Simplify Materials Selection

Your Guide to Making Choices That Reduce Corrosion

Swagelok

NACE Requirements for Alloy 6Mo Tube, Pipe, and Weld Fittings

Index

An offshore platform can have nearly 50,000 feet of tubing, more than 20,000 fluid system components, no fewer than 10,000 fittings, and as many as 8,000 mechanical connections.

No wonder choosing one material isn't easy.

In fact, there are many considerations when specifying materials for instrumentation lines, hydraulic power, chemical injection, deluge systems, and much more.

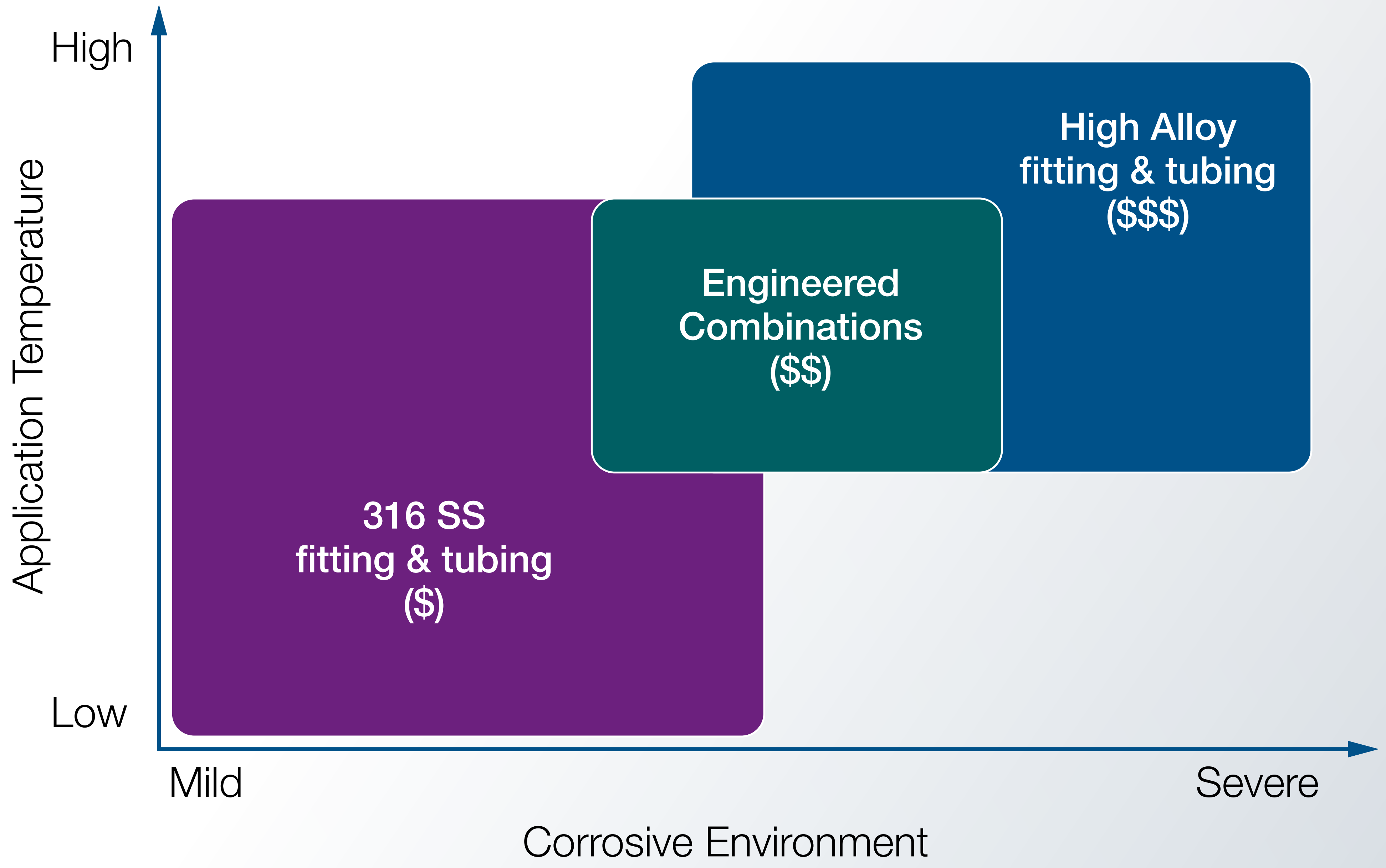
That's where Swagelok can help. We've been fighting corrosion since 1947. We simplify selection with our deep understanding of factors that contribute to corrosion, as well as the properties of our materials that help fight it. Our materials contain alloys, metals that contain two or more elements that help our products perform better. For instance:

Iron [Fe] + Carbon [C] = Carbon Steel
Iron [Fe] + Chromium [Cr] = Stainless Steel

With stringent quality control measures, expert-led instruction, and authorized sales and service center support, Swagelok offers unmatched expertise in the world's toughest environments. We make material selection a matter of confidence for our customers. Swagelok can make the material difference in your operation.

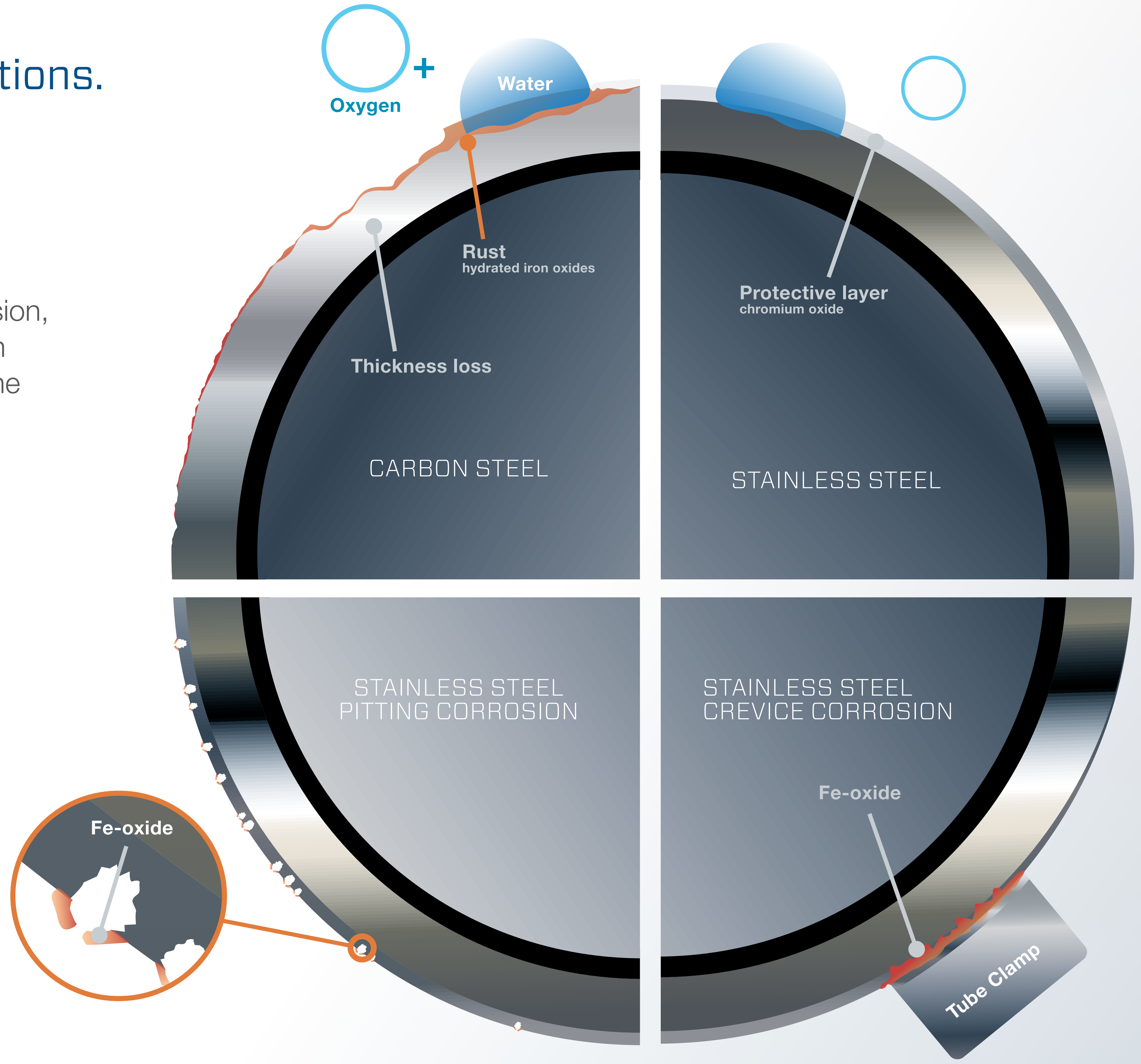
Fitting and Tubing Alloy Selection

Application and cost considerations



Just about every metal corrodes under certain conditions.

Corrosion is the physical degradation of a material due to interactions with its environment. Corrosion occurs when a metal atom is oxidized by a fluid, leading to a loss of material in the metal surface. This reduces the surface's thickness and makes it more prone to mechanical failure. Just about every metal corrodes under certain conditions. For example, rust is a commonly occurring byproduct of corrosion, resulting from iron corroding and forming iron oxide. Many other types of corrosion exist, however. Each type poses a threat that must be evaluated when selecting the optimal material for your application.



Total annual costs of corrosion are estimated at $1.3 billion USD for the entire oil and gas production industry.

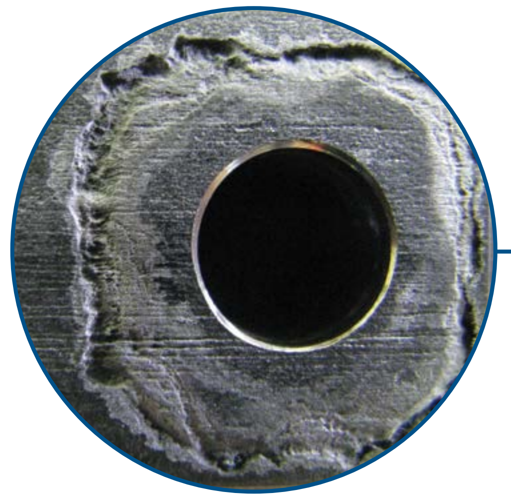
For oil and gas producers, the problem can be especially costly. The National Association of Corrosion Engineers (NACE) estimates the total annual cost of corrosion at $1.3 billion USD for the entire oil and gas production industry. But when personnel can visually identify corrosion and know where to look for it, the risk can be minimized. Better yet, when engineers can anticipate corrosion and make the best choices, system integrity, longevity of assets, performance, and safety improve.

Take these steps to reduce the impact of corrosion on your applications:

- *Identify types of corrosion*—what it looks like, where it occurs, and why it happens
- *Select materials* resistant to corrosion
- Minimize locations where *crevice corrosion* can occur and reduce contact with non-compatible metals
- Specify everything from the *supports and clamps* to the *tubing* itself to reduce the potential for corrosion
- *Understand requirements and standards*
- *Learn more*

Finding a proper materials solution means starting at the source of the problem.

Click to learn more about the many types of corrosion as well as the materials that help control it.



- 2507 Super Duplex Stainless Steel
- 6-Moly
- Engineered Combinations

Localized Crevice Corrosion

- 316/316L Stainless Steel
- 6-Moly
- Alloy 625

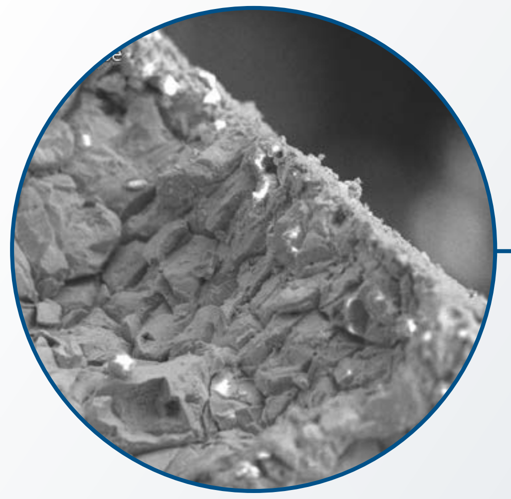
Hydrogen Embrittlement

- 316/316L Stainless Steel

General (or Uniform) Corrosion

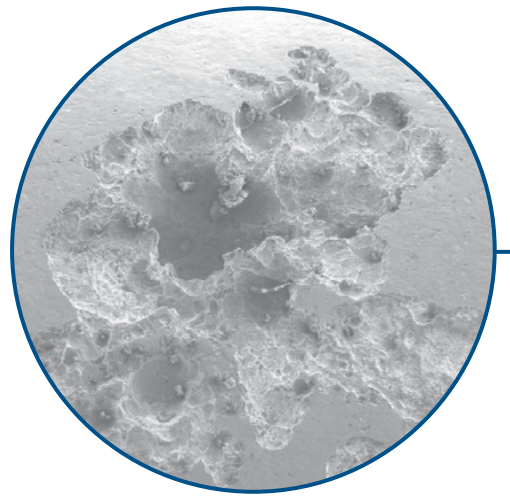
- 6-Moly
- Alloy 825
- 2507 Super Duplex Stainless Steel
- Alloy 400
- Alloy C-276
- Engineered Combinations

Stress Corrosion Cracking



- Low-carbon stainless steel grades with low carbon content
- Titanium- or niobium-stabilized stainless steel

Intergranular Corrosion



- 2507 Super Duplex Stainless Steel
- 6-Moly
- Engineered Combinations

Localized Pitting Corrosion

- 6-Moly
- Alloy 825
- 2507 Super Duplex Stainless Steel
- Alloy 625
- Allloy C-276

Sour Gas or Sulfide Stress Cracking

- Materials with voltage difference less than 0.2V

Galvanic Corrosion

General (or Uniform) Corrosion

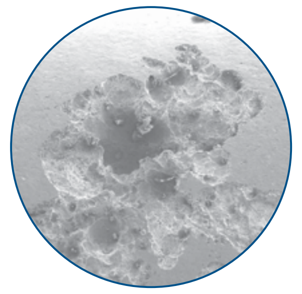
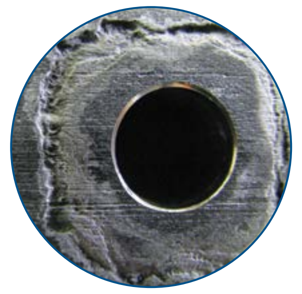
What it is: The most well-known type of corrosion is also the easiest to spot and predict. It is unusua—but not unheard of—for general corrosion to lead to disastrous failures. For this reason, general corrosion is often regarded as an eyesore rather than a serious problem. General corrosion occurs relatively uniformly across a metal surface, and is typically measured in milligrams per square centimeter of exposed material per day.

How it forms: In a marine or other corrosive environment, the surface of carbon or low-alloy steel, when exposed to caustic substances, begins to break down.

General corrosion can be measured by:

- How fast the material recedes on an annual basis. For example, an unprotected carbon steel may recede in a marine environment by 1 mm every year
- The weight loss that is experienced by an alloy when in contact with corrosive fluids, typically measured in milligrams per square centimeter of exposed material per day

See Potential Solutions: 316/316L Stainless Steel

Localized Corrosion: Pitting and Crevice Corrosion

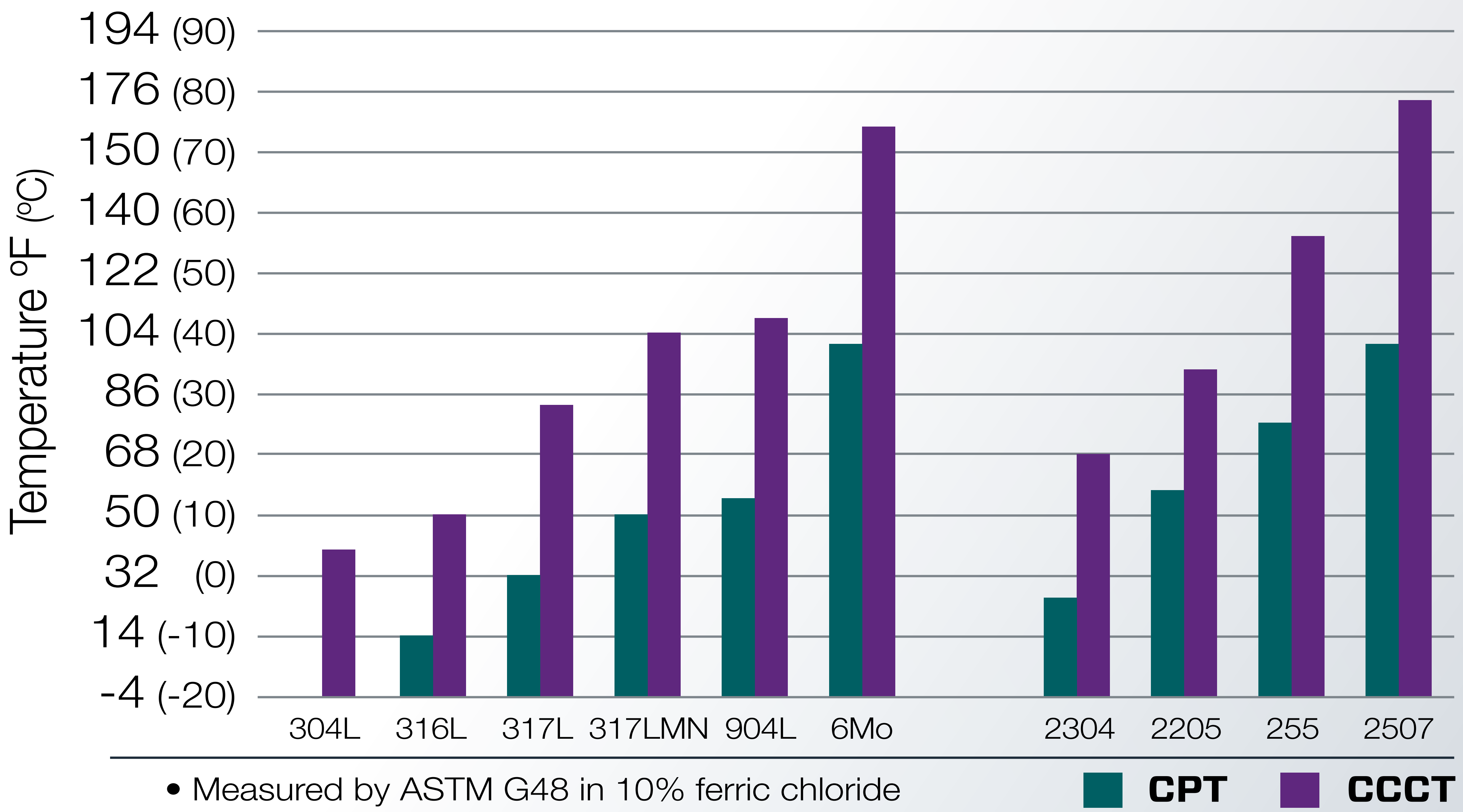
Common in caustic environments, or in installations with tight spaces

What it is: Both pitting corrosion and crevice corrosion are more difficult to detect than general corrosion, making these types of corrosion more challenging to identify, predict, and design against.

How it forms: The material's protective layer can break down when exposed to caustic fluids. A material is more resistant to localized corrosion the higher its Critical Pitting Temperature (CPT) and Critical Crevice Corrosion Temperature (CCCT). These are the minimum temperatures at which pitting and crevice corrosion are observed. Methods to measure CPT and CCCT are described in ASTM Standard G48.

Learn about pitting corrosion

Learn about crevice corrosion

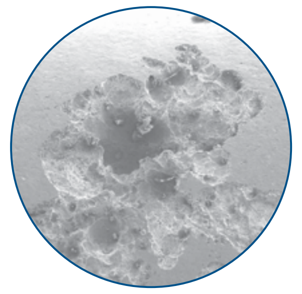


Crevice corrosion can occur at lower temperatures than pitting corrosion. For instance, for 316L stainless steel in a 10% ferric chloride environment, pitting corrosion can start to occur at 10° C whereas crevice corrosion can begin at 14° F (-10° C).

Source: Practical Guidelines for the Fabrication of Duplex Stainless Steels, Int. Molybdenum Assoc., 2001

Material Matters: For further reference, see "Preventing Pitting and Crevice Corrosion" as published in *World Oil*.

See Potential Solutions: 6-Moly Alloys; Alloy 2507; Alloy 400; Alloy 625; Titanium; Engineered Combinations



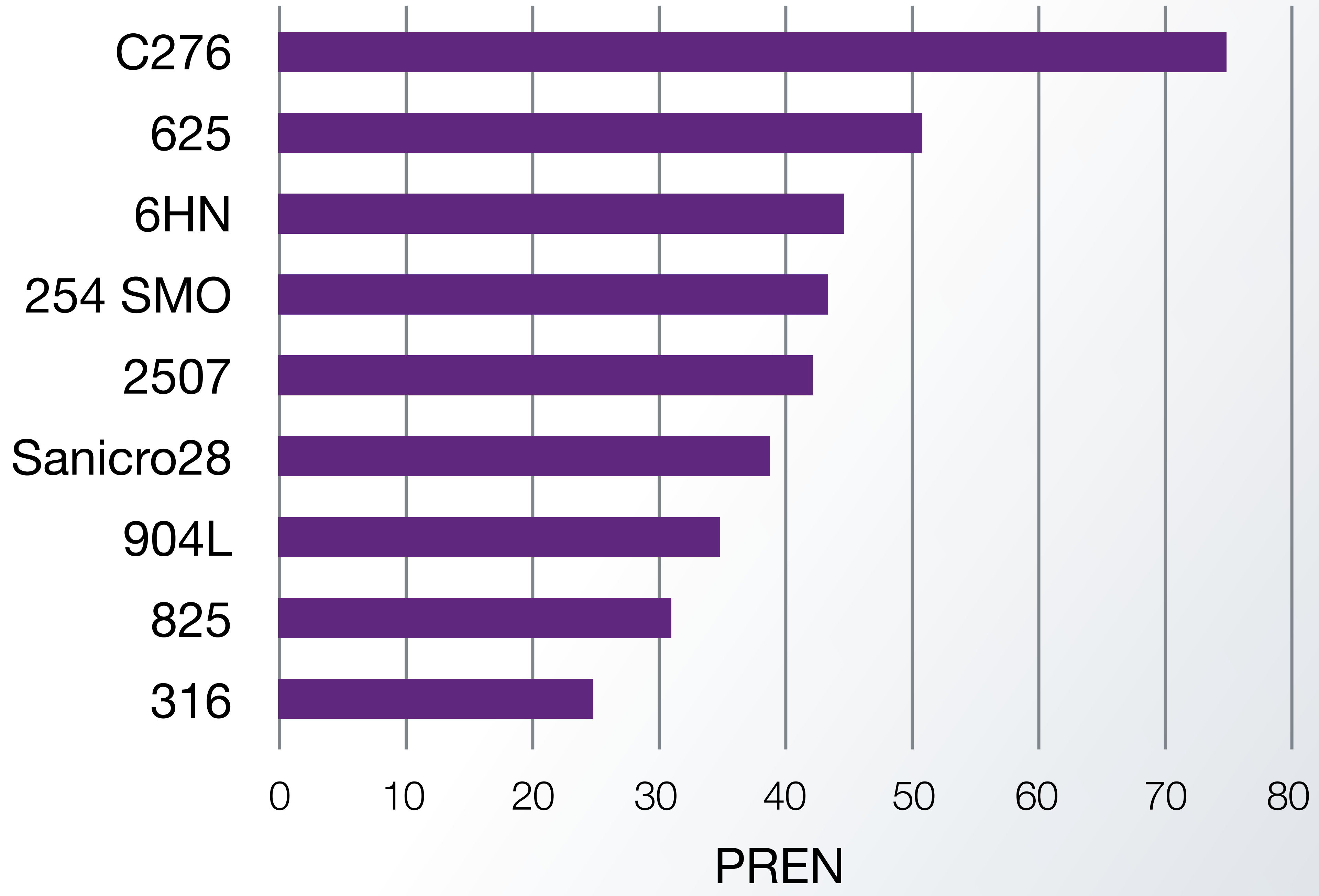
Pitting Corrosion

Common in high-chloride environments at elevated temperatures

What it is: Pitting corrosion causes small cavities, or pits, to form on the surface of a material.

Although detectable by thorough visual inspection, these pits can grow deep enough to perforate tubing. Pitting is more often observed in high-chloride environments at elevated temperatures.

How it forms: When the protective layer of oxide (or passive oxide layer) on the surface of the metal breaks down, the metal becomes susceptible to loss of electrons. This causes iron in the metal to dissolve into a solution in the more anodic bottom of the pit, diffuse toward the top, and oxidize to iron oxide, or rust. The iron chloride solution concentration in a pit can increase and become more acidic as the pit gets deeper. This results in accelerated growth of the pit, perforation of tubing walls, and leaks.



PREN = %Cr + 3.3 x (%Mo + 0.5W) + 16 x %N

Higher PREN values indicate greater pitting corrosion resistance

Pitting corrosion is best prevented by proper alloy selection. Different metals and alloys can be compared using their Pitting Resistance Equivalence Number (PREN), which is calculated from the chemical composition of the material. PREN increases with higher levels of chromium, molybdenum, and nitrogen.

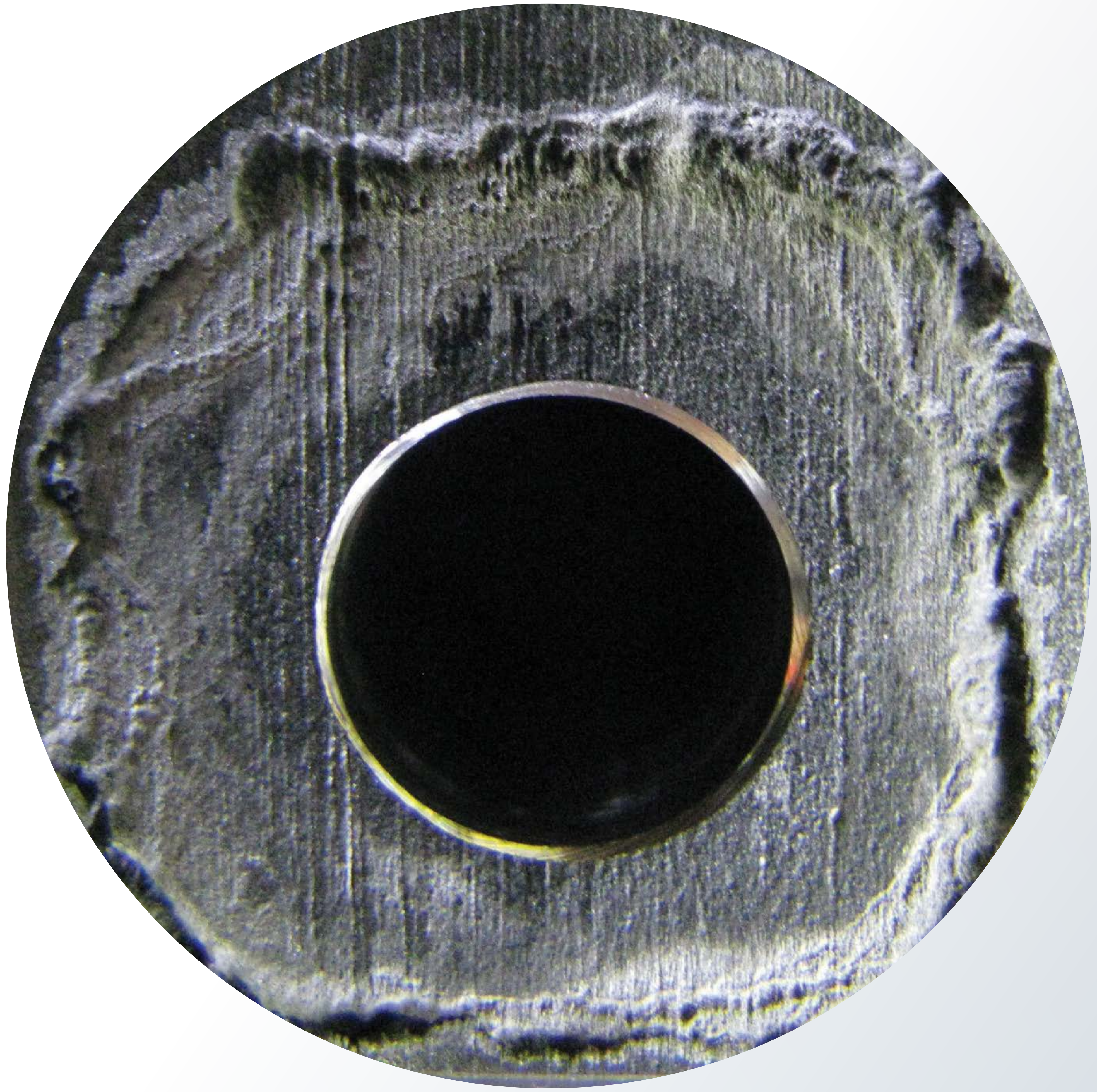
See Potential Solutions: **6-Moly Alloys; Alloy 2507; Engineered Combinations**

Crevice Corrosion

Common in caustic environments, or in installations with tight spaces

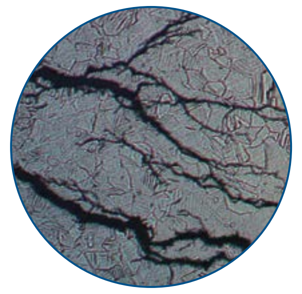
What it is: In a typical fluid system, crevices exist between tubing and tube supports or tube clamps, between adjacent tubing runs, and underneath dirt and deposits that may have accumulated on surfaces. Crevices are virtually impossible to avoid in tubing installations, and tight crevices pose the greatest danger for corrosion to occur.

How it forms: Shallow pits begin to form within crevices, and the passive oxide layer that protects the metal eventually breaks down. The pits grow larger and deeper until they cover the whole crevice. In some places, tubing can be perforated. Crevice corrosion occurs at far lower temperatures than pitting corrosion.



Material Matters: When seawater diffuses into a crevice, some Fe++ ions dissolve and cannot rapidly diffuse out of a tight crevice. In salt water, negatively charged chloride ions (Cl-) are attracted by these positively charged Fe++ ions and begin to diffuse into the crevice. As the chloride concentration increases, the crevice solution becomes more corrosive, causing more iron to dissolve, which in turn attracts more chloride ions to diffuse into the crevice. Ultimately, the crevice solution turns into an acidic solution with high chloride concentration, which is very corrosive.

See Potential Solutions: 6-Moly Alloys; Alloy 2507; Engineered Combinations



Stress Corrosion Cracking (SCC)

Common in stainless steels (chloride-induced), mild steel (alkali-induced), brass (ammonia-induced)

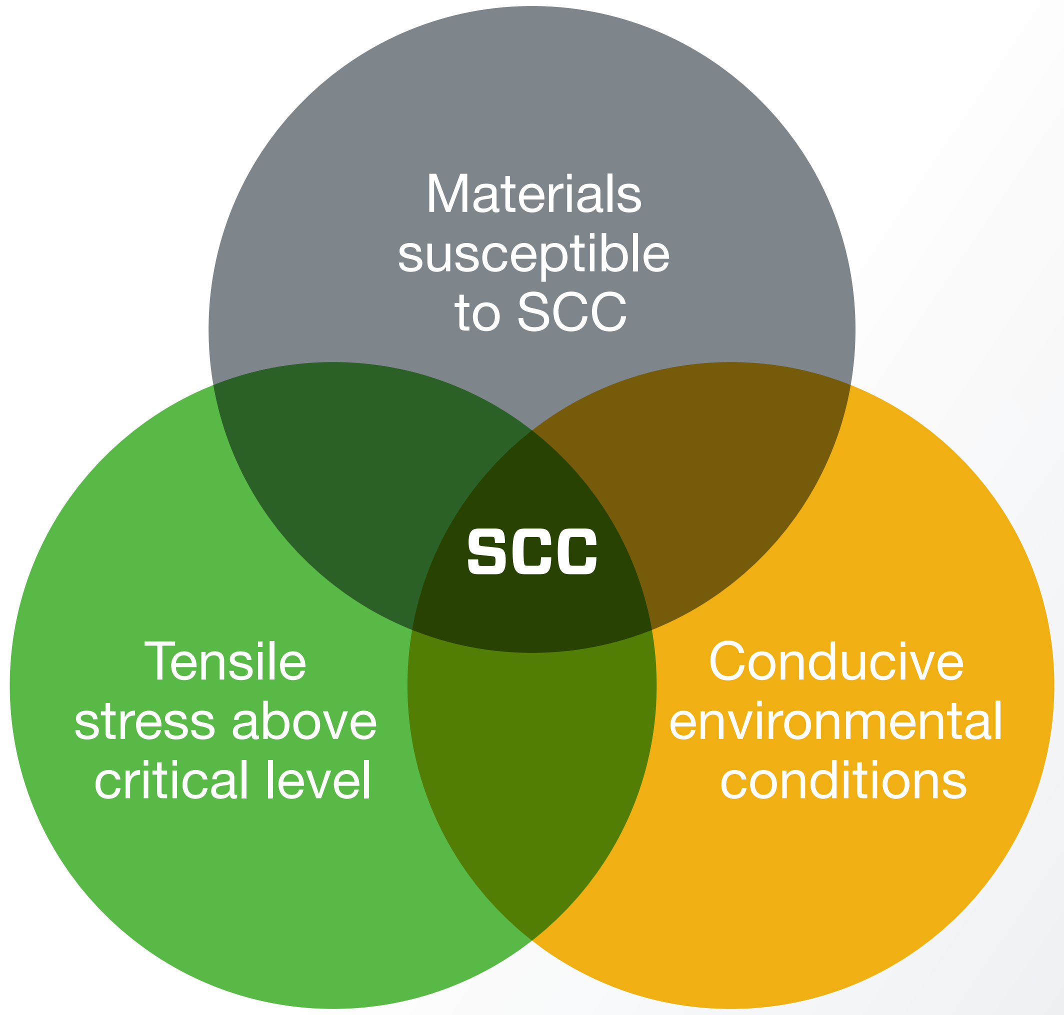
What it is: Stress Corrosion Cracking (SCC) is dangerous because it can destroy a component at stress levels below the yield strength of an alloy. In the presence of chloride ions, austenitic stainless steels are susceptible to SCC. The ions interact with the material at the tip of a crack where tensile stresses are highest, making it easier for the crack to grow. While in progress, it can be difficult to detect, and final failure can occur suddenly.

How it forms: For SCC to occur, three conditions must be met simultaneously:

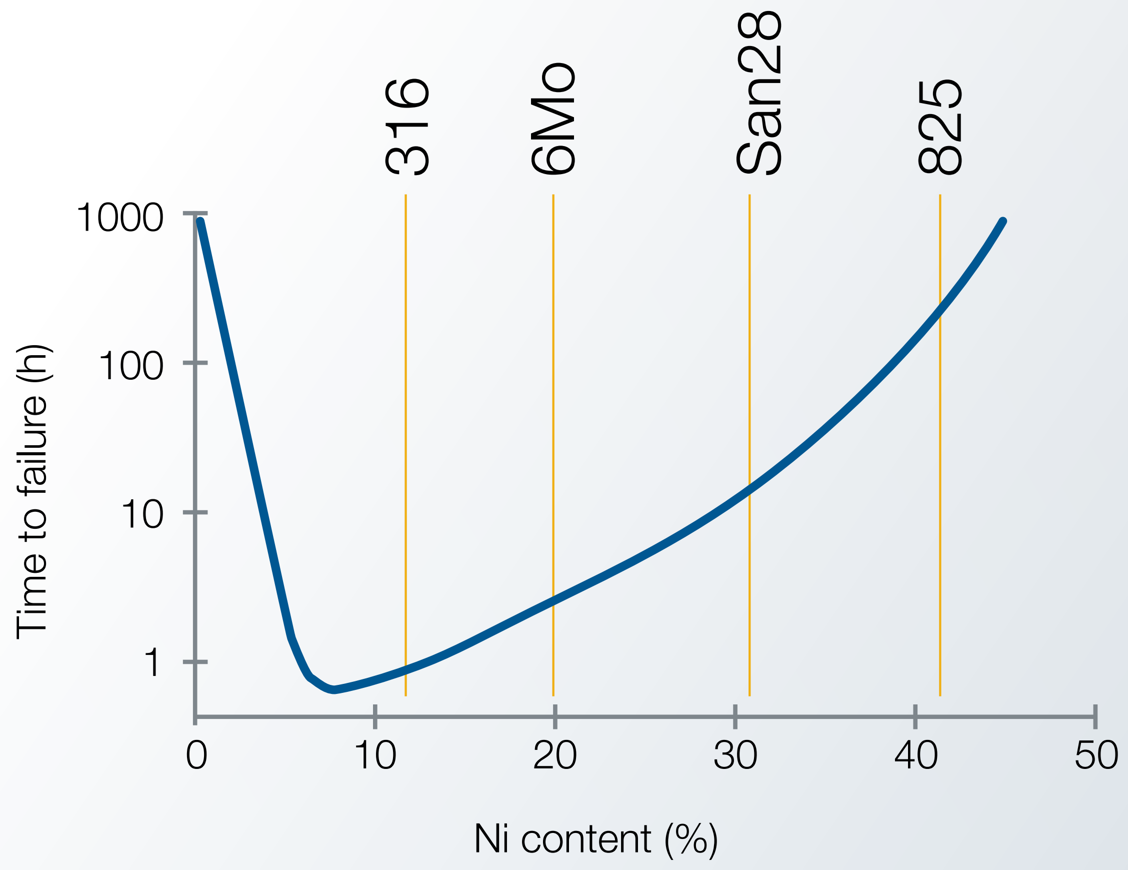
- The metal must be susceptible to SCC
- Environmental (fluid or temperature) conditions conducive to SCC must exist
- The tensile stress (applied + residual) must be above critical level

SCC-resistant materials include:

- Carbon steels
- Nickel-based alloys
- Duplex stainless steels



Higher nickel content shows higher resistance to chloride-induced SCC.



Material Matters: Learn more about selecting fluid system components for sour oilfields with Swagelok. Read the advice our leading expert has for *Offshore Magazine* readers.

See Potential Solutions: **316/316L Stainless Steel; 6-Moly Alloys; Engineered Combinations; Alloy 625**

Sour Gas or Sulfide Stress Cracking (SSC) Corrosion

Common in aging reservoirs where seawater has been injected for enhanced oil recovery, sour gas applications, sulfur-compound-rich environments

What it is: Stress Sour Gas Corrosion, also known as Sulfide Stress Cracking (SSC), is the deterioration of metal due to contact with hydrogen sulfide (H_2S) and moisture. H_2S becomes severely corrosive in the presence of water. This condition can lead to embrittlement of the material, resulting in cracking under the combined action of tensile stress and corrosion.

How it forms: For SSC to occur, three conditions must be met simultaneously:

- The metal must be susceptible to SSC
- The environment must be sufficiently sour (high in H_2S)
- The tensile stress (applied + residual) must be above a critical level

Increased risk for SSC occurs when greater amounts of the following occur, compared to materials less likely to experience SSC:

- Material hardness/tensile strength
- Hydrogen ion concentration (lower pH value)
- H_2S partial pressure
- Total tensile stress (applied + residual)
- Exposure time
- Lower-temperature environments

Material Matters: International standard MR0175/ISO 15156: Petroleum and Natural Gas Industries outlines suitable materials for sour environments in oil and gas production. And for more help selecting components for sour oilfields, refer to this article by Swagelok principal scientist Gerhard Schiroky as published in *Offshore Magazine*.

Reprinted from Science Direct, Volume 1, Issue 3, S.M.R. Ziaei, A.H. Kokabi, M. Nasr-Esehani, Sulfide Stress Corrosion Cracking and Hydrogen Induced Cracking of A216-WCC Wellhead Flow Control Valve Body case study, Pages 223-224, July 2013 with permission from Elsevier.

See Potential Solutions: 6-Moly Alloys; Alloy 2507; Engineered Combinations

Hydrogen Embrittlement[1]

Occurs when materials are subjected to tensile stress

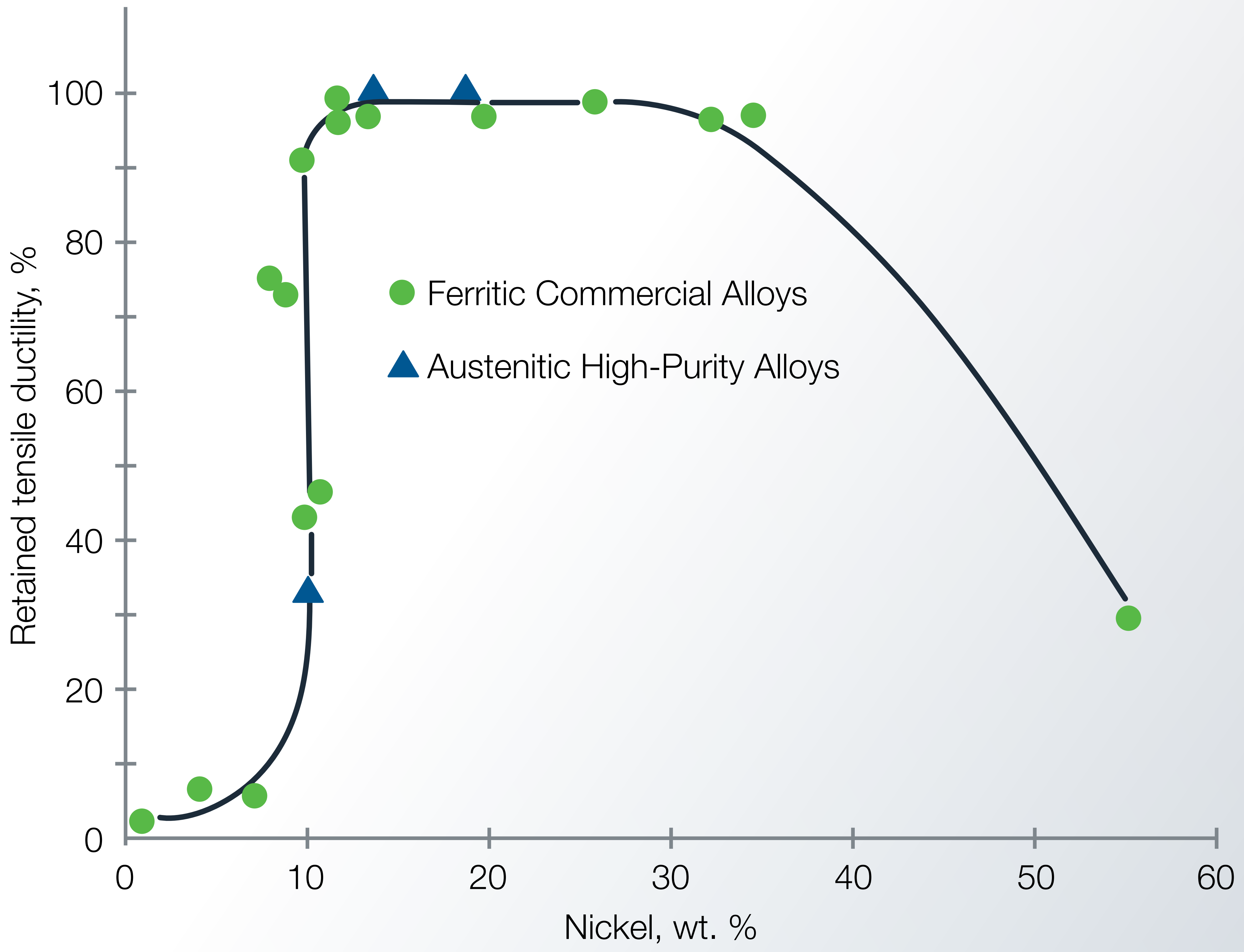
What it is: Hydrogen atoms can diffuse into metals, making them brittle. All materials susceptible to hydrogen embrittlement are very susceptible to stress corrosion cracking.

How it forms: Hydrogen-induced cracking can occur if the metal is subject to static or cyclic tensile stress.

Hydrogen can cause changes in the mechanical properties and behavior of the metal, including:

- Reduction of ductility (elongation and reduction of area)
- Reduction of impact strength and fracture toughness
- Increased fatigue behavior

Hydrogen embrittlement is not permanent, and can be reversed by selecting material resistant to hydrogen, such as austenitic alloys, or avoided by not using materials in a hydrogen-rich environment.



Ferritic alloys with very low nickel content (like the commercial alloys in the chart) become significantly embrittled, while austenitic alloys with nickel content between 10% and 30% (like the high-purity alloys in the chart) show relatively little embrittlement.

Source: G.R. Caskey, Hydrogen Compatibility Handbook for Stainless Steels (1983)

See Potential Solutions: 316/316L Stainless Steel; 6-Moly Alloys; Alloy 825

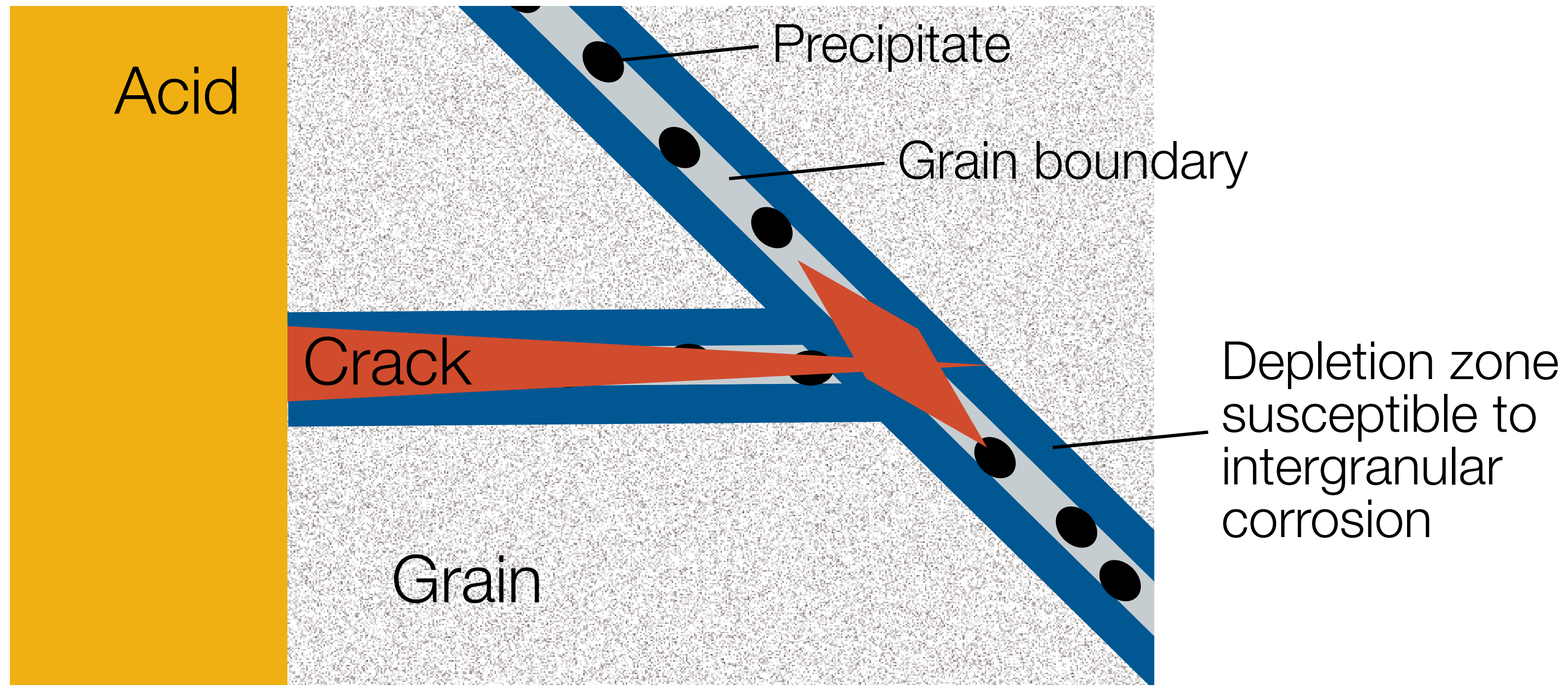
[1]Hydrogen Embrittlement Image Courtesy of Salim Brahimi, IBECA Technologies Corp.

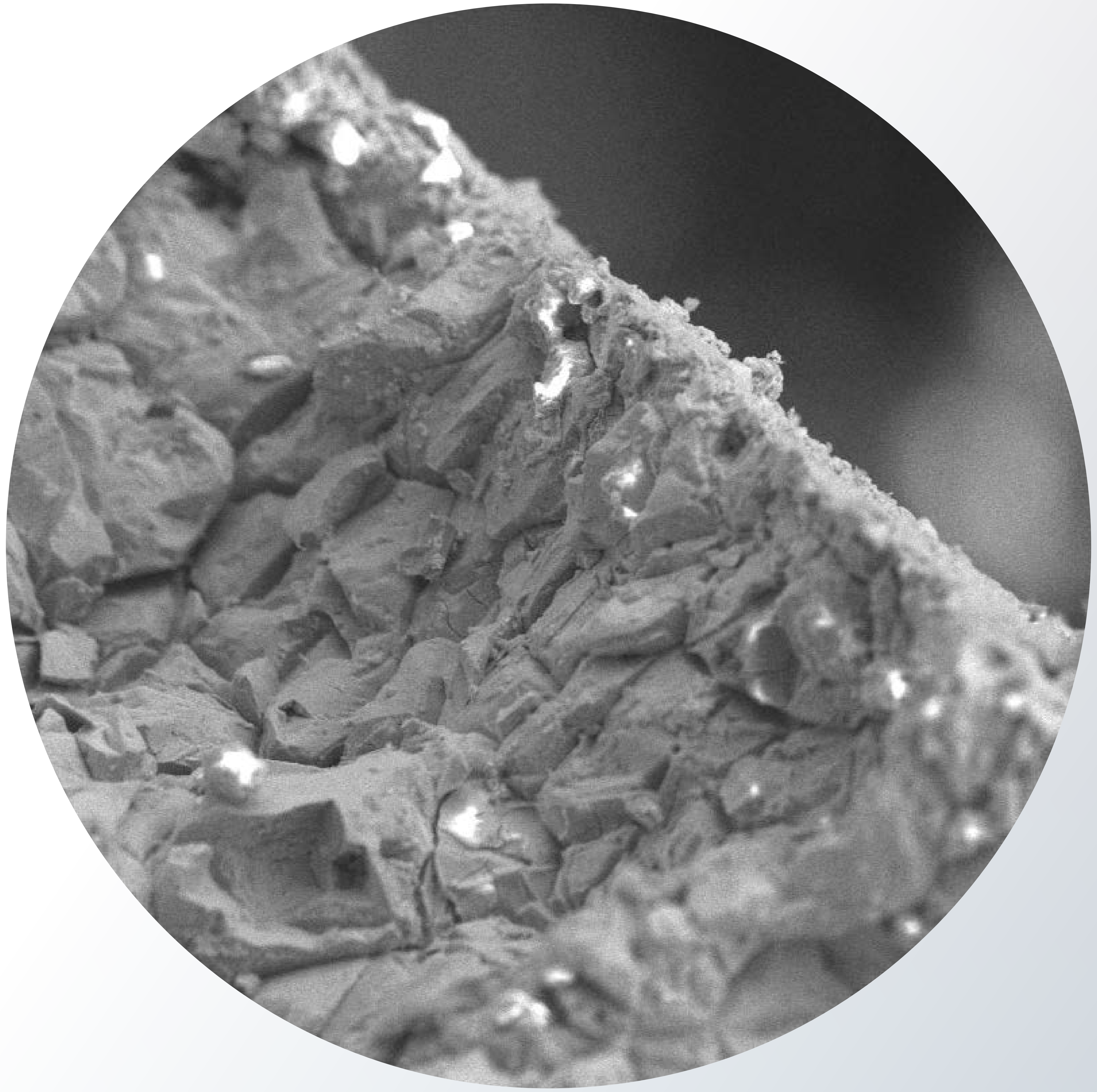
Intergranular Corrosion (IGC)

Common in welding operations, heat treatment, high-temperature applications

What it is: To understand IGC, consider that all metals consist of individual grains. Within each grain, the atoms are systematically arranged, forming a three-dimensional lattice. IGC attacks the material along the grain boundaries (where the grains that make up the metal come together).

How it forms: During welding, heat treatment, or exposure to high temperatures, compounds called carbides can build up along these boundaries, forming precipitate. This carbide formation affects the uniform distribution of elements within the metal by robbing material adjacent to grain boundaries of important elements, such as chromium. When corrosive fluids (like acids) attack the chromium-depleted regions, intergranular cracks can form. These cracks can propagate throughout a material and stay undetected, making IGC a dangerous form of corrosion.





See Potential Solutions: Stainless Steel Grades with Low Carbon Content, such as 316/316L; Titanium- or Nio-Stabilized Steels, such as 321 or 347

Galvanic Corrosion

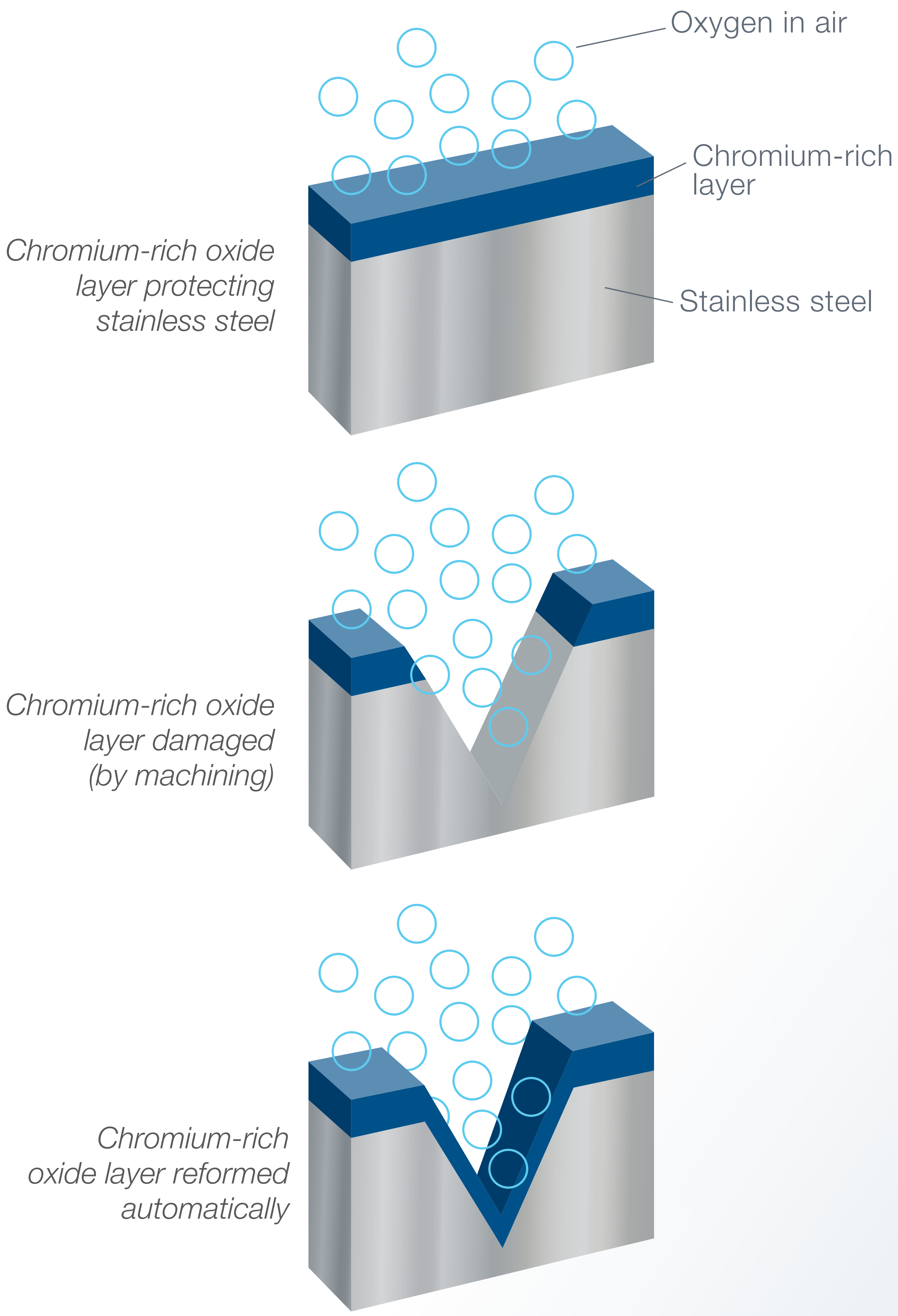
Can occur when the potential voltage difference between two materials is too high

What it is: Galvanic corrosion occurs when materials with a dissimilar electrode potential are in contact in the presence of an electrolyte. A passive surface, or layer, on stainless steel is a chromium-rich oxide layer that automatically forms on the surface in ambient air and protects the material from corrosion. The passive layer makes a material more noble and less susceptible to corrosion. The compatibility of metals can be determined by the Anodic Index, which describes the potential or voltage difference of metals measured in seawater against a standard electrode.

How it forms: When the potential difference between two dissimilar metals in the presence of an electrolyte is too great, the material's passive layer begins to break down.

To avoid galvanic corrosion, choose materials with a voltage difference that does not exceed 0.2V. For example, a 316 stainless steel fitting (-0.05V) with 6-Moly tubing (0.00V) would result in a voltage of 0.05V between the two alloys. This voltage is significantly less than 0.2V, meaning the risk of galvanic corrosion is low.

See Galvanic Chart



Volts vs. SCE		Material
-1.60	Active	Magnesium
-1.00		Zinc
-0.95		Aluminum
-0.70		Cadmium
-0.60		Steel
-0.50		Type 304 (Active)
-0.40		Type 316 (Active)
-0.35		Naval Brass
-0.30		Muntz Metal
-0.30		Copper
-0.30		Manganese Bronze
-0.25		90-10 Cu-Ni
-0.20		70-30 Cu-Ni
-0.20		Lead
-0.15		Nickel
-0.10		Type 304 (Passive)
-0.05		Type 316 (Passive)
0.00		E-BRITE® Alloy
0.00		AL 29-4C® Alloy
0.00		AL-6XN® Alloy
0.05		Alloy 625, Alloy 276
.010	Noble	Titanium
.025		Graphite

SCE stands for Standard Calomel Electrode.

Anodic Index
Highly noble materials with "passive surfaces" are not as susceptible to galvanic corrosion as less noble materials or as noble materials with "active surfaces." In this chart, magnesium is the least noble material, and graphite is the most noble material.

See Potential Solutions: Materials with voltage difference less than 0.2V

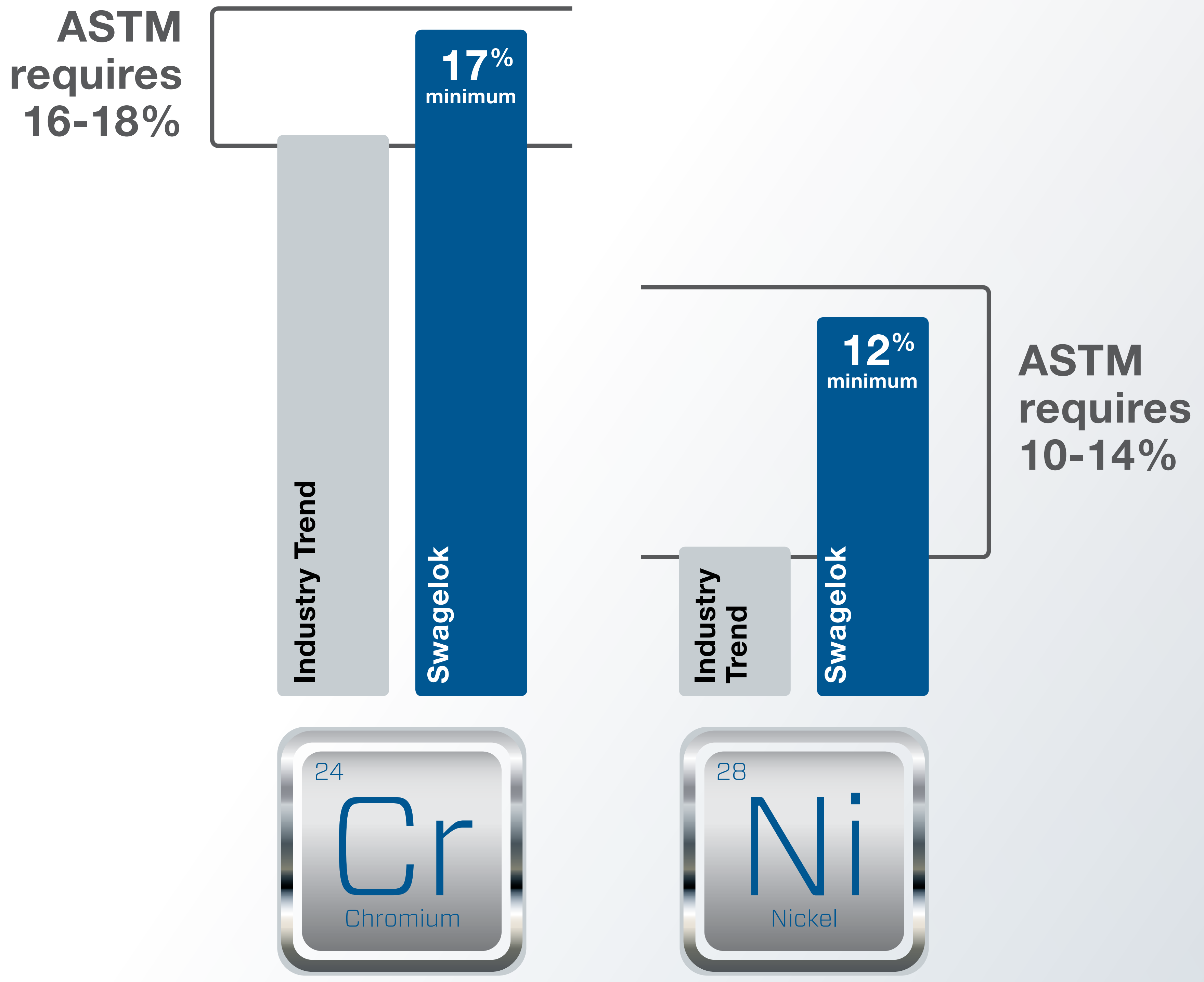
Stainless Steel

316 Stainless Steel

In all stainless steels, chromium and nickel are critical for corrosion resistance and ductility. The addition of >10% chromium transforms steel into stainless steel, creating an adherent and invisible oxide layer that is chromium-rich. This oxide layer forms when chromium in the alloy reacts with oxygen in ambient air. This layer gives steel its stainless character. The addition of nickel provides good ductility and ease of forming and welding.

But not all bar stock is the same. Swagelok materials contain more than minimum requirements, and in some cases, more than industry trends, of both chromium and nickel.

Note that although stainless steels will not suffer from general corrosion, they can be affected by localized corrosion.



Swagelok 316 stainless steel exceeds minimum ASTM specifications.

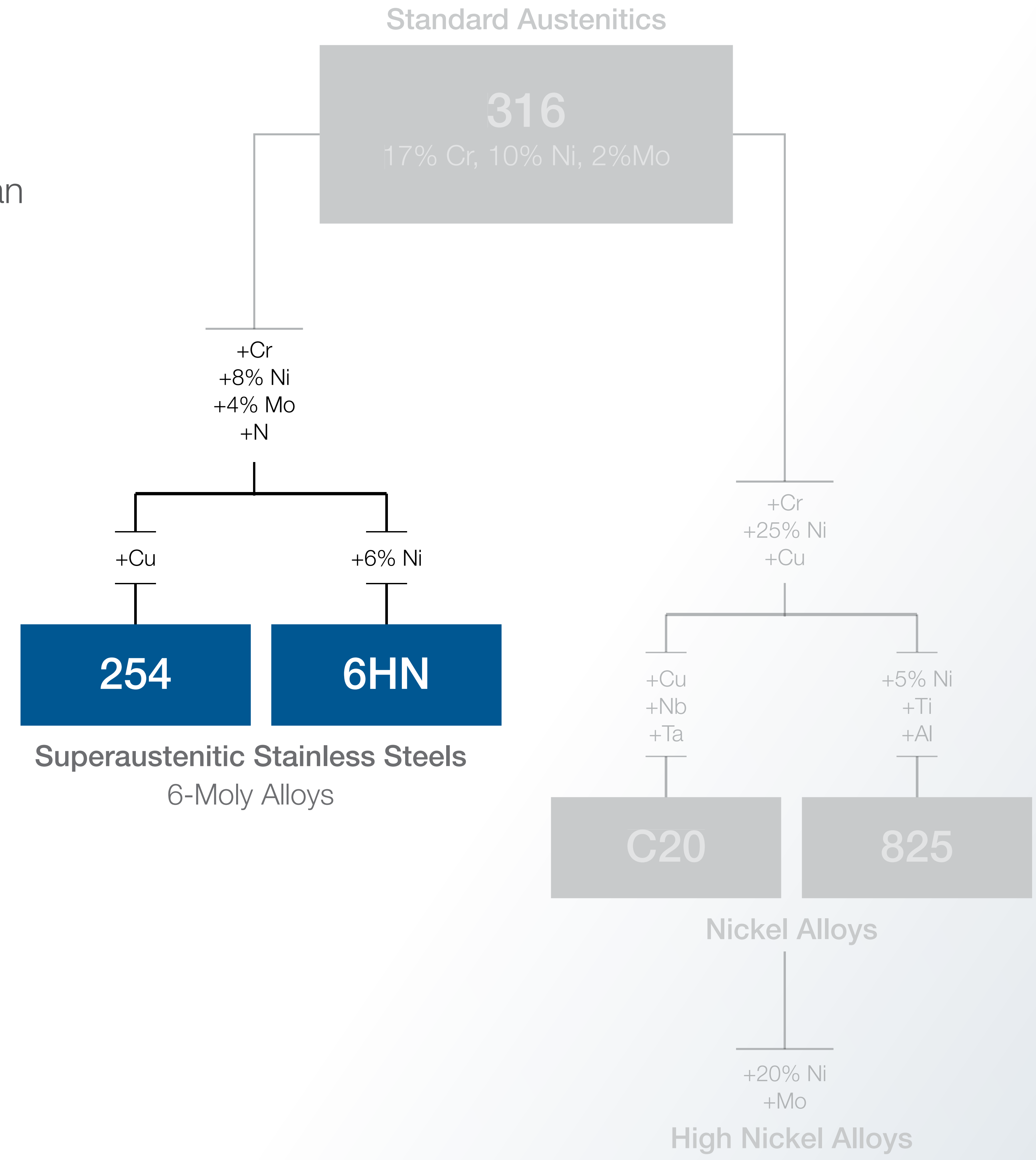
Material Matters: The risk of Stress Corrosion Cracking (SCC) increases when chloride concentrations, temperatures, and tensile stress are high.
No stainless steel is completely immune to SCC. We have performed SCC testing on pressurized tube fittings with exceptional results. *See the test results.*

Stainless Steel

6-Moly

With 6-Moly (6Mo) alloys such as 6HN, and 254, the addition of enhanced levels of chromium, molybdenum, and nickel results in greatly improved resistance to pitting and crevice corrosion in chloride-rich environments. 6HN has a higher nickel (Ni) content than 254, increasing corrosion resistance. These alloys are termed superaustenitic stainless steels because they contain at least 6% molybdenum.

- Resistant to chloride pitting and crevice corrosion
- Resistant to CSCC
- 50% stronger than 300-series austenitic stainless steels
- Impact toughness, workability, and weldability
- Available with NACE MR0175 compliance
- Available with NORSOK-approved supply chain qualification standard M-650



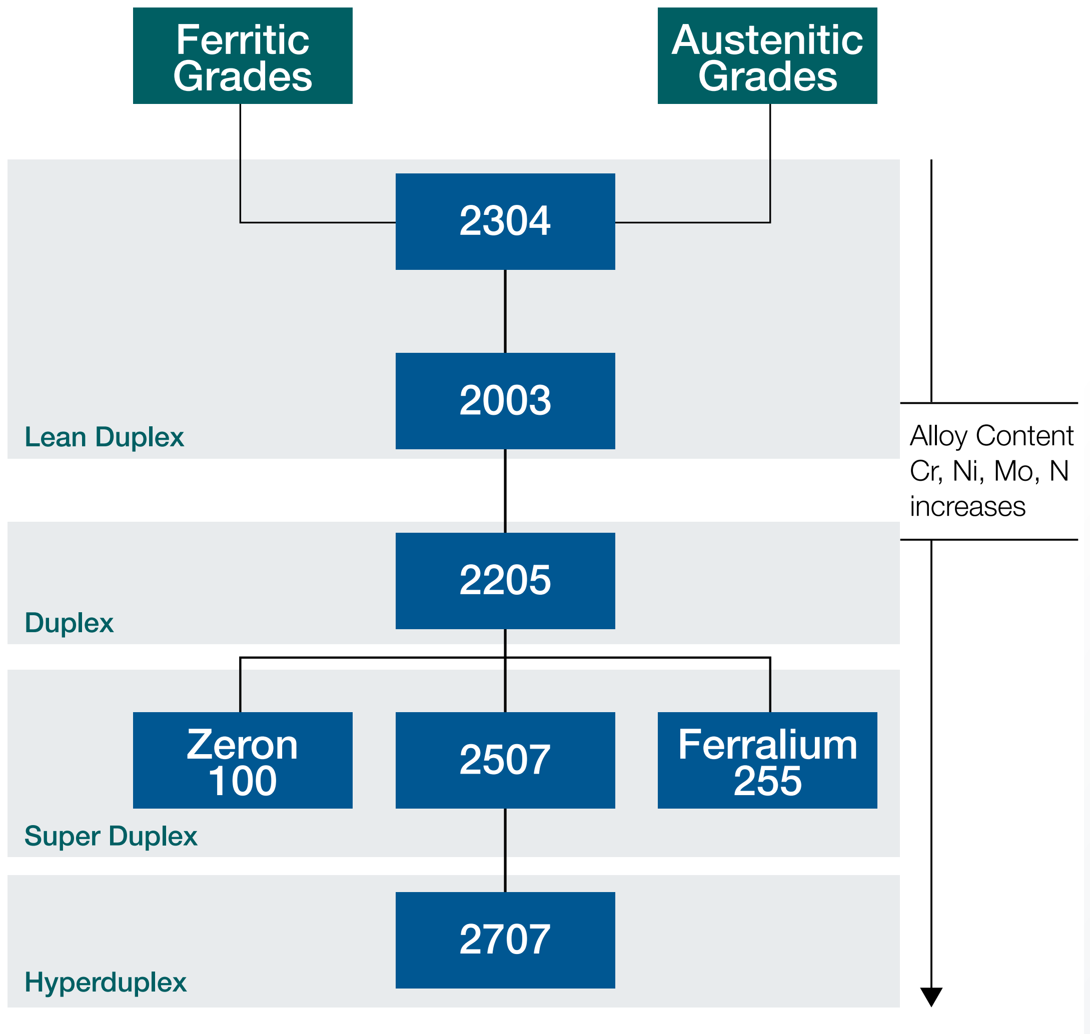
Stainless Steel

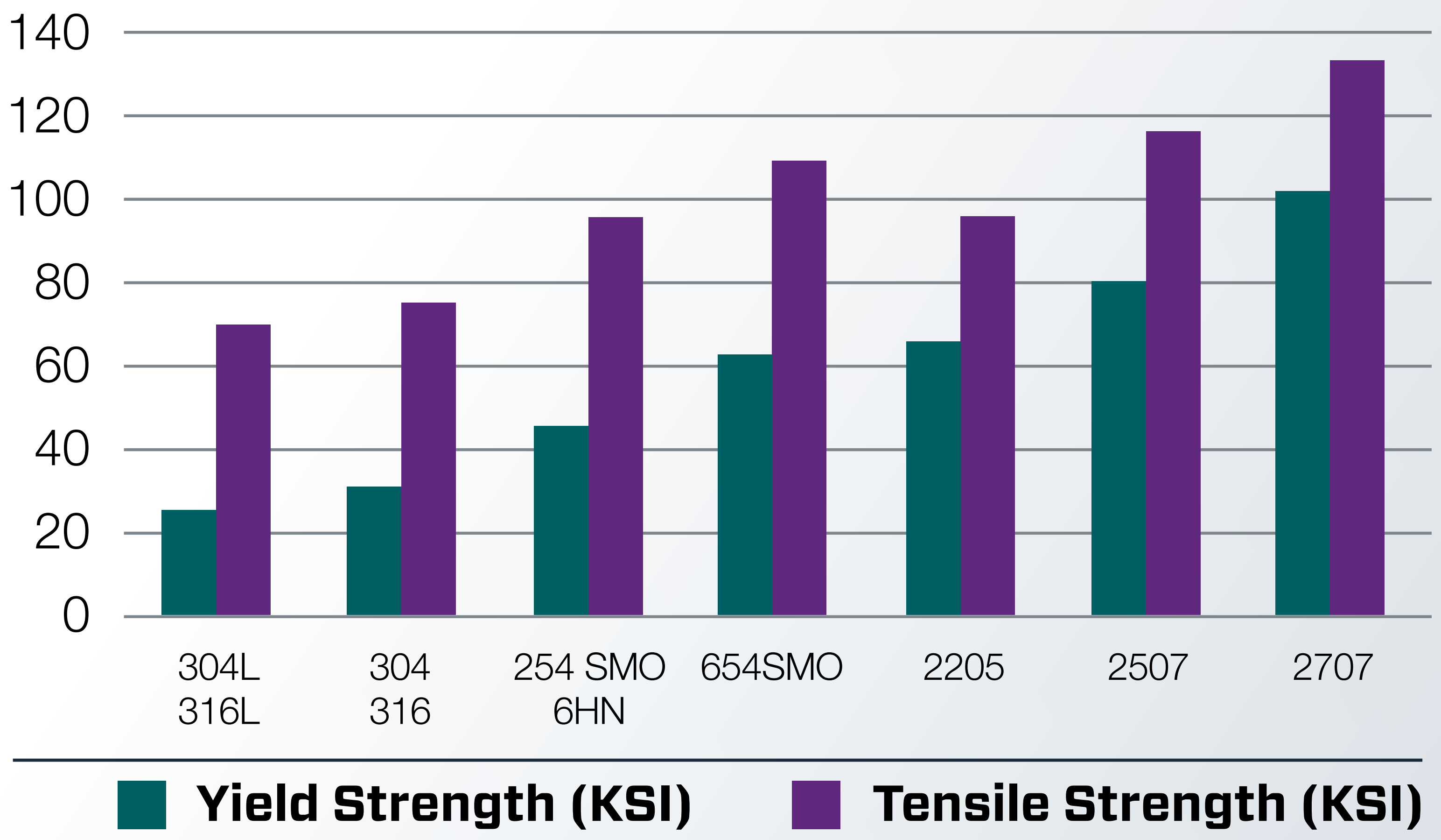
2507 Super Duplex Stainless Steel

Duplex stainless steels have a two-phase microstructure of austenite and ferrite grains. This structure gives these materials a combination of attractive properties, including strength, ductility, and corrosion resistance.

2507 Super Duplex, ferritic-austenitic stainless steel is well-suited for service in highly corrosive conditions. Its composition includes nickel, molybdenum, chromium, nitrogen, and manganese, offering excellent resistance to general corrosion, pitting, and crevice corrosion, and SCC, while maintaining weldability.

- Mechanical strength for higher tube pressure ratings
- Thinner-wall, higher-flow tube required to maintain pressure rating
- Weldability
- Applications up to 482°F (250°C)
- Higher thermal conductivity/lower coefficient of thermal expansion than 316SS
- Available with NACE MR0175 compliance
- Available with NORSOK-approved supply chain qualification standard M-650





Mechanical strength makes 2507 ideal for high-pressure offshore applications and subsea systems where corrosion, fluid flow, and weight are of concern.

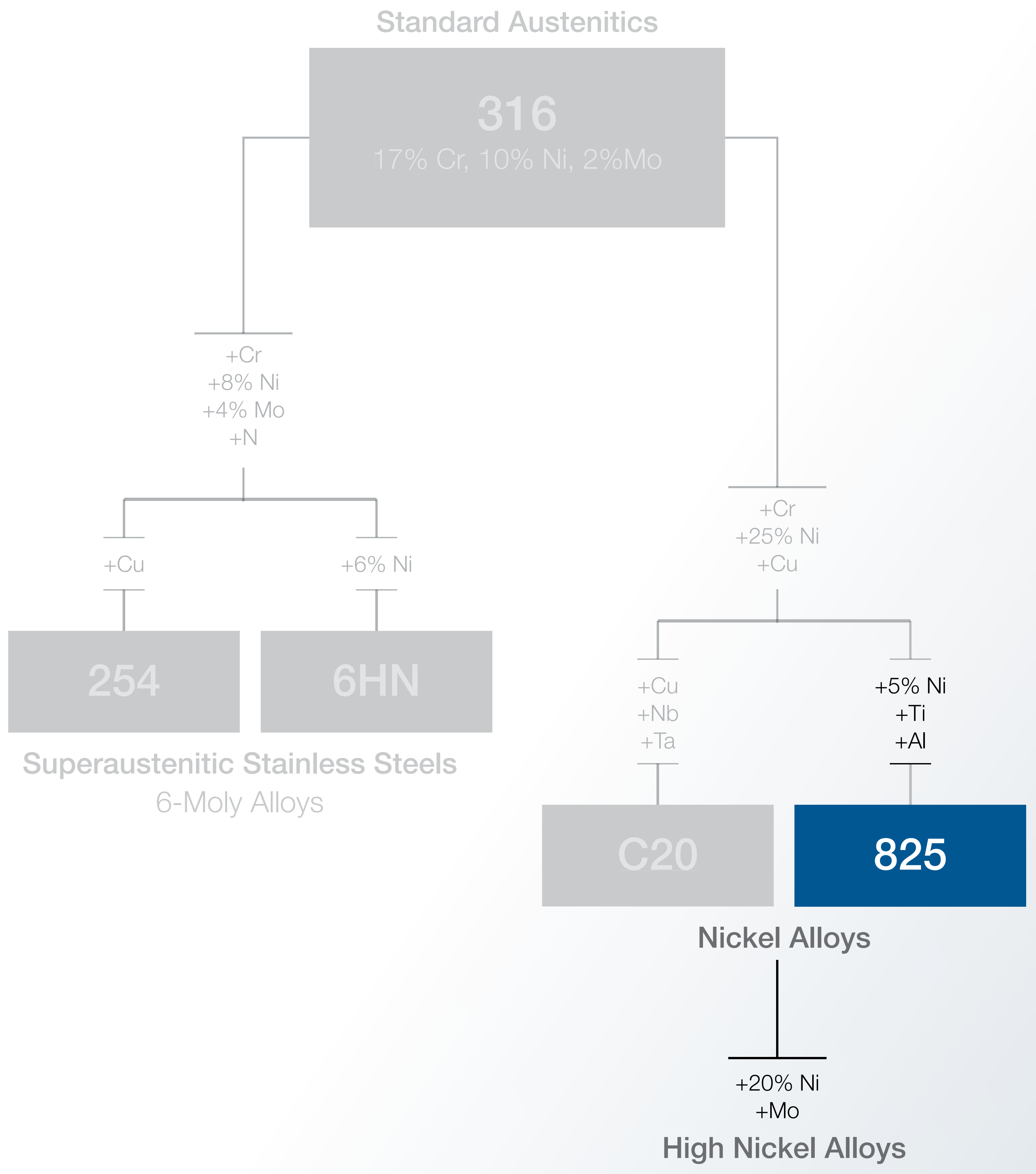
For Fighting: **General Corrosion; Localized Corrosion; Stress Corrosion Cracking; Sour Gas Corrosion; Intergranular Corrosion**

Nickel Alloys

Alloy 825

Alloy 825 (Incoloy® 825) is a nickel-iron-chromium-molybdenum alloy designed to resist general corrosion, pitting, and crevice corrosion, as well as Stress Corrosion Cracking, in a wide range of media.

- Stabilized with titanium (resistant to intergranular corrosion)
- Resistant in sour gas applications (NACE MR0175)
- Resistant in reducing environments (i.e., sulfuric or phosphoric acid)



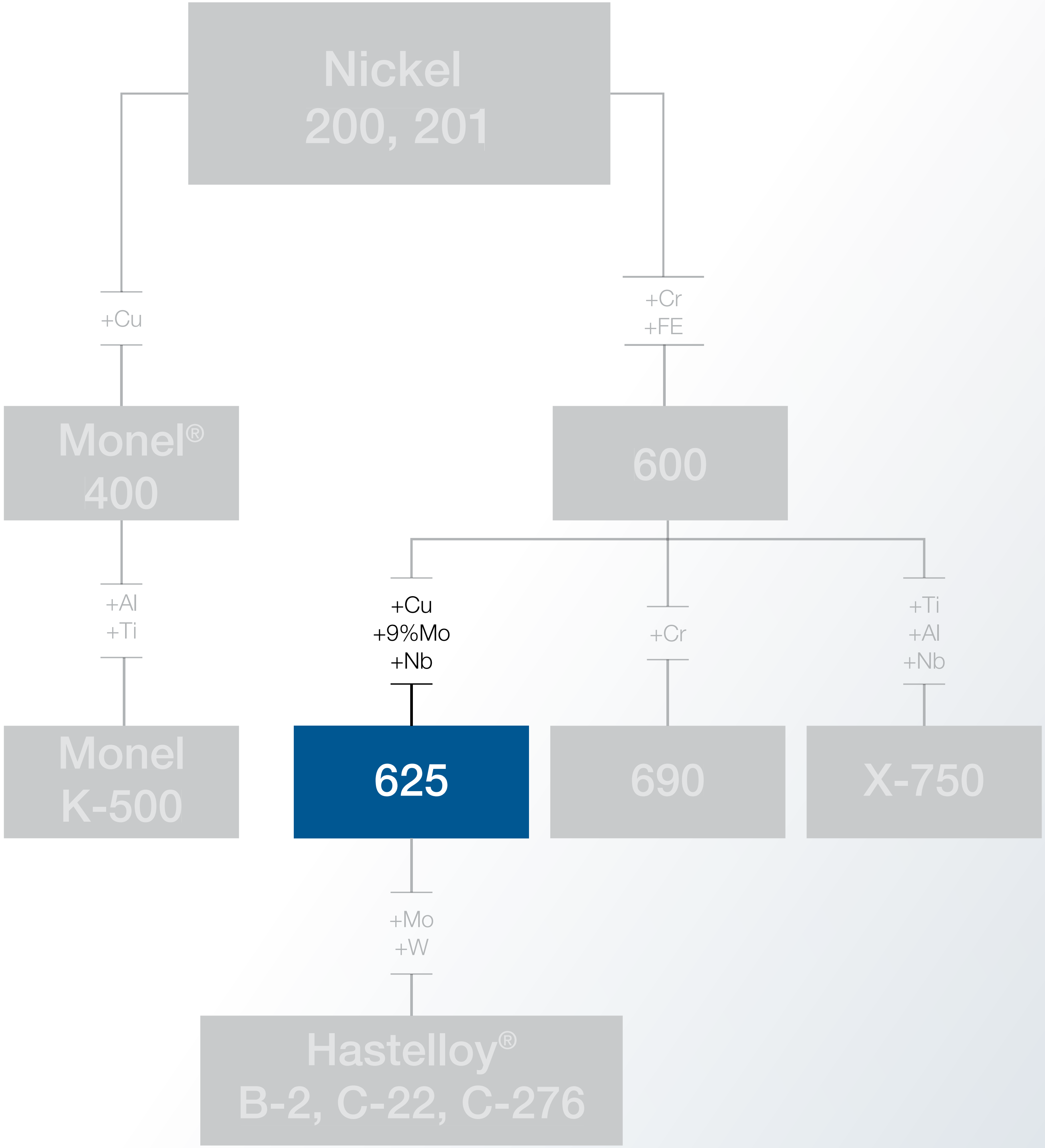
For Fighting: Stress Corrosion Cracking; Sour Gas Corrosion; Intergranular Corrosion

Nickel Alloys

Alloy 625

Alloy 625 (Inconel® 625) is a nickel-chromium-molybdenum alloy with a small quantity of niobium [Nb] to reduce the risk of intergranular corrosion in a wide variety of severely corrosive environments.

- Resistance to hydrochloric and nitric acids
- Strength and ductility
- Resistance to crevice and pitting corrosion in high-temperature use
- Suitability for sour gas applications (NACE MR075)



For Fighting: General Corrosion; Localized Corrosion; Stress Corrosion Cracking; Sour Gas Corrosion; Intergranular Corrosion

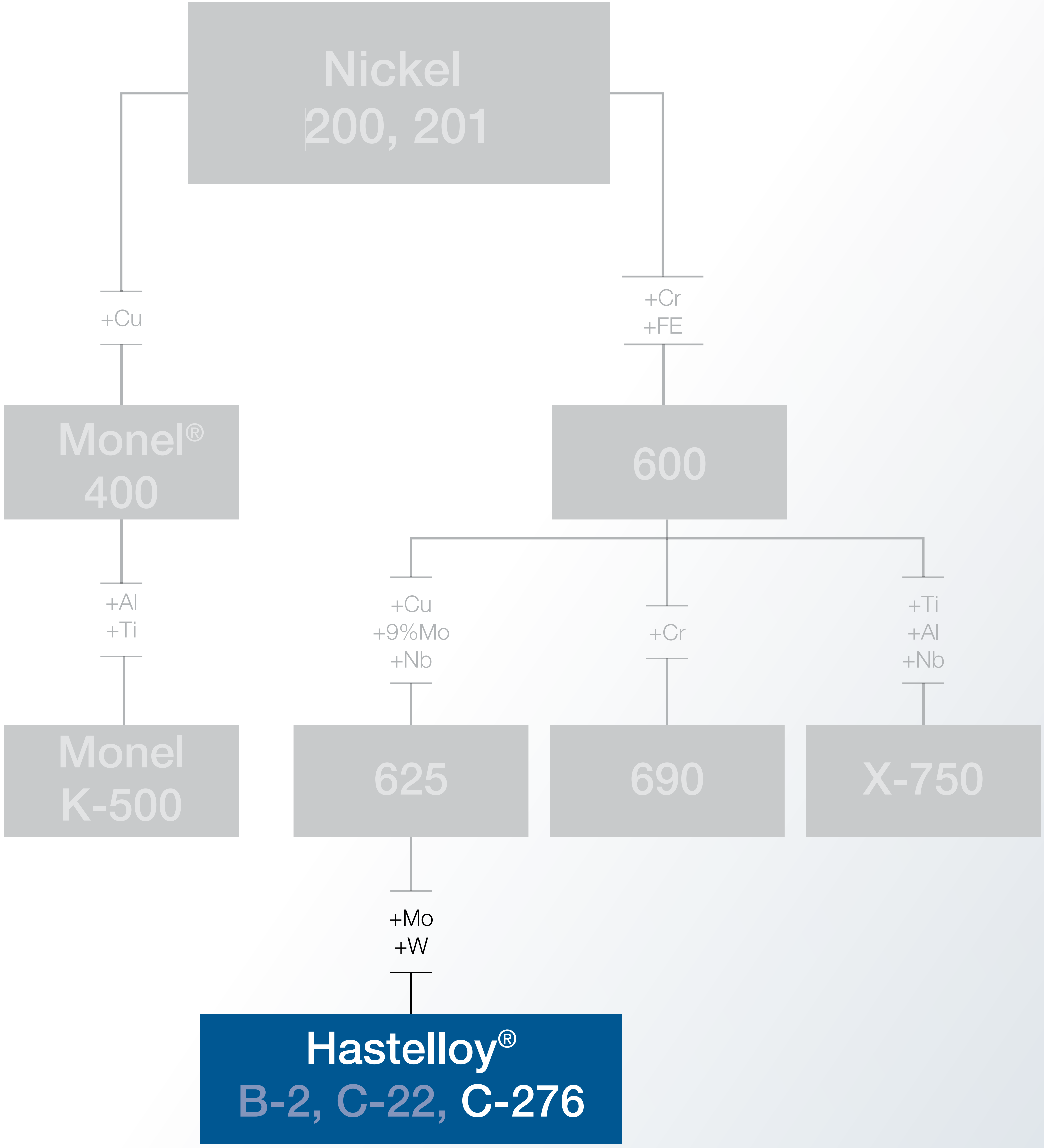
Nickel Alloys

Alloy C-276

Alloy C-276 (Hastelloy® C-276) contains nickel, molybdenum, and chromium. Its high molybdenum content makes it exceptionally resistant to pitting and crevice corrosion, and it is one of only a few materials that can withstand the corrosive effects of wet chlorine gas, hypochlorite, and chlorine dioxide.

- Resistance to oxidizing and reducing media
- Ductility, toughness, and strength at high temperatures
- Resistance to crevice and pitting corrosion, SSC, and IGC
- Suitability for sour gas environments

Note that this alloy is NOT recommended with highly oxidizing environments, such as hot and concentrated nitric acid.



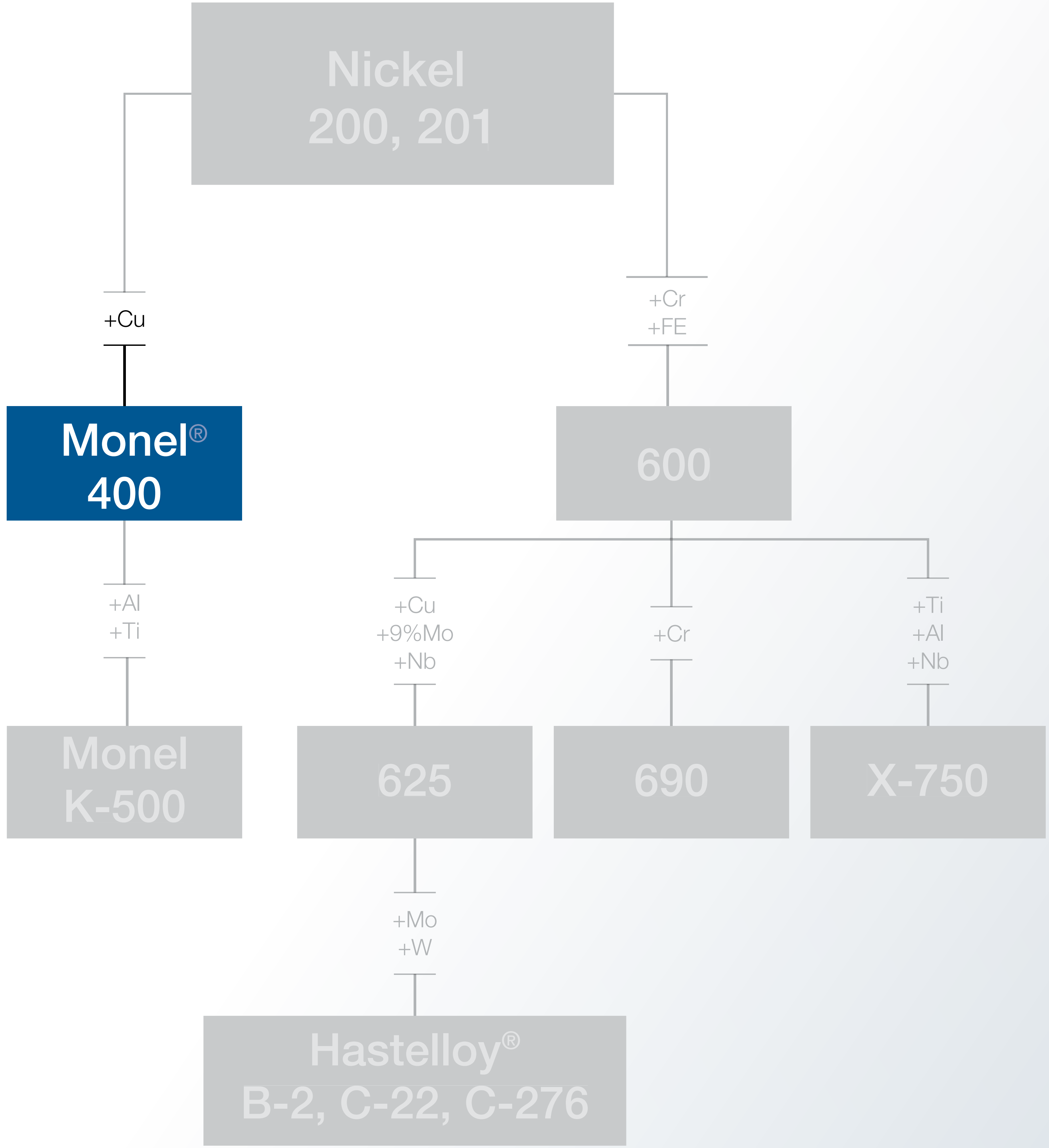
Nickel Alloys

Alloy 400

Alloy 400 (Monel® 400) is a nickel-copper alloy known for its exceptional resistance to hydrofluoric acid, as well as resistance to stress corrosion cracking and pitting in most fresh and industrial waters.

- Strength and corrosion resistance in a wide range of temperatures and media
- Mechanical properties retained at subzero temperatures

Note that stagnant seawater has been shown to induce crevice and pitting corrosion in this alloy.



Other Alloys

Titanium Alloys

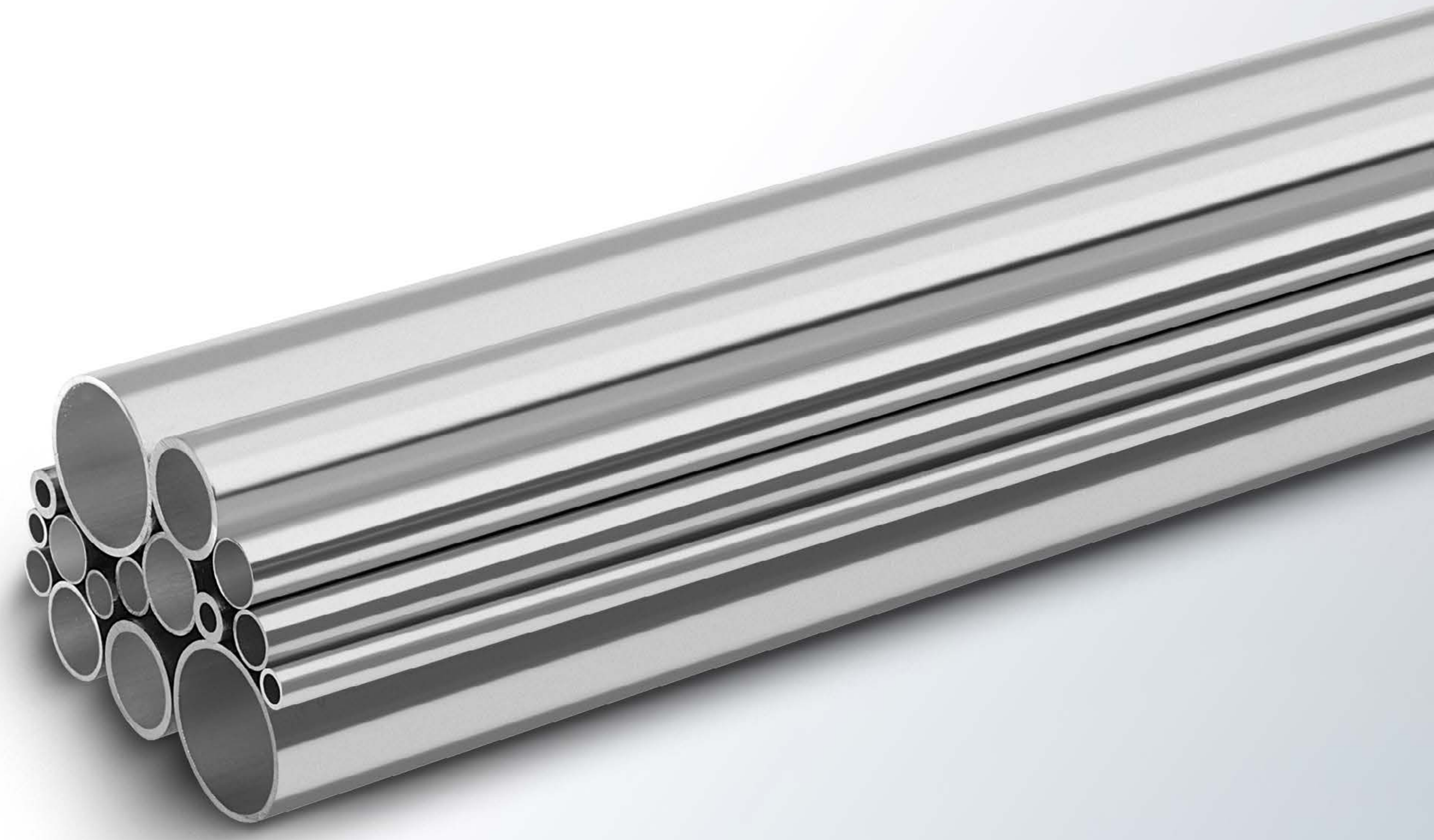
Titanium alloys have excellent resistance to corrosion in a wide variety of environments, including seawater, salt brines, inorganic salts, bleaches, wet chlorine, alkaline solutions, oxidizing acids, and organic acids where they generally outperform stainless steels.

Titanium is especially resistant to the following:

- Crevice corrosion
- Fatigue and cracking at moderate heat
- Creep (the tendency of a solid material to move slowly or deform permanently under the influence of mechanical stresses)

Note that unalloyed titanium (Grades 1, 2, 3, and 4) typically is not resistant to crevice corrosion at temperatures below 80° C (175° F).

Due to its combustibility, titanium is NOT suitable for oxygen service. It is also incompatible with fluorides, strong reducing acids, very strong caustic solutions, and anhydrous chlorine.



For Fighting: Localized Corrosion

Engineered Combinations

Engineered Combinations

Elevated chromium and nickel levels in Swagelok fittings, plus the unique low-temperature carburization process used to make our ferrules, mean we can offer engineered combinations as a rated alternative to full exotic alloy solutions in certain applications. Engineered combinations use Swagelok standard 316 stainless steel tube fittings with a variety of alloy tubing options. This can be a cost-efficient, corrosion-resistant solution for installations exposed to seawater that provides these advantages:

- Higher alloy content than required per ASTM A479
    - High chromium content (17.5% average vs. 16.0% required)
    - High nickel content (12.2% average vs. 10.0% required)
- Higher resistance to pitting corrosion
- Unique SAT 12 low-temperature carburization process provides superior tube grip, for use on alloys
- Increased resistance to hydrogen embrittlement
- Increased overall corrosion resistance
- Low risk of galvanic corrosion based on Anodic Index

As with any mixed-material assembly, pressure ratings for tubing and fittings from different alloys will be governed by the lower material rating.

How Corrosion Resistance is Calculated

PREN = %Cr + 3.3x%Mo + 16x%N

ASTM 316 = 16 + 3.3 x 2 + 16 x 0.03 = 23.1 PREN

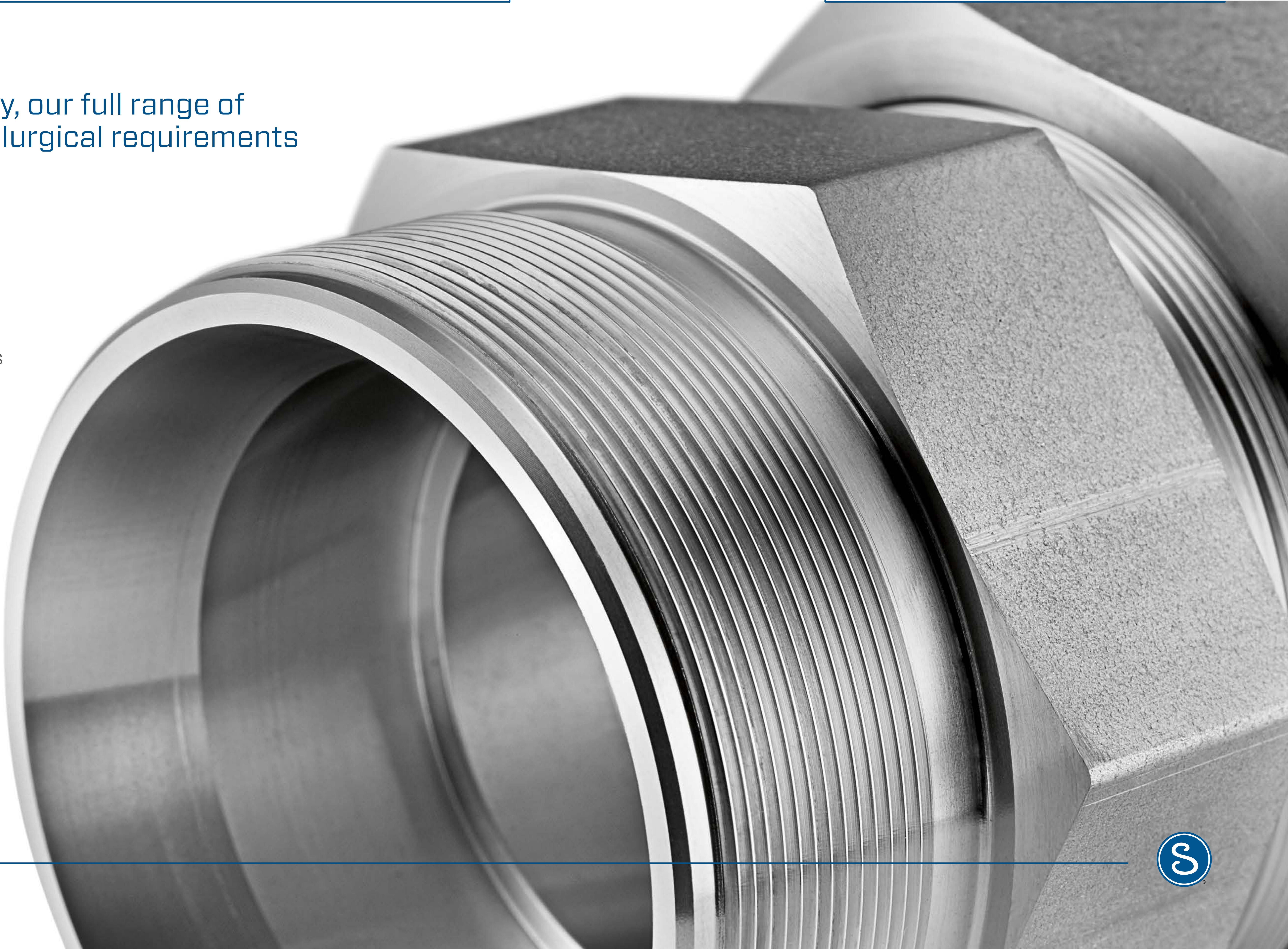
Swagelok 316 = 17.5 + 3.3 x 2 + 16 x 0.03 = 24.6 PREN

Pitting Resistance Equivalent Number (PREN) is the measurement of resistance to localized pitting corrosion. Higher PREN values indicate greater pitting corrosion resistance.

To ensure quality and consistency, our full range of materials is compliant with metallurgical requirements of NACE and NORSOK standards.

Learn more about:

- › NACE requirements
- › NACE MR0175/ISO 15156 Overview
- › NACE Requirements for Super Duplex Tube Fittings
- › NACE Requirements for Alloy 625
- › NACE Requirements for Alloy 625 Standard and Medium-Pressure Tube Fittings
- › NACE Requirements for Alloy 6Mo Tube, Pipe, and Weld Fittings
- › NORSOK Standards



NACE Requirements

The NACE MR0175/ISO 15156 standard lists prequalified materials for use in upstream oilfield equipment where sulfide-induced stress corrosion cracking may be a risk in sour environments, i.e., in oil/gas/seawater mixtures where hydrogen sulfide (H_2S) is present.

The standard allows the use of tube fittings produced from cold-drawn 316 Stainless Steel and 6-Moly, respectively, in instrumentation and control systems. Nickel alloys can also be used in strain-hardened condition for instrumentation and control systems, and to handle process fluids.

The document includes:

- Requirements for material condition and properties
- Environmental conditions for use of the materials
- Qualifications for material use under specific sour gas conditions

Read more about NACE

Material Matters: Read more about selecting fluid system components for sour oilfields in *Offshore Magazine*.

NACE MR0175/ISO 15156 Overview

Alloy	Condition of Alloy	Applicable NACE Table	Application	Maximum Temperature, °C (°F)	Maximum H2S Partial Pressure①, kPa (psi)
6Mo (254, 6HN)	Solution-annealed and cold-drawn	A.11	Instrument tubing, control-line tubing, and compression fittings	No restrictions; Refer to NACE MR0175/ISO 15156 for cautionary remarks.	
	Solution-annealed	A.8	Any equipment or component	60 (140)	100 (15)
625	Annealed and cold-drawn	A.14		232 (450)	200 (30)
				218 (425)	2000 (300)
				149 (300)	any
	Solution-annealed or annealed	A.13		No restrictions; Refer to NACE MR0175/ISO 15156 for cautionary remarks.	
2507	Solution-annealed and cold-drawn	Not NACE-compliant		N/A	
	Solution-annealed	A.24		232 (450)	20 (3)

① H_2S partial pressure is the pressure contribution of hydrogen sulfide gas to the total pressure. Example, for partial pressure: Air consists of 21% oxygen; if the total air pressure is 1.00 atm, then the partial pressure of oxygen is 0.21 atm.

Consult ANSI/NACE MR0175/ISO 15156 for detailed information on the environmental limits of alloys.

Read more about NACE

NACE Requirements for Super Duplex Tube Fittings

For a Swagelok Alloy 2507 tube fitting to function correctly, the nut and ferrules must be made from cold-drawn bar stock. This material has the strength necessary to grip to 2507 tubing (which has a high surface hardness) and to hold to the high working pressures listed in Swagelok Tubing Data, MS-01-107.

Swagelok 2507 tube fittings with ordering numbers having the -SG2 designator meet NACE MR0175/ ISO 15156 requirements for use in any equipment, according to Table A.24 of the standard, if the fittings are wetted internally, but not externally, by sour gas.

NACE MR0175/ ISO 15156 standard:

- Straight tube fitting bodies are produced from solution annealed Alloy 2507 bar stock
- Shaped tube fitting bodies are produced from solution-annealed Alloy 2507 forgings
- External threads of a tube fitting body that are not wetted by the system fluid may be produced by thread rolling
- Internally wetted threads are cut
- Tube fitting nuts are produced from cold-drawn 2507 bar stock but are not wetted by the system fluid
- Back ferrules are produced from cold-drawn 6-Moly bar stock but are not wetted by the system fluid
- Front ferrules are produced from cold-drawn 2507 bar stock
- Nose of the front ferrule comprises a wetted surface; it is under compression and, therefore, not subject to SCC or sour gas cracking, as the standard states a tensile stress component is required to enable these cracking modes
- Port connectors and plug inserts are produced from solution-annealed Alloy 2507 bar stock

Material Matters: For more information, access Swagelok's full data sheet Alloy 2507 Super Duplex Tube, Pipe, and Weld Fittings NACE MR0175 Compliant, MS-06-115.

Read more about NACE

NACE Requirements for Alloy 625

For solid-solution nickel-based alloys, the NACE MR0175/ISO 15156 sour gas standard Table A.13 and Table A.14 describe material requirements and limits for operating conditions for use in any equipment:

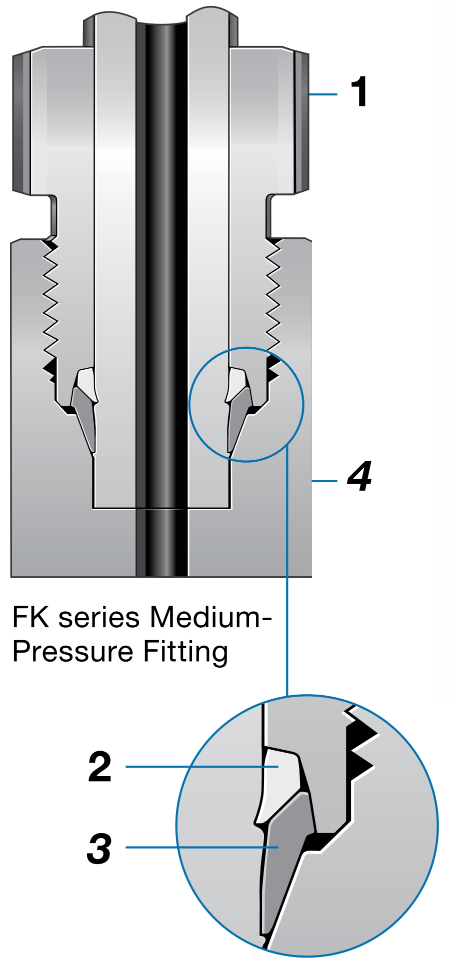
Table A.13 specifies the use of annealed or solution-annealed material but does not provide limits for maximum-use temperature and hydrogen sulfide partial pressure

Table A.14 allows the use of cold-worked material and states maximum use temperatures and hydrogen sulfide partial pressures.

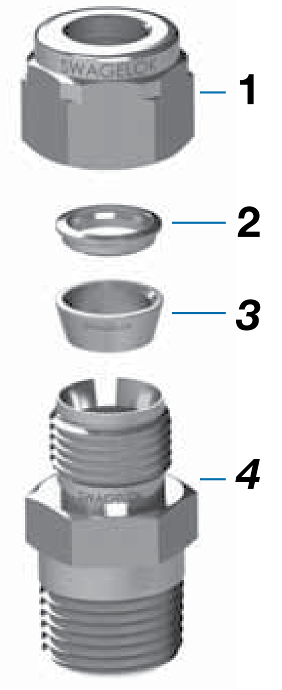
Standard Swagelok 625 tube, medium pressure, pipe, and weld fittings meet the requirements as listed in Table A.14

Read more about NACE

Materials of Construction, Alloy 625 Tube Fittings for Sour Gas Applications Requiring Compliance with Table A.13



FK series Medium-Pressure Fitting



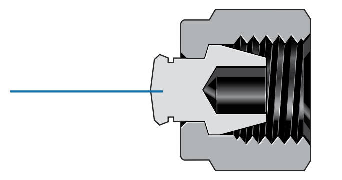
Standard Tube Fitting

Component	Material	ASTM Specification	Marking
1 Nut	Alloy 625 cold-drawn, hardness 40 HRC max	B446[1]	"625" on face
2 Back ferrule	Alloy 625 cold-drawn, hardness 40 HRC max	B446[1]	"625" on outer rim
3 *Front ferrule*	*Alloy 625 cold-drawn, hardness 40 HRC max*	*B446[1]*	*"625" on outer rim*
4 *Body*	*Alloy 625, annealed (Grade 1)*	*Straight body: B446* *Shaped body: B564*	*Tube & pipe fitting: "625" on neck, "SG" on body* *Weld fitting: "625" and "SG" on body*

Wetted components listed in *italics*

[1] B446 (except elongation)

Materials of Construction, Alloy 625 Plugs and Port Connectors for Sour Gas Applications Requiring Compliance with Table A.13



Plug for standard fitting shown

Port Connector for standard fittings 1 in./25 mm and under shown

Component	Material	ASTM Specification	Marking
5 *Plug*	*Alloy 625, annealed (Grade 1)*	*B446*	*"625" on outer rim*
6 *Port Connector*	*Alloy 625, annealed (Grade 1)*	*B446*	*"625" on tube diameter*

Wetted components listed in *italics*

Material Matters: For more information, access Swagelok's full data sheet Alloy 625 Tube, Medium-Pressure, Pipe, and Weld Fittings NACE MR0175 Table A. 13 Compliant, *MS-06-0119*.

NACE Requirements for Alloy 625 Standard and Medium-Pressure Tube Fittings

For a Swagelok Alloy 625 tube fitting and medium pressure tube fitting to function correctly, the nut and ferrules must be made from cold-drawn bar stock.

This material has the strength necessary to grip to 625 tubing and to hold to the high working pressures listed in Swagelok Tubing Data, MS-01-107 and Swagelok Medium and High-Pressure Fittings and Adapters—Special Alloy Materials, MS-02-474.

In compliance with the NACE MR0175/ ISO 15156 standard:

- Straight fitting bodies are produced from annealed bar stock
- Shaped fitting bodies are produced from annealed forgings or annealed bar
- Nuts are produced from solution-annealed and cold-drawn bar, but are not wetted by the system fluid
- Back ferrules are produced from solution-annealed and cold-drawn bar, but are not wetted by the system fluid
- Front ferrules are produced from solution-annealed and cold-drawn bar
- Nose of the front ferrule comprises a wetted surface; it is under compression and, therefore, not subject to SCC or sour gas cracking, as the standard states a tensile stress component is required to enable these cracking modes
- Plugs, port connectors, and tube adapters are produced from annealed bar

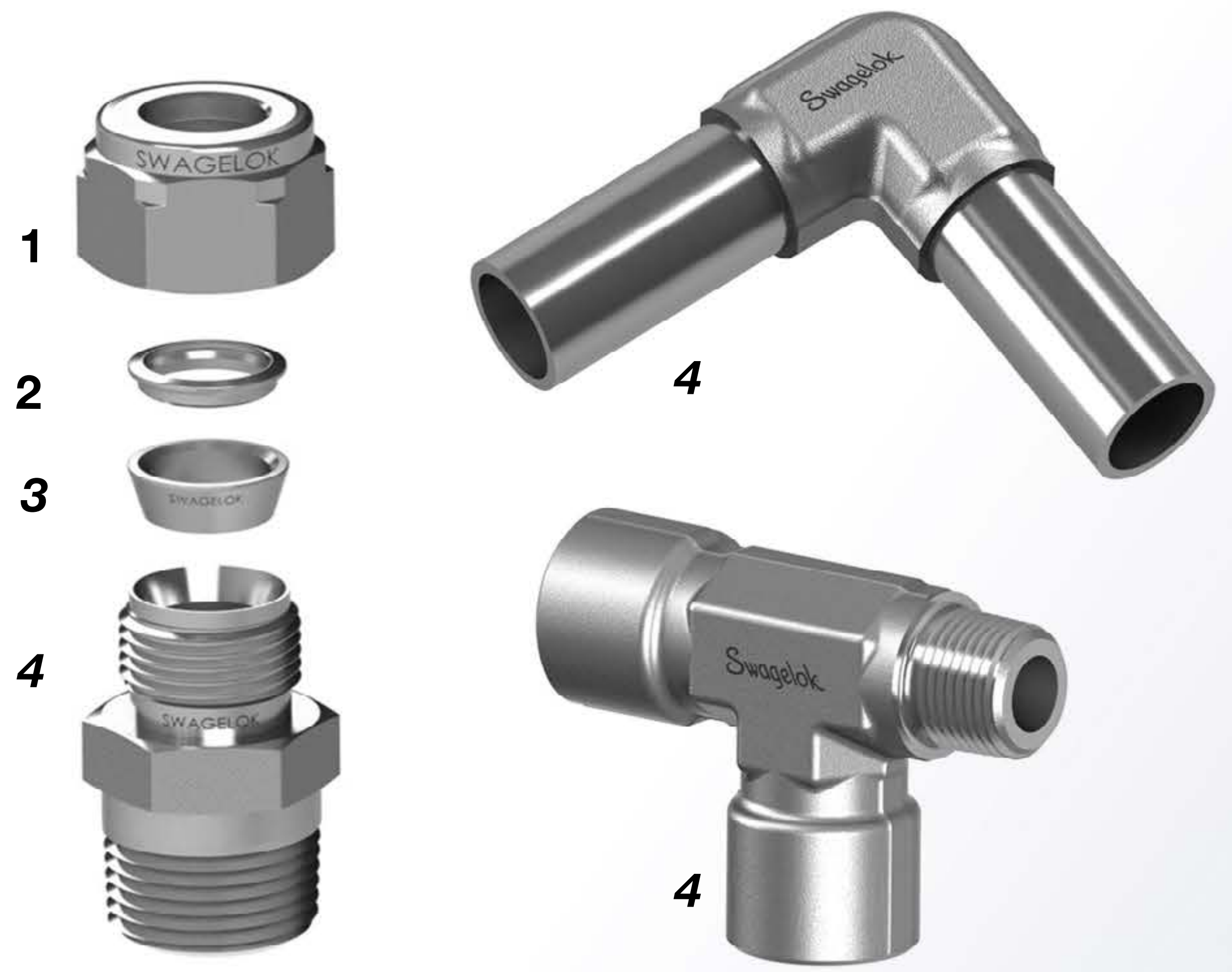
Read more about NACE

NACE Requirements for Alloy 6Mo Tube, Pipe, and Weld Fittings

The NACE MR0175/ISO 15156 standard contains tables that describe material requirements and environmental limits for various materials for use in those applications. The NACE MR0175/ISO 15156 tables that define requirements for alloys 6Mo are Tables A.8 and A.11.

Table A.8 specifies the environmental and material limits for highly alloyed austenitic stainless steels used for any equipment or components in any type of sour gas installation.

Table A.11 defines the environmental and material limits for highly alloyed austenitic stainless steels used as instrument tubing, control-line tubing, compression fittings, and surface and downhole screen devices



Component	Material	ASTM Specification	Marking
1 Nut	Alloy 254 (UNS S31254) or Alloy 6HN (UNS N08367)	A479①	254 or 6HN on face
2 Back ferrule	6HN (UNS N08367)	A479②	6HN on outer rim
3 *Front ferrule*	*Alloy 254 (UNS S31254) or Alloy 6HN (UNS N08367)*	*A479*①	*254 or 6HN on outer rim*
4 *Body*	*Alloy 254 (UNS S31254) or Alloy 6HN (UNS N08367)*	*Straight body—A479*① *Shaped body—A182*	*Tube and pipe fittings— 254 or 6HN on neck* *Weld fitting— 254 or 6HN on body* *Pipe and weld fittings— SG on body*

Wetted components listed in *italics*

① A479 (except for elongation, area of reduction, and hardness when cold-drawn bar)

② A479 (except for elongation and hardness)

Material Matters: For more information, access Swagelok's full data sheet Alloy 6Mo Tube, Pipe, and Weld Fittings / NACE MR0175/ISO 15156 Compliant, MS-06-122.

NORSOK Standards

NORSOK standards (developed by the Norwegian petroleum industry) outline material and supply chain requirements focused on:

- Ensuring the safety and cost-effectiveness of operations
- Replacing oil company specifications
- Providing a basis for international standardizations process
- Withdrawing standard upon publication of international standard

In response to the growing interest in NORSOK-approved products, Swagelok is pleased to quote orders for tube fittings, pipe fittings, and select general industrial valve products manufactured from NORSOK-certified material.

We offer products manufactured from 2507, 254, and 6HN bars and forgings that meet the requirements of the NORSOK M-650 supply chain qualification standard.

Read more about NORSOK

NORSOK Standards

The table provides details of the standards.

Standard	Description
M-650: Qualification of Manufacturers of Special Materials	Covers a set of qualification requirements to verify that the manufacturer has: • Sufficient competence and experience with the relevant material grades • Necessary facilities and equipment to manufacture these grades in the required shapes and sizes with acceptable properties Also covers data sheets for different product forms , including seamless pipes, welded pipes, fittings, forgings, plate, castings, bars, and tubes.
M-001: Materials Selection	Provides guidance, in conjunction with ISO 21457, for materials selection for oil and gas production on offshore installations, including: • Corrosion protection and control • Design limitations for specific materials • Qualification requirements for new materials and applications
M-630: Material Data Sheets and Element Data for Piping	Provides data sheets for the following materials: Carbon steels: Type 235, Type 235LT, Type 360LT Ferritic/Austenitic stainless steels: Type 22Cr, Type 25Cr • Copper/Nickel 90/10 and other copper alloys • Nickel base alloys: Type 625 • Polymers, including fiber-reinforced • Austenitic stainless steels: Type 6Mo • Austenitic stainless steels: Type 316 • Titanium • High-strength, low-alloyed steels

Materials Science Training

Make the best choices for your application

Swagelok offers *Materials Science Training*. Learn more about selecting the right corrosion-resistant materials based on pressure and temperature ratings, corrosive threats and compliance, as well as molecular structures and properties of metals.

- Choose proper materials to keep your fluid systems leak tight and operating efficiently
- Discover how specific alloys resist corrosion, how materials behave and how industry standards impact your material choice

What You'll Learn

- Principles of materials science, corrosion and other factors affecting material properties
- Types of corrosion and how specific alloys resist corrosion
- How to select optimal materials of construction for demanding applications based on pressure and temperature ratings, corrosive threats and compliance
- How to select proper components to address sour gas corrosion and NACE standards
- Critical concepts covering the nature and behavior of materials, including an atom-level view of metals, as well as the microstructural characteristics and mechanical properties of materials

Additional Resources

Quality and Reliability

For any fluid system solution to deliver high-caliber performance and long life, the design and material must work together. That's why Swagelok doesn't just have a dedicated quality department—our entire company is committed to excellence, including product ratings and test reports for all special alloys.

Rather than buy materials off the shelf, we choose to strictly control quality by:

- Holding mills to tighter alloy and quality specifications
- Employing positive material identification
- Making our own tooling
- Using technology-based methods of nondestructive testing
- Staffing dedicated engineers who work exclusively with the supply chain

These measures enhance material consistency and help prevent defects from reaching the final product. Once installed in your system, everything we sell is backed by our limited lifetime warranty.

Read more about Additional Resources

Additional Resources

Product and Systems Training

Learn more about fluid systems and enhance your team's capabilities with our complete suite of training programs.

Evaluation and Advisory Services

When you need extra support, we can survey your site to evaluate and troubleshoot sampling systems, hose, steam systems, and more.

Custom Solutions

We can help you design, specify, and build fluid system assemblies. We produce a professional, repeatable solution, with testing, inspection, and packaging – all with Swagelok's limited lifetime warranty.

Find a Technical Advisor

Want to talk more about your material requirements? Contact your local sales and service center.

Read more about Additional Resources

Additional Resources

Use the links below to access other helpful reference materials:

Articles

World Oil: Preventing pittitng and crevice corrosion of offshore stainless steel tubing

Offshore Magazine: Selecting fluid system components for use in sour oilfields

Reference Guide

Tubing Data Sheet MS-01-107

Tubing Data - Engineered Combinations MS-06-117

Galvanic Compatibility Table

Product Test Reports

Chloride Stress Corrosion Cracking (CSCC) Test of 316 Stainless Steel Swagelok® Tube Fitting Engineered Combinations

PTR-4183 - Chloride Stress Corrosion Cracking Test

Super Austenitic 254 SMo® (6-moly) Stainless Steel Tubing With Stainless Steel Swagelok® Tube Fittings

PTR-2834 - Tensile Pull Test

PTR-2835 - High-Temperature Thermal Cycling and Hydrostatic Proof Test

PTR-2836 - Low-Temperature Thermal Cycling and Hydrostatic Proof Test

PTR-2841 - Rotary Flexure Test

PTR-2849 - Hydraulic Impulse Test and Hydrostatic Proof Test

PTR-2852 - Hydrostatic Pressure Test

PTR-2853 - Nitrogen Gas Seal Test with Repeated Reassembly

Hydrostatic Pressure Test of 316 Tube Fittings on:

PTR-385 - Hard to Extra-Hard Stainless Steel Tubing

PTR-390 - Normal to Extra-Hard Stainless Steel Tubing

PTR-394 - Hard to Extra-Hard Stainless Steel Tubing

NACE and NORSOK

NACE and NORSOK Compliant Valves *SCS-00193*

SAFE PRODUCT SELECTION

When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

Galvanic Corrosion Compatibility Between Common Swagelok Materials

	Platinum	Titanium passive	Incoloy 825	2205 /2507 /254SMO /6HN	Alloy 20 SS	A286 passive	316SS passive	Inconel 625 passive	Silver	Hastelloy C & C276 passive	304SS passive	17-4PH	Inconel 600 passive	Monel 400	Titanium active	Inconel 600 active	Hastelloy C & Inconel 625 active	Hastelloy C276 active	Brass	316SS active	304SS active	Low Alloy Steel	Cast, Wrought Iron	Aluminum	Zinc
Platinum		O	O	O	O	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Titanium passive			E	E	E	E	E	E	E	O	O	O	O	O	O	X	X	X	X	X	X	X	X	X	X
Incoloy 825				E	E	E	E	E	E	O	O	O	O	O	O	X	X	X	X	X	X	X	X	X	X
2205 / 2507 / 254SMO / 6HN					E	E	E	E	E	E	E	E	E	E	O	X	X	X	X	X	X	X	X	X	X
Alloy 20 SS						E	E	E	E	E	E	E	E	E	E	X	X	X	X	X	X	X	X	X	X
A286 passive							E	E	E	E	E	E	E	E	E	O	O	X	X	X	X	X	X	X	X
316SS passive								E	E	E	E	E	E	E	E	O	O	X	X	X	X	X	X	X	X
Inconel 625 passive									E	E	E	E	E	E	E	O	O	X	X	X	X	X	X	X	X
Silver										E	E	E	E	E	E	O	O	X	X	X	X	X	X	X	X
Hastelloy C & C276 passive											E	E	E	E	E	O	O	O	O	X	X	X	X	X	X
304SS passive												E	E	E	E	O	O	O	O	X	X	X	X	X	X
17-4PH													E	E	E	O	O	O	O	X	X	X	X	X	X
Inconel 600 passive														E	E	O	O	O	O	X	X	X	X	X	X
Monel 400															E	O	O	O	O	X	X	X	X	X	X
Titanium active																O	O	E	O	X	X	X	X	X	X
Inconel 600 active																	E	E	E	X	X	X	X	X	X
Hastelloy C & Inconel 625 active																		E	E	X	X	X	X	X	X
Hastelloy C276 active																			E	X	X	X	X	X	X
Brass																				X	X	X	X	X	X
316SS active																					E	E	O	X	X
304SS active																						E	E	X	X
Low Alloy Steel																							E	O	X
Cast, Wrought Iron																								O	X
Aluminum																									X
Zinc																									

Galvanic coupling rating

Good to Excellent	E
Acceptable	O
Not suitable	X

Notes

Certain metals & alloys in poorly aerated or shielded areas may become "active" (lose their protective oxide layer)

Galvanic corrosion is also affected by anode / cathode surface area ratio

This galvanic series is determined by the materials electrical potential in 3.5% NaCl vs SCE

"Passive" refers to the materials' natural protective oxide layer

Return to Types of Corrosion Page

Return to Galvanic Corrosion Page

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