EPRI Corrosion Study in Northern California Setting

Coupon Testing of Multiple Alloys at The Geysers

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Collaborative US-Japan project

- Corrosion persistent in some well tubing
  - Shutdown of wells

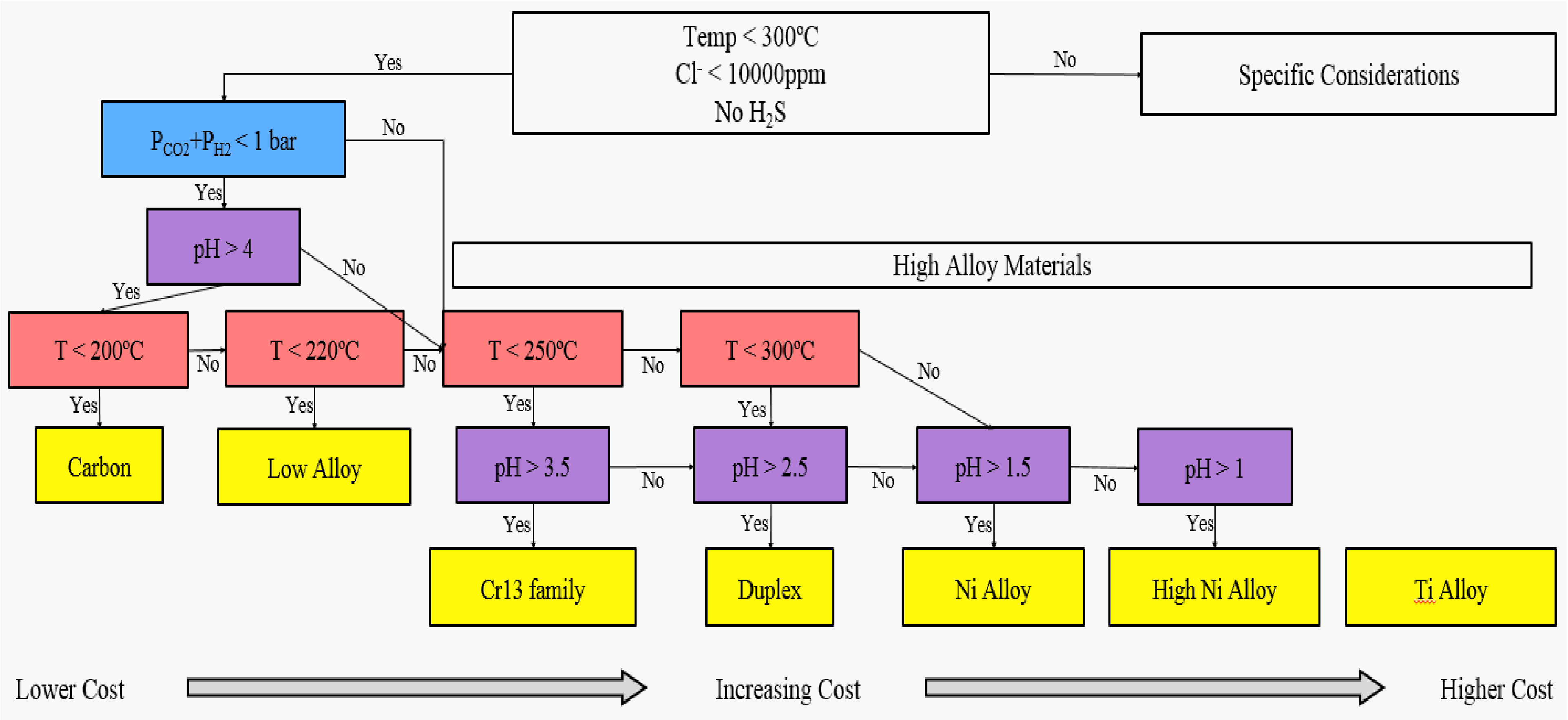
- Transfer of knowledge from Japan steel industry to US
  - Assessments of geothermal condition

- Variabilities in geothermal environments

http://kwikzip.com/using-spacers-to-mitigate-water-pipeline-corrosion/

Material Selection was first step to evaluate corrosion and serve purpose of supporting operational life.

Material Selection Process



Sakura et. al. 2017 GRC Annual Meeting

Project Objectives

Baseline Objectives

- Determine best conditions for Duplex stainless-steel (DSS) applications
- Compare DSS to other common downhole casing materials used in Japan geothermal and oil and gas market for various corrosive conditions
- Determine what future tests need to be conducted to improve long-term performance

Locating specific corrosion-prone tubing instrumental

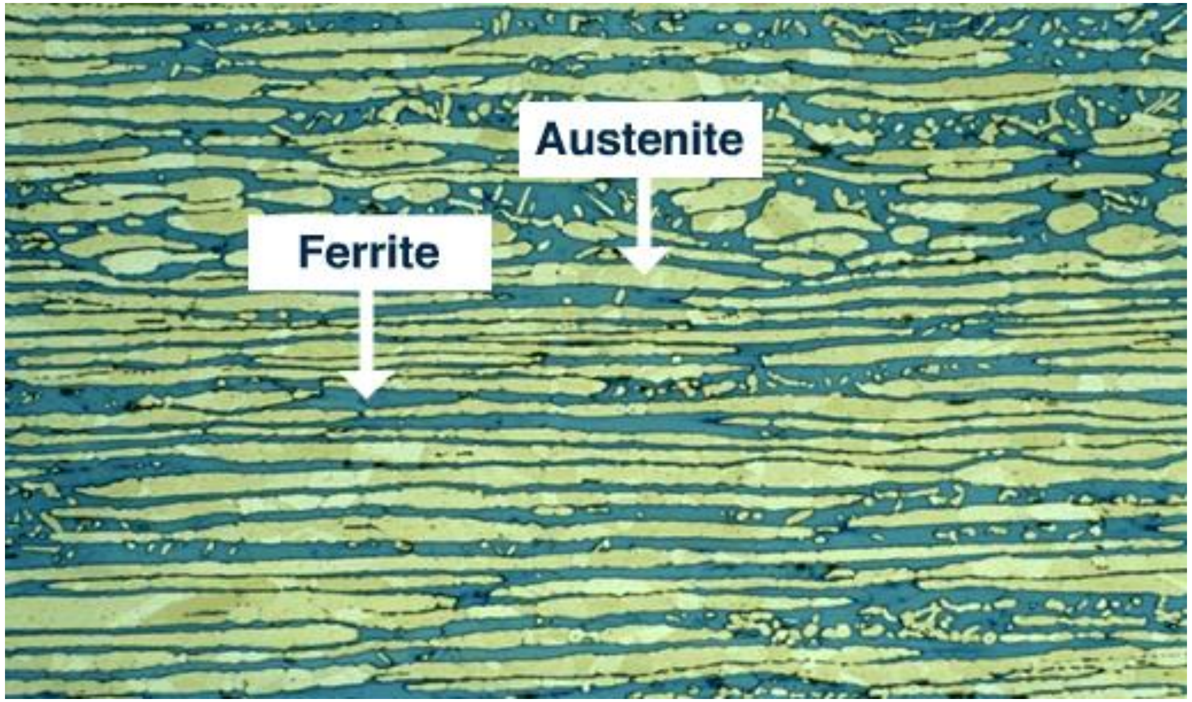
Duplex

- Duplex stainless steels are a combination of austenitic (300-series) and ferritic (400-series) stainless steels
  - 50-50 ratio
- 3 types:

  - Lean

  - Standard

  - Super

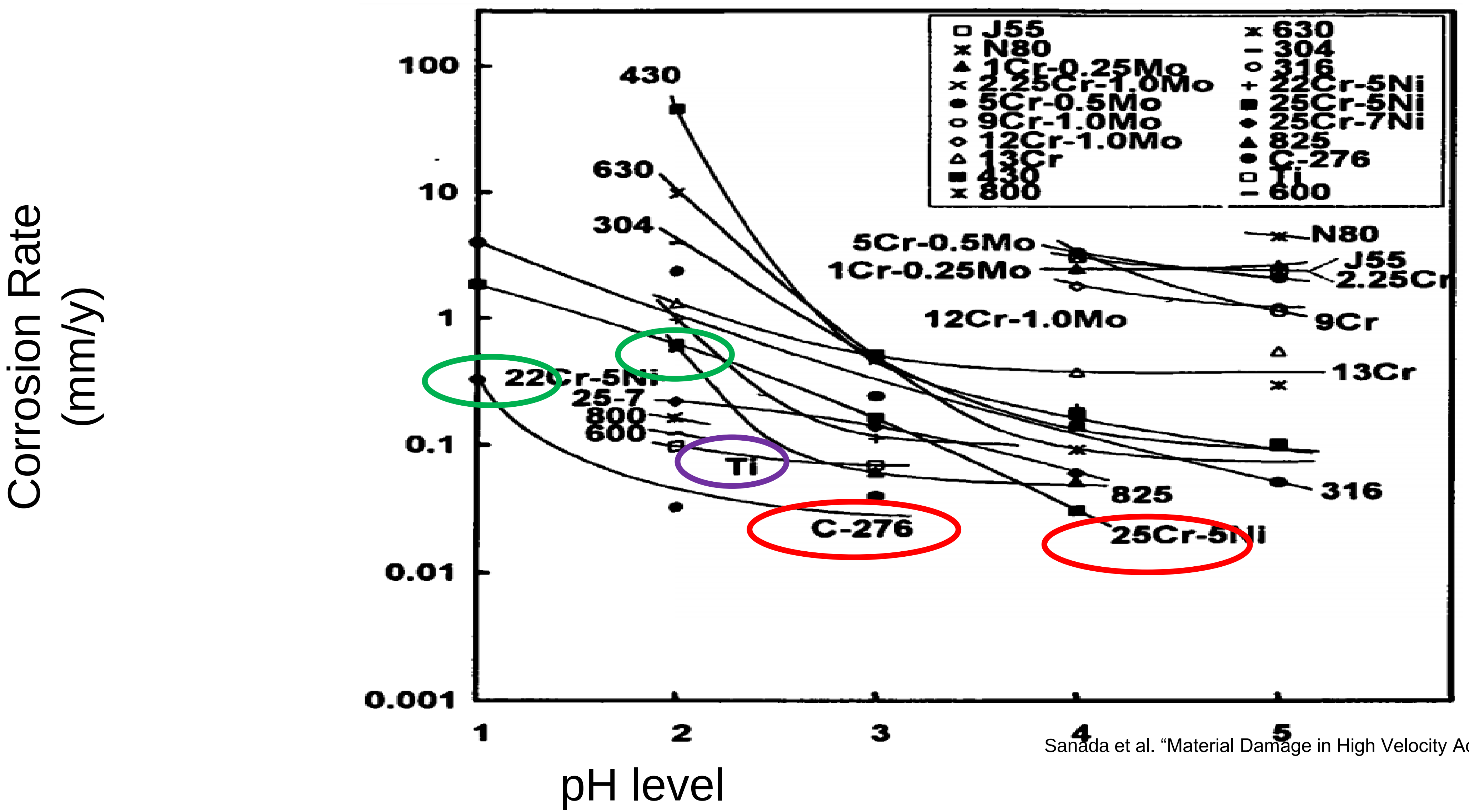


International Molybdenum Association. “Duplex Stainless Steel.”

Material Comparisons

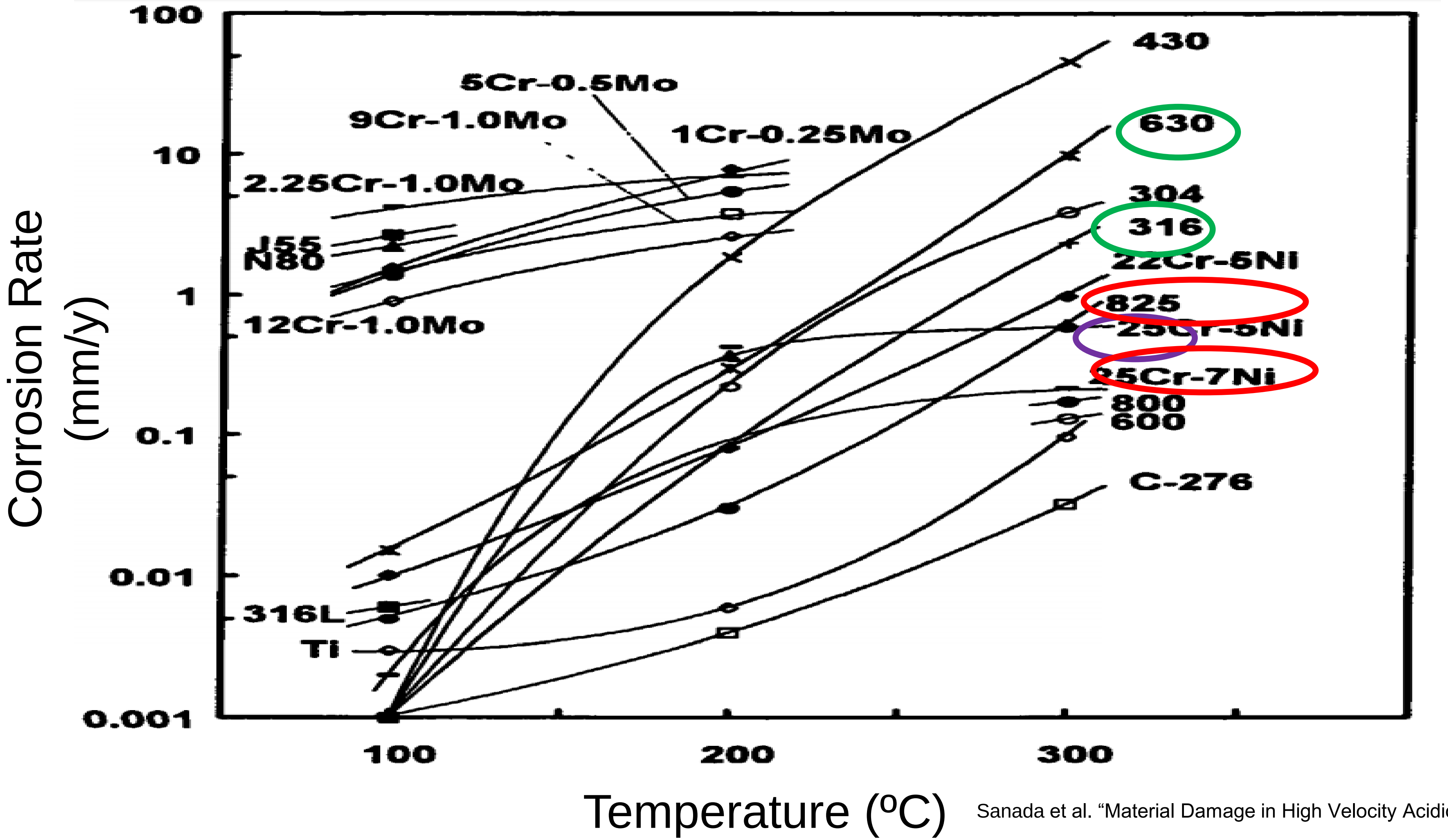
Grade	Structure	Composition				PREN*	Tensile Strength (MPa)	Hardness (Rockwell)	Cost Ratio
		N	Cr	Ni	Mo				
AISI SS 304	Austenitic	0.11	18-20	8-10.5	-	19	505	70 HRB	1.0
AISI SS 430	Ferritic	-	16/18	-	-	18	586	90 HRB	-
Lean Duplex 2304	Duplex	0.05-2	21-24	3-3.5	0.2	26	600	20 HRC	0.97
Standard Duplex 2205	Duplex	0.2	21-23	4.5-6.5	2.5-3.5	35	655	31 HRC	1.2
Super Duplex 2507	Duplex	0.25	24-26	6-8	4	43	800	32 HRC	1.96
Inconel 625	Austenitic	-	20-30	58	8-10	41	880	33 HRC	7.75

Tests in Low pH



Sanada et al. “Material Damage in High Velocity Acidic Fluids.” 1995.

Tests in High Temp



Sanada et al. “Material Damage in High Velocity Acidic Fluids.” 1995.

Problems with DSS

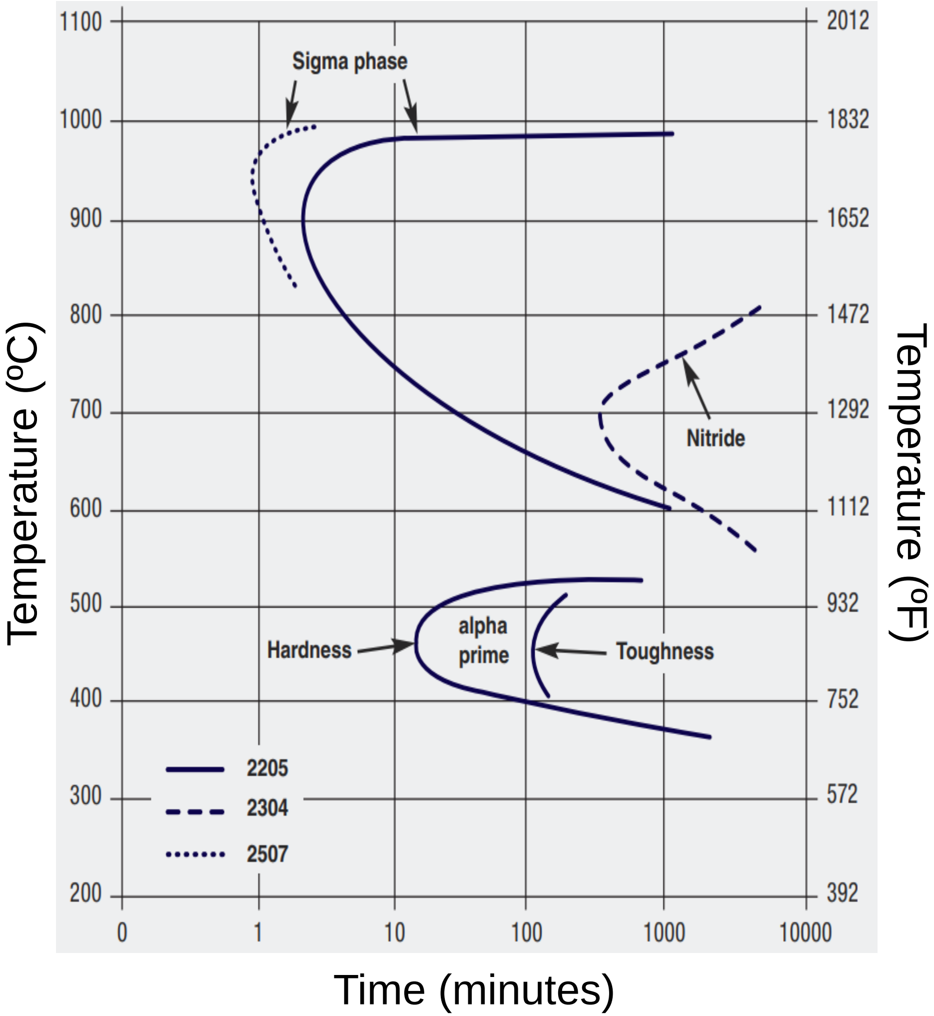
1) Manufacturing Flaws

a) Sigma phase precipitation

- 700-1000ºC
- Depletes Mo and Cr in surrounding areas

b) Chromium nitride precipitation

- 600-900ºC
- Nitride formation occurs because of nitrogen oversaturation



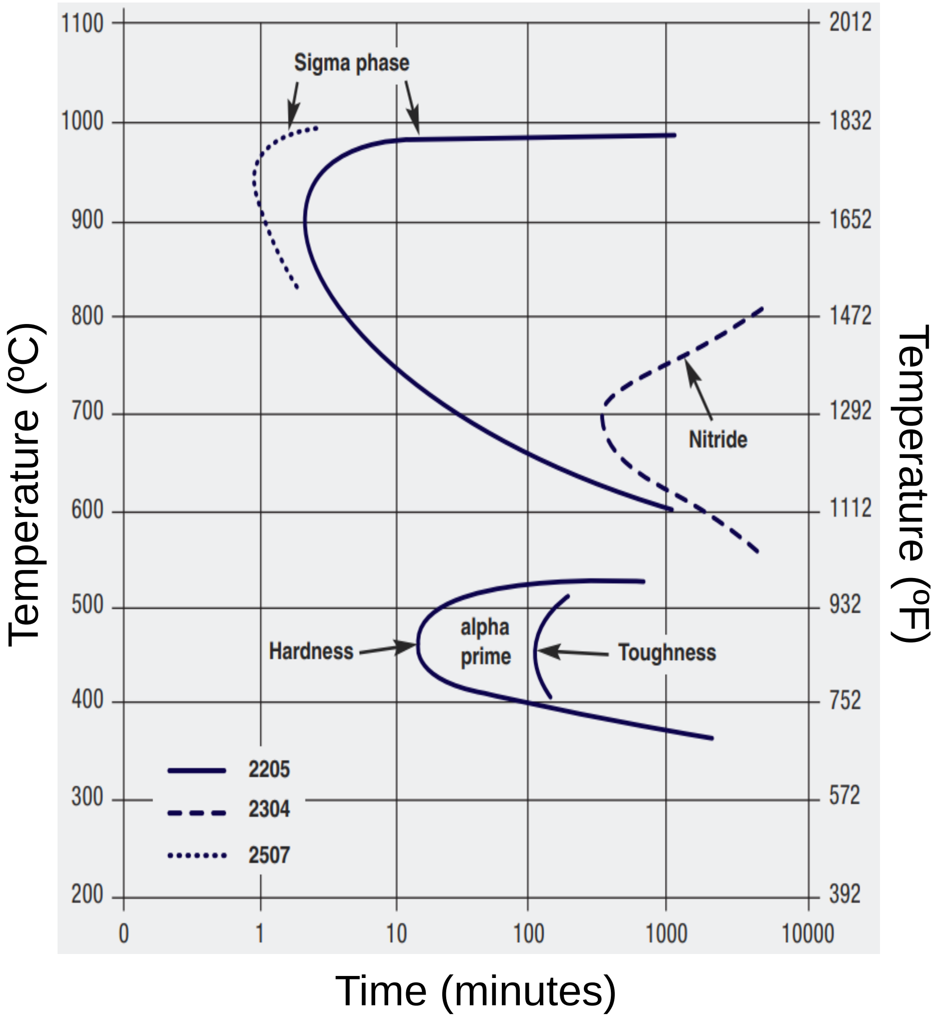
Lacoviello, et. al . High temperature embrittled duplex; influence of the chemical composition of fatigue crack propagation 2017

Problems with DSS

2) Field Failure

a) Alpha phase precipitation

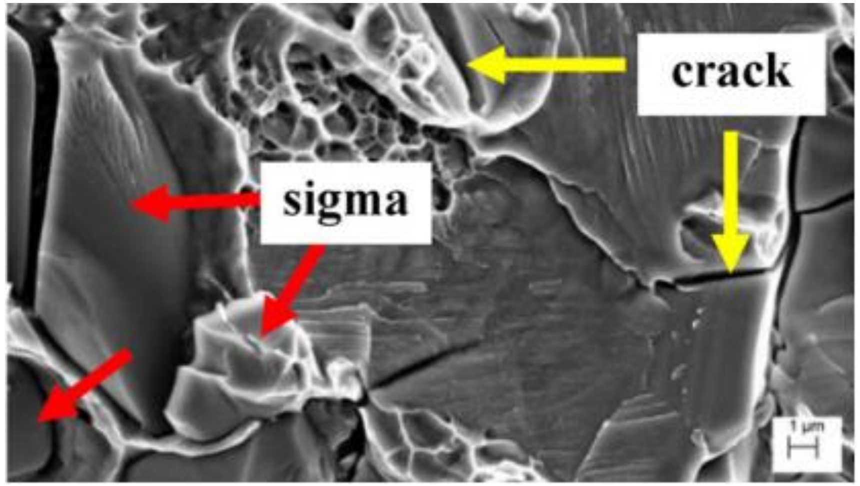
- 280-500ºC
- 475ºC Embrittlement
- Occurs due to the decomposition of the ferritic phase to chromium-rich and iron-rich-phase
- Iron-chromium binary alloy systems embrittles the microstructure



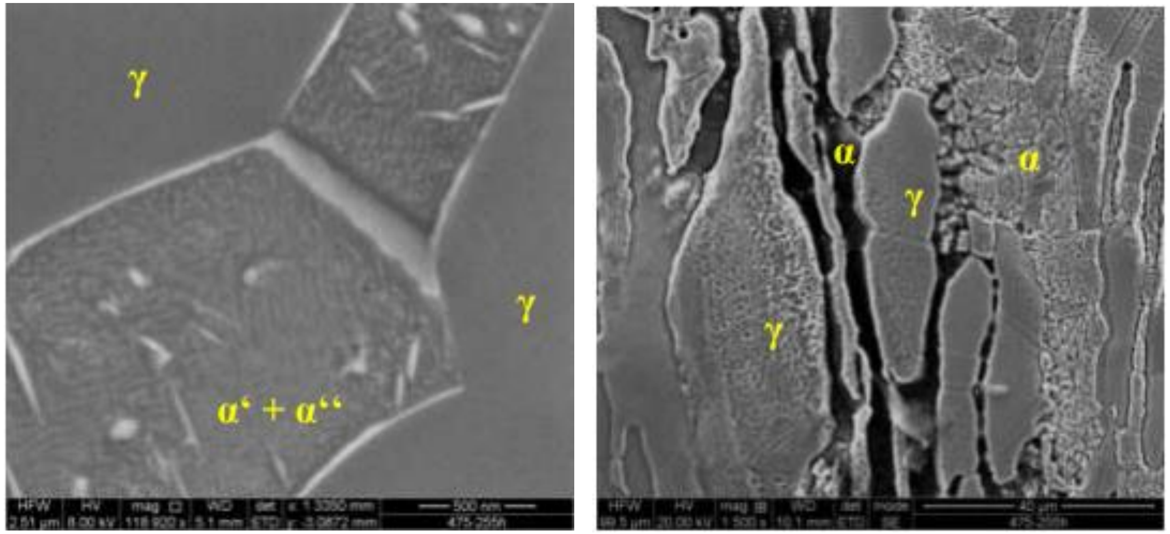
Lacoviello, et. al . High temperature embrittled duplex; influence of the chemical composition of fatigue crack propagation 2017

Problems with DSS

Sigma Phase Precipitates



Wang et al. “Effect of sigma phase precipitation on the mechanical and wear properties of Z3CN20.09M cast duplex stainless steel.” 2013



475°C Embrittlement

Ornek. “Effect of “475°C Embrittlement” on the Corrosion Behaviour of Grade 2205 Duplex Stainless Steel Investigated Using Local Probing Techniques.” 2013.

DSS corrosion susceptibility partially tied to crystalline cooling during production of tubing

Conclusions

1. Strong resistance in sulphuric, chloric, and nitric acid environments
2. Minimum corrosion rates at temperatures at or below 250ºC, even at low pH (2) when compared to standard austenitic stainless steels
3. Competitive and cheaper alternatives to nickel and titanium alloys at low-mid range temperatures
4. Still susceptible to embrittlement at high temperatures (>300ºC), limiting their applications although some studies have produced mixed results
5. Difficult to predict exact chemical and corrosive response from DSS due to the variabilities in geothermal environments
6. Develop a tailored approach to using Cr-Ni alloy adjustments in corrosion specific environments in tubing

Going Forward

- **Coupon Testing**
- High temperature coupon testing with geothermal fluids at site specific locations
- Areas to focus during tests:
  - General corrosion rates
  - Onset of localized corrosion (SCC and Pitting)
  - Effect of fluid flow velocity

Bassler et al. "Materials Evaluation for Geothermal Applications." 2015

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