Static Equipment

Awareness Session

Part 3

Materials Selection

Baher Elsheikh

Contents

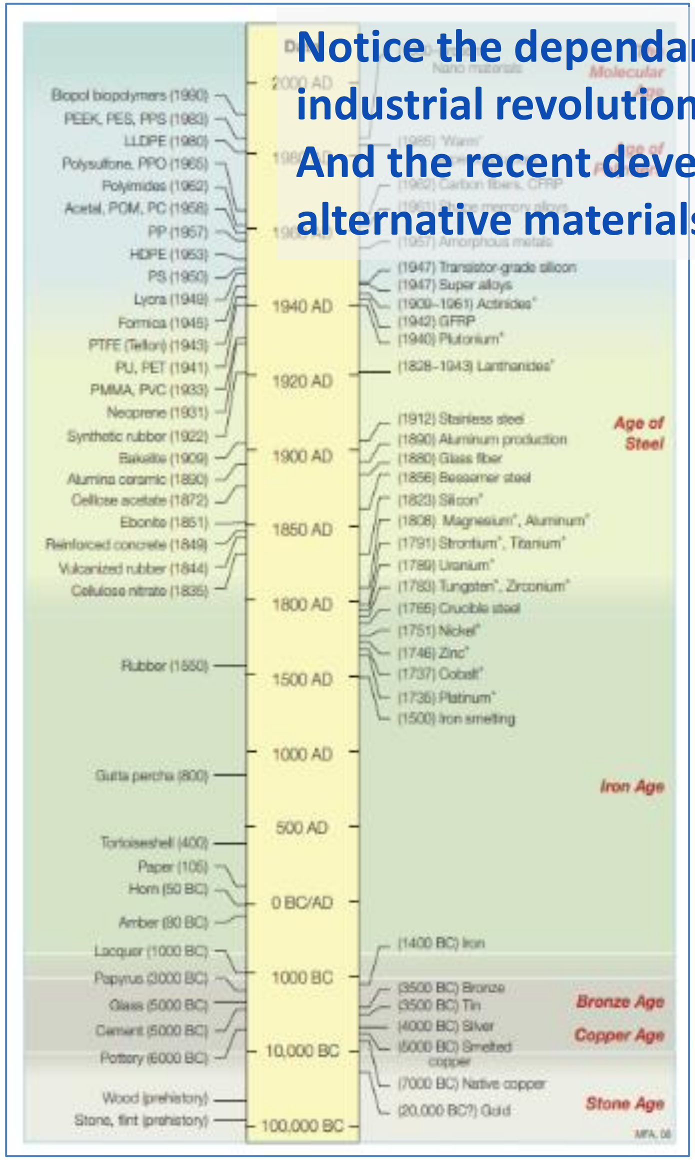
Materials Selection – Alternative Choices

- There is always different alterative materials can be used for same application each has its own characteristics , pros and cons

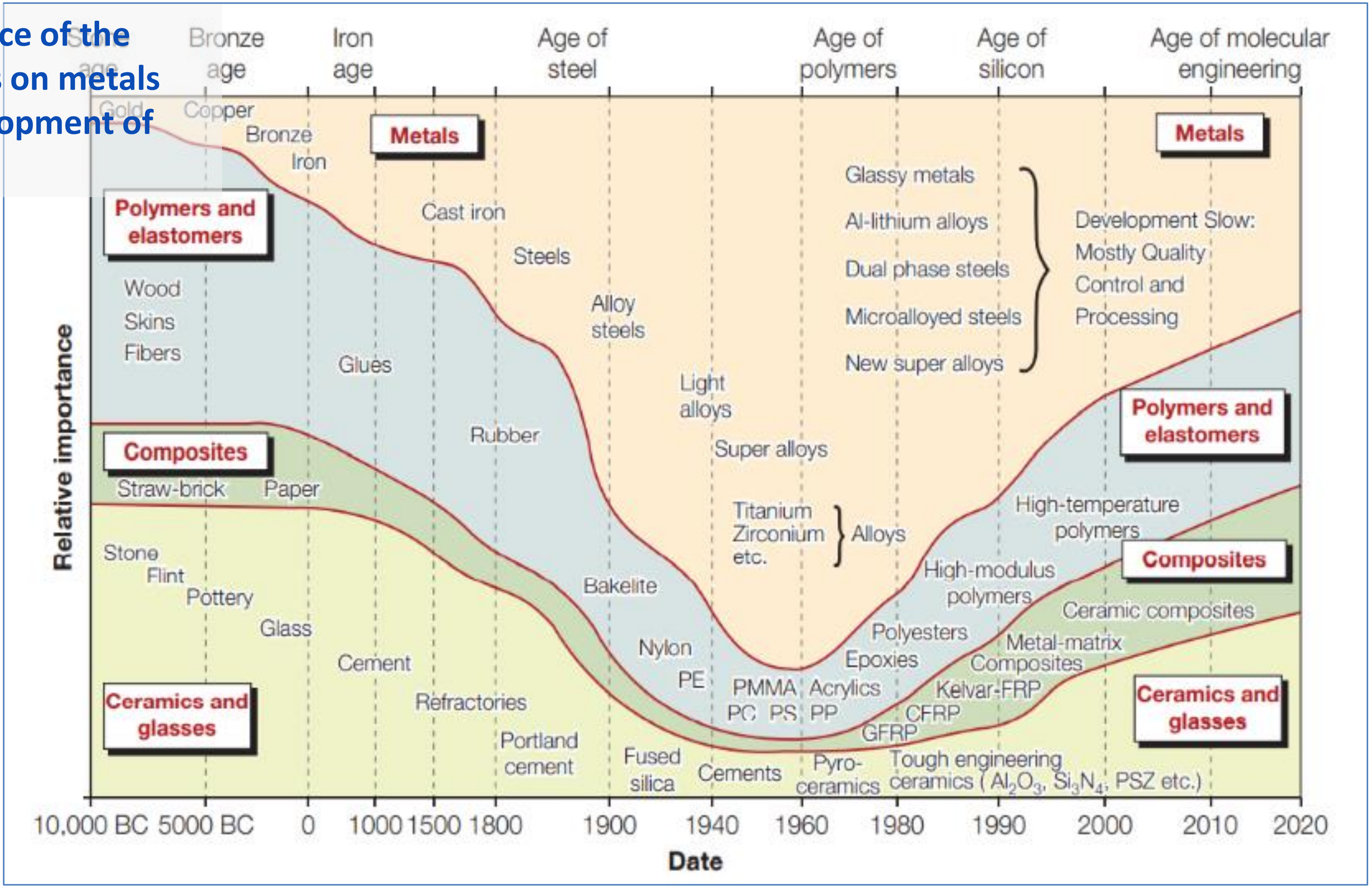
- A familiar item that is fabricated from three different material types is the drinks container.

- Drinks are marketed in aluminum (metal) cans , glass (ceramic) bottles , and plastic (polymer) bottles

The Evolution of Engineering Materials



Notice the dependance of the industrial revolutions on metals
And the recent development of alternative materials



Note: Scale is nonlinear

Source: Material Selection in Mechanical Design – 4th Edition, Michael F. Ashby

Evolution of Materials in Products


Cast Iron Kettle


Bronze Kettle


Polypropylene Kettle


plate camera from 1900


Leica from 1960


Plastic camera, 2006


Wright biplane, 1903


Douglas DC3, 1935


Boeing 787, 2010

Source: Material Selection in Mechanical Design – 4th Edition, Michael F. Ashby

Materials Selection

Material Selection

Mechanical & Physical Properties

- Strength, toughness, ductility, hardness, Creep resistance, fatigue resistance
- Thermal conductivity, thermal expansion
- Compliance with applicable design code

Cost & Availability

- Lifecycle cost consideration
- Availability and in desired form
- Listed in design code
- Future inspection and maintenance requirements

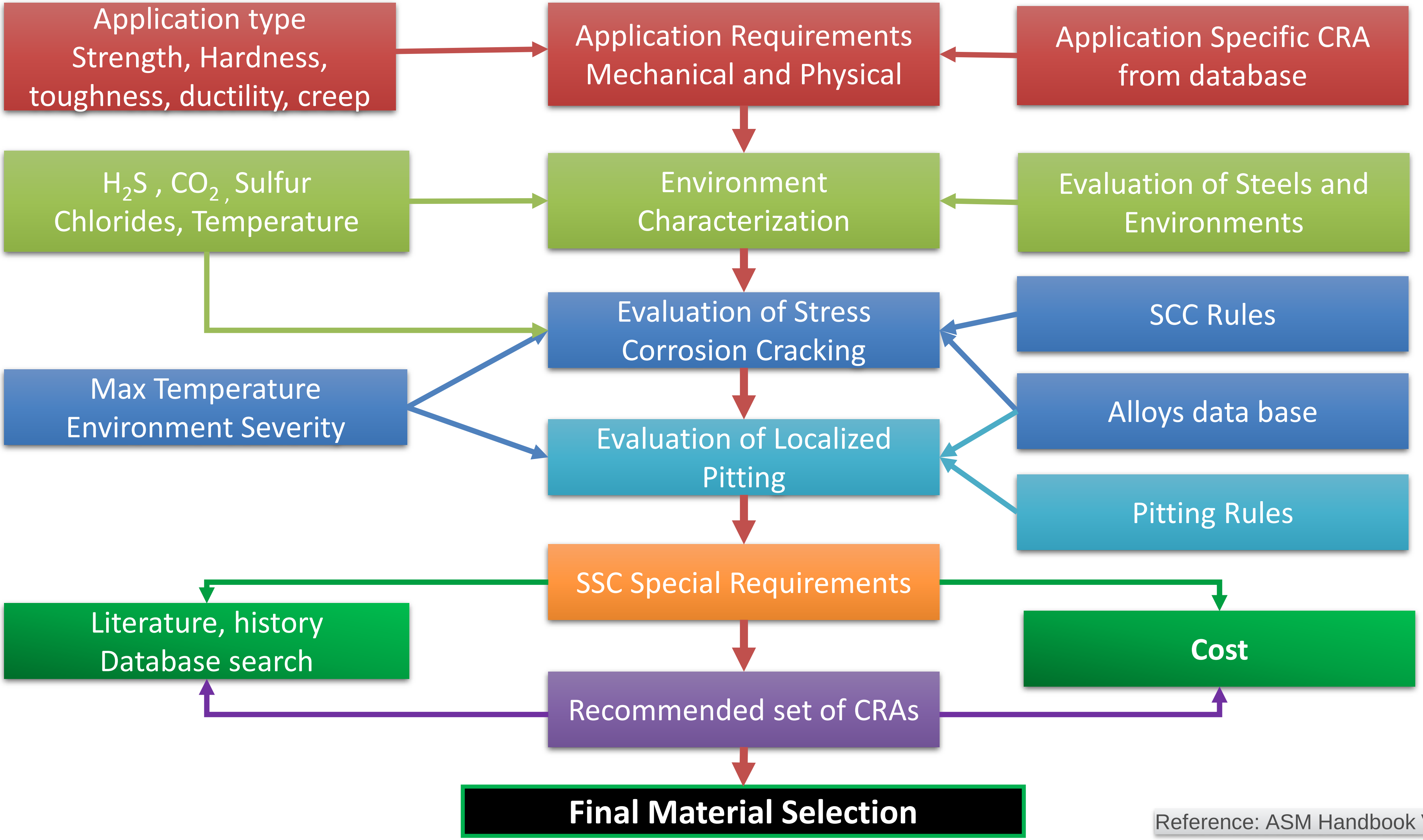
Corrosion Resistance

- Corrosion (internal / external), erosion, SCC,….
- All operating conditions to be considered
- Availability of corrosion control techniques
- All operating conditions shall be considered
- Experience in similar application and design
- Lining and protection layers
- Applicability of CA consideration

Fabrica-bility

Weldabaility, formability, machinability, ….

Selection of CRA of Through Environmental Specification



Reference: ASM Handbook Volume 13C

Materials Selection Based on Temperature – No Hydrogen, No Corrosion

°C

1000	Refractory Lined materials
700	304H, 347H, 310H SS, Incoloy 800 H, Inconel
650	304 SS (care for sigma phase formation)
500	1.25 Cr-Mo Steel up to 9 Cr Steel
345	Carbon steel
-29	Impact tested killed carbon steel
-45	Impact tested low alloy Ni steel
-100	5% Ni Steel, 9% Ni 301, 302, 304L Aluminum
-200	Quenched tempered 9% Ni 301, 302, 304L Aluminum
-273	304L, Low carbon stainless steel casting alloys Monel, Hastelloy, Inconel 718 Aluminum

High temperatures are temperatures where creep resistance is important

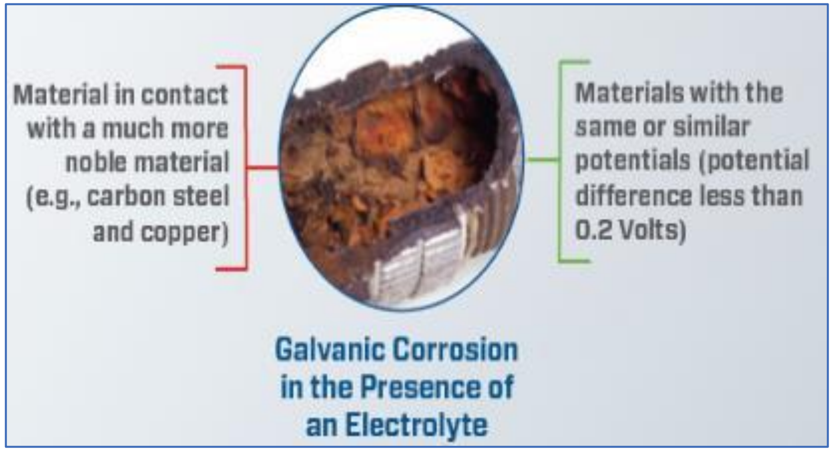
Low (or cryogenic) temperatures are temperatures where fracture toughness is important

Reference Materials Selection for Refineries and Associated Facilities ; R.A White, E.F Ehmke

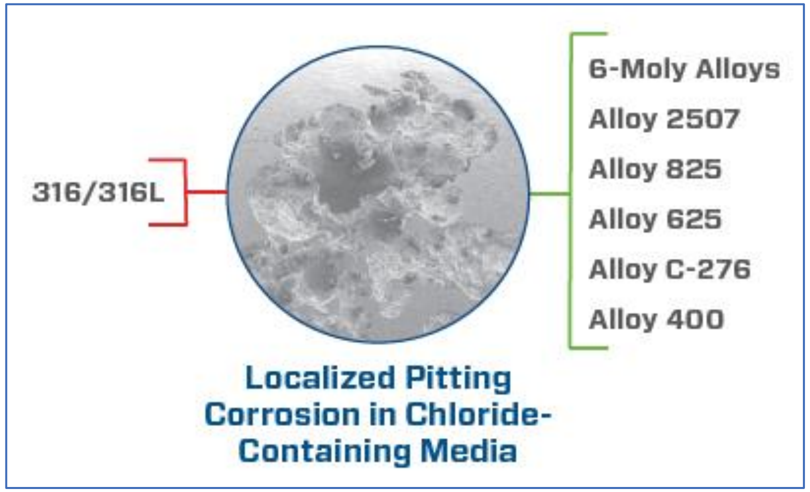
Common Corrosion Forms and Material Selection

General (or Uniform) Corrosion

Stress Corrosion Cracking in Chloride-Containing Media

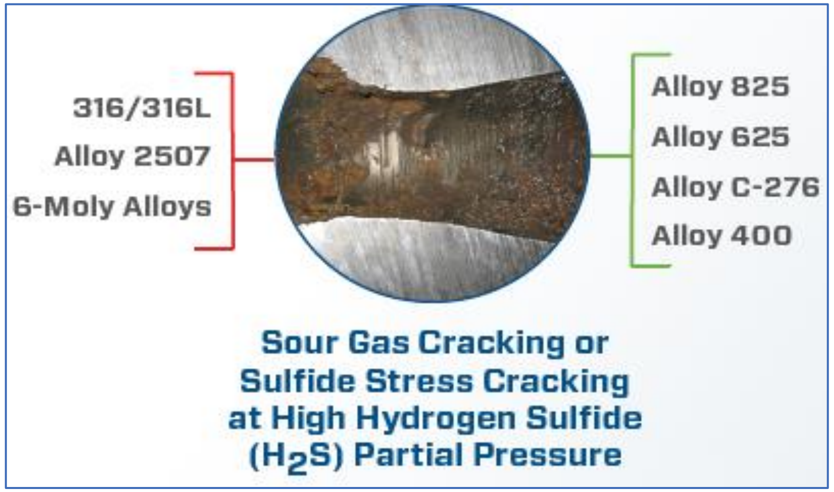


Galvanic Corrosion in the Presence of an Electrolyte



Localized Pitting Corrosion in Chloride-Containing Media

Hydrogen Embrittlement



Sour Gas Cracking or Sulfide Stress Cracking at High Hydrogen Sulfide (H_2S) Partial Pressure

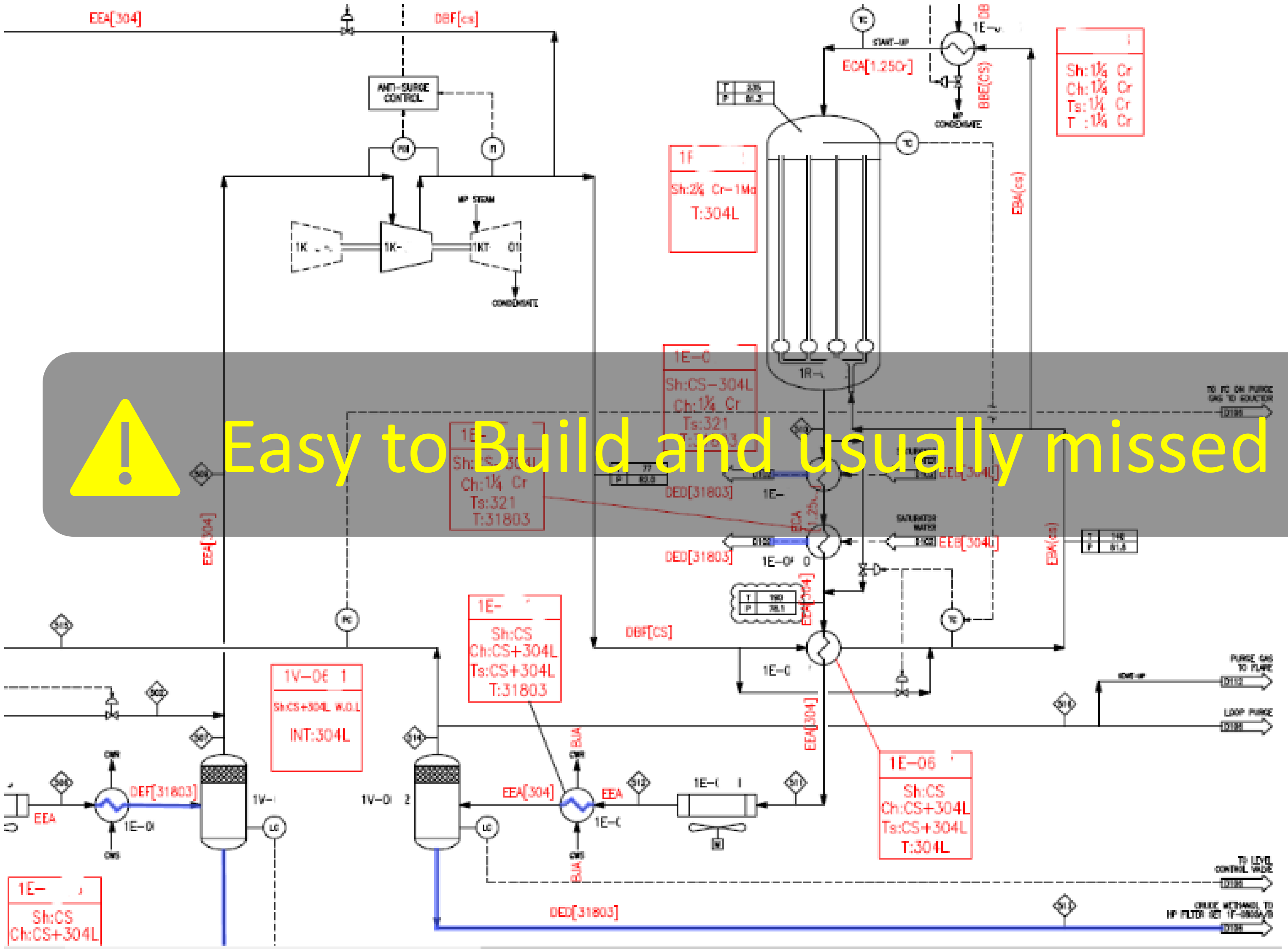
Reference: Simplified Materials Selection Guide - Swagelok

Highlights for Materials Selection

- Materials Selection Should be based on design conditions, not operated conditions
- Process flow diagram, contaminants level, upset, all internal and external media should be considered for the entire design life. Stages of transportation, storage, installation, testing and preservation.
- Should be listed / identified under design codes and standards (ASTM, ASME, ….)
- When welding is involved, the low carbon grades of Stainless steels (304 L, 316 L) are preferred to avoid sensitization, unless for high design temperature conditions (>425 C)
- Design life to be considered in the application of proper corrosion allowance
- Configuration of the equipment to be considered (crevices, high localized heat flux, tendency to sedimentation and stagnation, long idle time ……)
- Maintainability and inspection requirements (PWHT, step cooling, impact testing)

Reference Materials Selection for Refineries and Associated Facilities ; R.A White, E.F Ehmke

Material Selection Diagram [MSD]



⚠ Easy to Build and usually missed

MSD (Material Selection Diagrams) is a typical overlaid version of PFD that shows relevant operating conditions and process data, material selection information and applications of other material degradation prevention measures.

MSD became an efficient and helpful document during the development of the P&IDs, piping materials specifications and in the identifications of the corrosion loops during the RBI study

Reference: NACE SP0407-2018 "Guidelines for Developing Material Selection Diagram"

Materials Selection Report

Corrosion evaluations and materials selection should be documented in a report for further use by the project and operations

- **The following elements should be included:**
- Short description of the project and expected facilities, e.g. field layout, remoteness of location, manned versus unmanned facilities, etc.;
- Materials-related design input data for the operating conditions during the design life of the facility, e.g. temperatures, pressures, fluid composition, sand production, etc.
- Corrosion evaluations and materials selection;
- Requirements for corrosion inhibitor efficiency and availability;
- Requirements for corrosion control, e.g. CP and coatings;
- Requirements for corrosion monitoring;
- Identification of uncertainties from a materials perspective, new application for materials, use of new grades;
- Need for material qualification testing.

Reference ISO-21457 : Materials selection and corrosion control for oil and gas production systems

Main Materials Properties

Static Equipment Awareness

Part03: Materials Selection

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Main Factors Affecting Materials Properties

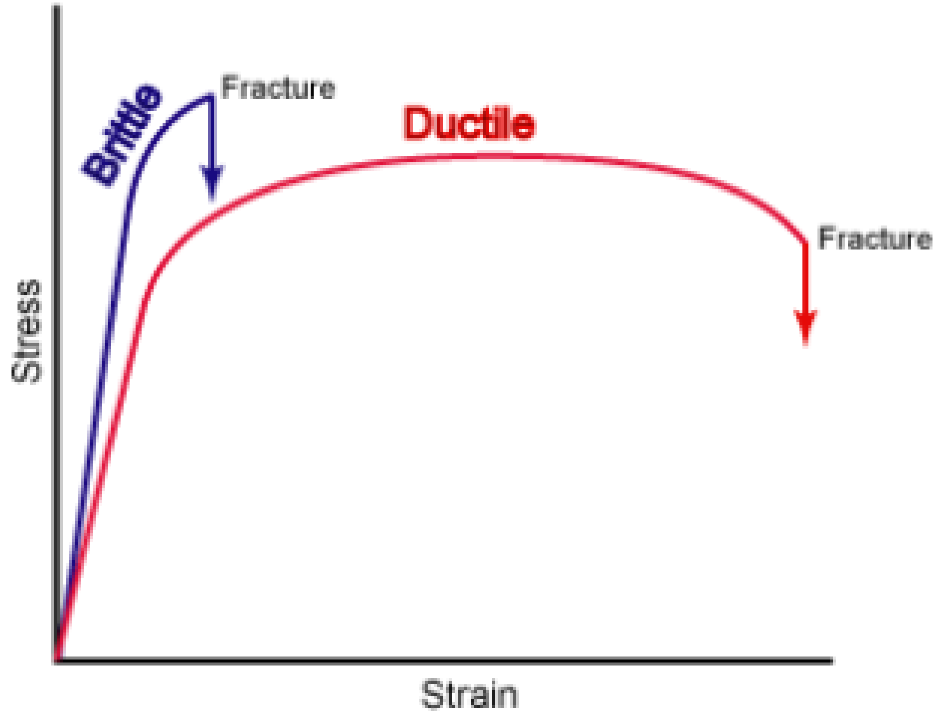
- Matrix structure & grain size
- Forming (Hot / Cold)
- Composition & Alloying Elements
- Heat Treatment
- Welding

Ductility

The ductility of a material is a measure of the extent to which a material will deform before fracture

The amount of ductility is an important factor when considering forming operations such as rolling and extrusion

Many damage mechanisms are causing material embrittlement (loss of ductility)



Brittle Ductile

Hardness

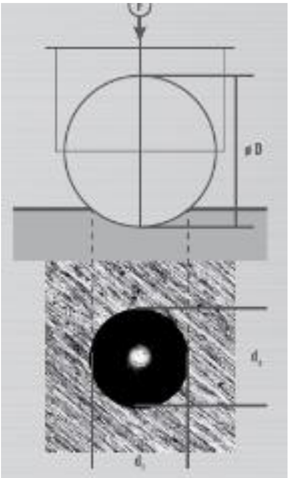
Hardness is the resistance of a material to localized deformation usually measured by indentation. The term can apply to deformation from indentation, scratching, cutting or bending

The hardness of parent materials, welds and HAZ play important roles in determining the SSC resistance of carbon and low alloy steels. Hardness control can be an acceptable means of obtaining SSC resistance.

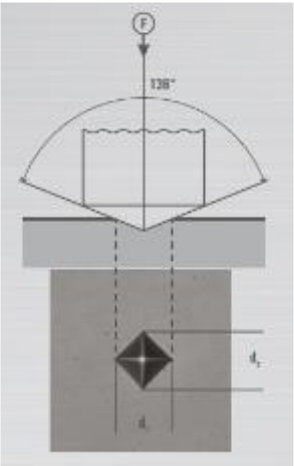
High Hardness is desirable in applications require abrasion resistance.

Hardness testing used to indicate change in material strength without destructive mechanical testing

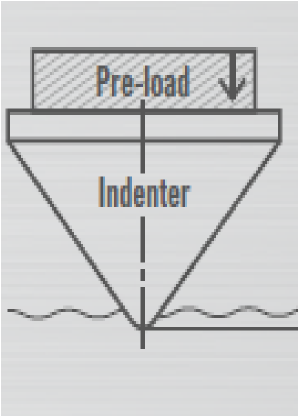
In situ Hardness testing is widely used to indicate embrittlement damage mechanisms



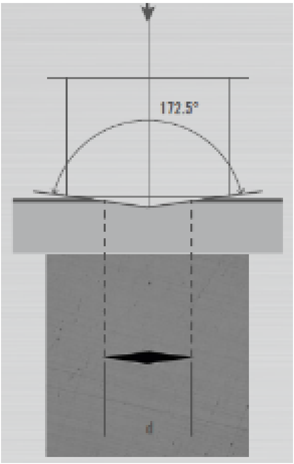
Brinnel Hardness Test



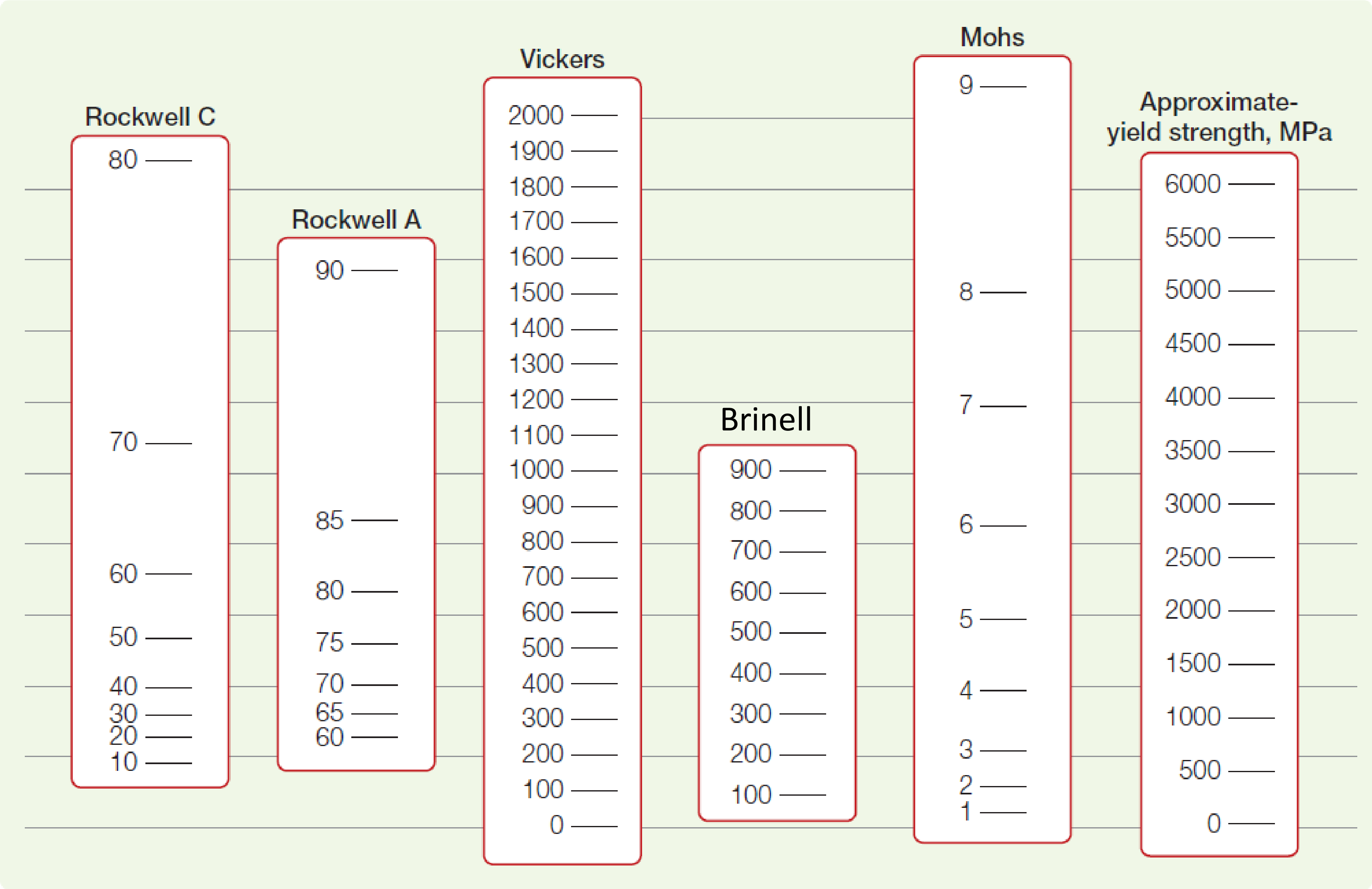
Vickers Hardness Test

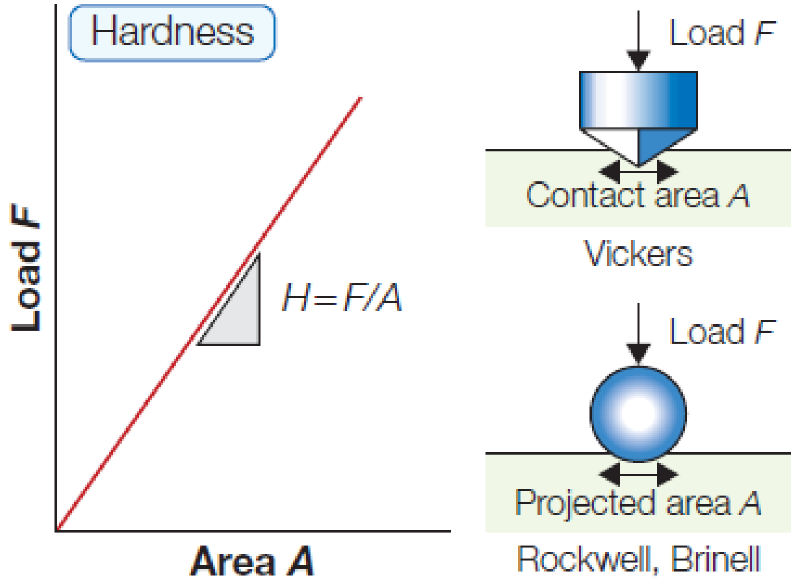


Rockwell Hardness Test



Knoop Hardness Test

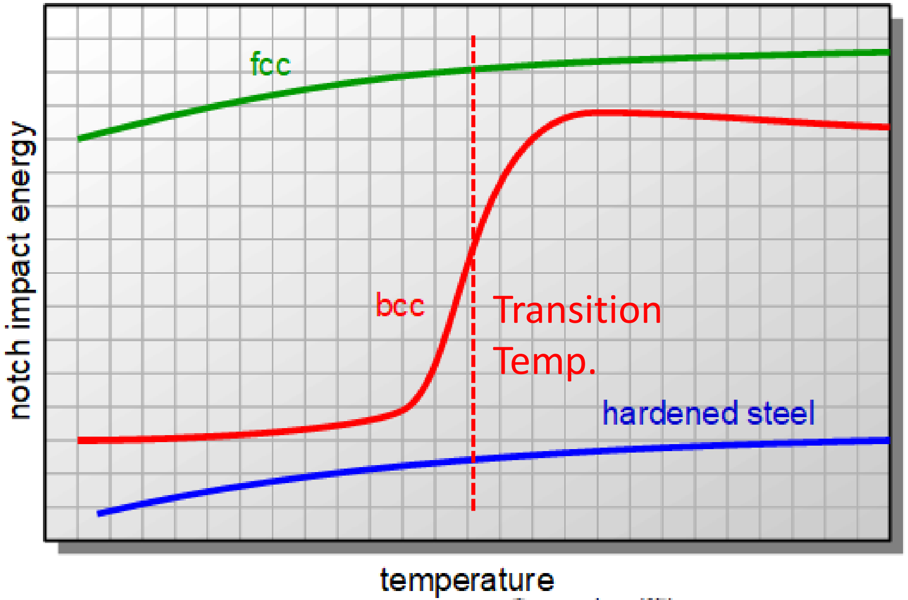




Hardness is measured as the load, F, divided by the projected area of contact, A, when a diamond-shaped indenter is forced into the surface

Approximate Relationships between common hardness scales and Material Yield Strength

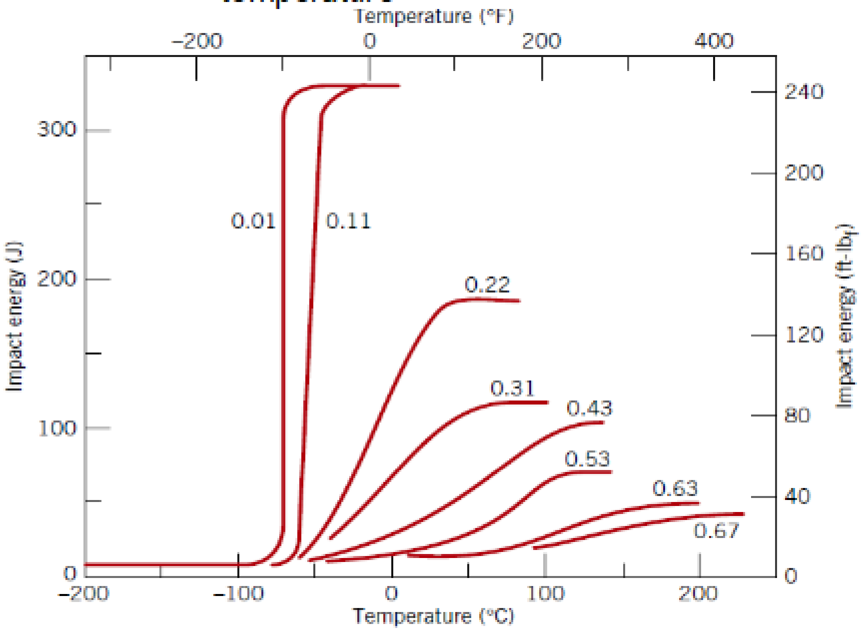
The fracture toughness of a material is a measure of material ability to resist failure by the onset of crack extension to fracture. Toughness is an important factor when the material will be subjected to low temperature service



Effect of material compositions and Microstrucre

- In comparison to materials with BCC lattice structures, the temperature has hardly any influence on the toughness for materials with FCC lattice structures.
- Some materials behave relatively tough over the entire temperature range, such as aluminium, or show relatively brittle behaviour, such as hardened steels (not tempered).

Influence of carbon content on the Charpy V-notch energy–versus–temperature behavior for steel.



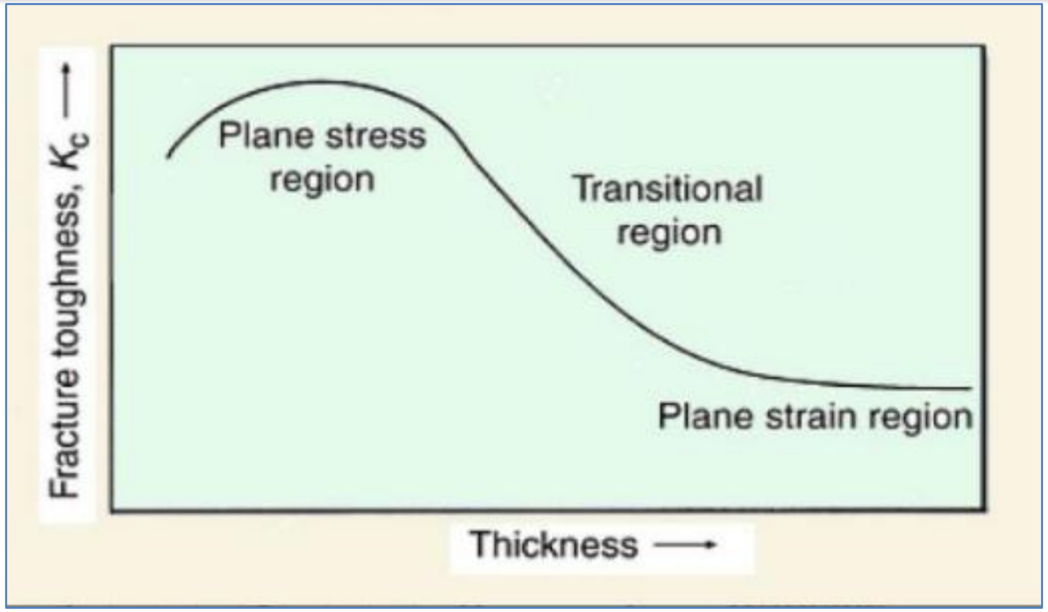
Effect of Thickness

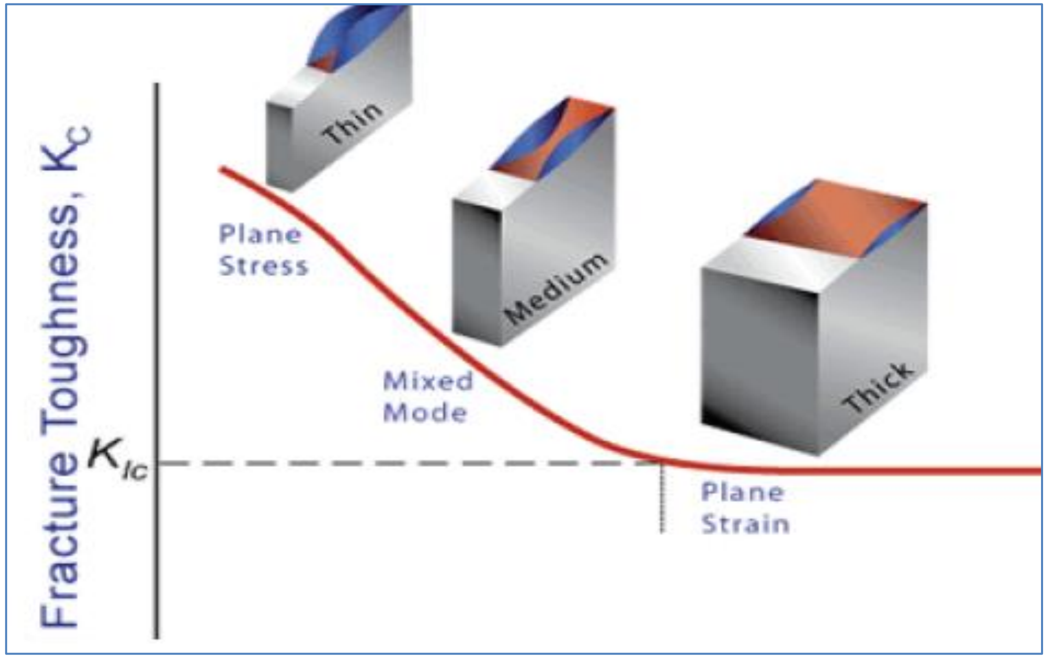
Impact test exemption figure also indicates that by increasing the thickness, the exemption temperature increases as well. Which points out reduction in toughness (increase in DBTT).

Figure demonstrates the effect of plate thickness, which is governed by the stress state in the plate. For thin plates, the prevailing stress state is plane stress and fracture toughness is represented by Kc.

As the plate thickness increases, stress state transitions to plane strain conditions, where fracture toughness is represented by KIc which is lower than Kc.

KIc can be used to obtain fracture toughness of brittle materials or thick sections

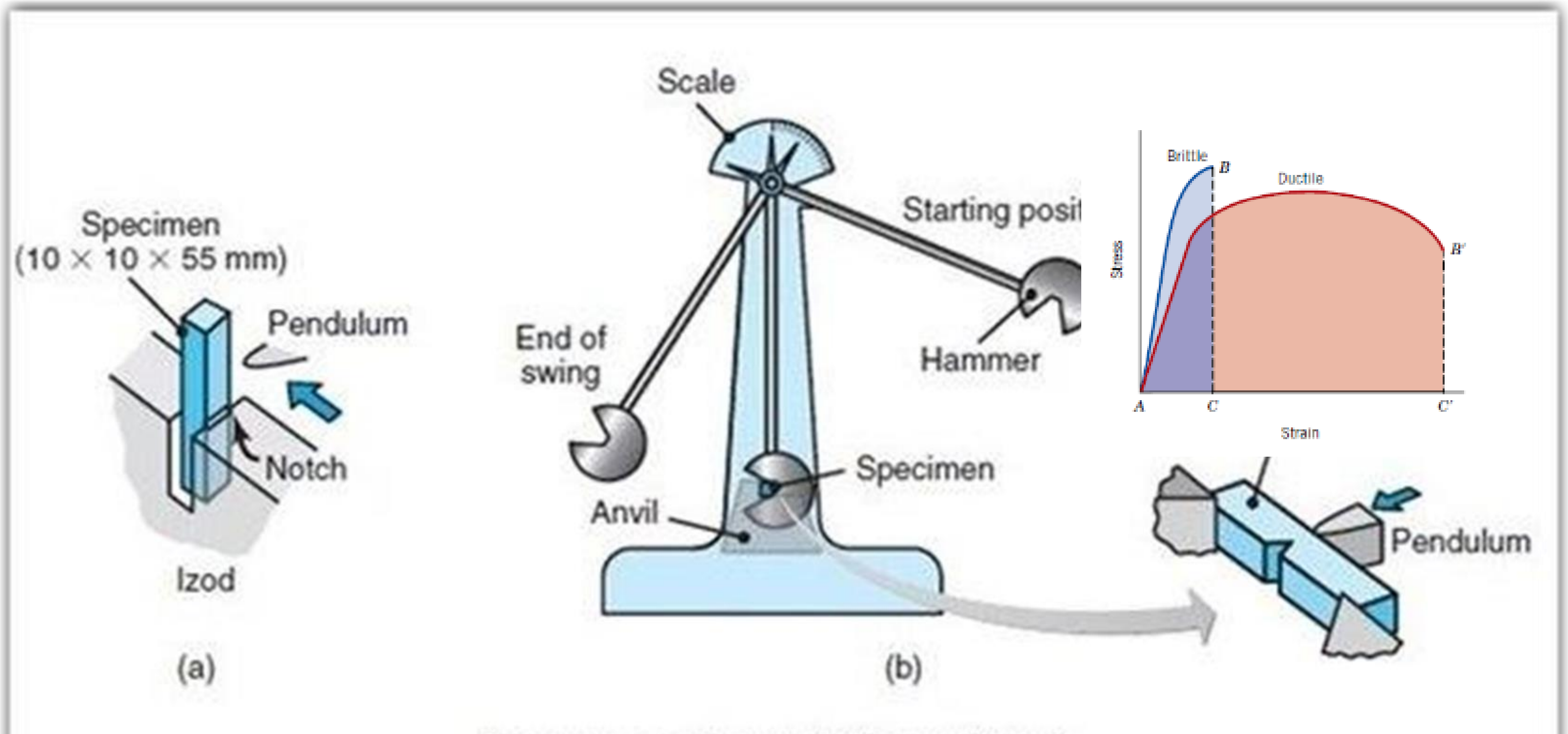




Source: - API 579-1 Part 9
- ASM Handbook volume 11 - Failure analysis and prevention

Toughness – Charpy Impact Test

DBTT and toughness is traditionally measured by impact test as per the below figure



Impact test specimens: (a) Charpy; (b) Izod.

Hydrotest of pressure vessels can be safely applied in winter using water temperature of 5º C or less as material will be of high strength and with no risk of failure

a. YES

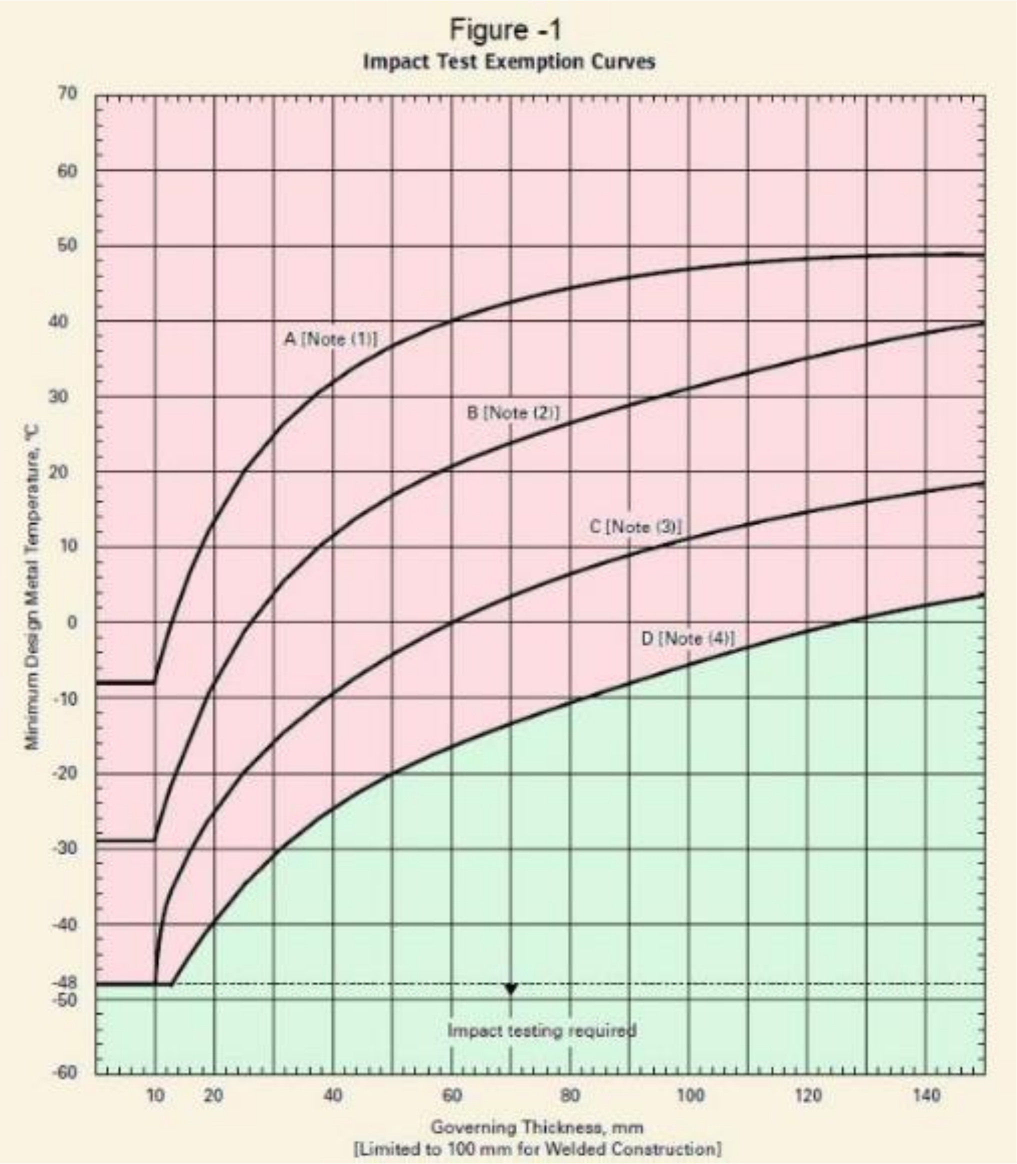
b. NO

Photo: www.labtesting.com

[Codes are the Industry Guide]()

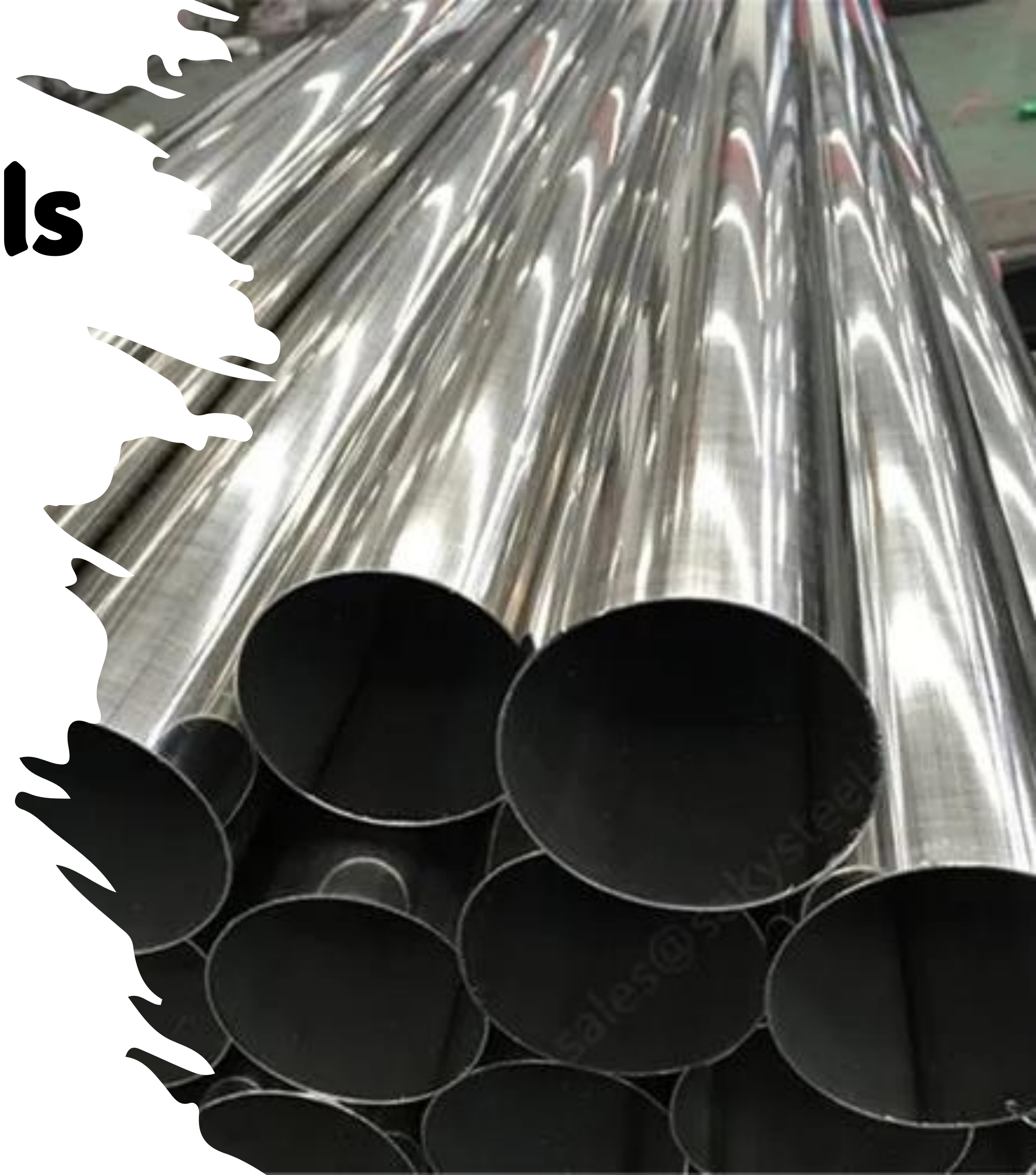
The figure is the impact test exemption curve from ASME BPVC Sec. VIII Div.1 which used for the determination of the Minim Design Metal Temperature (MDMT).

The figure indicates how the toughness fracture reduced with temperature decrease. The figure is colored so that for group D, green portion indicates impact test is required and in red part exempted



Source: ASME BPVC SEC. VIII Div.1 – UCS 66

Common Materials



Static Equipment Awareness

Part03: Materials Selection

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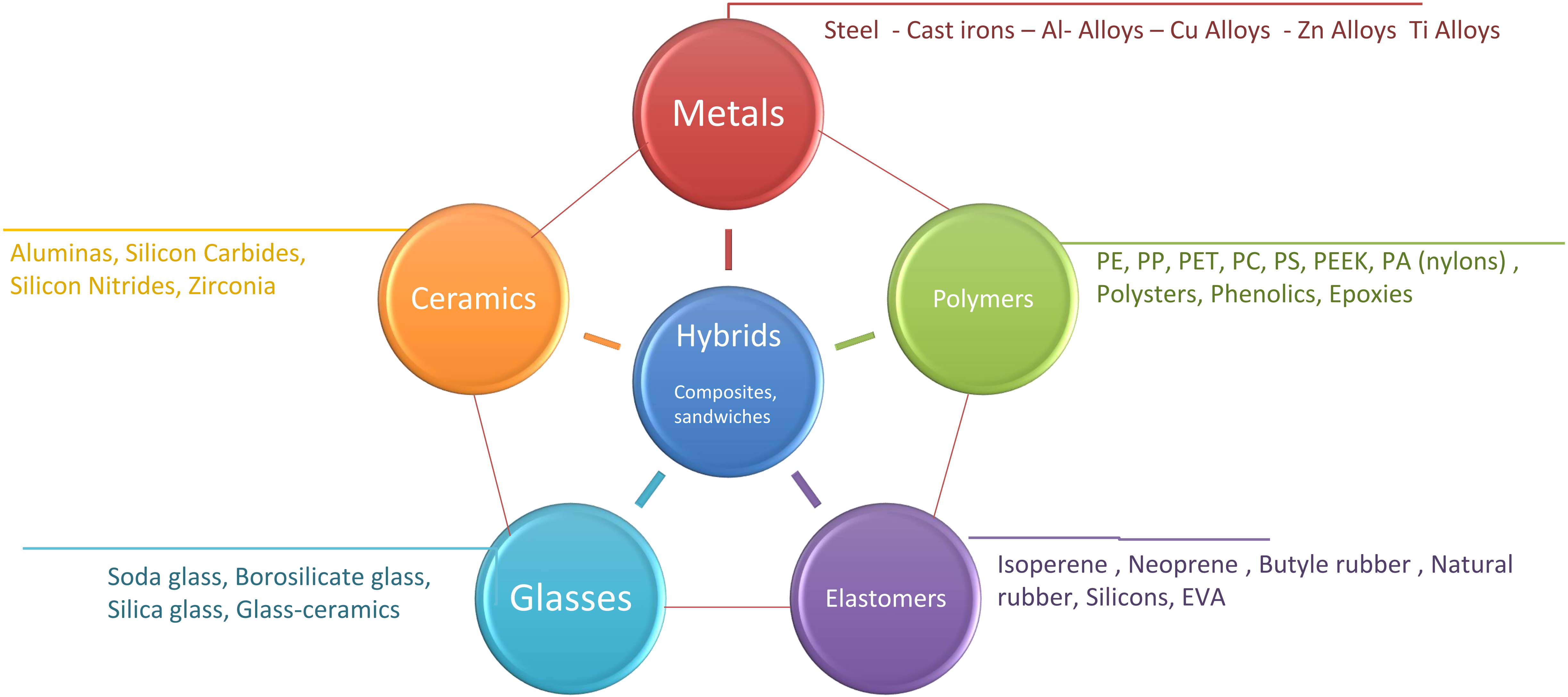
Common Engineering Materials



Major Materials – Ferrous Alloys

Ferrous Alloys

High Carbon Iron Alloy
C > 2%

C < 2%

Cast Iron

- **Gray CI** (2-4%C, 1-3% Si) - Graphite Flakes - Better water corrosion compared to steel)
- **White CI** (iron carbide) , Less Si – Hard and Brittle
- **Malleable CI** (produced by heat treatment of white irons)- good workability
- **Ductile Iron** (Nodular CI) – good ductility
- **High Si CI** (Gray CI with SI >14%) – Good corrosion resistance and inherent hardness (0.95% c and 14.5% Si)

Steel

Plain Carbon Steel

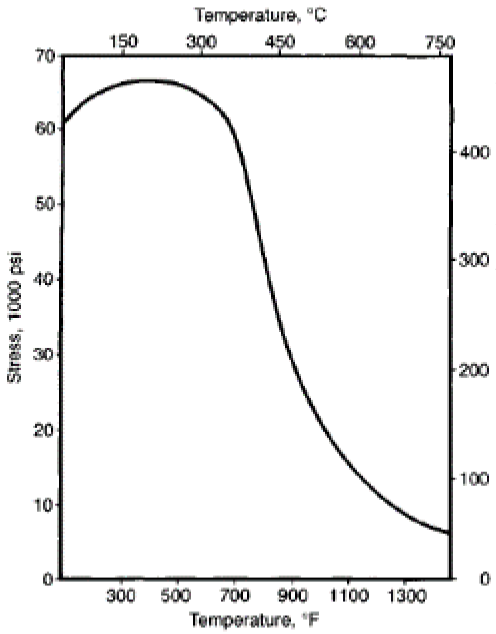
- Low CS (C<0.2%)
- Medium CS (C: 0.2-0.5%)
- High CS (C > 0.5%)

Low Alloy Steel

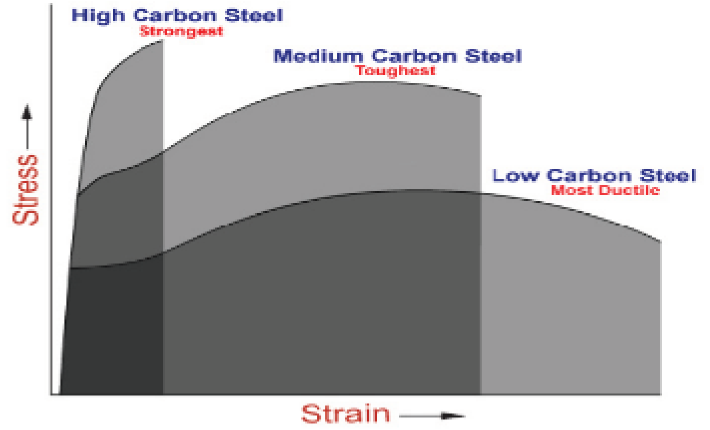
- Alloying elements < 8%
- Examples:
- Cr-Mo Steels
- Used for high temperature applications

High Alloy Steel

- Alloying elements < 9%
- Examples:
- Stainless Steels (Cr > 9%)
- Used for high temperature applications, corrosion resistance, wear resistance



Yield stress of plain carbon steel as a function of temperature. Note the rapid strength decrease above 430 C



Classification of Steels

Composition	Manufacturing Method	Finishing Method	Deoxidation Practice	Microstructure	Required Strength	Heat Treatment
Such as	Such as	such as	such as	such as	As specified in ASTM	Such as
Carbon Steel	**Open hearth**	**Hot Rolling**	**killed**	**Ferritic**	**High strength**	**Annealing**
Low Alloy Steels	**Basic Oxygen Process,**	**Cold Rolling**	**Semikilled**	**Pearlitic**	**Intermediate strength**	**Tempering**
Stainless Steels	**Electric Furnace methods**		**Capped**	**Martensitic**	**Low strength**	**Quenching**
			Rimmed steel			

Reference : ASM Handbook, Volume 1, Properties and Selection: Irons, Steels, and High Performance Alloys

Creep Resistance Cr-Mo Low Alloy Steels

Plain Carbon Steel

+Mo for Creep Resistance

Grade 1
1/2 Mo Steels

+Cr & Mo for Creep Resistance

Grade 11 (1Cr-0.5 Mo)
Grade 22 (2.25Cr-1 Mo)

+V for Creep Resistance

½ to 3% Chrome-Moly-Vanadium Steels
0.5-3Cr;1Mo;0.25 V1

Micro Alloyed Improved Creep

Grades 23 & 24 steels micro-alloyed
2.5Cr–0.2Mo–0.25V–1.5W–B
2.5Cr–1Mo–0.25V–B–Ti

+Cr for Hydrogen And Corrosion Resistance

Grade 5 (5Cr-0.5 Mo)
Grade 9 (9Cr-1 Mo)

+C, Cr, W&V Improved Creep

Grades X20
(0.2 C-12Cr-1Mo-0.5W-0.3V)

+Nb, V & N for improved Creep Resistance

Grades 91
(0.1C-9Cr-1Mo-Nb-V-N)

Low C, +Nb, N&Co Better Weldability

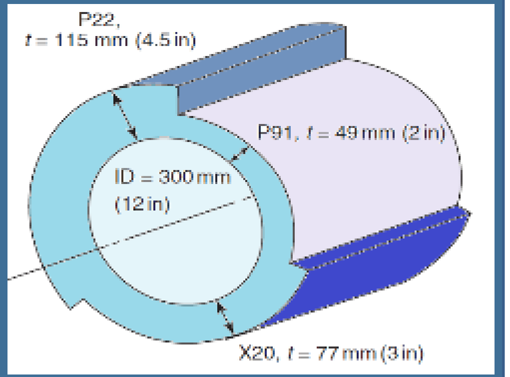
Grades HCM12A/122
Advanced 12% Cr steels
0.C-11Cr-Nb-V-N(up to 3Co)

+ 1-2% W for even greater Creep Resistance

Grade 92 (9Cr-0.5Mo-1.8W)
Grade 911 (9Cr-1Mo-1W)
Tungsten-Bearing (% Cr-Steel

Thickness Required From Differnt Grades of Cr-Mo Steel

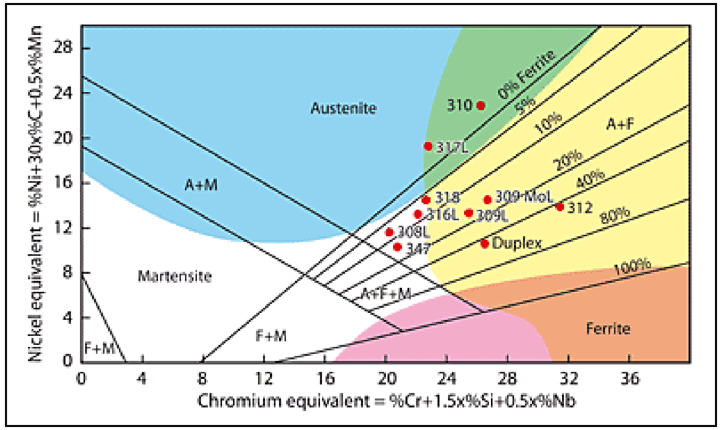
Steam Pipe temperature 600 °C, pressure 30MPa



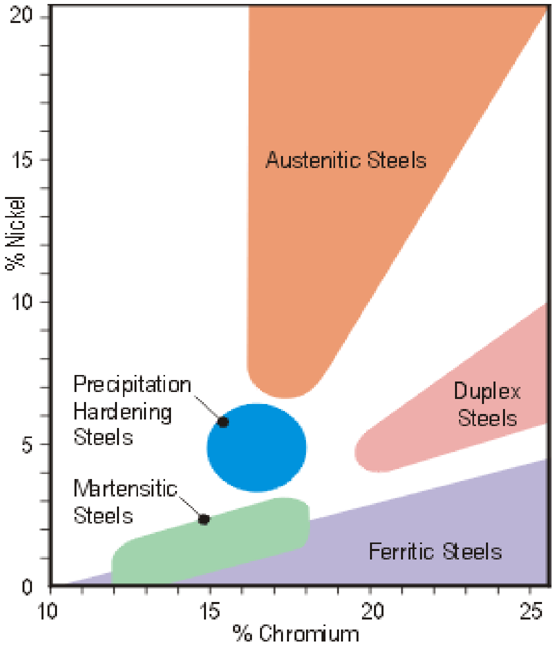
Elevated temperatures are temperatures in the range where creep and stress rupture properties are important for the steels in this specification

Reference: The alloy tree, J. C. M. Farrar

Stainless Steel Families



Shaeffler Diagram (A-austenite; M – Martensite; F – ferrite)



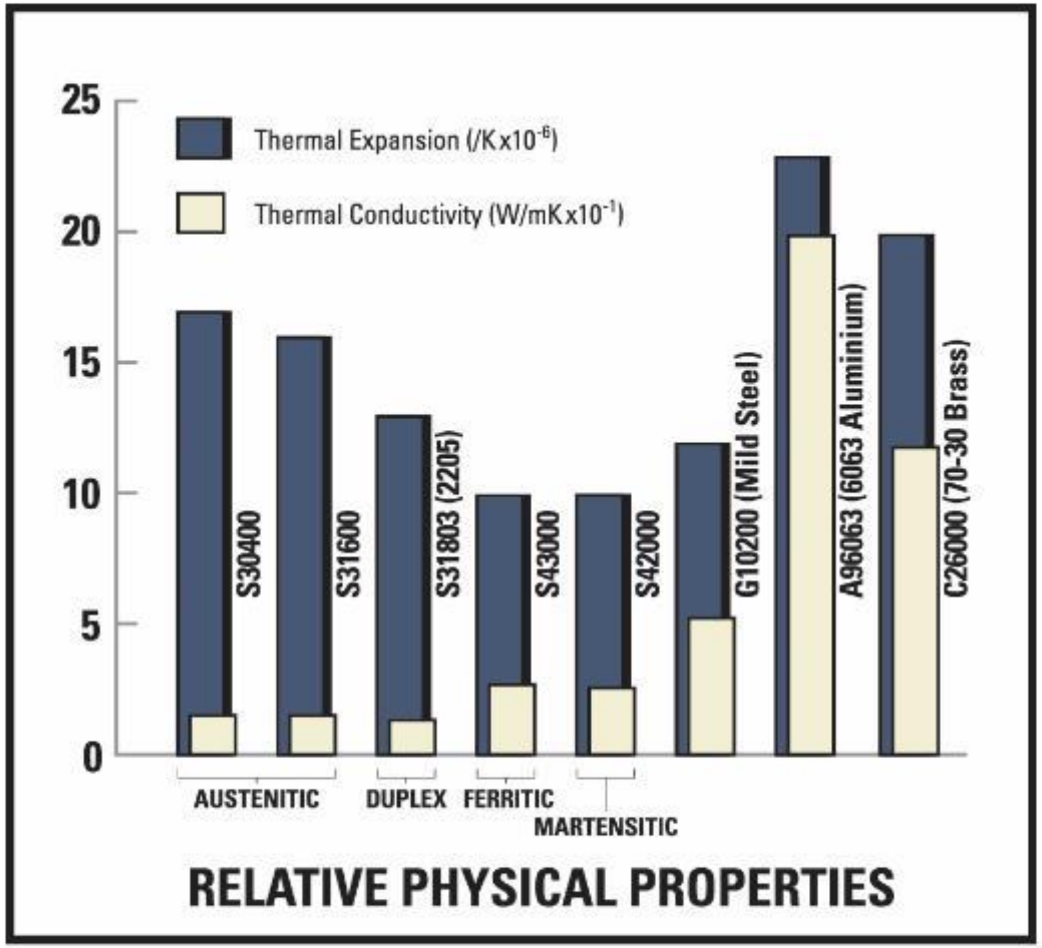
Stainless steel families

Austenitic Stainless Steels	**This group contains at least 16% chromium and 6% nickel (the basic grade 304 is referred to as 18/8**
Ferritic Stainless Steels	**Plain chromium (10.5 to 18%) grades such as Grade 430 and 409**
Duplex Stainless Steels	**Have microstructures comprising a mixture of austenite and ferrite. Duplex ferritic. Examples : 2205 and 2304**
Martensitic Stainless Steels	**Chromium as the major alloying element but with a higher carbon and generally lower chromium content (e.g. 12% in Grade 410 and 416) than the ferritic types**
PH Stainless Steels	**Chromium and nickel containing steels that can develop very high tensile strengths. The most common grade in this group is "17-4 PH"**

Reference: Azo Materials [www.azom.com]

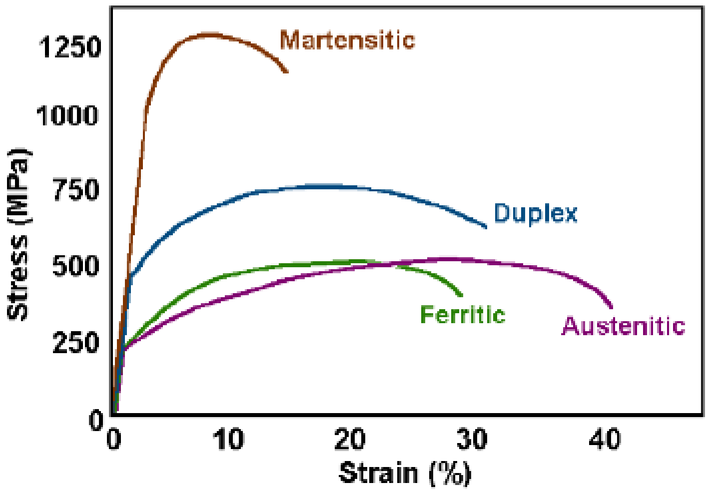
Relative Mechanical and Physical Properties of Stainless Steel

Thermal Expansion and Thermal Conductivity

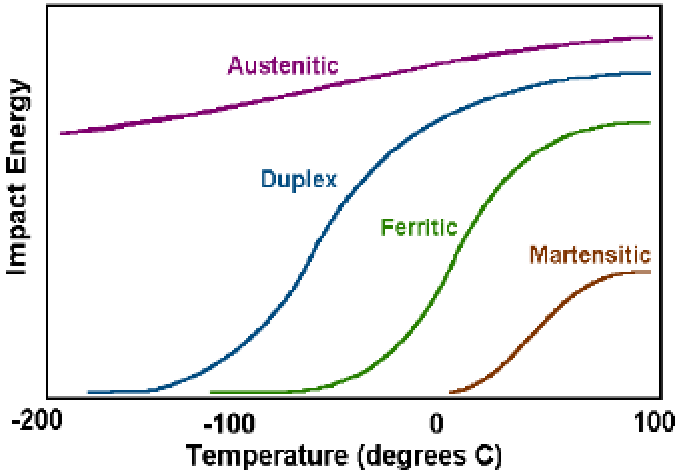


Note: These figures are approximate as there can be a wide variability in quoted results that relate to variations in the actual temperature range and the specific composition.

Typical Tensile Properties



Typical Impact Properties



Austenitic Stainless-Steel Families

- **304** General Purpose 18-8 **S30400**
  - **302B** Si added to increase scaling resistance **S30200**
  - **202** N and Mn Partly replace Ni **S20200**
  - **205** N and Mn partly replace Ni **S20500**
  - **201** N and Mn partly replace Ni **S20100**
  - **316** Mo added to increase corrosion resistance **S31600**
    - **317** More Mo and Cr added for better corrosion resistance **S31700**
      - **317L** C reduced for better welding characteristic **S31703**
        - **317LMN** Mo added N added
    - **316L** C reduced for better welded corrosion resistance **S31603**
      - **316LN** C reduced; N added to increase strength **S31653**
    - **316F** S and P added to improve machinability **S31620**
    - **316N** N added to increase strength **S31651**
  - **319 309S** Cr and Ni increased for heat resistance **S30900 S30905**
    - **310 310S** More Cr and Ni for better heat resistance **S31000 S31008**
      - **314** Si increased for highest heat resistance **S31400**
  - **308** Higher Cr and Ni used primarily for Welding **S30800**
    - **347** Nb and Ta added to oppose Cr Carbides precipitation **S34700**
      - **348** Ta and Co restricted for nuclear applications **S34800**
  - **321** Ti added to oppose Cr Carbides precipitation **S32100**
  - **302** Higher C for increased strength **S30200**
    - **304L** C reduced or further better corrosion resistance in welded parts **S30403**
      - **304N** N added to increase strength **S30451**
      - **304LN** N added to increase strength **S30453**
  - **305** Ni increased to lower work hardening **S30500**
    - **384** More Ni to lower work hardening **S38400**
      - **S304430** Cu added to improve cold working **S30430**
  - **303** S added to improve machinability **S30300**
    - **303Se** Se added for better machined surfaces **S30323**
  - **301** Cr and Ni lowered to increase work hardening **S30100**

Magnetic X
Ni √
Cr √

- Corrosion Resistance
- good mechanical properties
- Suitable for High Temp. Application
- Good toughness at low temperature

- Susceptible to Cl SCC and pitting
- Lower oxidation resistance – prone to oxide spalling

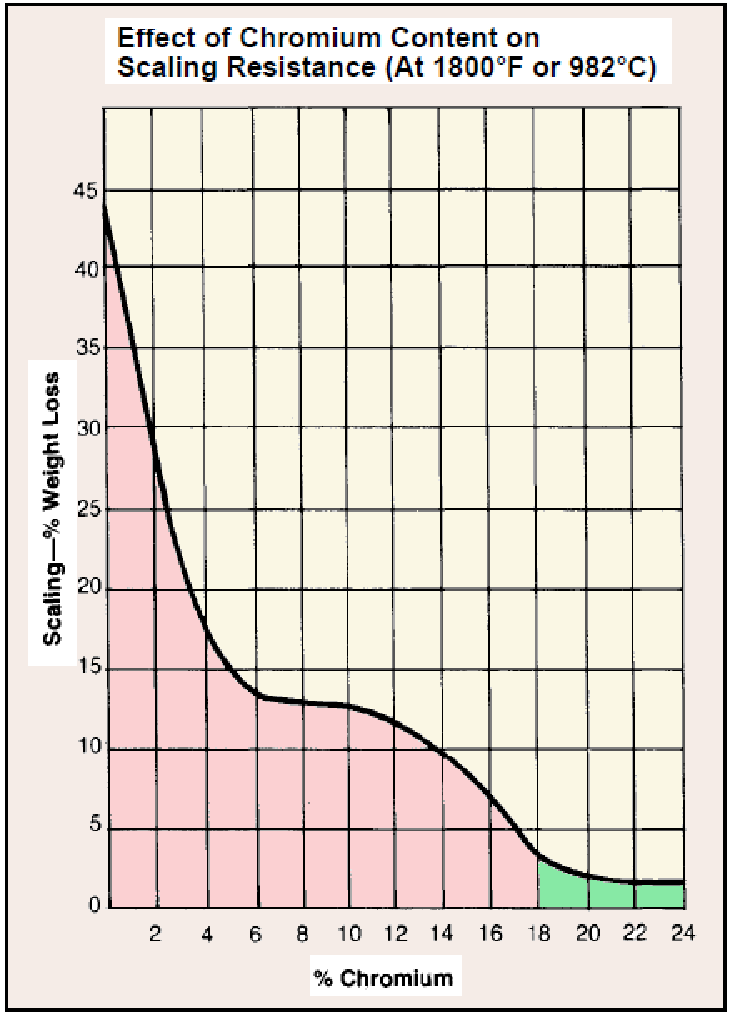
Al: Aluminum	**P:** Phosphorous
C: Carbon	**S:** Sulfur
Cr: Chromium	**Se:** Selenium
Cb: Columbium	**Si:** Silicon
Co: Cobalt	**Ta:** Tantalum
Cu: Copper	**Ti:** Titanium
Mn: Manganese	**V:** Vanadium
Mo: Molybdenum	**W:** Tungsten
N: Nitorgen	
Ni: Nickel	

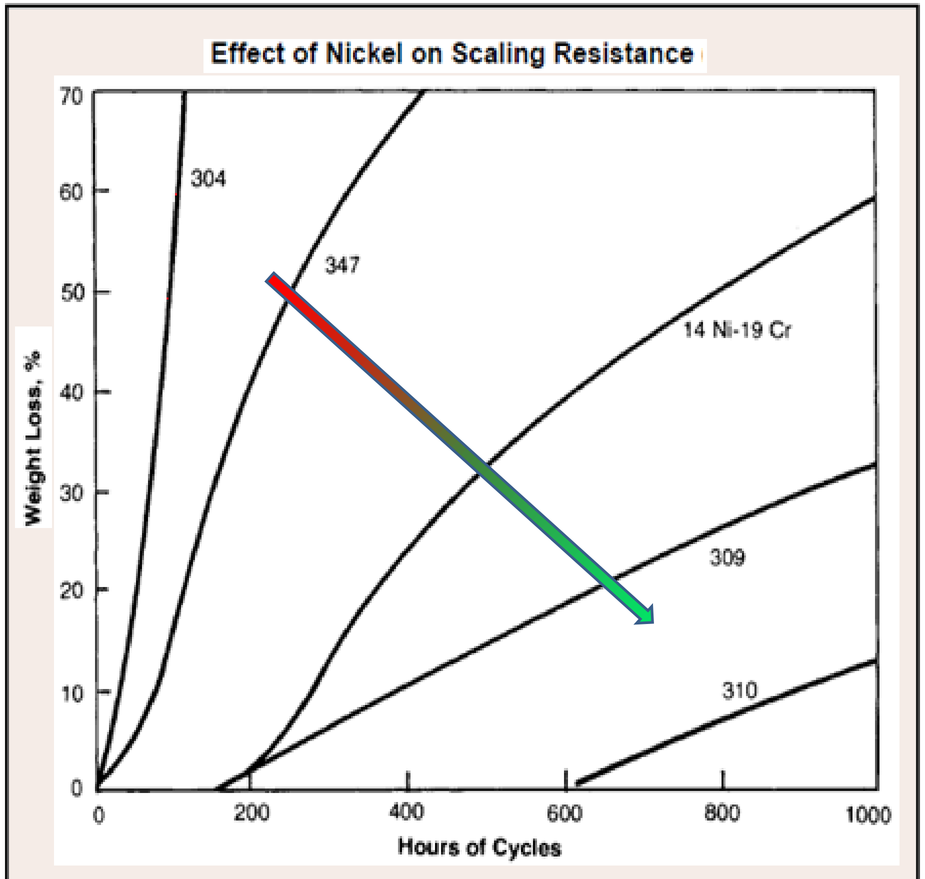
Source: ASM- Stainless Steel for Design Engineers

Austenitic Stainless-Steel Families
Scaling Resistance

Suggested Maximum Service Temperatures in Air (1)

AISI Type	Intermittent Service °C	Intermittent Service °F	Continuous Service °C	Continuous Service °F
201	815	1500	845	1550
202	815	1500	845	1550
301	840	1550	900	1650
302	870	1600	925	1700
304	870	1600	925	1700
308	925	1700	980	1800
309	980	1800	1095	2000
310	1035	1900	1150	2100
316	870	1600	925	1700
317	870	1600	925	1700
321	870	1600	925	1700
330	1035	1900	1150	2100
347	870	1600	925	1700
410	815	1500	705	1300
416	760	1400	675	1250
420	735	1350	620	1150
440	815	1500	760	1400
405	815	1500	705	1300
430	870	1600	815	1500
442	1035	1900	980	1800
446	1175	2150	1095	2000





Scaling resistance of some iron-chromium-nickel alloys in cycling-temperature conditions at 1800°F (982°C). Cycle consisted of 15 min. in the furnace and 5 min. in air. Sheet specimens 0.031 in. (0.787 mm) thick were exposed on both sides.

Source: NiDi- High Temperature Characteristics of Stainless Steels

Ferritic Stainless Steel Families

430
General Purpose
S43000

- **446** Cr increased to improve scaling resistance **S44600**
- **442** Cr increased to improve scaling resistance **S44200**
- **444** C reduced, Mo added to improve corrosion resistance; Ti and Nb added **S44400**
- **429** Slightly less Cr for better Weldability **S42900**
- **439** C reduced; Ti added to oppose carbide precipitation **S43035**
- **405** Lower CR, Al added to prevent hardening when cooled from elevated temperatures **S40500**
- **409** Lower Cr; Primarily used for automotive exhaust systems **S40900**
- **430F** P and S increased to improve machinability **S43020**
  - **430F Se** Se added for better machined surfaces **S43023**
- **434** Mo added for improved corrosion resistance in automotive trim **S43400**
  - **436** Mo, Nb and Ta added for corrosion and heat resistance **S43600**

Magnetic √
Ni X
Cr √
-Corrosion Resistance

- Not Suitable for High Temp. Application (subject to 475 embrittlement)

Al: Aluminum
C: Carbon
Cr: Chromium
Cb: Columbium
Co: Cobalt
Cu: Copper
Mn: Manganese
Mo: Molybdenum
N: Nitorgen
Ni: Nickel
P: Phosphorous
S: Sulfur
Se: Selenium
Si: Silicon
Ta: Tantalum
Ti: Titanium
V: Vanadium
W: Tungsten

Source: ASM- Alloying, Understanding the Basics

Martensitic Stainless Steel Families

410
General Purpose
S41000

431
Cr increased and Ni added for better corrosion resistance, good mechanical properties
S43100

414
Ni added for better corrosion resistance
S41400

422
Strength and toughness to 1200^{0}F via addition of Mo, V, W
S41400

403
Select quality for turbines and highly stressed parts
S40300

420
C increased to improve mechanical properties
S42000

420F
P and S increased to improve machinability
S42020

416
P and S increased to improve machinability
S41600

416Se
Se added for better machined surfaces
S41623

440C
C increased for highest hardness; Cr increased for corrosion resistance
S44004

440B
C decreased slightly to improve toughness
S44004

440A
C decreased even more than for 440B to improve toughness
S44002

Magnetic √
Ni X
Cr √
-Corrosion Resistance
- Hardenable

- Hard to weld

Al: Aluminum
C: Carbon
Cr: Chromium
Cb: Columbium
Co: Cobalt
Cu: Copper
Mn: Manganese
Mo: Molybdenum
N: Nitorgen
Ni: Nickel
P: Phosphorous
S: Sulfur
Se: Selenium
Si: Silicon
Ta: Tantalum
Ti: Titanium
V: Vanadium
W: Tungsten

Source: ASM- Alloying, Understanding the Basics

Duplex Stainless Steel Families

Duplex Stainless Steel
50/50
Austenite / Ferrite

Lean DSS
Lower Ni, no Mo
- S32101
- S32202
- S32304
- S32003
- S82011
- S82441

Standard DSS
Higher Ni, and Mo
- S31803
- S2205

Super DSS
25 Cr and higher Ni, and Mo
- S32520
- S32550
- S32750
- S32760
- S82906

Hyper DSS
More Cr, Ni Ni, Mo and N
- S32707

Magnetic √
Ni √
Cr √

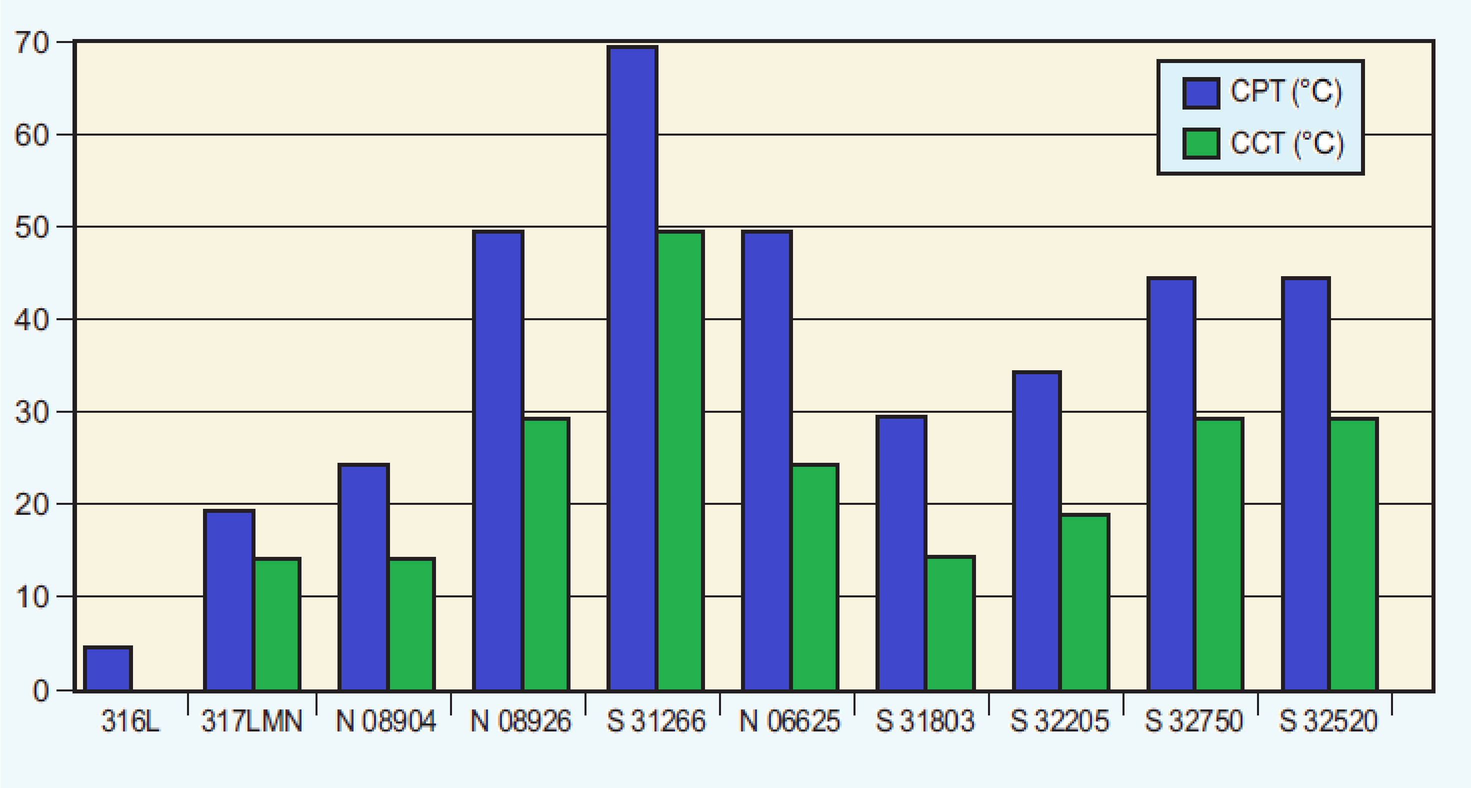
-Corrosion Resistance
- Pitting resistance in Cl service (High PREN)
- High strength

- Not suitable for High T applications (subject to 475 embrittlement)

Al: Aluminum
C: Carbon
Cr: Chromium
Cb: Columbium
Co: Cobalt
Cu: Copper
Mn: Manganese
Mo: Molybdenum
N: Nitorgen
Ni: Nickel
P: Phosphorous
S: Sulfur
Se: Selenium
Si: Silicon
Ta: Tantalum
Ti: Titanium
V: Vanadium
W: Tungsten

Source: API 938C, Use of DSS in Oil Refinery Industry

Duplex Stainless Steel Families



PREN = %Cr + 3.3Mo + 16N

PREN: % Cr + 3.3 × (% Mo + 0.5 × % W) + 16 % N

Grade	PREN
304L	19
316L	24
2205 S3205	35
2507 S32750	43

PREN: Pitting Resistance Equivalent Number
CPT : Critical Pitting Resistance Temperature
CCT : Critical Crevice Corrosion Resistance

Is standard DSS more resistance to pitting than 316L ?

a. YES
b. NO

Source: API 938C, Use of DSS in Oil Refinery Industry

Duplex Stainless Steel Families

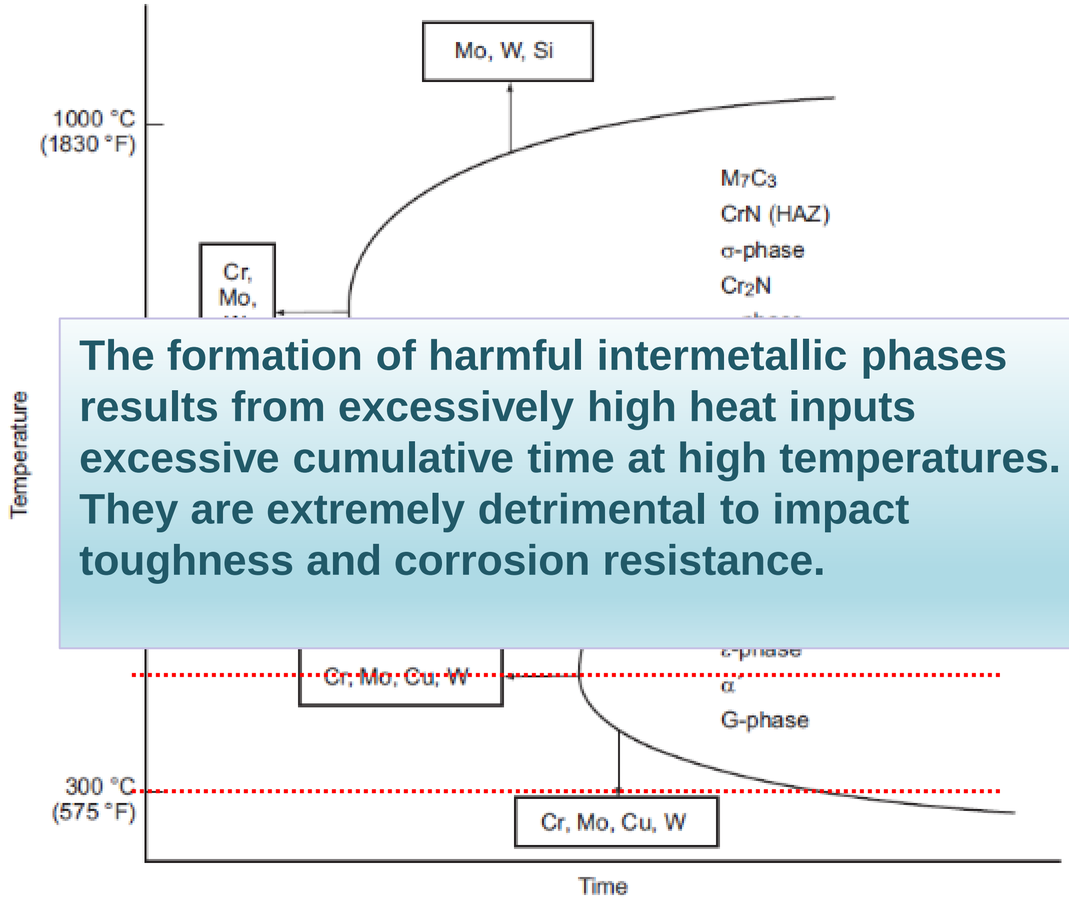
Table 5—ASME Code Maximum Allowable Temperatures

Grade	ASME Section VIII (Div. 1) °C (°F)	ASME B31.3 °C (°F)
S32304	316 (600)	316 (600)
S32101	316 (600) Code Case 2418	NL
S32202	316 (600)	NL
S32003	343 (650) Code Case 2503	343 (650)
S32906	316 (600)	NL
S32707	260 (500) Code Case 2586	NL

NOTE 1 NL = not listed.

NOTE 2 S32205 can use the design allowables for S31803 if the material is dual-certified.

Maximum operating temperatures are limited by the susceptibility of the ferritic phase to 475 °C (885 °F) embrittlement.
Most Codes applicable to refinery equipment and piping limit the various DSS grades to between 260 °C to 340 °C (500 °F to 650 °F)



The formation of harmful intermetallic phases results from excessively high heat inputs excessive cumulative time at high temperatures. They are extremely detrimental to impact toughness and corrosion resistance.

A vessel in a service suffers from pitting corrosion at 350 ºC, can be fabricated from super duplex SS as it has high pitting resistance ?

a. YES

b. NO

Source: API 938C, Use of DSS in Oil Refinery Industry

Precipitation hardening stainless steel (PHSS) family

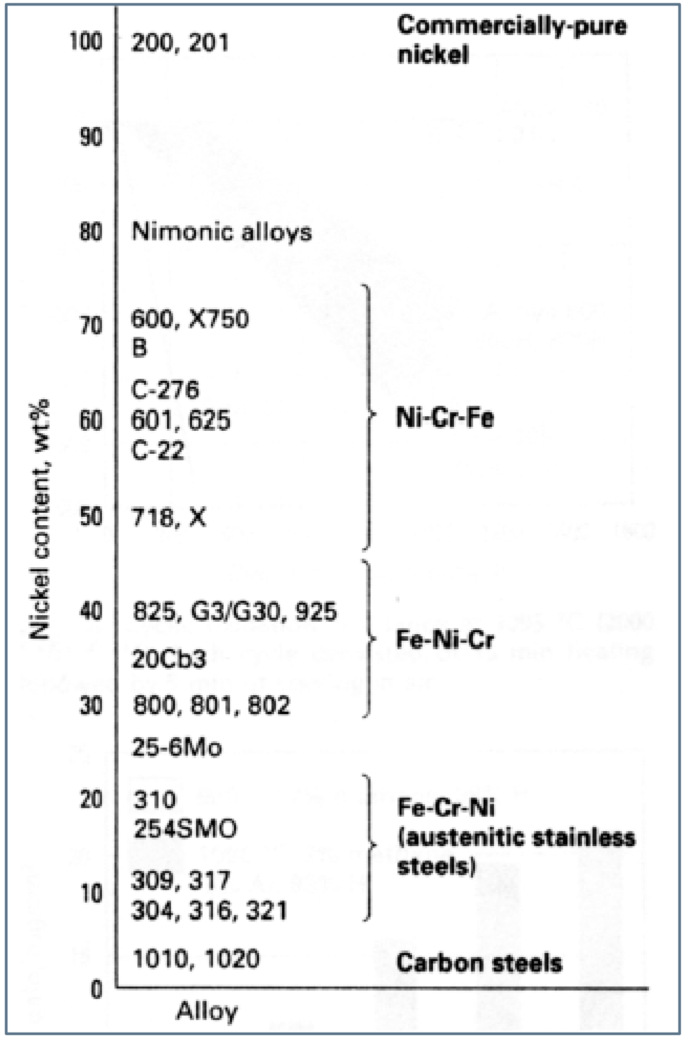
PHSS are typically based on iron, chromium and nickel with one or more of the following elements copper, aluminum, titanium, niobium and molybdenum.

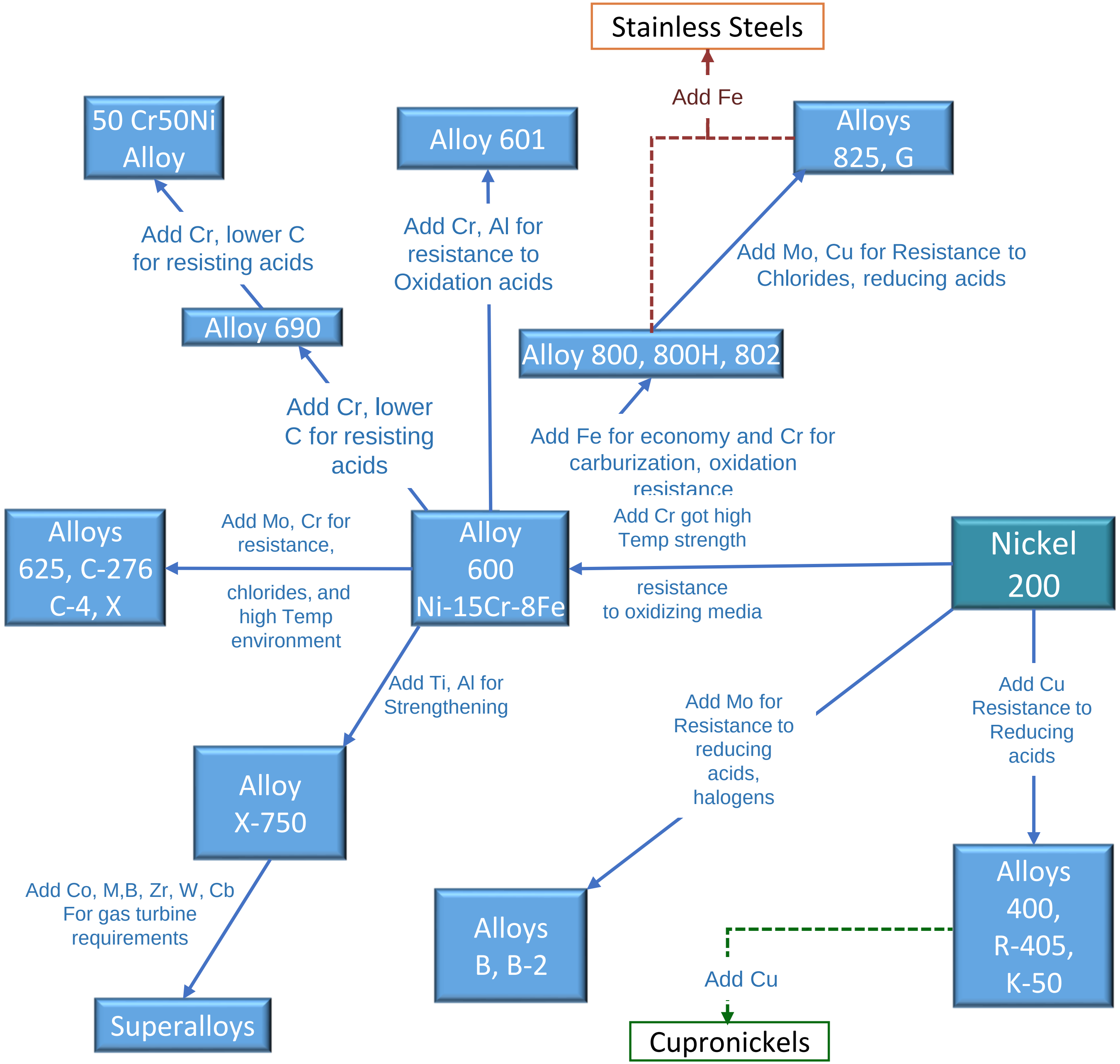
The precipitation strengthening is then performed by a final tempering treatment

Alloy	UNS No.	Composition, %								
		C	Mn	Si	Cr	Ni	Mo	Cu	Ti	Other
Martensitic										
PH 13-8 Mo	S13800	0.05	0.10	0.10	12.8	8.0	2.3			Al=1.1
15-5PH	S15500	0.07	1.0	1.0	14.8	4.5	-	3.5		Nb=0.3
17-4PH	S17400	0.09	1.0	1.0	16.3	4.0	-	4.0		Nb=0.3
Semi-austenitic										
PH15-7Mo	S15700	0.09	1.0	1.0	15.0	7.1	2.5	-	-	Al=1.1
17-7PH	S17700	0.08	0.9	0.5	16.5	7.5	-			Al=1.0
Austenitic										
A-286	S66286	0.08	2.0	1.0	15.0	25.5	1.25	-	-	Ti: 2.1 Al: ≤0.35 V: 0.3

Reference: Sandvic – Precipitation hardening stainless steel

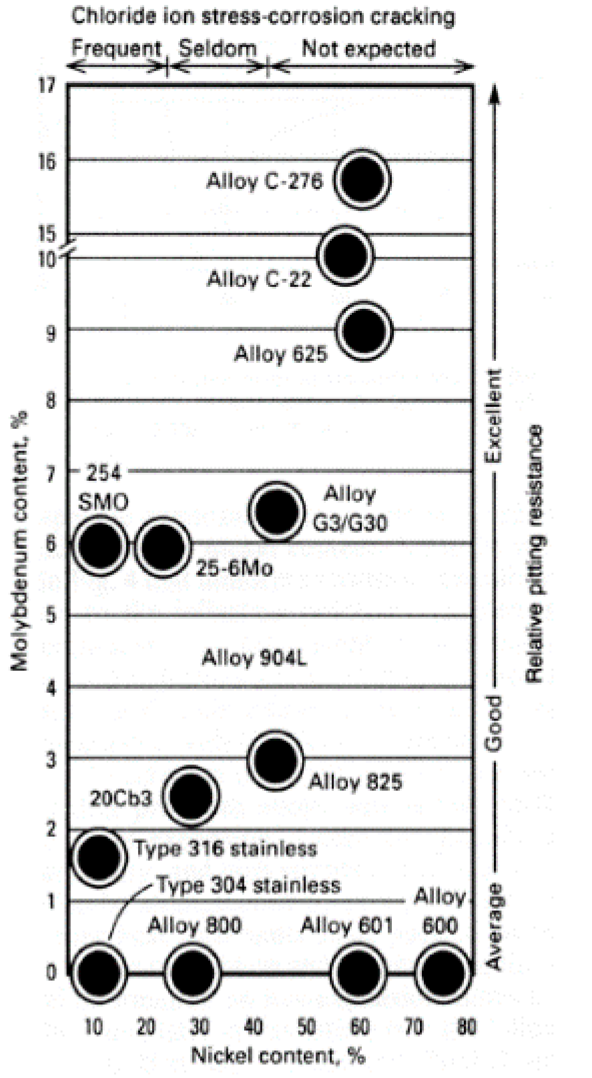
Nickel Alloys

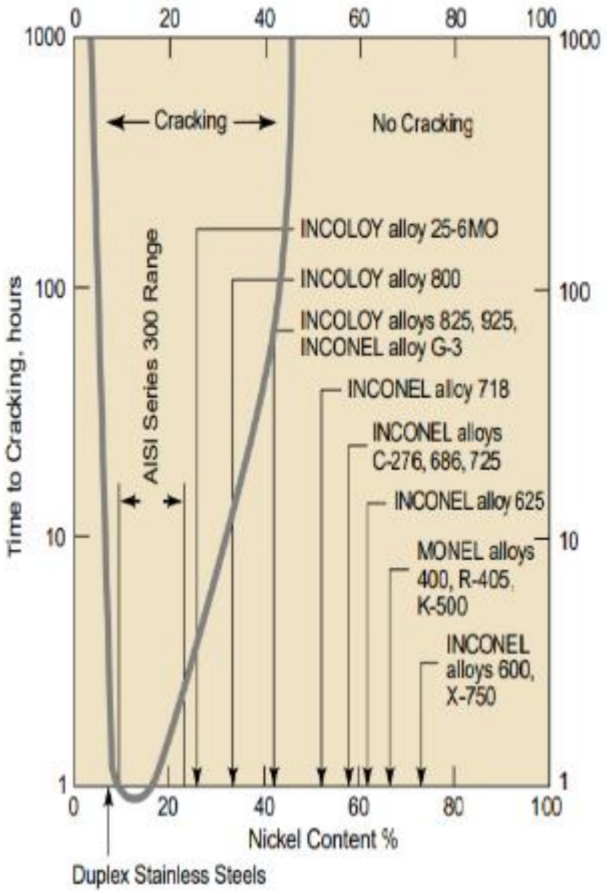




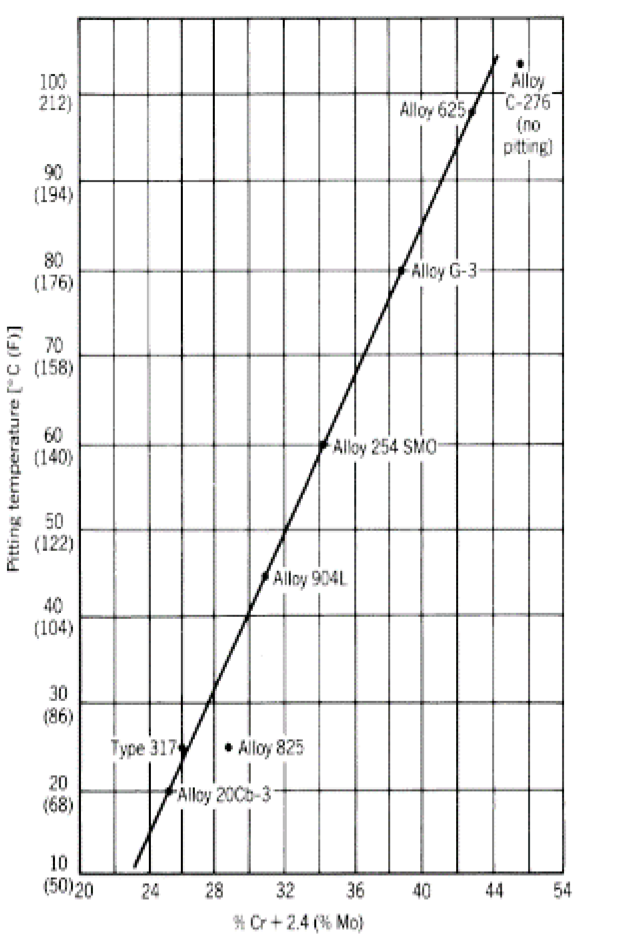
Source: ASM Corrosion of Weldments

Nickel Alloys





Copson Curve - Effect of Ni content on SCC susceptibility of SS wires containing 18-20% Cr in Mg Cl solution boiling at 154 C



Critical temperature for pitting in 4% NaCl + 1%$Fe_2(SO_4)_3$ + 0.01 M HCL versus composition for Fe-Ni-Cr-Mo alloys

High Ni contents (about 50%) would be required for resistance to chloride SCC.

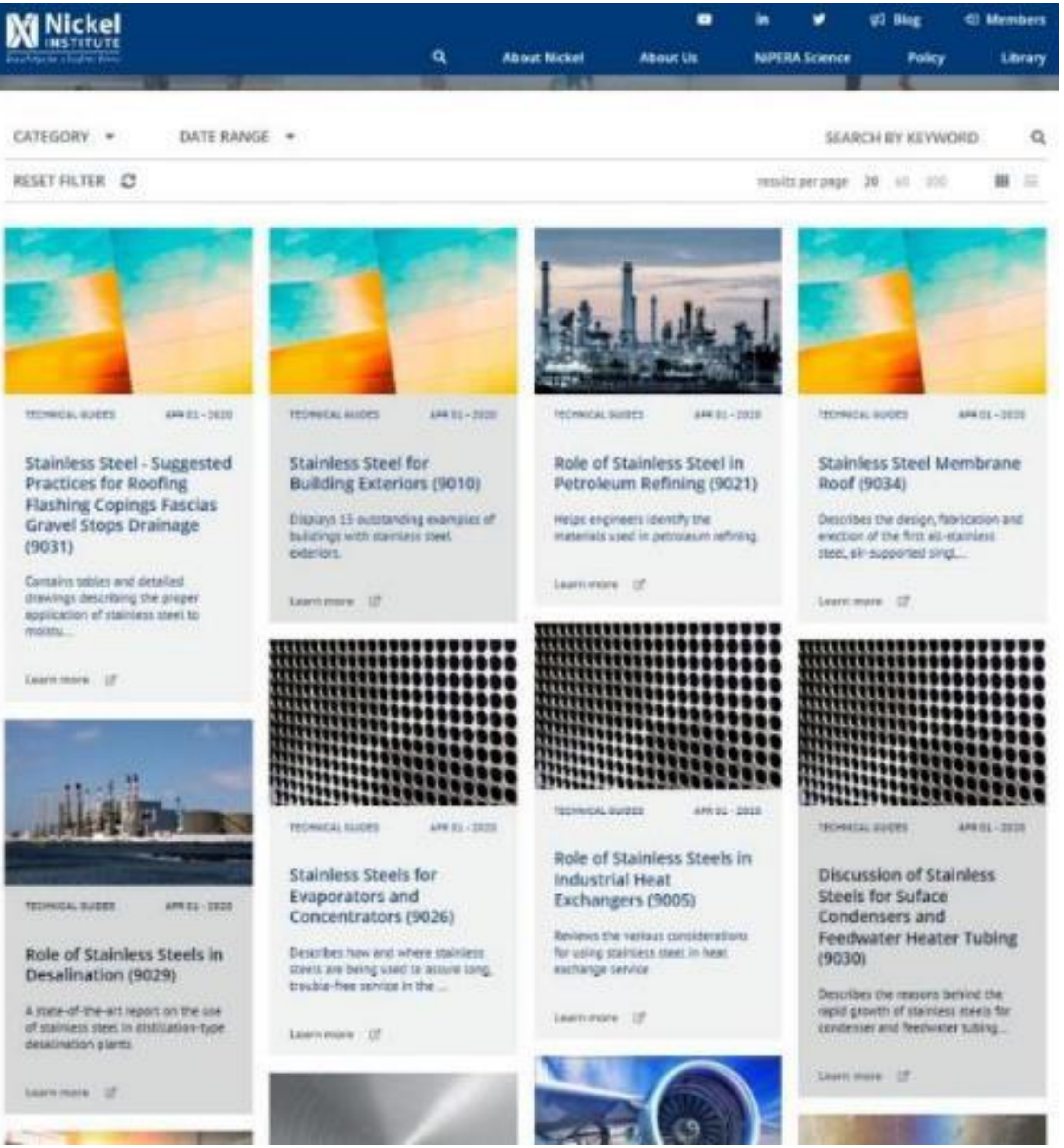
SCC is not usually observed at nickel contents at or above 42%.

Cr and Mo has a very good relationship to enhance critical pitting temperature in a salt solution.

PREN: % Cr + 3.3 (% Mo + 0.5 × % W) + 16 % N

Reference: ASM – Material Selection handbook
ASM Stress Corrosion Cracking

Recommended Readings for SS and Nickel Alloys



Recommended Readings for SS and Ni Alloys

Nickel INSTITUTE

knowledge for a brighter future

https://www.nickelinstitute.org/library

Materials Applications

Static Equipment Awareness

Part03: Materials Selection

Baher Elsheikh

Materials Application – Carbon Steel

Carbon Steel is widely used in oil and gas industry mainly due to its cost, availability and easy fabrication and welding.

Limitations:

Low corrosion resistance in many applications

Limitations in low temperature < -29 C.   Carbon Steel loose toughness

High Temperature: > 425 C . CS low creep strength, high oxidation rate, and susceptibility to carburization

Susceptible to FAC in condensate service

Materials Application – Low Alloy Cr-Mo Steel

Low alloy Chromium Molybdenum (Cr-Mo) Steels are replacing the Carbon steels as a candidate material where:

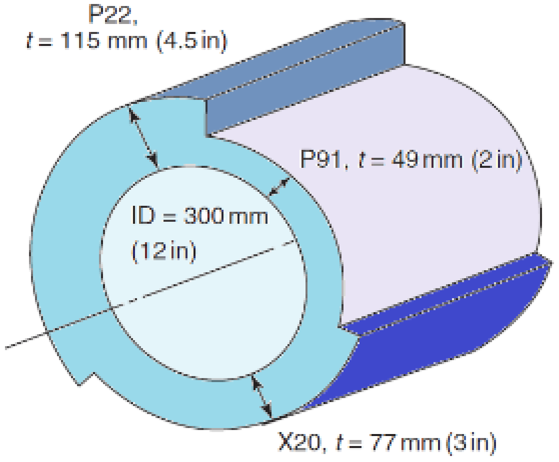
- Temperature is higher than the maximum limits of carbon steels

- In application where Hydrogen is present at relative high temperature and partial pressure to resist High Temperature Hydrogen Attack (HTHA)

Common Grades:

- P11 (1.25 Cr- 0.5 Mo)
- P22 (2.5 Cr – 0.5 Mo)
- P5 (5 Cr- 0.5 Mo)
- P91 (9 Cr- 1 Mo)

Note: Cr-Mo steel is usually require application of Post Weld Heat Treatment (PWHT) during fabrication or repair, which sometimes are difficult to apply at site



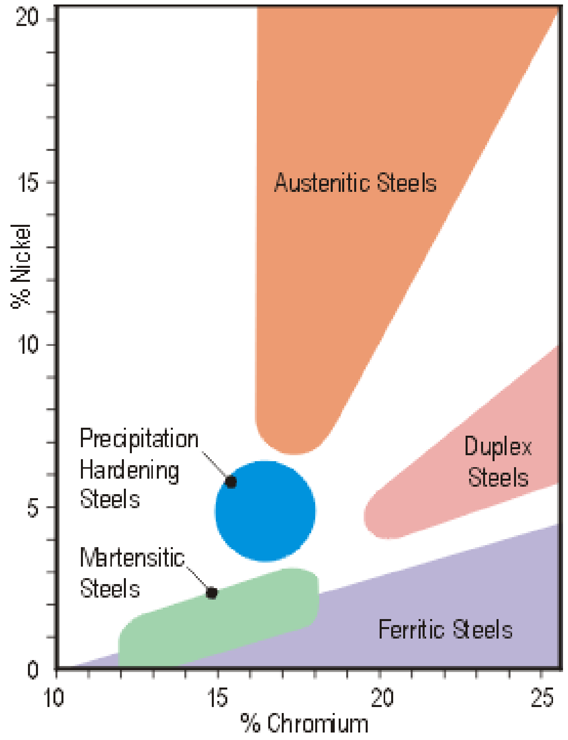
Steam Pipe temperature 600 °C, pressure 30MPa

Materials Application – Stainless Steel

Stainless steels is a material of Cr > 11 % where Cr formed the distinguishing surface oxide layer of the stainless steels.

Austenitic stainless steels is applied widely where:	Higher Corrosion resistance is required
	Temperature is higher than the maximum limits of Cr-Mo Steels
	Temperature is lower than the lower limit of CS to avoid brittle fracture and toughness loss

A main concern of austenitic SS is the susceptibility to pitting and cracking in Cl services, Where DSS is preferred for this aspect



Duplex and ferretic stainless steels limited for Temp. <=316 C to avoid 475 C (885 F) embrittlement

Materials Application – Nickel Based Alloys

Ni Based alloys (Incoloy, Inconel, Monel,…..) are replacing Stainless steels when:

- Higher Corrosion resistance is required
- Temperature is higher than the maximum limits of stainless Steels (oxidation, metal dusting, Nitriding, carburization,..)

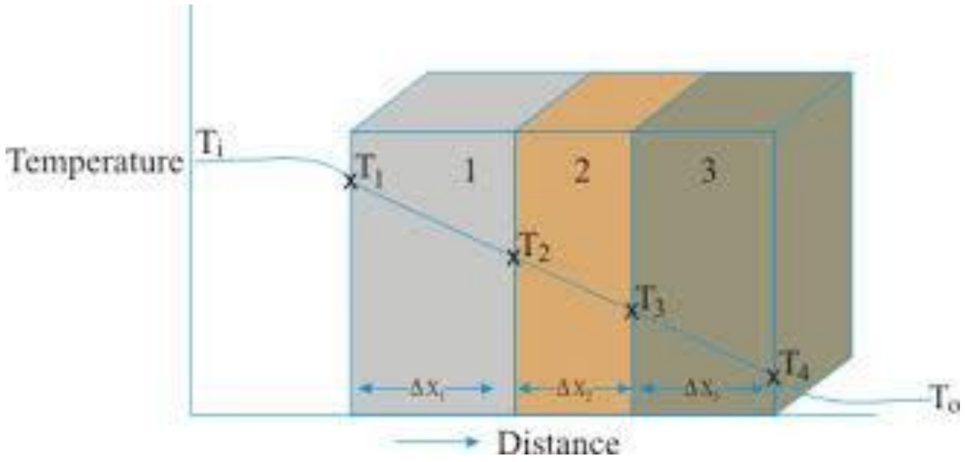
Ni Alloys are of much higher cost compared to stainless steels which limits its application.

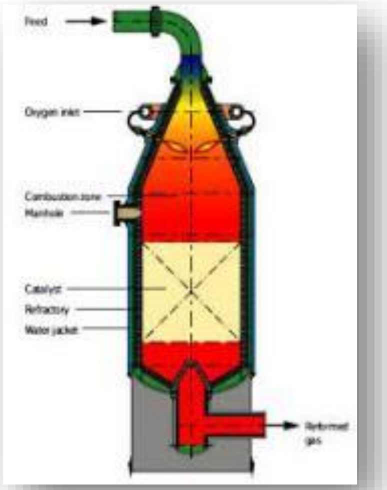
Alloys with Ni >42% is almost immune for chloride SCC.

Alloy 825 (42% Ni) is often specified for applications requiring resistance to chloride SCC.

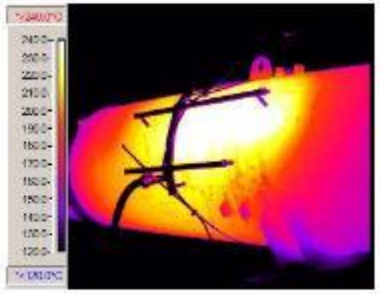
Materials Application – Refractory Lined

Refractory lining is applied where the metals cannot withstand the operating temperature and / or to reduce the cost of the equipment by using lower design temperature and hence lower material grade

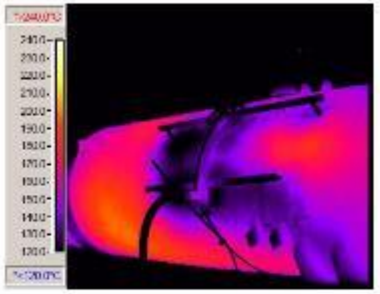




Hot Spots due to degradation of refractory or quality issues once occurred, damage of the metallic enclosure can be very fast with potential catastrophe failure



Piping Hot Spot: Steam Cooling Off



Piping Hot Spot: Steam Cooling On

Materials Application – Non Metallic Piping and Vessels

Non metallic materials include wide range of different materials like: FRP, PVC, PE, Cement, lined equipment

Usually applied where corrosion resistance is required

Limited in temperature application

Special precautions (Protection from UV, vent holes for PTFE lined, ……..)

Preferred application for underground piping to have good corrosion resistance without need of Cathodic Protection

Industrial Challenges

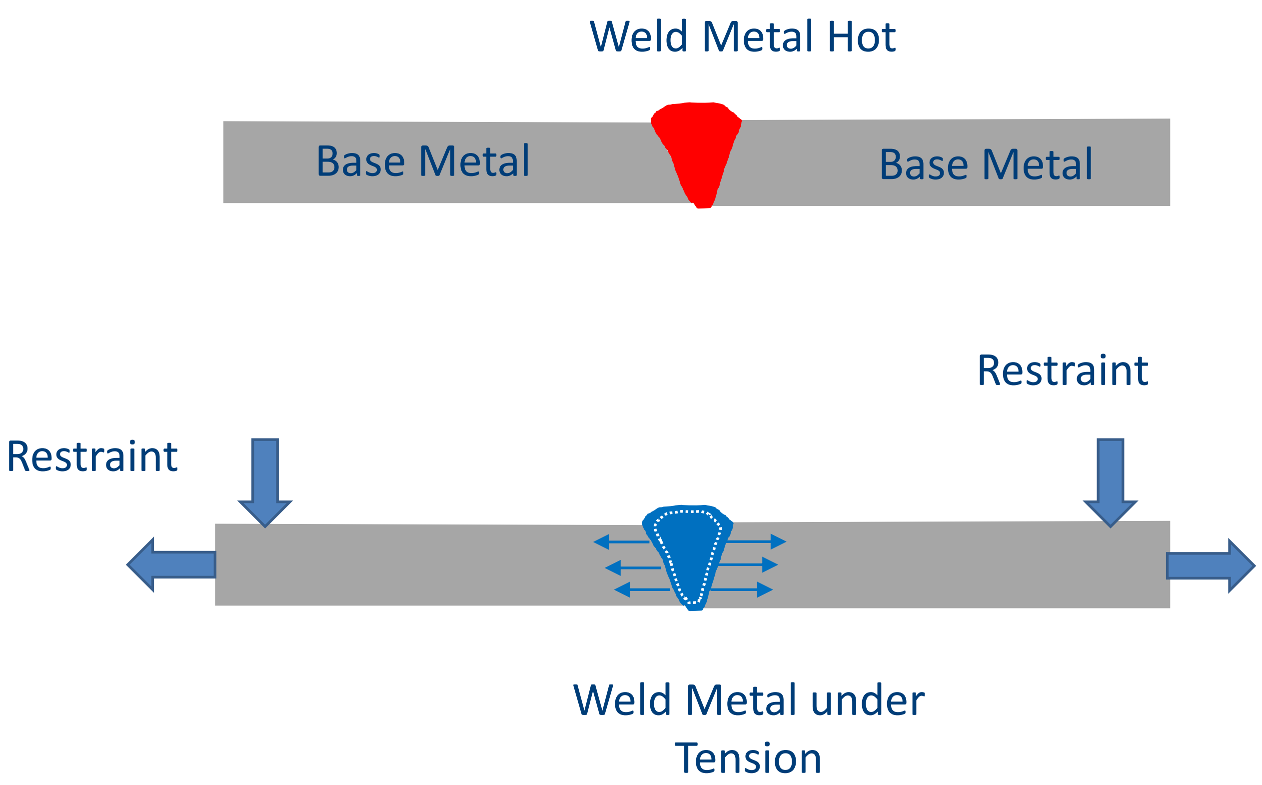
Static Equipment Awareness

Part03: Materials Selection

Baher Elsheikh

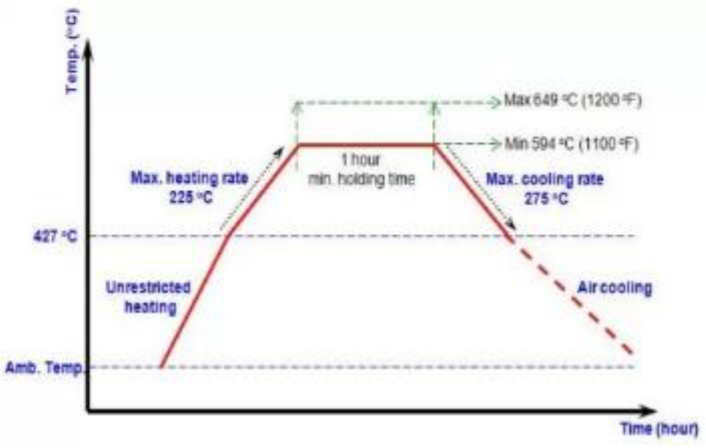
Post Weld Heat Treatment [PWHT]

- When weld is applied it is molten metal and thermally expanded when filling a groove.
- When weld metal cools, it will shrink a lot. Yield Strength is low for much of the cooling range.
- Surrounding metal that was not heated to molten temperatures will constrain or keep the weld from shrinking as it cools.
- Post Weld Heat Treatment is a procedure to reduce residual stress, temper the HAZ, and remove hydrogen from the weld region after a seam weld is made.



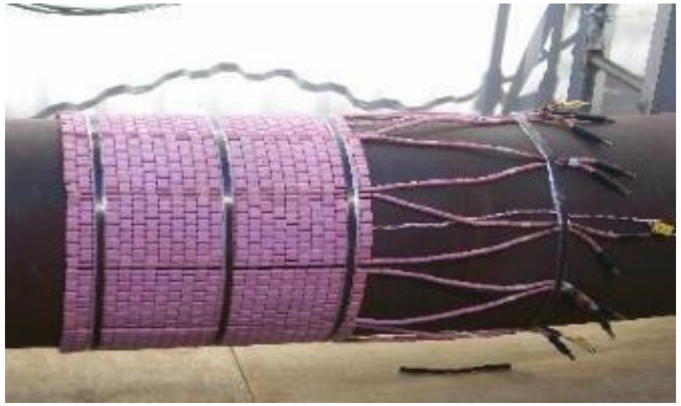
Post Weld Heat Treatment [PWHT]

- Weld and HAZ heated below the transition temperature for several hours and then gradually allowed to cool.
- Can Global (entire vessel)
- Can be Local (weld seam and surrounding metal



Rule of thumb

- Hold at temperature for 1 hour per inch of plate thickness
- Minimum duration of 30 minutes



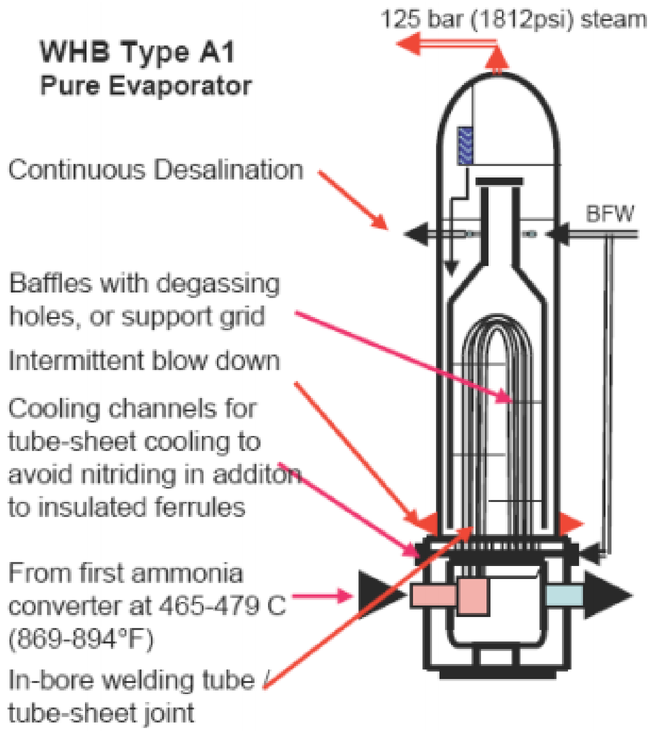
Oxidation scale generated during Post Weld Heat Treatment can cause in-service failure

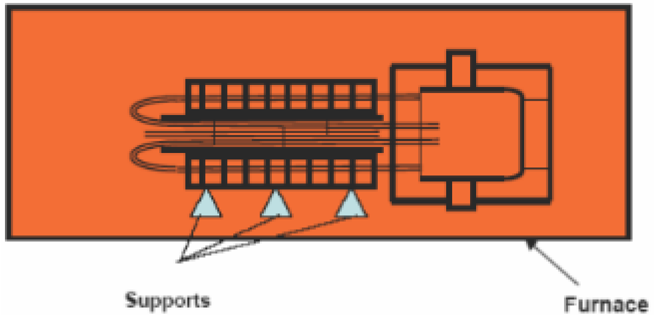
Case Histories In WHBs in ammonia plant doing the PWHT for the full equipment in a furnace caused high scales on the tubes which thought to be a major contributing factor for experienced immature failure

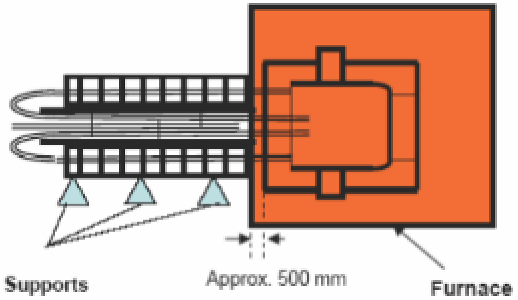
The material of the tubes and the tube-sheet is 2 ¼ Cr steel due to hydrogen partial pressure requirements as per API 941, requiring a post weld heat treatment (PWHT).

suspicion that oxide layers formed during PWHT of the boilers would not be removed by the boil-out procedure and could cause damages in boiler.

PWHT to be performed on Channel assembly only, or in a furnae with the bundle under Nitrogen atmosphere

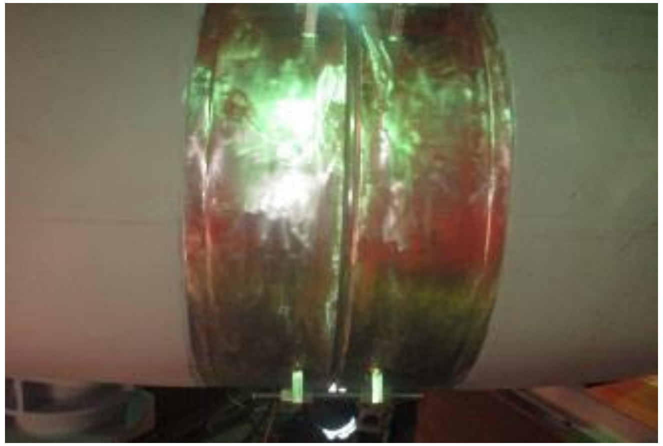






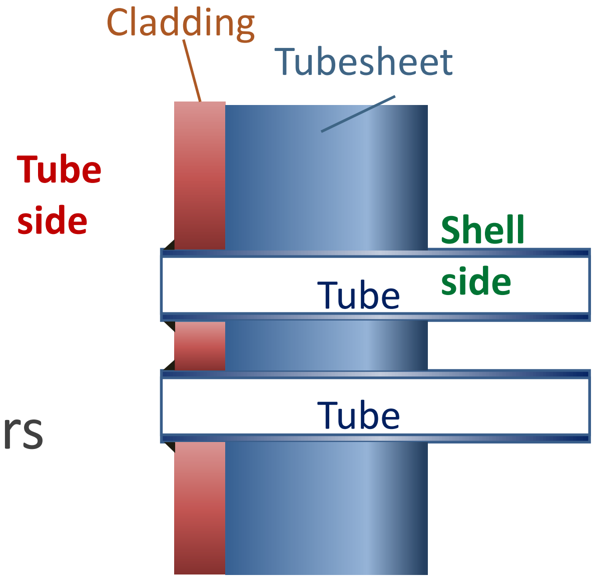
Reference: Failures in Ammonia Plant Vertical Waste Heat Boilers Potential Causes & Remedies, Pan Orphanides and Reinhard Michel - 2008

Practical ideas to avoid filed PWHT and enhance maintainability and in service repair

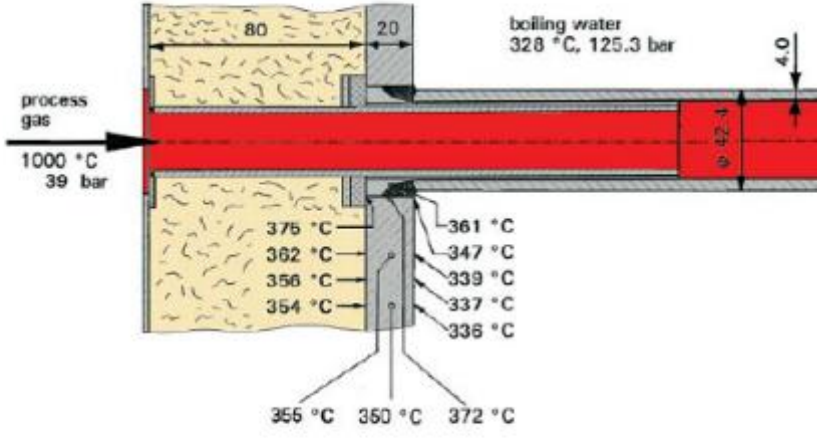


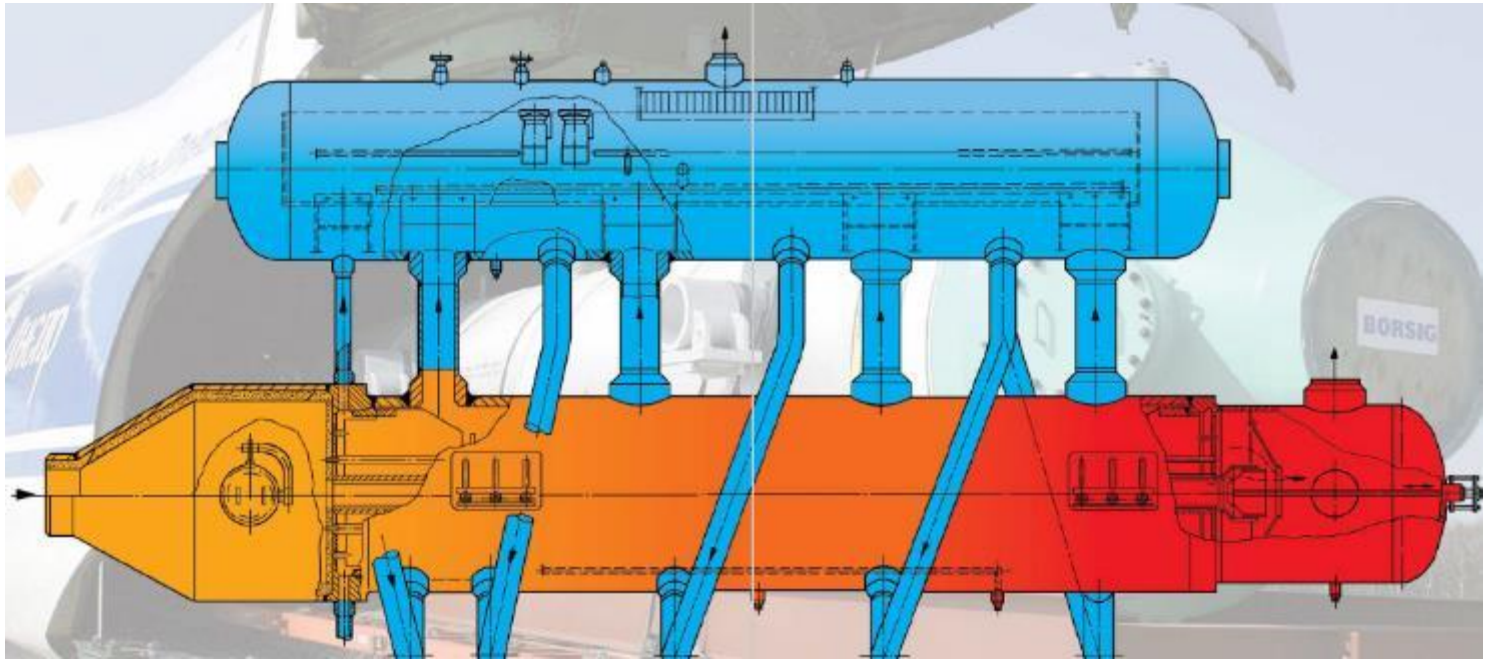
Weld transition piece of alloys doesn't require non PWHT alloys

Cladding / Weld overlay of tubesheet in shell and tube heat exchangers

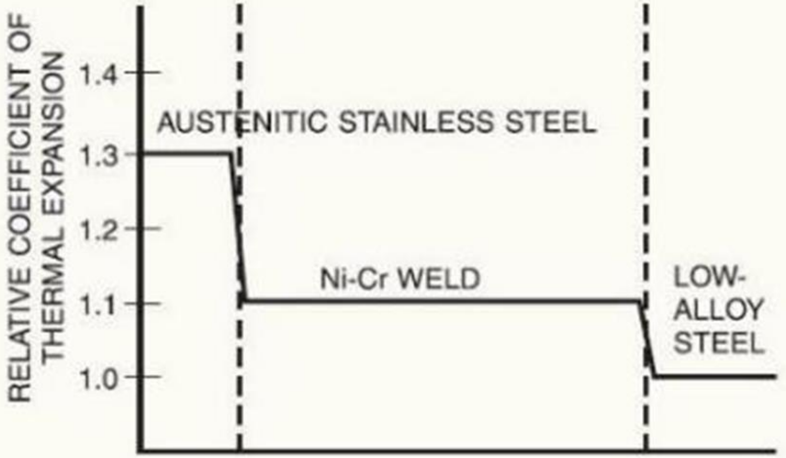


Inconel Ferrules used in WHBs (RGB) to withstand the inlet high gas temperature ~1000 ^{o}C and the tube material to be of low alloy steel

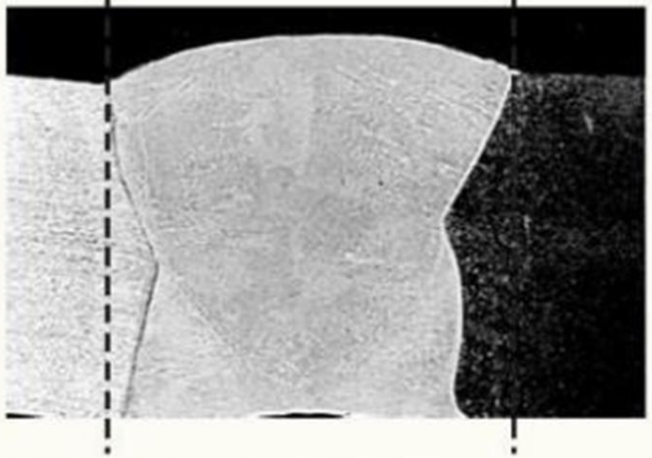




Dissimilar Metal Weld [DMW]



(A) Relative Expressions



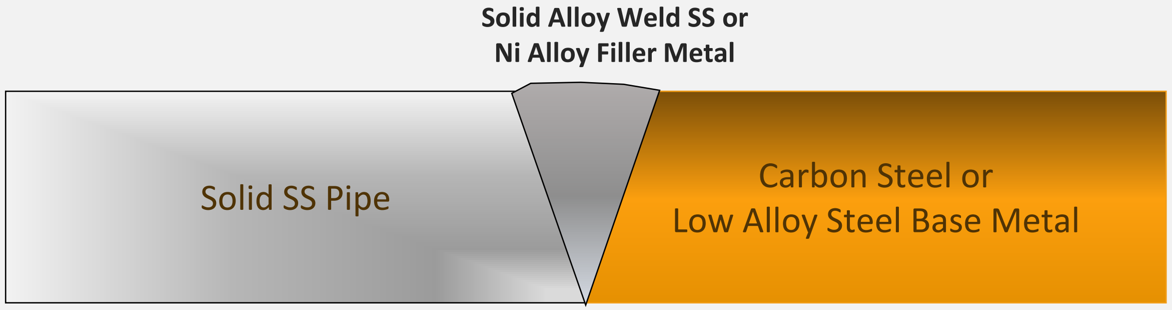
(B) Joint Between Type 304 Stainless Steel (Left) and 2-1/4Cr-1Mo (Right) Welded with ERNiCr-3 Filler Metal

Note: Values shown in (A) represent ratio comparisons to carbon steel (as in Table 6.2), not actual values of properties.

Table 6.2
Relationship of Physical Properties of Various Base Metals to Those of Carbon Steel

Relative Property	Ratio of Properties[a]					
	Carbon Steel	Copper	Aluminum	Austenitic Stainless Steel	70Ni-30Cu	76Ni-16Cr-8Fe
Mean coefficient of thermal expansion[b]	1.0	1.4	1.9	1.3	1.2	1.1
Thermal conductivity	1.0	7.8	3.1	0.3	0.5	0.3
Heat capacity	1.0	0.8	1.9	1.0	1.1	0.9
Density	1.0	1.1	0.3	1.0	1.1	1.1
Melting temperature	1.0	0.7	0.4	0.9	0.9	0.9

a. Values shown represent ratio comparisons to carbon steel, not actual property values.
b. From room temperature to 260°C (500°F).



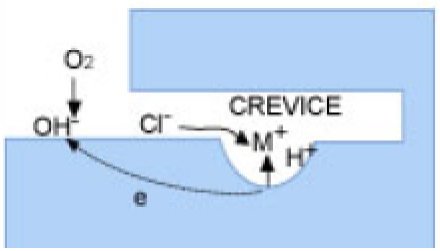
Solid Stainless Steel Pipe (Left) Welded to Ferritic Steel

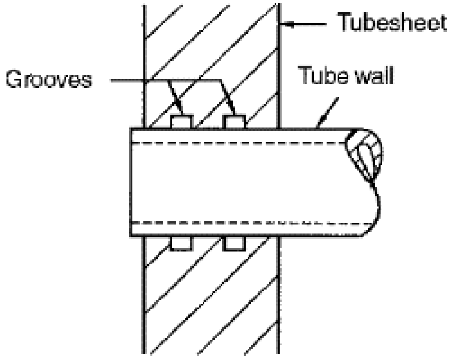
References: AWS – Welding Handbook, Volume 4 Part 1
API 571

Unrecognized Contamination

Austenitic Stainless Steel is highly sensitive to chloride especially at relative high temperature >60 C

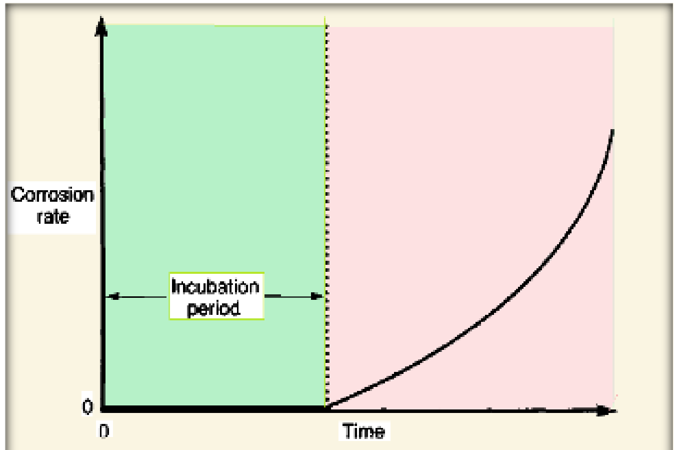
Crevice Corrosion is an intense localized corrosion frequently occurs within crevices and other shielded areas on metal surfaces exposed to corrosives. This type of attack is usually associated with small volumes of stagnant solution caused by holes, gasket surfaces, lap joints, surface deposits, and crevices under bolt and rivet heads





Control

- Redesign of equipment to eliminate crevices.
- Close crevices with non-absorbent materials or incorporate a barrier to prevent of moisture penetration into crevice.
- Prevent or remove builds-up of scale or solids on surface.
- Use of one-piece or welded construction versus bolting or riveting.
- Select more corrosion resistant or inert alloy



Schematic representation of corrosion rate as a function of time in a crevice in stainless steel exposed to chloride-containing water. The time before corrosion initiation is called the incubation period.

Reference: NALCO Guide to Cooling Water System Failure Analysis

Industries Special Requirements

Corrosion from ammonium carbamate—an intermediate product formed during the conversion of NH_3 and CO_2 to urea—is a major problem. The intensity of corrosion is greatest in the reaction section and the first recycle, where pressures, temperatures and concentrations are higher than downstream.

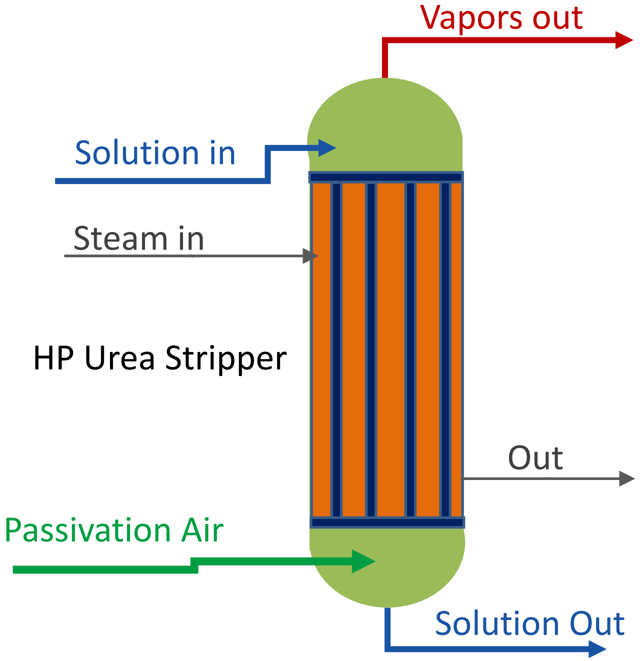
HP equipment in Urea plants are lined by either 316L Urea grade or 310 Urea grade (25-22-2). Urea grade materials should have very low ferrite content and should subject to Intergranular Corrosion Testing.

Material	C (max)	Cr	Ni	Mo	Mn	P	Si
316L	0.03	16-18	10-14	2-3	2	0.045	1
316L UG	0.03	18	13.5	2.6	2	0.045	0.5

Material	C (max)	Cr	Ni	Mo	Mn	P	Si
310S	0.08	24-26	19-22	0.2	2	0.045	1
310LMoN	0.02	25-26	22-23	2-2.5	2	0.045	0.7

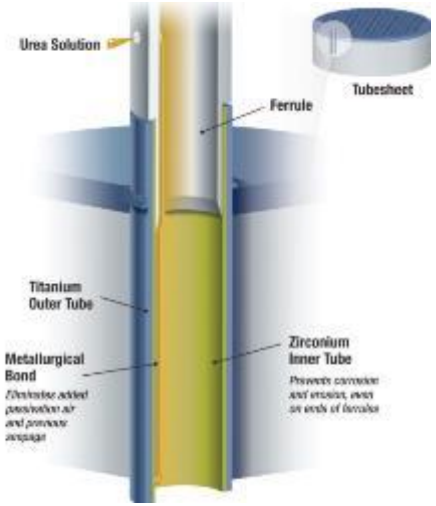
Industries Special Requirements

Leak of tube to tubesheet joints in carbamate service can in hours cause sever attack to the carbon steel base metal



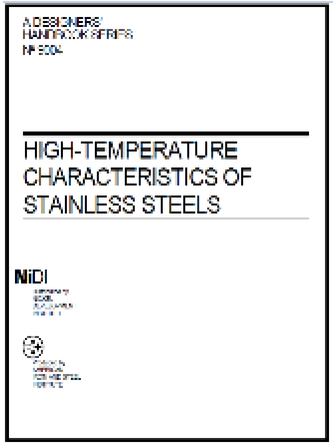
Even with special alloys, in Urea Reactor and HP Stripper, continuous passivation air must be injected otherwise corrosion rate will be high. Although ow the risk of flammability of gas mixture.

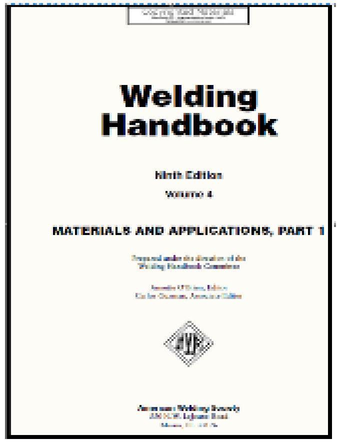
Materials specialists and licensors are continually working on developing materials of higher corrosion resistance, less need of passivation air and longer lifetime

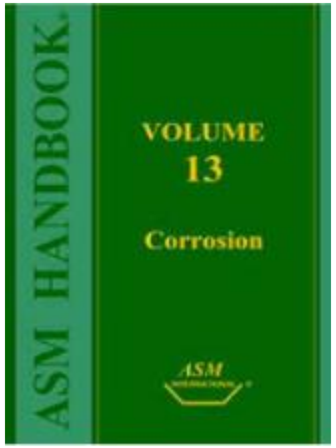


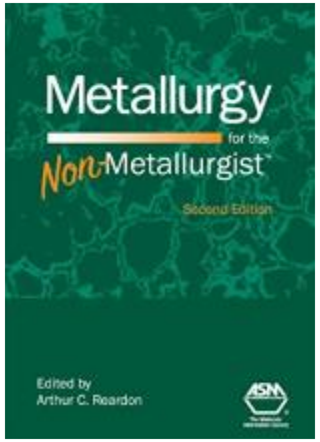
The urea stripper strips out vapors (In the form of Ammonia and Carbon dioxide) from Urea solution.

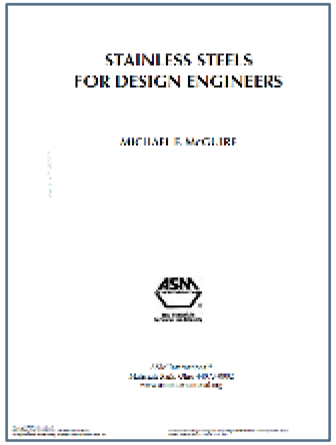
https://www.nickelinstitute.org/library

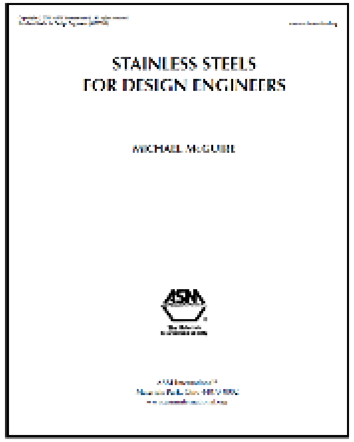


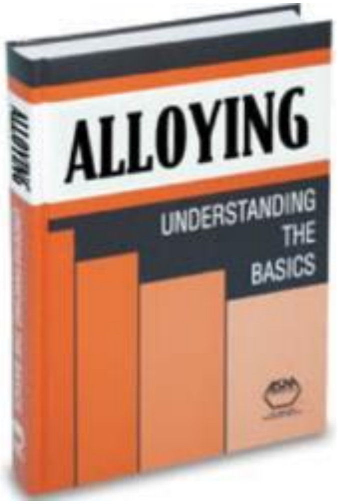


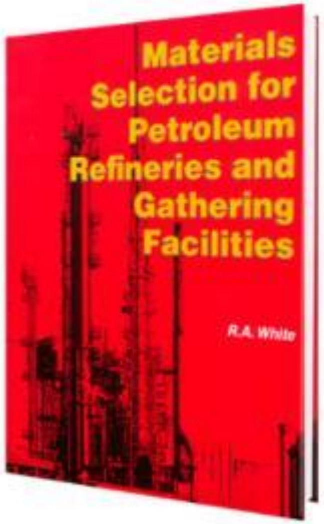


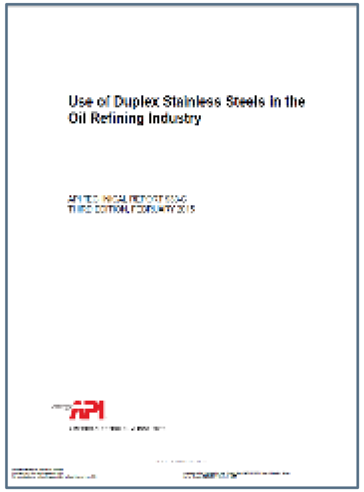


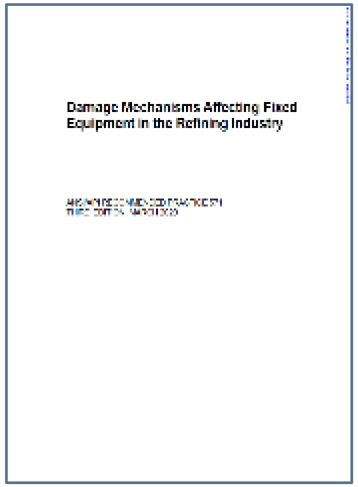


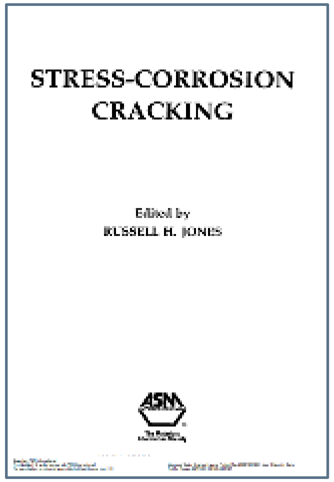


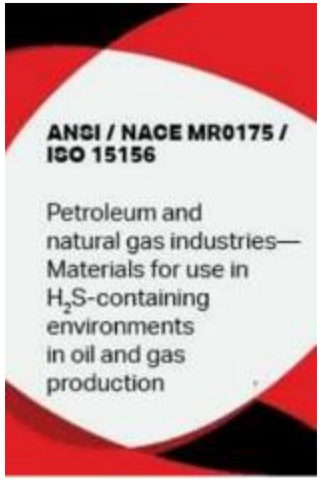












Recommended Readings

Material Selection for Pressure Equipment

Overview and Challenges

Thank you for Listening

Stay Tuned

Next Session:

Heat Treatment

Baher Elsheikh

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