



# Valve Materials of Construction Part 1 - Metals

May 20, 2020

Mitchell Anderson and Stan Allen

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# Your Presenters

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- **Stan Allen, PE**

- Engineering Fellow, Bray International Inc., Houston, TX
- 42 Years in the Valve Industry - R & D, Design Engineering, Applications Engineering, Test Lab Management, and Technical Services Roles
- VMA Technical and Education Committees
- Participant in standards development for API, MSS, AWWA, NACE and ASTM.



- **Mitchell Anderson**

- Technical Director, Bray International Inc., Houston, TX
- 15 Years in the Valve Industry – Product Development, Manufacturing Engineering, Quality, Operations
- Participant in standards development for API, ASME, ISO, EN

# Agenda

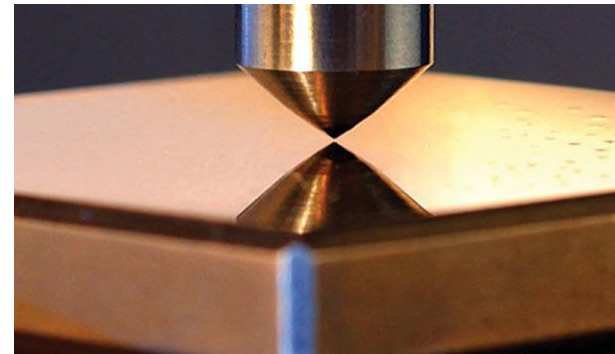
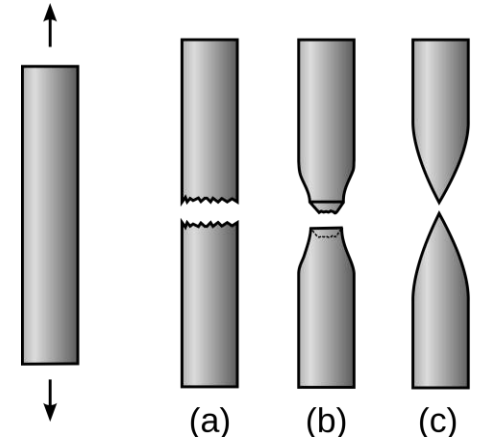
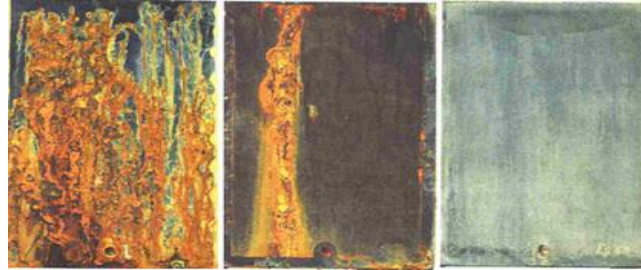
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- Properties
- Iron
- Carbon Steel
- Low Alloy Steel
- Stainless Steel
- Corrosion and NACE Material Recommendations
- Martensitic and Precipitation Hardened Stainless Steels
- Duplex Stainless Steel
- Aluminum Bronze
- CRA's
- Titanium
- Overlays and Coatings
- ASME B16.34 Pressure-Temperature Ratings
- ASME B31.1 and B31.3 Code Requirements
- Selection Process



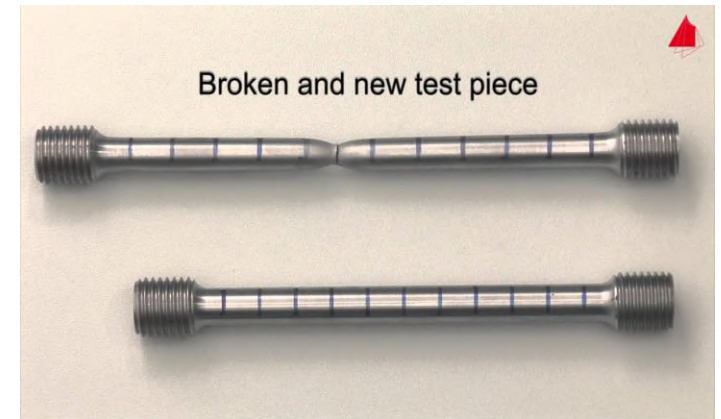
# Properties

- Chemical Properties
  - Corrosion Resistance
- Physical Properties
  - Strength
  - Toughness
  - Ductility
  - Hardness
  - Temperature Resistance
- Metal Alloys
  - Other metals added (*Cr, Ni, Mo, Mn, etc.*)
    - Some for strength
    - Some for corrosion resistance
    - Some for bearing properties



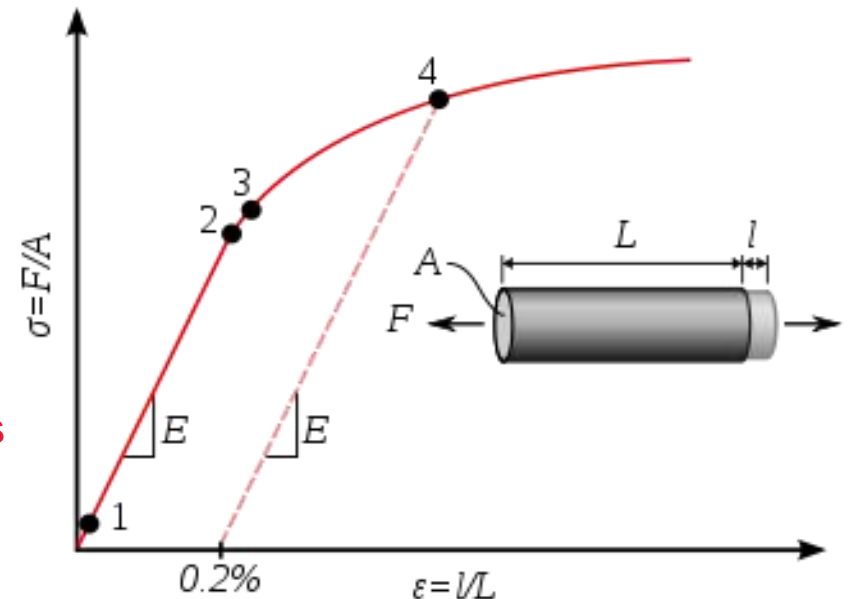
# Physical Properties

- Yield Strength
  - A “force” at which a material begins to permanently deform
- Tensile Strength
  - Force value at which a material breaks
- Elongation
  - How far the material stretches before it breaks
- Hardness
  - Resistance to being deformed



## Strength vs. Hardness?

**Empirical relationships – For example, tensile strength of steel (in ksi) is approximately half the Brinell (BHN), and for many materials the Vickers (VHN) is roughly 3 times the yield strength (in kgf/mm<sup>2</sup>)**



# Gray Cast Iron (CI)

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- Graphite microstructure in flake shape
- Brittle and should be avoided from impact
- Good surface finish and dimensional accuracy
- Good machinability
- Good corrosion resistance compared to carbon steel
- Wear resistance due to graphite
- Specifications: ASTM A 126, BS EN 1561

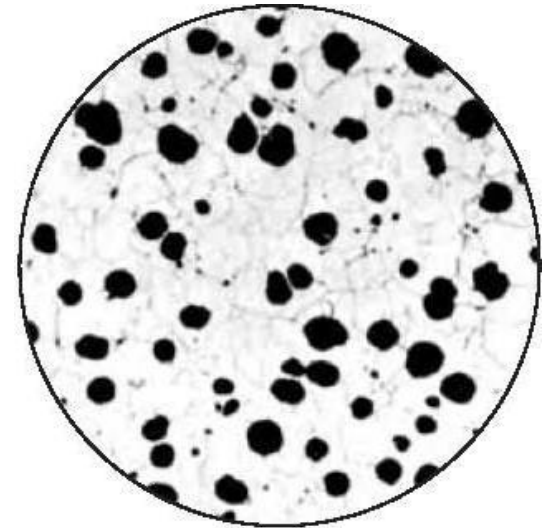




# Ductile Iron (DI)

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- Graphite microstructure are in spherical shape
- Excellent resistance to impact & shock
- Twice the tensile strength of cast iron
- Considerable degree of ductility due to ferrite matrix
- Anti-corrosion like CI but strength like carbon steel
- Specifications
  - **ASTM A 395:** For pressure containing castings
    - 60-40-18 must be heat treated (Up to 650°F)
    - 65-45-15 may be as cast (Up to 450°F)
    - No welding allowed
  - **ASTM A 536:** For general castings
    - Eight grades including 60-40-18
    - No mandatory heat treatment
  - **DIN EN 1563 (DIN 1693)**



# Carbon Steel

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- Carbon steel is the most common and most versatile metal used in industry
- Mild (low) Carbon Steel
  - 0.05% to 0.26% Carbon – 0.4% Mn
  - AISI 1018 Wrought; A36 Structural Steel; A105 Forging; WCB Casting
- Medium Carbon Steel
  - 0.29% to 0.54% Carbon – 0.3 to 0.9% Mn
  - AISI 1040 wrought; B7 bolt; WC6 casting
- High Carbon (Spring) Steel
  - 0.55%+ Carbon – 0.3 to 0.9% Mn
  - AISI 1080; AISI 1095

As carbon percentage content rises:

- Becomes harder and stronger through heat treating
- Becomes less ductile
- Reduces weldability
- Lowers melting point





# Cast Carbon Steel

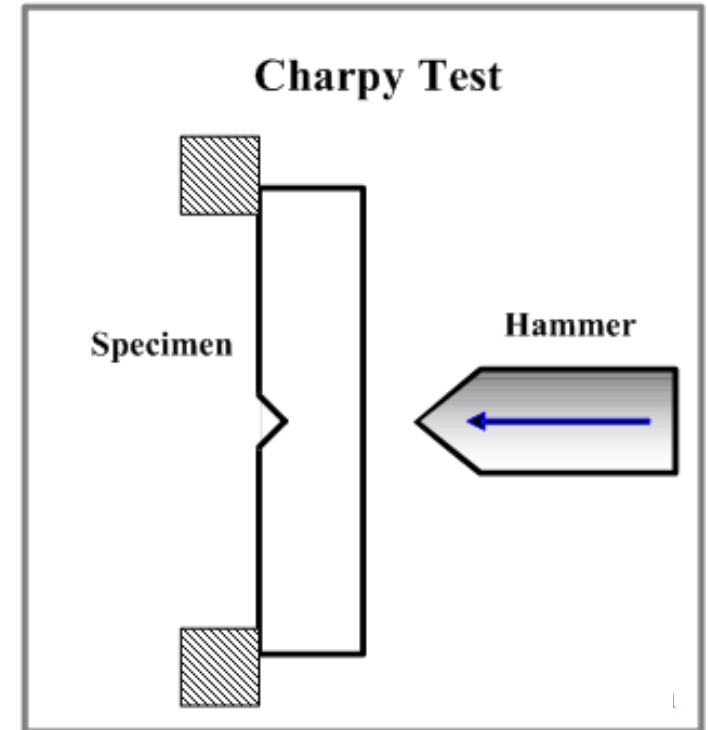
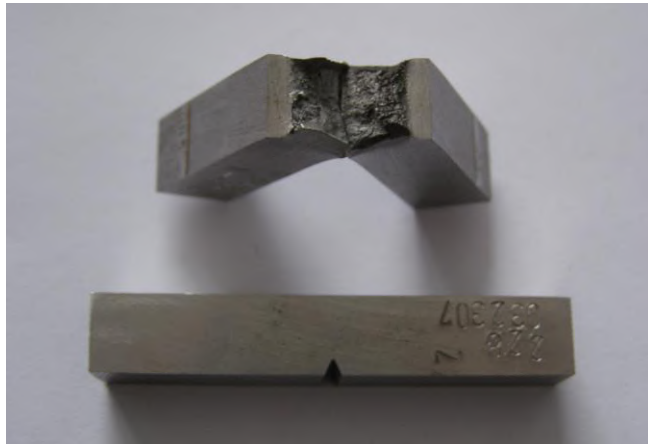
Parameter	A 216 Gr WCB	A 216 Gr WCC	A 352 Gr LCB	A 352 Gr LCC
Carbon %	0.30	0.25	0.30	0.25
Manganese %	1.00	1.20	1.00	1.20
Tensile Strength, ksi	70-95	70-95	65-90	70-95
Min. Yield Strength, ksi	36	40	35	40
Min Temp	-20°F (-29°C)	-20°F (-29°C)	-50°F (-46°C)	-50°F (-46°C)
Max Temp	800°F (427°C)	800°F (427°C)	650°F (345°C)	650°F (345°C)

**WC** - stands for "wrought carbon" with the third letter indicating grade - the higher the grade the higher the tensile/yield strength.

**LC** - stands for "low temp (wrought) carbon" with the third letter indicating grade - the higher the grade the higher the tensile/yield strength.

# Impact Testing

- Most commonly applies to carbon steels used in low temperature services (below  $-29^{\circ}\text{C}/-20^{\circ}\text{F}$ )
  - Impact Testing: Measure of a material's toughness (strength and ductility)
  - Energy values at a temperature (ft-lbs, Joules)
  - Usually for low temperature applications – either for fluid going through valve or for environmental conditions



# Low Alloy Steels

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- Steels For High Temperature Hydrogen Service
  - 1-1/4% Chrome, 1/2% Moly (ASTM A217 Gr WC6 / ASTM A182 Gr F11)
  - 2-1/4% Chrome (ASTM A217 Gr WC9 / ASTM A182 Gr F22)
  - 5% Chrome (ASTM A217 Gr C5 / ASTM A182 Gr F5)
  - ASME B31.12, API RP 941, CSA CHMC1– Guidelines for (Hot) Hydrogen Service
- Power Industry, High Pressure, High-Temperature Steam
  - 9% Chrome, 1% Moly (ASTM A217 Gr C12A / A182 Gr F91)
- AISI 4130, 4140, 4142 are low-alloy steels containing chromium and molybdenum with good atmospheric corrosion resistance and reasonable strength, toughness, wear resistance and fatigue strength – used for valve drive components in relatively non-corrosive applications
  - ASTM A193 Gr B7 and B7M, and ASTM A194 Gr 2H and 2HM (4140) – Pressure Containing Fasteners
- AISI 8620 Alloy Steel is a case-hardened steel containing nickel, chromium and molybdenum with good strength and toughness – used for valve stems and shafts in relatively non-corrosive applications

# Stainless Steel

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## Definition:

Stainless steel is an iron-based metal that has at least 10.5% chromium (Cr). Other alloying elements, such as Nickel (Ni), Molybdenum (Mo), Manganese (Mn), can be added as well as additional amounts of chromium to achieve specific corrosion resistance and physical properties.

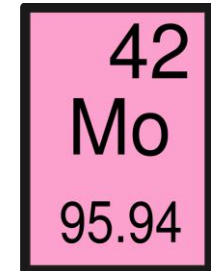
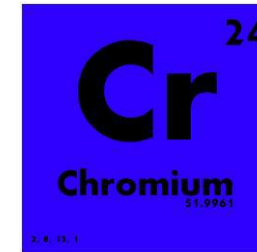
Five Groups	Corrosion Resistance	Hardness	Strength	Magnetic	Examples
Austenitic	1	5	5	No	AISI 304, 316, Alloy 20
Duplex	1	3	3	Yes	CD4MCuN, 2205, 2507
Ferritic	4	4	4	Yes	AISI 429, 430, 446
Martensitic	5	1	1	Yes	AISI 410, 416, 440
Precipitation Hardened	3	1	2	Sometimes	17-4 PH

**Note:** Lower number is better

# Stainless Steel – Alloying Elements

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- Corrosion resistance obtained by a passive oxide layer on metal surface (Chromium oxide)
- Alloying elements affect corrosion resistance
  - Cr – general corrosion, pitting and crevice corrosion, oxidizing environments
  - Mo – pitting and crevice corrosion, reducing environments
  - N – pitting and crevice corrosion, strength
  - Cu – atmospheric corrosion
  - W – reducing environments, high temperature
  - Ni – general corrosion, SCC resistance, high temperature. Also promotes austenitic structure
  - Ti, Nb – stabilizers (321 SS is Ti stabilized; 347 SS is Nb stabilized)



# Stainless Steel

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- Common cast “austenitic stainless steels”
  - ASTM A351 Grade CF8M (316 SS)
  - ASTM A351 Grade CF3M (316L SS) – lower C (0.03%)
  - ASTM A351 Grade CF8C (347 SS) – H<sup>2</sup> services
- Major Technical Advantages:
  - Corrosion Resistance
  - Toughness at Low Temperature (Cryogenic)
  - Oxygen Service
  - Clean Services
- Alloy 20 (UNS N08020) – Niobium added, used for sulfuric acid service





# Corrosion

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## General Corrosion

Destructive attack on the material resulting in damage to its properties



## Localized Corrosion

Results in cavities and pits in the material - pitting, crevice, galvanic

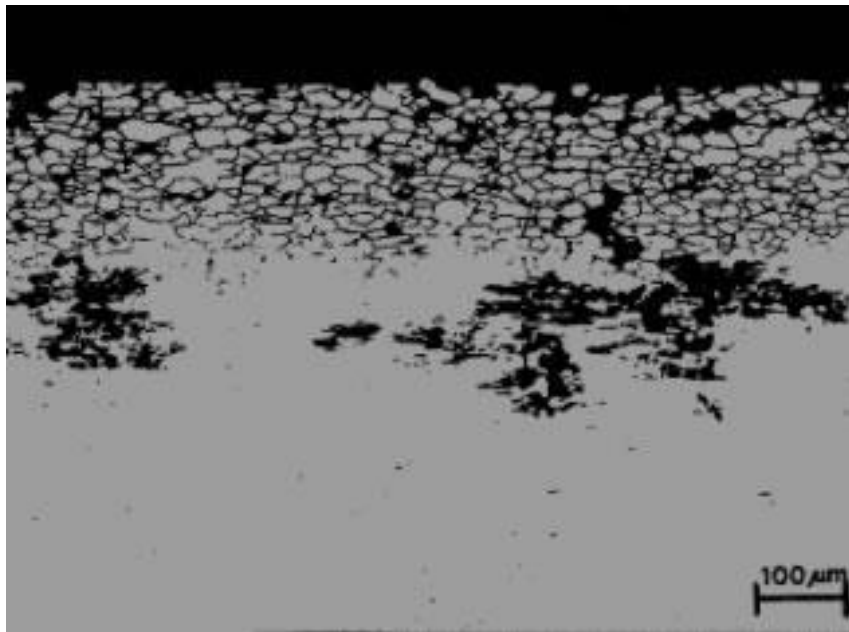


# Corrosion

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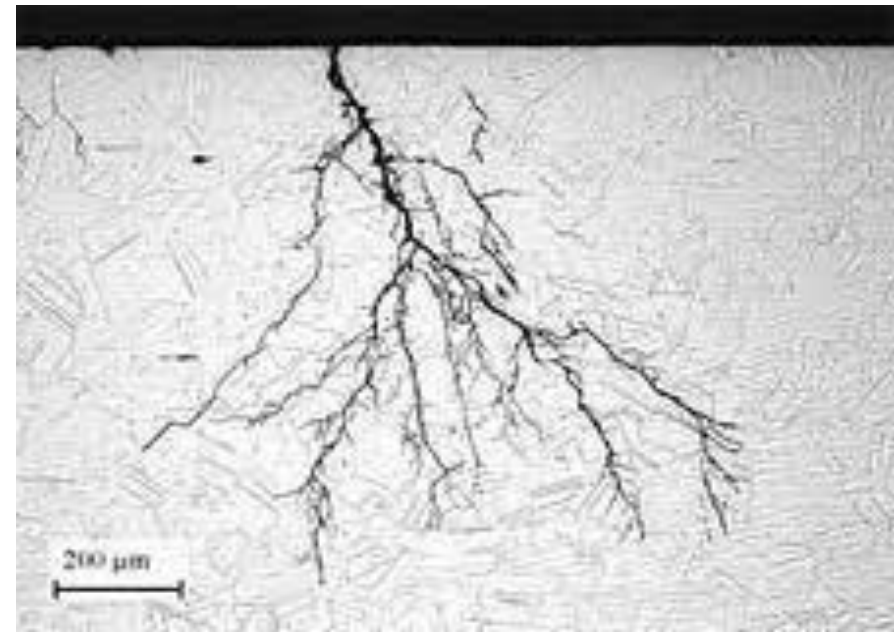
## Stress Corrosion Cracking

Accelerated cracking due to internal stresses – sulfide stress cracking and chloride stress cracking



## Intergranular Corrosion

At grain boundaries – results in loss of strength and ductility



# Corrosion

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- Other Types of Corrosion – liquid metal embrittlement, cavitation, hydrogen attack, velocity accelerated corrosion, MIC
- Factors causing or influencing corrosion in any given material – oxidizing agents, pH, concentration, temperature, velocity, pressure, passive film formation
- Combating corrosion – material selection, inhibitors, altering the design, altering the environment, coatings



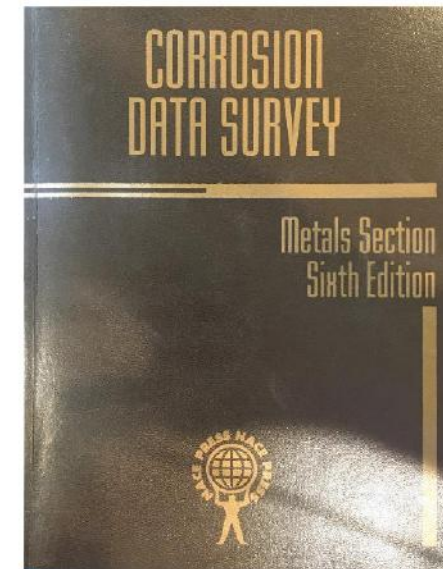
# NACE - National Association of Corrosion Engineers

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- **MR0175 / ISO15156** – “Petroleum and natural gas industries—Materials for use in H<sub>2</sub>S-containing environments in oil and gas production” – addresses sulfide stress cracking in production environments
- **MR0103 / ISO 17495** – “Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments” – addresses sulfide stress cracking in process environments



Excellent  
Reference for  
Material  
Compatibility:

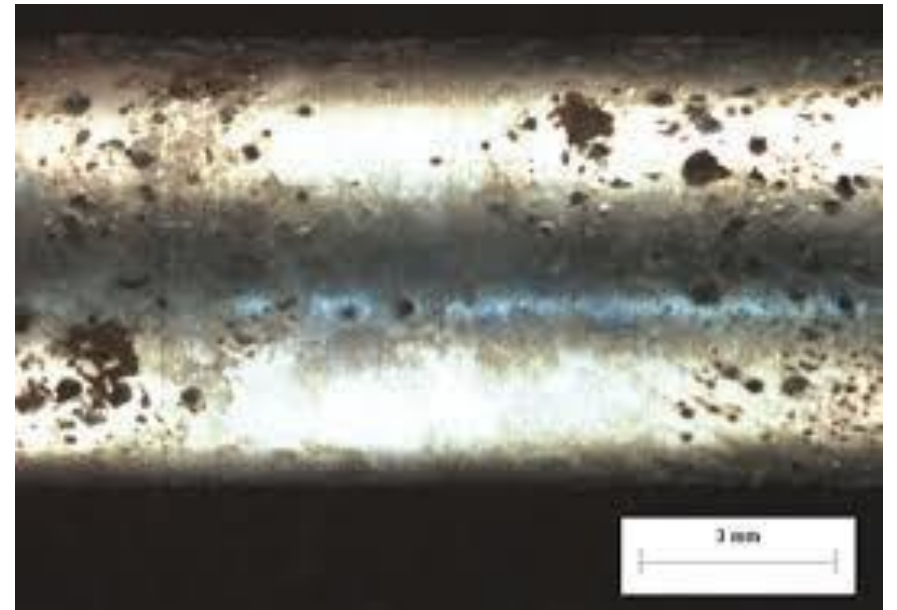




# Pitting Resistance Equivalent Number (PREn)

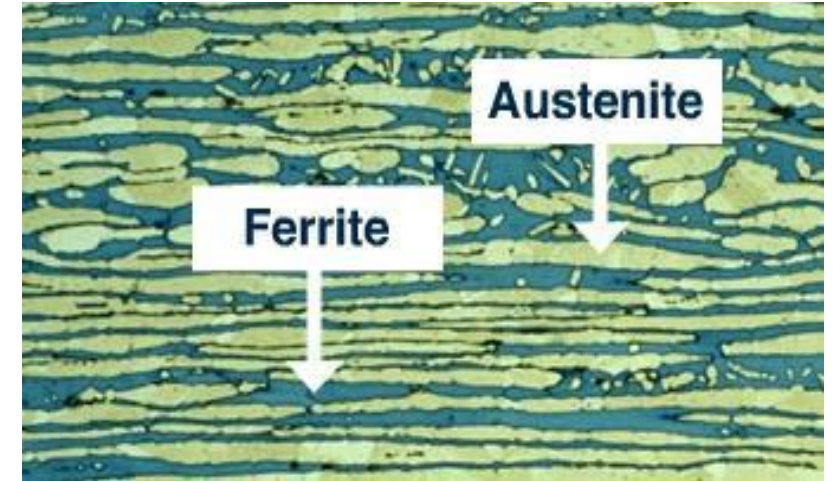
- Comparative and predictive measurement of pitting resistance of stainless steels
- $PREn = 1 \times \%Cr + 3.3 \times \%Mo + 16 \times \%N$
- If Tungsten included,  $PREn = 1 \times \%Cr + 3.3 ( \%Mo + 0.5 \times \%W ) + 16 \times \%N$

SS Alloy	PREn
304	17.5-20.8
316/316L	23.1-28.5
316L (2.5% min Mo)	25.3-30.7
904L	32.2-39.9
SAF 2205	30.8-38.1
SAF 25072	> 40
Zeron 100	> 40
254SMO	42.2-47.6



# Duplex SS

- Equal amounts of austenitic and ferritic phase – used extensively offshore (40-50% ferrite common)
- 22 Cr (ASTM A995 Grade 4A; UNS S31803) – Duplex
- 25 Cr (ASTM A995 Grade 5A, UNS S32750) – Superduplex
- Zeron® 100 (ASTM A995 Grade 6A) – Superduplex
- Why duplex or superduplex?
  - High Strength
  - Corrosion Resistance in Seawater and Hydrocarbons
  - Resistance to “Chloride Stress Cracking”





# Super Austenitic SS

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## Super austenitic stainless steels

- Contain high levels of chromium and higher levels of nickel together with additions of molybdenum and nitrogen
- The result is a series of austenite, stronger than conventional 300 series stainless with superior resistance to pitting, crevice corrosion, and stress corrosion cracking
- 904L (UNS N08904) – A high strength 316L (higher nickel and chrome) – Rolex made popular – used in mining industry
- 254 SMO and 6Mo (UNS S31254)
- ASTM A351 & A744 Gr CK3MCuN & CN3MN (UNS J93254)



# Martensitic SS

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- AISI 410 SS
- ASTM A 217 Gr CA15 Castings
- Not “as good” for chloride stress cracking resistance
- Relatively low cost
- Good strength
- Used for stem materials in non or mildly corrosive environments
- Not used for cryogenic applications
- 416 SS is used in valves for machining and bearing properties but is less corrosion resistant than 410 SS. Used for bushings and bearings.

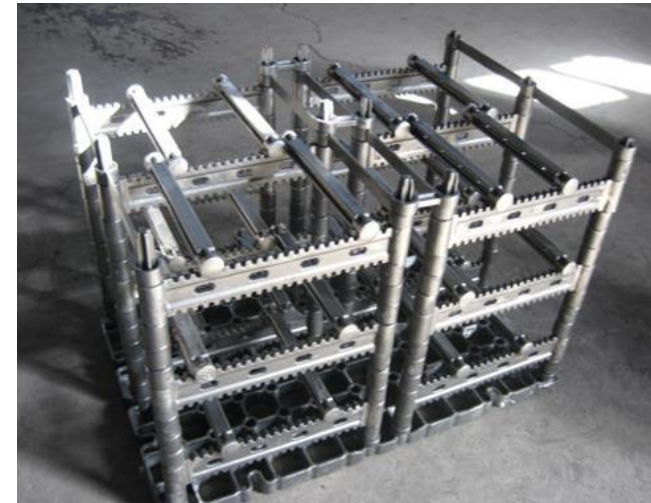


# Precipitation Hardened SS

- 17-4PH SS (martensitic)
  - ASTM A564 Grade 630
  - H1075 Common heat treatment
  - H1150D (NACE compliant)
  - Cast ASTM A747 Gr CB7Cu-1
- ASTM A638 Grade 660 SS (Austenitic PH)
  - Fasteners (formerly A286)
  - Stem
- Technically not PH, but often included:
  - Nitronic 50 and Nitronic 60 (austenitic)
  - Nitrogen strengthened
  - UNS S20910 (Nippon Yakin XM-19)
  - Preferred for high strength, cryogenic valve trim components

- Yield strengths 3 to 4 times austenitic stainless steel such as type 304.
- Combination of high strength, corrosion resistance and acceptable degree of toughness is required.
- Precipitation hardening is achieved by the addition of copper, molybdenum, aluminum and titanium

**PH SS's are good valve stem materials...but**



**Correct Heat Treatment is Critical**

# Aluminum Bronze

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- ASTM B148 UNS C95400 - used in seawater, but generally replaced with Nickel Aluminum Bronze (NiAB)
- ASTM B148 UNS C95800 - NiAB
- Valves for Ships and Submarines
- Valves for Offshore Vessels (FPO, FPSO, FLNG)
- Valves for Offshore Production Platforms
- Seawater Service
- Used as a bearing material



# Common High Nickel Alloys

- Selected for acids and extremely corrosive fluids
- Also called CRA's (Corrosion-Resistant Alloys)
- Monel K500 – (Nickel-Copper Alloy – 67% Ni)
  - ASTM A494 M35C; Fed Spec QQ-N-288 Comp C
  - Non-sparking material, used in oxygen service
  - Seawater service
  - HF Alkylation
- Monel 400 - good wrought material for corrosion-resistant bearings; also used for castings



- Inconel 718 – common valve stem material
- Inconel 625 (ASTM A494 Gr CW6MC)
- Incoloy 800
- Inconel X750 – used for springs in ball valves
  - Inconels and Incolloys are trademarked by Kenametal Deloro-Stellite Company
- Hastelloy B2, B3, C22 – Chemical applications
- Hastelloy C276 (Cast ASTM A494 Gr CW12MW)
  - Hastelloy's trademarked by Haynes International
- Nickel 200

# Titanium

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- Strong but lightweight (low density)
- Used in the chemical and petrochemical industries primarily for corrosion resistance
- Titanium is resistant to corrosion by sea water
- Water industry (desalination plants)
- Used in the pulp and paper industry for corrosion resistance in sodium hypochlorite and wet chlorine gas

- ASTM Specifications

- B 265 - plate
- B 348 – bar
- B 367 – castings

- Common grades for valves:

- Grade 2 (cast)
- Grade 5 (also known as Ti6Al4V, Ti-6Al-4V or Ti 6-4)
- Grade 12 (listed within NACE MR0175)





# Hard Coating Techniques

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- Weld Overlays – MIG, TIG and other processes to deposit corrosion and erosion resistant materials and form a strong metallurgical bond
- Thermal Spraying - melted (or heated) materials are sprayed onto a surface
  - High Velocity Oxygen Fuel (HVOF)
  - Plasma Spraying
  - Tungsten Carbide
  - Chromium Carbide



- Plating
  - Electroless Plating (ENP)
  - Electroplating (Hard Chrome)
- Anodizing
  - Electrolytic Passivation
  - Actuators



# Specialty Material - Stellite™

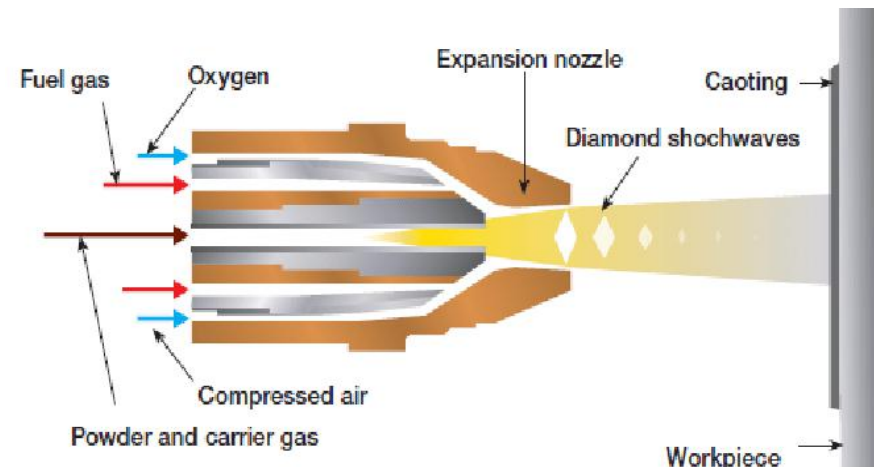
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- Stellite™ proprietary alloy used for demanding mechanical and chemical service over a wide temperature range
- Excellent anti-galling properties, high temperature hardness and a strong resistance to impact and cavity corrosion
- Retains hardness up to 1470 F (800 C)
- Stellite™ 6 - often used for hard-facing; strengthened by W carbides, HRC 428 typical
- Stellite™ 21 – low W, solid solution type, work hardens and provides greater wear resistance; HRC 32 typical
- Ultimet™ – Ni added; more corrosion resistant version of Stellite™ 21 HRC, 32 typical

™ Trademarked by Kennametal Deloro-Stellite Company

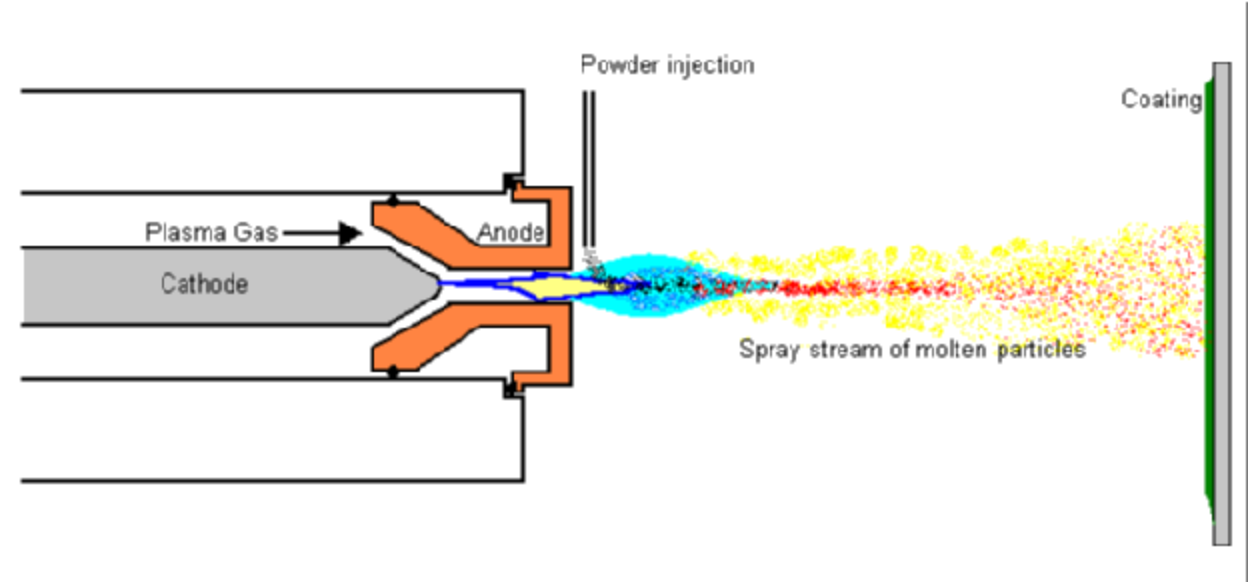
# High Velocity Oxygen Fuel Spraying (HVOF)

- A mixture of gaseous or liquid fuel and oxygen is fed into a combustion chamber, where they are ignited and combusted
- The hot gas goes through a converging–diverging nozzle which accelerates the powder up to 800 m/s towards the surface to be coated
- The powder partially melts in the stream and deposits upon the substrate, which is also mechanically deformed
- The resulting coating has low porosity and high bond strength.
- HVOF coatings may be as thick as 12 mm (1/2").
- Typically used to deposit wear and corrosion resistant coatings such as Stellite™, tungsten carbide and chromium carbide.



# Plasma Spray Process

- Spraying of molten or heat softened material onto a surface to provide a coating
- Material in the form of powder is injected into a very high temperature plasma flame, where it is rapidly heated and accelerated to a high velocity.
- The hot material impacts on the substrate surface and rapidly cools forming a coating.
- Plasma spray coating tend to have more porosity, un-melted particles, and form oxides.



# ENP

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- Electroless nickel plating (ENP) is an autocatalytic (single reaction) chemical technique used to deposit a layer of nickel-phosphorus or nickel-boron alloy on a metal substrate
- Applied for wear resistance, hardness and corrosion protection, with corrosion protection being the primary objective
- Used in seawater, high chlorides, wet carbon dioxide, and hydrogen sulphide
  - Carbon steel with ENP is a cost-effective option for general corrosion resistance against solid SS in many applications
  - Coating thickness varies from 25 to 100 micrometers (1 to 4 mils)
  - Key to effectiveness is proper application to avoid flaking



# Boronizing, Nitriding, and other Surface Treatments

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- Seats, stems, bearings, bushings, balls and discs often require hardening treatments to improve resistance to abrasion or erosion.
- Nitriding – diffuse nitrogen into the surface of steel or stainless steel to create a case-hardened surface.
  - Salt-bath (QPQ), gas, and ion nitriding are different methods.
  - Surface hardness of 900-1200 HV.
- Boronizing (also called boriding) – diffusion of boron into the surface of a steel, stainless steel, and other high nickel alloys to form iron, nickel or cobalt borides.
  - Purpose is to increase hardness and wear resistance
  - Hardness may be 1200-1600 HV
  - higher (1700-2300 HV) for nickel boronizing of Inconel and Hastelloy
- Dry-film lubrication (Moly-disulfide)
- Nano-materials



# ASME B16.34 – 2017 (Valves – Flanged, Threaded, and Welding End)

## Pressure-Temperature Ratings

Table 1 - Material Specification List: Applicable ASTM Specifications

Material Group No.	Nominal Designation	Forgings		Castings		Plates		Bars		Tabular	
		Spec. No.	Grade	Spec. No.	Grade	Spec. No.	Grade	Spec. No.	Grade	Spec. No.	Grade
<b>GROUP 1 MATERIALS</b>											
1.1	C-Si	A105	---	A216	WCB	A515	70	A105	---	---	---
	C-Mn-Si	A350	LF2	---	---	A516	70	A350	LF2	A672	C 70
	C-Mn-Si	---	---	---	---	A537	Cl. 1	A696	C	A672	B 70
	3½ Ni	A350	LF3	---	---	---	---	A350	LF3	---	---
	C-Mn-Si-V	A350	LF6 Cl. 1	---	---	---	---	A350	LF6 Cl. 1	---	---

# ASME B16.34 – 2017 (Valves – Flanged, Threaded, and Welding End)

Table 2-2.2 Ratings for Group 2.2 Materials

A182 Gr. F316 (1)	A312 Gr. TP316 (1)	A351 Gr. CF8M (1)	A376 Gr. TP316H
A182 Gr. F316H	A312 Gr. TP316H	A351 Gr. CF10M	A430 Gr. FP316 (1)
A182 Gr. F317 (1)	A312 Gr. TP317 (1)	A351 Gr. CG3M (3)	A430 Gr. FP316H
A240 Gr. 316 (1)	A351 Gr. CF3A (2)	A351 Gr. CG8M (4)	A479 Gr. 316 (1)
A240 Gr. 316H	A351 Gr. CF3M (3)	A358 Gr. 316 (1)	A479 Gr. 316H
A240 Gr. 317 (1)	A351 Gr. CF8A (2)	A376 Gr. TP316 (1)	

A — Standard Class

**Pressure-  
Temperature  
Ratings**

Temperature, °C	Working Pressures by Class, bar						
	150	300	600	900	1500	2500	4500
-29 to 38	19.0	49.6	99.3	148.9	248.2	413.7	744.6
50	18.4	48.1	96.2	144.3	240.6	400.9	721.7
100	16.2	42.2	84.4	126.6	211.0	351.6	632.9
150	14.8	38.5	77.0	115.5	192.5	320.8	577.4
200	13.7	35.7	71.3	107.0	178.3	297.2	534.9
250	12.1	33.4	66.8	100.1	166.9	278.1	500.6
300	10.2	31.6	63.2	94.9	158.1	263.5	474.3
325	9.3	30.9	61.8	92.7	154.4	257.4	463.3

# ASME B31.1 and B31.3 Material Requirements

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- Tables within ASME B31.1 and B31.3 provide maximum allowable stress values in tension for the range of temperatures for which the specified grade is suitable. Pay attention to “Notes”.
- Most, but not all, valve materials listed in ASME B31.1 and B31.3 have allowable stresses in-line with those listed in ASME Boiler and Pressure Vessel Code, Section II, Part D, or Section VIII, Division 1. ASME B31.1 and B31.3 may have higher allowable stresses for some materials.
- For materials unlisted in ASME B16.34, stress values listed in ASME Boiler and Pressure Vessel Code, Section II, Part D, or Section VIII, Division 1, are used to determine pressure-temperature ratings of valves (per Non-mandatory Appendix B). Most conservative approach.

# Selecting Valve Materials

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- Purpose
  - Pressure Boundary Elements (bodies, bonnets)
  - Pressure Controlling (ball, disc, plug, gate)
  - Trim – Exposed (stems, seats, bearings)
  - Non-exposed components (handwheels, adapters)
- Design Parameters
  - Mechanical properties
  - Properties at temperature extremes
  - Adhesive Wear (galling)
- Environment
  - Corrosion mechanisms
  - Abrasive Wear
  - Erosion



# Valve Materials of Construction – Part 2, Non-Metals

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Friday, May 22, 2020

10:00 to 11:00 CDT



Mitch Anderson, Technical Director of Valve Products, Bray  
Richard DeBuck, VP Engineering & Quality, Amresist



Second part of a 2-part series on valve materials of construction will introduce engineers and purchasers to common non-metals used in the construction of valves for various process and production industries. Particular attention will be given to elastomer and plastic benefits and technical limitations in various service fluids and applications.



**Valve Materials of Construction  
Part 1 – Metals**

**Thank You!**

**Questions?**