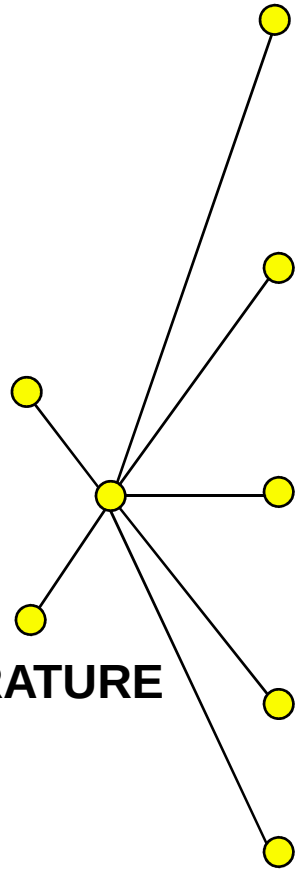


CONTROL OF FERRITE

Not required for 2304 when using fully austenitic 309L 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 2304 when using 309L filler metal

CONTROL OF THERMAL CYCLE

Thermal stability minimizes potential for sigma phase from slow cooling

Standard Specifications

Grade	ASTM	ASME	(Sect VIII Div I)
201LN	A240	A240	
2202	A240	in 2008	
2304	A240	SA240	yes
2101/2003	A240		Code Case
2205(S31803)	A240	SA240	yes
2205(S32205)	A240	--	no
255	A240	SA240	yes
2507	A240	SA789/790	tube/pipe

ASTM A923

- Tests used to verify acceptable thermal history of Duplex SS(no sigma phase).
- Normally used to qualify plate mill product.
- May be used to qualify weld procedures.
- Requires G48 CPT corrosion test.
- Requires -40ºF charpy test
- Pass/Fail requirements are given for 2205 material only. Requirements for other materials must be agreed upon.

Cost Comparison

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

Duplex	Austenitic
• 22022101 = 0.73	*201LN = .70*
• 2304 = 0.93	
•	304L = 1.00
• 2003 =	
• 2205 = 1.28	
•	316L = 1.39
•	317L = 1.81
• 255 = 1.83	
• 2507 = 2.04	
•	317LMN = 2.21
•	904L = 2.90
•	6Mo = 4.00

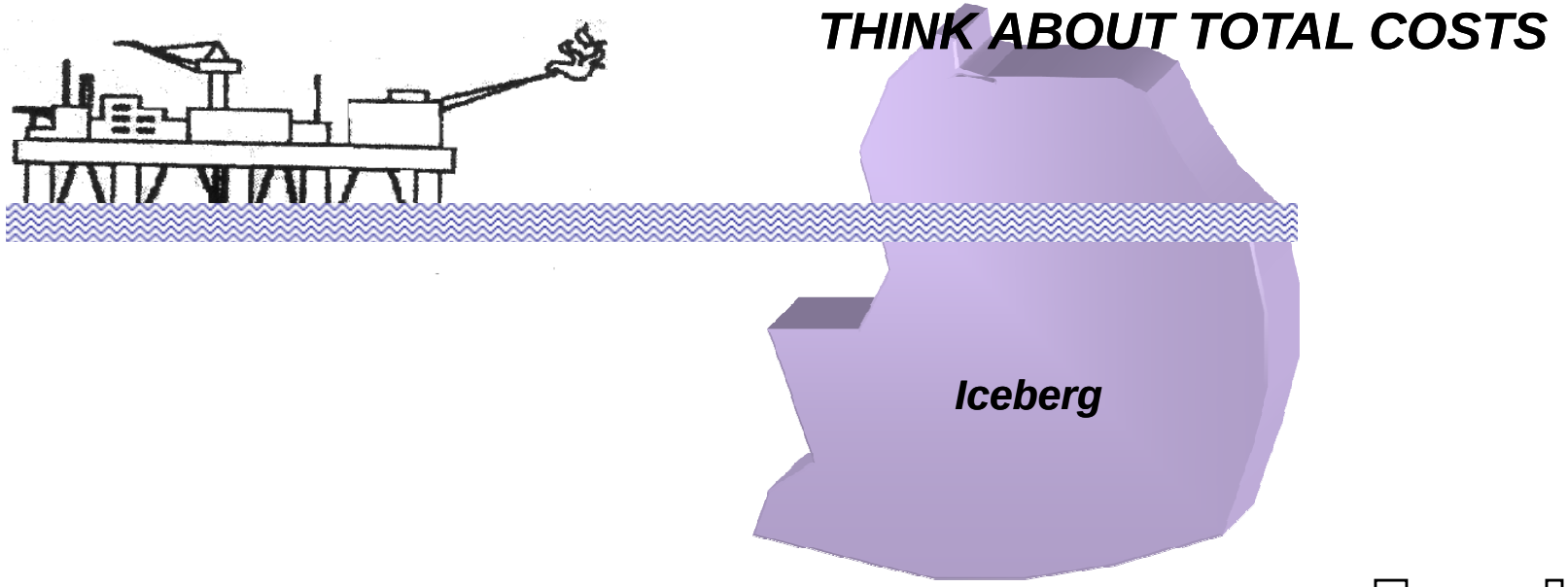
Cost Advantage

- 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.

2205 - 2304 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…)**



Some Duplex SS Precautions

- Thermal history control, to reduce the risk of forming secondary phases(sigma and alpha prime), is minimized for 2202 and2304.

- 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 2202 and2304 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.**

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