

# D

## **DEALLOYING**

See “Dezincification.”

## **DECARBURIZATION**

See “[Hydrogen Damage](#).”

## **DEPOSIT ATTACK**

See “[Poultice Corrosion](#).”

## **DEPOSIT CORROSION**

See “[Poultice Corrosion](#).”

## **DEW POINT CORROSION**

Dew point corrosion is a form of attack that occurs when the temperature of the metal surface is below the dew point of the atmosphere. This can occur outdoors during the night when the surface temperature may decrease by radiant heat transfer between the metal structure and the sky. It is also possible to have dew formation in the early morning when the temperature of the air increases faster than the temperature of the metal surface. Dew may also form when metal products are brought into warm storage after cold transport.

Dew point corrosion can also take place in the low-temperature sections of fossil fuel power plant combustion equipment as a result of acidic flue gas vapors that condense and cause corrosion damage.

## **DEZINCIFICATION (DEALLOYING)**

When one element of a solid alloy is removed by corrosion, the process is known as selective leaching, dealloying, or dezincification. The most common example is the removal of zinc from brass alloys that contain more than 15% zinc. When the zinc corrodes preferentially, a porous residue of copper and corrosion products remains. The corroded part often retains its original shape and may appear undamaged except for surface tarnish. However, its tensile strength and particularly its ductility are seriously reduced.

Dezincification of brasses takes place in either localized areas on the metal surface, called plug type, or uniformly over the surface, called layer type. Low-zinc alloys favor plug-type attack while layer-type attack is more prevalent in high-zinc alloys. The nature of the environment seems to have a great effect in determining the type of attack. Uniform attack takes place in slightly acidic water, low in salt content and at room temperature. Plug-type attack is favored in neutral and alkaline water, high in salt content and above room temperature. Crevice conditions under a deposit or scale tend to aggravate the situation.

A plug of dezincified brass may flow out, leaving a hole, while a water pipe having layer-type dezincification may split open.

Conditions that favor selective leaching are

1. High temperatures
2. Stagnant solutions, especially if acidic
3. Porous inorganic scale formation

Brasses that contain 15% or less zinc are usually immune. Dezincification can be suppressed by alloying additions of tin, aluminum, arsenic, or phosphorus.

Corrective measures that may be taken include

1. Use a more resistant alloy. This is the most practical approach. Red brass, with less than 15% zinc, is almost immune. Cupronickels provide a better substitute in severely corrosive atmospheres.
2. Periodic removal of scales and deposits from the inside surface of pipelines.
3. Removal of stagnation of corrosives, particularly acidic.
4. Use of cathodic protection.

Other alloy systems are also susceptible to this form of corrosion. Refer to [Table D.1](#). Selective leaching of aluminum takes place in aluminum bronze exposed to hydrofluoric acid or acid-containing chlorides. Copper-aluminum alloys containing more than 8% aluminum are particularly susceptible. Selective leaching of tin in tin bronzes in hot brine or steam and of silicon from silicon bronzes in high-temperature steam are other examples.

Selective leaching of iron from gray iron is termed graphitic corrosion. Iron will leach out selectively from gray iron pipe buried in soil. Graphite corrosion does not occur in ductile iron or malleable iron.

See [Refs. 1–3](#).

## DIFFERENTIAL AERATION CELL

See "[Oxygen Concentration Cell](#)."

## DISSIMILAR METAL CORROSION

See "[Galvanic Corrosion](#)."

**Table D.1** Combinations of Alloys and Environments for Selective Leaching

Alloy	Environment	Element removed
Aluminum	Hydrofluoric acid, acid chloride solutions	Aluminum
Bronzes, brasses	Many waters	Zinc
Cupronickels	High heat flux and low water velocity (in refinery condenser tubes)	Nickel
Gray iron	Soils, many waters	Iron
Gold alloys	Nitric, chromic, and sulfuric acids, human saliva	Copper or silver
High-nickel alloys	Molten salts	Chromium, iron, molybdenum, tungsten
Iron-chromium alloys	High-temperature oxidizing atmospheres	Chromium
Medium and high-carbon steels	Oxidizing atmospheres, hydrogen at high temperatures	Carbon
Monel	Hydrogen and other acids	Copper in some acids, nickel in others
Nickel-molybdenum alloys	Oxygen at high temperatures	Molybdenum
Silicon bronzes	High-temperature steam, acidic solution	Silicon
Tin bronzes	Hot brine, steam	Tin

## DUCTILE (NODULAR) IRON

Ductile iron not only retains all of the attractive qualities of gray iron, such as machinability and corrosion resistance, but also provides additional strength, toughness, and ductility. Ductile iron differs from gray iron in that its graphite form is spheroidal, or nodular, instead of the flake form found in gray iron. Due to its nodular graphite form, ductile iron has approximately twice the strength of gray iron as determined by tensile, beam, ring bending, and bursting tests. Its tensile and impact strength and elongation are many times greater compared with gray iron.

The corrosion resistance of ductile iron is essentially the same as that of gray iron. It exhibits good resistance to alkaline solutions, such as sodium hydroxide and molten caustic soda. It is also resistant to alkaline salt solutions, such as cyanides, carbonates, sulfides, and silicates. Acids and oxidizing salts rapidly attack ductile iron.

See [Refs. 4 and 5](#).

## DUPLEX STAINLESS STEELS

The duplex stainless steels are those alloys whose microstructures are a mixture of austenite and ferrite. These alloys were developed to improve the corrosion resistance of the austenitic stainlesses, particularly in the areas of chloride stress corrosion cracking and maintenance of corrosion resistance after welding. The original duplex stainlesses developed did not meet all of the criteria desired. Consequently, additional research was undertaken.

Duplex stainless steels have been available since the 1930s. The first-generation duplex stainless steels, such as type 329 (S32900), have a good general corrosion resistance because of their high chromium and molybdenum contents. When welded, however, these

grades lose the optimal balance of austenite and ferrite, and consequently corrosion resistance and toughness are reduced. While these properties can be restored by a postweld heat treatment, most of the applications of the first-generation duplexes use fully annealed material without further welding. Since these materials do not meet all of the criteria of duplex stainless steels, they have been included with the austenitic stainless steels.

In the 1970s, this problem was made manageable through the use of nitrogen as an alloy addition. The introduction of argon-oxygen decarburization (AOD) technology permitted the precise and economical control of nitrogen in stainless steel. Although nitrogen was first used because it was an inexpensive austenite former, replacing some nickel, it was quickly found that it had other benefits. These include improved tensile properties and pitting and crevice corrosion resistance.

The original duplex stainless steels did not have nitrogen added specifically as an alloying ingredient. By adding 0.15–0.25% nitrogen, the chromium partitioning between the two phases is reduced, resulting in the pitting and crevice corrosion resistance of the austenite being improved. This nitrogen addition also improves the weldability of the stainless steel without losing any of its corrosion resistance.

Nitrogen also causes austenite to form from ferrite at a higher temperature, allowing for restoration of an acceptable balance of austenite and ferrite after a rapid thermal cycle in the heat-affected zone (HAZ) after welding. This nitrogen enables the use of duplex grades in the as-welded condition and has created the second generation of duplex stainless steels.

The duplex grades characteristically contain molybdenum and have a structure of approximately 50% ferrite and 50% austenite because of the excess of ferrite-forming elements such as chromium and molybdenum. The duplex structure, combined with molybdenum, gives them improved resistance to chloride-induced corrosion (pitting, crevice corrosion, and stress corrosion cracking), in aqueous environments particularly.

However, the presence of ferrite is not an unmixed blessing. Ferrite may be attacked selectively in reducing acids, sometimes aggravated by a galvanic influence of the austenite phase, while the sigma phase produced by thermal transformation (as by heat of welding) is susceptible to attack by strong oxidizing acids. The duplex structure is subject to 885°F (475°C) embrittlement and has poor NDT properties. Except for temper embrittlement these problems can be minimized through corrosion testing and impact testing.

The high chromium and molybdenum contents of the duplex stainless steels are particularly important in providing resistance in oxidizing environments and are also responsible for the exceptionally good pitting and crevice corrosion resistance, especially in chloride environments. In general, these stainless steels have greater pitting resistance than type 316, and several have an even greater resistance than alloy 904L. The critical crevice corrosion temperature of selected duplex stainless steels in 10% FeCl<sub>3</sub> 6H<sub>2</sub>O having a pH of 1 are shown below.

UNS number	Temperature (°F/°C)
S32900	41/5
S31200	41/5
S31260	50/10
S32950	60/15
S31803	63.5/17.5
S32250	72.5/22.5



The resistance to crevice corrosion of the duplexes is superior to the resistance of the 300 series austenitics. They also provide an appreciably greater resistance to stress corrosion cracking. Like 20Cb3, the duplexes are resistant to chloride stress corrosion cracking in chloride-containing process streams and cooling water. However, under very severe conditions, such as boiling magnesium chloride, the duplexes will crack, as will alloy 20Cb3.

To achieve the desired microstructure, the nickel content of the duplexes is below that of the austenitics. Because the nickel content is a factor for providing corrosion resistance in reducing environments, the duplexes show less resistance in these environments than do the austenitics. However, the high chromium and molybdenum contents partially offset this loss, and consequently they can be used in some reducing environments, particularly dilute and cooler solutions. Although their corrosion resistance is good, the boundary between acceptable and poor performance is sharper than with austenitic materials. As a result, they should not be used under conditions that operate close to the limits of their acceptability.

### Alloy 2205 (31803)

Alloy 2205 exhibits an excellent combination of both strength and corrosion resistance. The chemical composition is shown in [Table D.2](#).

The approximate 50/50 ferrite-austenite structure provides excellent chloride pitting and stress corrosion cracking resistance. The high chromium and molybdenum contents coupled with the nitrogen addition, provide general corrosion pitting and crevice corrosion resistance superior to those of types 316L and 317L.

Compared with type 316 stainless steel, alloy 2205 demonstrates superior erosion-corrosion resistance. It is not subject to intergranular corrosion in the welded condition.

Alloy 2205 resists oxidizing mineral acids and most organic acids in addition to reducing acids, chloride environments, and hydrogen sulfide.

The following corrosion rates have been reported for alloy 2205:

Solution	Corrosion rate (mpy)
1% hydrochloric acid, boiling	0.1
10% sulfuric acid, 150°F/66°C	1.2
10% sulfuric acid, boiling	206
30% phosphoric acid, boiling	1.6
85% phosphoric acid, 150°F/66°C	0.4
65% nitric acid, boiling	2.1
10% acetic acid, boiling	0.1
20% acetic acid, boiling	0.1
20% formic acid, boiling	1.3
45% formic acid, boiling	4.9
3% sodium chloride, boiling	0.1

Alloy 2205 will be attacked by hydrochloric and hydrofluoric acids. Applications are found primarily in oil and gas field piping applications, condensers, reboilers, and heat exchangers. Its mechanical and physical properties are shown in [Table D.3](#).

**Table D.2** Chemical Composition of Alloy 2205 Stainless Steel

Chemical	Weight percent
Carbon	0.03 max.
Manganese	2.00 max.
Phosphorus	0.03 max.
Sulfur	0.02 max.
Silicon	1.00 max.
Chromium	21.00–23.00
Nickel	4.50–6.50
Molybdenum	2.50–3.50
Nitrogen	0.14–0.20
Iron	Balance

**Table D.3** Mechanical and Physical Properties of Alloy 2205 Duplex Stainless Steel

Modulus of elasticity $\times 10^6$ , psi	29.0
Tensile strength $\times 10^3$ , psi	90
Yield strength 0.2% offset $\times 10^3$ , psi	65
Elongation in 2 in., %	25
Hardness, Rockwell	C30.5
Density, lb/in. <sup>3</sup>	0.283
Specific gravity	7.83
Thermal conductivity at 70°F (20°C), Btu/h °F	10
Thermal expansion coefficient at 68–212°F in./in. °F $\times 10^{-6}$	7.5

**7-Mo Plus (S32950)**

7-Mo Plus stainless steel is a trademark of Carpenter Technology. It is a duplex alloy with approximately 45% austenite distributed within a ferrite matrix. Alloy S32950 displays good resistance to chloride stress corrosion cracking, pitting corrosion, and general corrosion in many severe environments. The chemical composition is shown in Table D.4.

**Table D.4** Chemical Composition of Type 7-Mo Plus Stainless Steel

Chemical	Weight percent
Carbon	0.03 max.
Manganese	2.00 max.
Phosphorus	0.035 max.
Sulfur	0.010 max.
Silicon	0.60 max.
Chromium	26.00–29.00
Nickel	3.50–5.20
Molybdenum	1.00–2.50
Nitrogen	0.15–0.35
Iron	Balance



This alloy is subject to 885°F (475°C) embrittlement when exposed for extended period of times between 700°F and 1000°F (371–538°C).

The general corrosion resistance of 7-Mo Plus stainless is superior to that of stainless steels such as type 304 and type 316 in many environments. Because of its high chromium content, it has good corrosion resistance in strong oxidizing media such as nitric acid. Molybdenum extends the corrosion resistance into the less oxidizing environments. Chromium and molybdenum impart a high level of resistance to pitting and crevice corrosion. It has a PREN of 40.

Alloy S32950 exhibits excellent resistance to nitric acid, phosphoric acid, organic acids, alkalis, seawater, and chloride stress corrosion cracking. It is not suitable for service in hydrochloric or hydrofluoric acids or some salts. Refer to Table D.5 for the mechanical and physical properties of 7-Mo Plus stainless steel.

**Zeron 100 (S32760)**

Zeron 100 is a trademark of Weir Materials Limited of Manchester, England. Table D.6 details the chemical composition of Zeron 100, which is tightly controlled by Weir Materials, while the chemical composition of S32760 is a broad compositional range.

Zeron 100 is a highly alloyed duplex stainless steel for use in aggressive environments. In general, its properties include high resistance to pitting and crevice corrosion, resistance to stress corrosion cracking in both chloride and sour environments, resistance to erosion-corrosion and corrosion fatigue.

Zeron 100 is highly resistant to corrosion in a wide range of organic and inorganic acids. Its excellent resistance to many nonoxidizing acids is the result of the copper content.

**Table D.5** Mechanical and Physical Properties of Type 7-Mo Plus<sup>a</sup> Stainless Steel

Modulus of elasticity × 10 <sup>6</sup> , psi	29.0
Tensile strength × 10 <sup>3</sup> psi	90
Yield strength 0.2% offset × 10 <sup>3</sup> , psi	70
Elongation in 2 in., %	20
Hardness, Rockwell	C30.5
Density, lb/in. <sup>3</sup>	0.280
Specific gravity	7.74
Specific heat (75–212°F), Btu/lb °F	0.114
Thermal conductivity, Btu/h °F	
at 70°F (20°C)	8.8
at 1500°F (815°C)	12.5
Thermal expansion coefficient in./in. °F × 10 <sup>-6</sup>	
at 75–400°F	6.39
at 75–600°F	6.94
at 75–800°F	7.49
at 75–1000°F	7.38
Charpy V-notch impact at 75°F (20°C), ft-lb	101

<sup>a</sup>Registered trademark of Carpenter Technology Corp.

**Table D.6** Chemical Composition of Zeron 100 (S32760) Stainless Steel

Chemical	Weight percent
Carbon	0.03 max.
Manganese	1.00 max.
Phosphorus	0.03 max.
Sulfur	0.01 max.
Silicon	1.00 max.
Chromium	24.0–26.0
Nickel	6.0–8.0
Molybdenum	3.0–4.0
Copper	0.5–1.0
Nitrogen	0.2–0.3
Tungsten	0.5–1.0
Iron	Balance

A high resistance to pitting and crevice corrosion is also exhibited by Zeron 100. It has a PREN of 48.2. Intergranular corrosion is not a problem since the alloy is produced to a low carbon specification and water quenched from solution annealing, which prevents the formation of any harmful precipitates and eliminates the risk of intergranular corrosion.

Resistance is also exhibited to stress corrosion cracking in chloride environments and process environments containing hydrogen sulfide and carbon dioxide.

### Ferralium 255 (S32550)

The chemical composition of Ferralium 255 is shown in [Table D.7](#). This is a duplex alloy with austenitic distributed within a ferrite matrix. Ferralium 255 exhibits good general corrosion resistance to a variety of media, with a high level of resistance to chloride pitting and stress corrosion cracking. The following corrosion rates for Ferralium 255 have been reported:

Solution	Corrosion rate (mpy)
1% hydrochloric acid, boiling	0.1
10% sulfuric acid, 150°F (66°C)	0.2
10% sulfuric acid, boiling	40
30% phosphoric acid, boiling	0.2
85% phosphoric acid, 150°F (66°C)	0.1
65% nitric acid, boiling	5
10% acetic acid, boiling	0.2
20% formic acid, boiling	0.4
3% sodium chloride, boiling	0.4

This alloy has a maximum service temperature of 500°F (260°C).

See [Refs. 7–10](#).

This alloy has a maximum service temperature of 500°F (260°C).

See [Refs. 6–9](#).



**Table D.7** Chemical Composition of Ferralium 255 (S32550) Stainless Steel

Chemical	Weight percent
Carbon	0.04
Manganese	1.50
Phosphorus	0.04
Sulfur	0.03
Silicon	1.00
Chromium	24.0–27.0
Nickel	4.5–6.5
Molybdenum	2.9–3.9
Copper	1.5–2.5
Nitrogen	0.1–0.25
Iron	Balance

## DURALUMIN

Duralumin is a heat-treatable aluminum-copper alloy developed in Germany in 1919. It is produced in the United States as alloy 2017, containing approximately 4% copper and usually lesser amounts of magnesium, manganese, and on occasion silicon. Recently lithium has also been added.

See [Ref. 10](#).

## DURIRON

See “[High-Silicon Iron](#).”

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