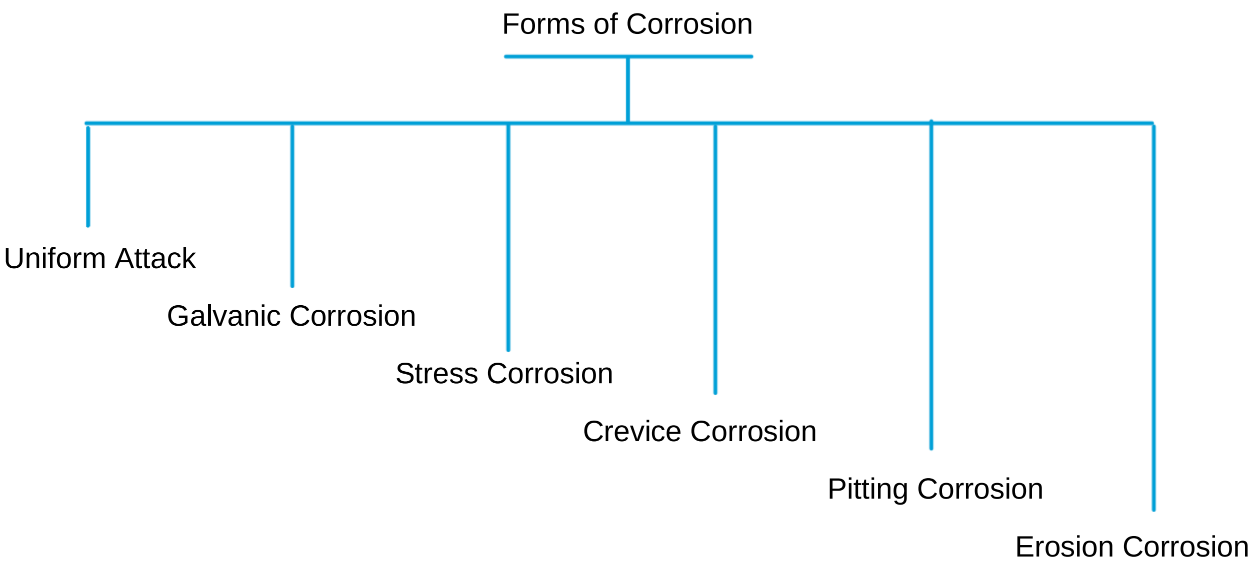
Educational Institute for Equipment and Process Design

Common Materials and Their Categories

Corrosion Types



Corrosion Types

Corrosion Type	Uniform Attack	Galvanic Corrosion	Stress Corrosion
How	Corrosion occurs uniformly over the entire surface as a result of chemical or electrochemical reaction between the metal and the fluid in contact with it.	When two dissimilar metals are in contact with one another, either physically or electrically, in a corrosive or conductive solution(electrolyte), any potential difference which exists produces a flow of electrons between them.	An insidious form of attack is stress corrosion which results from a combination of tensile stress and general corrosion from a specific corrosive medium.
Detectable	it is usually detected visually well before failure.		It is often difficult to detect because there may be no apparent loss of metal due to general corrosion, but it ultimately reveals its presence, without warning, in the form of cracks - which may be intergranular or trans-granular - and is commonly known as stress corrosion cracking.
Notes	thus, enabling remedial action to be taken, such as replacement, change of material, coatings, inhibitors, cathodic protection, etc.	Compared with their resistance to corrosion when not in contact with one another, there is usually an increase in corrosion of the less noble or less corrosion-resistant metal, and a reduction in the corrosion of the more noble or more corrosion-resistant metal. The more noble end is termed the cathode and the less noble end the anode. The mechanism is termed galvanic corrosion.	Combinations of metals and their specific corrosive media which may exhibit stress-corrosion cracking are: aluminum alloys: sodium chloride solutions copper alloys: ammonia, amines, mercury salt solutions MonelTM: hydrofluoric acid nickel: fused sodium hydroxide, fused potassium hydroxide type 300 stainless steels: chloride and caustic solutions titanium: red fuming nitric acid, methanol.

Corrosion Types

Corrosion Type	Crevice corrosion	Pitting corrosion	Erosion corrosion
How	Localized corrosion, often intense, may occur in stagnant crevices, or shielded areas in contact with the corrosive media and is termed crevice corrosion.	A particularly destructive form of corrosion is that due to pitting in which. intense localized attack results in pits or holes in the metal, the pits having a depth about the same size as the diameter at the surface	Erosion is the physical deterioration of a metal surface due to the action of the fluid flowing over it, and the wear will be increased if the fluid contains solid particles in suspension. If the attack is intensified by corrosion, the process is termed erosion corrosion.
Detectable		The pits are usually small and therefore difficult to detect, particularly if they are obscured by dirt or corrosion product, and complete failure may be sudden.	It is revealed as grooves, waves or holes in a pattern related to the direction of the flowing fluid. As expected, soft metals, such as copper and lead, and metals which depend on a surface film for corrosion resistance, such as aluminum and stainless steel, are particularly prone to erosion corrosion.
Notes	The presence of a crevice, or shielded area, does not necessarily mean that corrosion will occur, and it depends on the particular metal/fluid combination. Prevention of corrosion consists of either changing the metal or eliminating the crevice by a change in design.	Once pits begin to form, the attack usually proceeds at an accelerated rate, so that an increase in corrosion allowance of a component provides no protection. It is not clear why pitting occurs in particular areas and leaves other identical areas unscathed, but the surface finish is regarded as an important factor.	Cavitation is a special form of erosion corrosion caused by the growth and collapse of vapor bubbles in a liquid adjacent to a metal surface. The attack is caused by both chemical and mechanical action in which the collapsing bubble is capable of removing the protective film and the metal itself from the surface.

Uniform attack

Corrosion occurs uniformly over the entire surface as a result of chemical or electrochemical reaction between the metal and the fluid in contact with it. It is the most common form of industrial corrosion. Unlike some of the other forms of corrosion it is usually detected visually well before failure, thus enabling remedial action to be taken, such as replacement, change of material, coatings, inhibitors, cathodic protection, etc.

Galvanic corrosion

When two dissimilar metals are in contact with one another, either physically or electrically, in a corrosive or conductive solution(electrolyte), any potential difference which exists produces a flow of electrons between them. Compared with their resistance to corrosion when not in contact with one another, there is usually an increase in corrosion of the less noble or less corrosion-resistant metal, and a reduction in the corrosion of the more noble or more corrosion-resistant metal. The more noble end is termed the cathode and the less noble end the anode. The mechanism is termed galvanic corrosion.

Stress corrosion

An insidious form of attack is stress corrosion which results from a combination of tensile stress and general corrosion from a specific corrosive medium. It is often difficult to detect because there may be no apparent loss of metal due to general corrosion, but it ultimately reveals its presence, without warning, in the form of cracks - which may be intergranular or transgranular - and is commonly known as stress corrosion cracking. Failure may occur in a few hours or many years, at any stress level, in almost all metals and alloys. It is achieved more quickly under the combined action of stress and corrosion than either by itself.

Stress-corrosion cracking of carbon and low-alloy steels may occur in the presence of nitrate solutions, mixtures of sulphuric and nitric acids and calcium chloride brines. Combinations of metals and their specific corrosive media which may exhibit stress-corrosion cracking are:

aluminum alloys: sodium chloride solutions

copper alloys: ammonia, amines, mercury salt solutions

MonelTM: hydrofluoric acid

nickel: fused sodium hydroxide, fused potassium hydroxide

type 300 stainless steels: chloride and caustic solutions

titanium: red fuming nitric acid, methanol

It should be noted that stress-corrosion cracking can occur even with concentrations of chlorides as low as 3 p.p.m.

Crevice corrosion

Localized corrosion, often intense, may occur in stagnant crevices, or shielded areas in contact with the corrosive media and is termed crevice corrosion. Deposits of dirt and corrosion products also provide shielded areas under which crevice corrosion can occur and for this reason it is sometimes termed 'deposit corrosion'. The presence of a crevice, or shielded area, does not necessarily mean that corrosion will occur, and it depends on the particular metal/fluid combination. Prevention of corrosion consists of either changing the metal or eliminating the crevice by a change in design.

In the case of deposit corrosion, flow passages should be designed to avoid stagnant areas and ensure complete drainage. Fluid velocities should be sufficiently high to discourage solid matter from settling, but this may only be successful if the unit is operated continuously at near-full design throughput.

Pitting corrosion

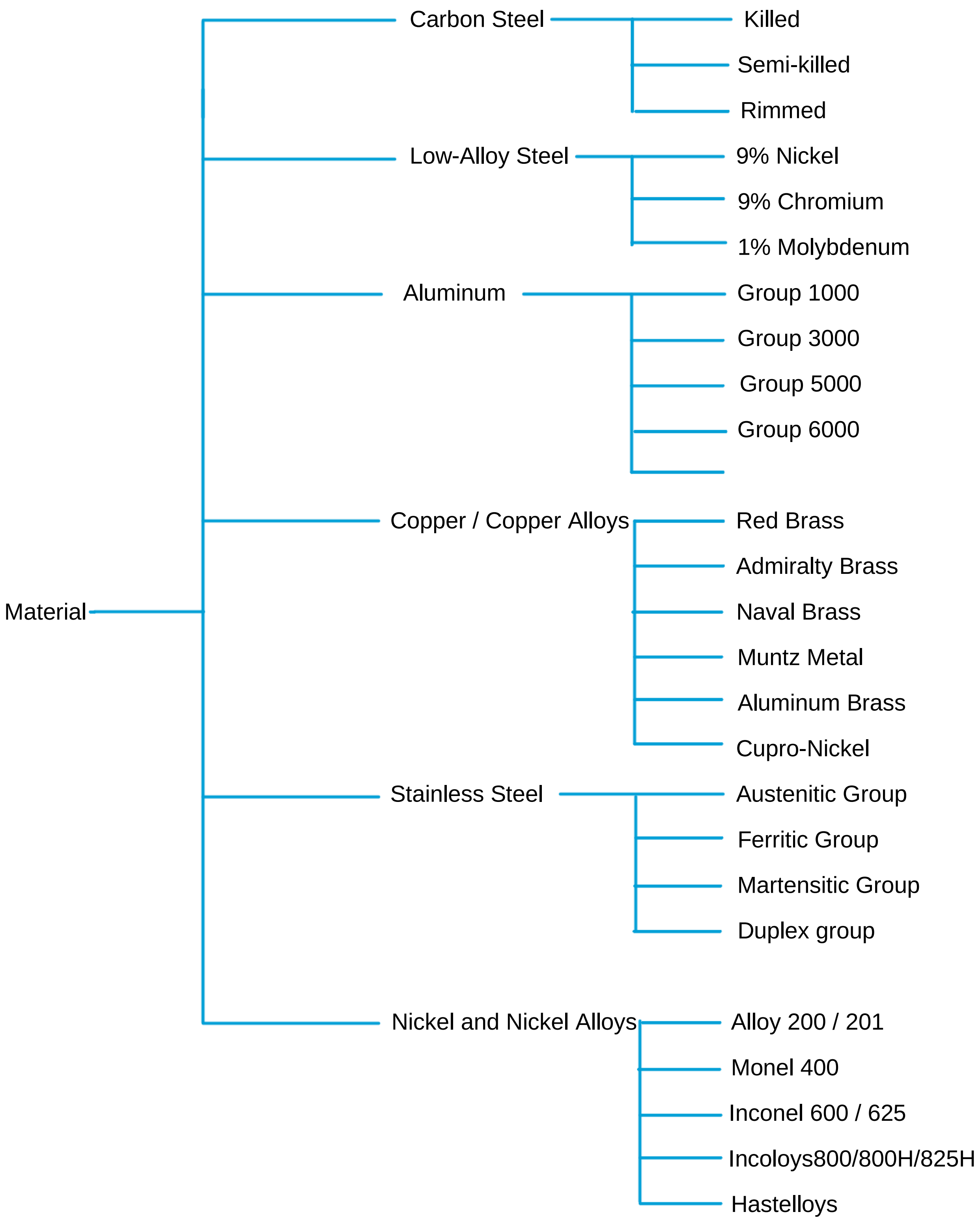
A particularly destructive form of corrosion is that due to pitting in which. intense localized attack results in pits or holes in the metal, the pits having a depth about the same size as the diameter at the surface. The pits are usually small and therefore difficult to detect, particularly if they are obscured by dirt or corrosion product, and complete failure may be sudden. Although only a small quantity of metal is lost, a single small hole in the wall of a heat exchanger tube, for instance, renders it useless. Once pits begin to form, the attack usually proceeds at an accelerated rate, so that an increase in corrosion allowance of a component provides no protection. It is not clear why pitting occurs in particular areas and leaves other identical areas unscathed, but the surface finish is regarded as an important factor. Pitting is more likely to occur where the surface has rough areas or scratches.

Erosion corrosion

Erosion is the physical deterioration of a metal surface due to the action of the fluid flowing over it, and the wear will be increased if the fluid contains solid particles in suspension. If the attack is intensified by corrosion, the process is termed erosion corrosion. It is revealed as grooves, waves or holes in a pattern related to the direction of the flowing fluid. As expected, soft metals, such as copper and lead, and metals which depend on a surface film for corrosion resistance, such as aluminum and stainless steel, are particularly prone to erosion corrosion. The location in a shell-and-tube heat exchanger which is particularly prone to erosion corrosion is the initial 100-150 mm of the internal tube surfaces at the inlet end, where high turbulence exists. Erosion corrosion in this area may be prevented by the provision of tube-end inserts. These consist of 100-150 mm long metallic or plastic tubes. sometimes flared or collared at the inlet end, which make a tight fit inside each tube. The exit end of the insert is feathered in order to provide a gentle transition from the insert to the tube. thus, preventing erosion corrosion occurring in the tube just beyond the exit of the insert If metallic inserts are used, the metal should be chosen' to avoid galvanic corrosion. In most cases, however, the problem of erosion corrosion is overcome by the correct choice of metal.

Cavitation is a special form of erosion corrosion caused by the growth and collapse of vapor bubbles in a liquid adjacent to a metal surface. The attack is caused by both chemical and mechanical action in which the collapsing bubble is capable of removing the protective film and the metal itself from the surface. Another special form of erosion corrosion is fretting which may occur when two surfaces slide over one another with repeated oscillatory motion under load. Corrosion may occur when cither frictional heat oxidizes the metal, which then wears away, or when the protective layer of oxide or corrosion product is removed by mechanical means. In either case exposure of unprotected surfaces leads to continual corrosion and the parts may be damaged by seizing or galling. Flow induced vibration may cause damage of this nature when tubes pass through the shell-side baffles of a shell-and-tube exchanger, particularly if the baffles are harder than the tubes. Table 18.2 lists desirable velocities for water flowing inside tubes of various alloys.

Metal	Velocity Range
Steel	0.8-1.5
Copper	0.9-1.2
Admiralty Brass	0.9-1.8
Aluminum Brass	1.2-2.4
Aluminum Bronze	1.8-2.7
90/10 Cupro-Nickel	1.8-3
70/30 Cupro-Nickel	1.8-4.5
Monel	1.8-4.5
Stainless Steel Type 316	2.4-4.5



- Material
  - Carbon Steel
    - Killed
    - Semi-killed
    - Rimmed
  - Low-Alloy Steel
    - 9% Nickel
    - 9% Chromium
    - 1% Molybdenum
  - Aluminum
    - Group 1000
    - Group 3000
    - Group 5000
    - Group 6000
  - Copper / Copper Alloys
    - Red Brass
    - Admiralty Brass
    - Naval Brass
    - Muntz Metal
    - Aluminum Brass
    - Cupro-Nickel
  - Stainless Steel
    - Austenitic Group
    - Ferritic Group
    - Martensitic Group
    - Duplex group
  - Nickel and Nickel Alloys
    - Alloy 200 / 201
    - Monel 400
    - Inconel 600 / 625
    - Incoloys800/800H/825H
    - Hastelloys

Carbon and Low Alloy Steels

The most widely used metals for construction in the process industries are iron, carbon steel, and low-alloy steel. In the case of heat transfer equipment, cast iron is sometimes used for low-pressure applications such as headers for shell-and-tube exchangers in cooling-water service, cascade coolers and components for boilers and economizers, but its usage is small in relation to carbon and low-alloy steels. Low-alloy' steels for heat exchangers and pressure vessels relate to steels alloyed chiefly with chromium (max. 9% with negligible nickel present), nickel (max.9%with negligible chromium present) and molybdenum (max. 1%). Other elements which may be added intentionally in definite quantities include aluminum, boron, cobalt, tungsten and vanadium. Alloys of iron and carbon containing less than 1.7% carbon are regarded as steels, but for heat exchanger construction, which involves rolling, cutting, welding, etc., the carbon content is usually less than 0.35%.

Corrosion resistance

Because of its versatility in almost every shop operation, ready availability and low cost in relation to other metals, carbon steel is widely used in heat transfer equipment. As it is suitable for many hydrocarbons and natural waters. it is widely used in petroleum and petrochemical applications. It is attacked by all concentrations of hydrochloric, phosphoric and nitric acids. but resists sulphuric acid at all concentrations above 70% and temperatures below 50 °C. and hydrofluoric acid at all concentrations above 80% and temperatures below 65 °C. It is resistant to alkalis such as sodium hydroxide, carbonate and phosphate. Hot concentrated alkalis are particularly aggressive and stressed parts are liable to stress-corrosion cracking. Hot dry gases such as sulphur dioxide, hydrogen chloride and chlorine do not affect steel, but if water vapor is present, severe attack may occur once condensation begins.

Aluminum and aluminum alloys

Low density is the special property of aluminum and its alloys being only one-third of that of steel. They also offer an attractive appearance, high thermal conductivity, excellent resistance against corrosion from the atmosphere, salt water and a variety of chemicals, ease of fabrication, and excellent low-temperature strength and shock-resistance properties (as low as -269°C for liquid helium). In addition, they are non-sparking and non-toxic.

1000 group

These are high-purity metals in which the aluminum content is not less than 99.00%. They are used extensively except where high strength is required because they offer excellent properties relating to corrosion resistance, thermal conductivity and ease of fabrication. Alloys from the other groups are used when greater strength is required although their corrosion resistance is usually less.

3000 group

These metals, which have manganese as the main alloying element, offer similar properties as the 1000 group but with the advantage of higher strength. The alloys are widely used in heat exchangers.

5000 group

Magnesium is the main alloying element, but some of the alloys contain significant quantities of manganese. The strength of these alloys is considerably greater than the 1000 and 3000 groups. The 5000 group alloys listed in Table 18.4 with a magnesium content greater than about 3% (i.e. alloys 5083, 5086, 5154 and 5456) are limited to an operating temperature of about 65 °C because they are susceptible to stress corrosion cracking. The alloys are widely used in cryogenic equipment.

Strength Comparison	**5000 group > 3000 group > 1000 group**

6000 group

Magnesium and silicon are the main alloying elements of the 6000 group which offer good corrosion resistance, ease of fabrication and medium strength.

Copper and copper alloys

Summary of Copper Alloys			
Alloy	Composition	Application	Notes
Red brass	1.85% copper 2.15% zinc	Not good for sulphur-bearing products	Good resistance to corrosion and dezincification
Admiralty brass	1.71% copper 2.28% zinc 3.1% tin	1.It is used chiefly in the form of tubes. It is also available for clad or solid tubesheet but its strength decreases rapidly above about 175 C. 2.It offers a good corrosion resistance against most waters and sulphur bearing products.	It is immune to pitting and crevice corrosion. However,, it is prone to stress corrosion and erosion corrosion.
Naval brass	1.60% copper 2.39% zinc 3.1% tin	It is used for clad or solid tubesheet in moderately corrosive conditions.	Its corrosion resistance is not as good as admiralty brass

High-purity copper is well known for its high thermal and electrical conductivities, being second only to silver and nearly twice that of aluminum. Copper generally provides good corrosion resistance against dilute air-free acetic and sulphuric acids, caustic alkalis, sea water and the atmosphere. In order to improve strength and corrosion resistance in certain environments, elements such as iron, zinc, tin, aluminum and nickel are added, although the resulting alloys have significantly lower thermal and electrical conductivities. Copper and its alloys have good low-temperature properties and may be used at temperatures of -200 °C. They are noted for being attacked by moist chlorine, moist ammonia and its compounds, and minute quantities of mercury and its compounds, Moist acetylene under pressure forms an explosive compound with copper, and alloys having a copper content greater than 65% should not be used. A major industrial application for copper and its alloys is in heat transfer equipment involving a variety of cooling waters.

Red brass

This alloy contains 85% copper and 15% zinc (85/15) and has good resistance to corrosion and dezincification. Because of its relatively low zinc content, however, it does not offer a high resistance to attack by sulphur-bearing products and admiralty brass is usually preferred.

Admiralty brass

Admiralty brass is nominally 71% copper, 28% zinc and 1% tin (71/28/1) and is used chiefly in the form of tubes. It is also available for clad or solid tubesheet but its strength decreases rapidly above about 175 C. There are three alloys available differing only be the small quantity of inhibitor (0.02-0.10%) which is added as arsenic, antimony or phosphorus to prevent dezincification. It has a low price compared with some of the other copper alloys, and offers a good corrosion resistance against most waters and sulphur bearing products. It is also immune to pitting and crevice corrosion. However,, it is prone to stress corrosion and erosion corrosion.

Naval brass

Naval brass is nominally 60% copper, 39% zinc plus 1% tin (60/39/1) which is added for greater strength and to increase its resistance against corrosion and dezincification. Its corrosion resistance is not as good as admiralty brass but it is used for clad or solid tubesheet in moderately corrosive conditions.

Austenitic group

Standard 200 series

The 200 series chromium content of 16-18% is similar to that of types 302 and 304, but about half of the 302's and 304's 8-10% nickel has been replaced by manganese and nitrogen. In the past when nickel was in short supply, the 200 series became a useful substitute for the 300 series. They also have a higher yield strength than the 300 series, but their corrosion resistance is inferior.

Standard 300 series

The heart of the 300 series are the types 302 and 304 containing an average of 18% chromium and 8% nickel (18/8), type 304 being the general-purpose stainless steel and produced in larger quantities than any of the others. Table 18.6(a) shows that these steels are modified by the introduction of elements such as chromium, nickel, molybdenum, titanium, niobium, tantalum and nitrogen. The 300 series cannot be hardened by heat treatment and therefore exposure at elevated temperature does not cause an appreciable change in hardness or tensile strength. Unfortunately, certain metallurgical changes occur which affect their corrosion resistance and toughness. The general-purpose types 302 and 304, for instance, together with types 316 and 317, suffer sensitization, or harmful carbide precipitation, when exposed to temperatures of 500-800 °C, which is likely to occur during welding, for instance. Carbon which is normally present in solution diffuses to the grain boundaries where it combines with chromium to form carbides. The zone adjacent to the grain boundaries, which is then depleted of chromium, may be preferentially attacked by certain corrosive media over a long period of time. When this type of attack occurs as a result of welding, it is referred to as the more familiar 'weld decay".

Sensitization may be overcome by reducing the carbon content of the alloy to at least 0.03% as provided by the low-carbon versions of types 304, 316 and 317, namely, 304L, 316Í. and 317L. It may also be overcome by adding elements such as titanium, niobium and tantalum during steel-making, which tie-up the carbon and leaves little available to form chromium carbides during subsequent heating in the critical temperature range. These alloys are termed 'stabilized stainless steels', the stabilizer being titanium for type 321, niobium + tantalum for type 347, and niobium + restricted tantalum and cobalt for the nuclear application type 348. Matching welding electrodes or wires, containing niobium would be used. Another method of preventing sensitization of unsterilized stainless steels is to anneal after welding at about 1050 °C, but this may be expensive and difficult to carry out, particularly with large fabrications, or site welds. In order to improve the strength of types 304 and 316, nitrogen is added and these steels are then designated types 304N and 316N. By controlling the carbon content and grain size, better elevated temperature creep and stress-rupture properties are obtained for types 304, 316, 321,347 and 348 and these steels are designated type 304H, 316H, 321H,347H, and 348H.

Sigma formation, an undesirable intermetallic phase, may occur as a result of long exposure at temperatures in the range 565-925 °C. It increases hardness, but at the expense of reduced ductility, corrosion resistance and notch toughness. This problem is one encountered in service, not heat treatment, because the rate of sigma formation is slow. The greater the chromium content, the greater the possibility of sigma formation, which is accentuated by the presence ot molybdenum, titanium and silicon. Increasing the nickel content reduces the possibility of sigma formation.

The chief disadvantage of the 300 series stainless steels is that the alloys are prone to stress-corrosion cracking, particularly in hot chloride solutions. High-nickel alloys or special stainless steels have been developed to overcome this problem. The chloride content of the water used for hydraulic testing of heat exchangers constructed of these steels must be considered. The maximum acceptable chloride level for testing depends on the extent to which the exchanger can be drained afterwards and the maximum metal temperature which will be experienced in service. The water temperature is usually too low to cause stress corrosion cracking during test, but it will occur during service if the exchanger operates at a higher temperature and all chlorides have not been flushed away. Crevices holding chloride-containing water accentuate the risk of stress-corrosion cracking. Hot-air drying should be employed only after flushing-out. If the service temperature exceeds 50 °C, a chloride content of 200 p.p.m, for instance, is acceptable for testing only if the exchanger can be drained completely or flushed out with condensate or demineralized water. If the service temperature never exceeds 50 °C a chloride content of 200 p.p.m. is acceptable without special provision for draining or flushing. However, caution should be exercised as a shell-and-tube exchanger is not crevice-free and bellows cannot be drained.

Ferritic group

Standard 400 series

The compositions of some 400 series ferritic stainless steels, including the better known 13% and 17% chrome steels (types 405 and 430), are listed in Table 18.6(b), from which it will be seen that the chromium content lies in the range 10.5-30%. Unlike the 300 series, however, there is little nickel, being less than 0.75%. Corrosion resistance increases as the chromium content increases, but the higher chromium content may provide fabrication problems as described later. The 400 series is not used as widely as the 300 series. Compared with the 300 series, their toughness, formability and corrosion resistance is lower, but because of their low nickel content, they are cheaper and have the added advantage that they are considered to be almost immune from chloride stress-corrosion cracking. The 400 series is similar to the 300 series in that the alloys cannot be hardened by heat treatment, but exposure at certain temperatures causes metallurgical changes which adversely affect corrosion resistance and other properties. Ferritic stainless steels are subject to embrittlement following long exposure to temperatures of 400-550 °C, whereas austenitic stainless steels do not experience such attack. An increase in hardness is accompanied by a reduction in ductility and toughness at and below the service temperature. Because the worst embrittlement occurs at about 475 °C, the phenomenon is termed '475 °C (or 885 °F) embrittlement' and becomes more pronounced with increasing chromium content above 13%. Significant embrittlement has been observed at temperatures of only 315 °C with a chromium content of 15% after an exposure time of about 3000 hours. Although 475 °C embrittlement may be remedied by reheating to 600 °C, prolonged heating of these steels having a chromium content greater than 20% may cause sigma formation, as mentioned in section 18.7.1. Cold work and the presence of molybdenum assist sigma formation. Any area of the weld and heat-affected zone, which has reached a temperature of about 900 °C or greater, is prone to intergranular attack, but unlike the 300 series, the problem is not remedied by a reduction in carbon content or the addition of stabilizing elements. Re-annealing the steel to about 800 °C is a remedy.

Martensitic group

The standard 400 series martensitic stainless steels have a chromium content of 11.5-18% and the most popular of these is the 12% chrome, type 410, the composition of which is given in Table 18.6(c), together with its lower carbon version type 410S. They can be hardened by heat treatment and are selected when good mechanical properties are required in a moderately corrosive environment. The 300 series have a greatly superior corrosion resistance but like the 400 series ferritic, the martensitic are considered almost immune to chloride stress-corrosion cracking. Although cheaper than the 300 series, the 400 series are less widely used.

Duplex (austenitic/ferritic)

group Standard 300 series Duplex stainless steels contain both austerite and ferrite and the composition of the only standard steel, type 329, is shown in Table 18.6(d), the chromium and nickel contents being 23-28% and 2.5-5%, respectively. The amount of the austenitic and ferrite phases may be altered by the addition of austenite stabilizers (carbon, nitrogen, nickel)and ferrite formers (molybdenum, silicon, titanium, aluminum).The duplex stainless steels are noted for their high yield strengths, being about double those of the 'standard' austenitic and ferritic listed. In the annealed condition, they offer better resistance to stress-corrosion cracking than the low-alloy austenitic. They are also more resistant to sensitization, but less resistant to crevice corrosion and pitting.

Nickel

Summary of Nickel			
Alloy	Composition	Application	Notes
Monel 400	1.A minimum of 63% nickel 2.28% copper, 3.Iron 4.manganese	1.Sea water 2.De-aerated sulphuric acid 3.De-aerated hydrochloric acid 4.Hydrofluoric acid	1.Good strength 2.Ease of fabrication 3. Excellent corrosion resistance 4.High modulus of elasticity 5.Low thermal conductivity
Inconel 600	1.76% nickel 2.15% chromium 3.8% iron	1.Ammonia cracker systems 2. Nitriding plant 3. Dry chlorine 4.Dry hydrogen chloride 5. Hot fatty acids 6. Magnesium chloride 7. Nuclear Engineering (Primary and secondary water in pressurised water circuits)	1. Resistant to stress-corrosion cracking 2.Good high-temperature strength up to 1150 °C and chemical corrosion.
Inconel 625	1.61% nickel 2.21% chromium 3.9% molybdenum 4.Iron 5.Niobium 6.Tantalum.	1. Fresh and sea water, neutral salts and alkaline media 2.Oxidizing chemicals 3.Non-Oxidizing Environment 4.	1.It has excellent tensile, creep and rupture properties and is suitable for temperatures ranging from cryogenic to 1100 °C, while the various alloying elements enables it to withstand a wide range of corrosive environments

Nickel-copper alloy (Monel^{TM} 400)

Monel 400, which contains a minimum of 63% nickel and 28% copper, plus iron and manganese, was first made over seventy-five years ago and is regarded as one of the most versatile nickel alloys on the market for general engineering applications. It offers good strength, ease of fabrication and excellent corrosion resistance against a variety of fluids Although it has a high modulus of elasticity and its thermal expansion coefficient is only slightly greater than steel, it has a low thermal conductivity, being roughly half that of steel at 100 Ci Its resistance to sea water, particularly at velocities greater than 3 m/s, is superior to the copper alloys including 70/30 cupro-nickel. It offers good resistance against de-aerated sulphuric acid at temperatures below 100 °C and 80% concentration, de-aerated hydrochloric acid below 50 °C and 20% concentration and hydrofluoric acid below 50°C.

Nickel-chromium-iron alloy (Inconel 600)

Inconel 600, which is nominally 76% nickel, 15% chromium and 8% iron, has good high-temperature strength up to 1150 °C and is resistant to high temperatures and chemical corrosion. It resists attack by nitrogen/ hydrogen mixtures and gaseous ammonia at high temperatures and is a standard material for ammonia cracker systems. As it does not suffer from nitride formation, it is used for nitriding plant. It is resistant to dry chlorine, dry hydrogen chloride, all concentrations of ammonia, hot fatty acids and hot concentrated solutions of magnesium chloride.

In the chemical and process industries, it is resistant to stress-corrosion cracking in the presence of chlorides, water and dissolved oxygen, and to general attack and stress-corrosion cracking in sea and saline waters. In nuclear engineering, it is resistant to primary and secondary water in pressurised water circuits, including ammoniated and lithium hydroxide treated primary water and is the standard material for steam generators of pressurised water reactors.

Nickel-chromium-molybdenum alloy (Inconel 625)

Inconel 625 contains nominally 61% nickel, 21% chromium,9% molybdenum plus iron, niobium and tantalum. It has excellent tensile, creep and rupture properties and is suitable for temperatures ranging from cryogenic to i100 °C, while the various alloying elements enables it to withstand a wide range of corrosive environments. It provides bolts having high strength at elevated temperatures. In environments, such as the atmosphere, fresh and sea water, neutral salts and alkaline media, there is almost no attack. In more severe corrosive environments, the combination of nickel and chromium provides resistance to oxidizing chemicals, while the high nickel and molybdenum content provides resistance to non-oxidizing environments. The high molybdenum content in particular makes Inconel 625 exceptionally resistant to pitting in chlorides, even in oxidizing acid conditions, and resistant to crevice corrosion, particularly in sea water and at elevated temperatures. The high nickel content ensures virtual immunity to chloride stress-corrosion cracking and provides excellent resistance to caustic stress-corrosion cracking. Due to the high niobium content, alloy 625 shows unusual stability after being welded, or when subjected to heat treatments which might cause serious sensitization in other nickel-chromium and nickel-iron-chromium alloys.

Appendix

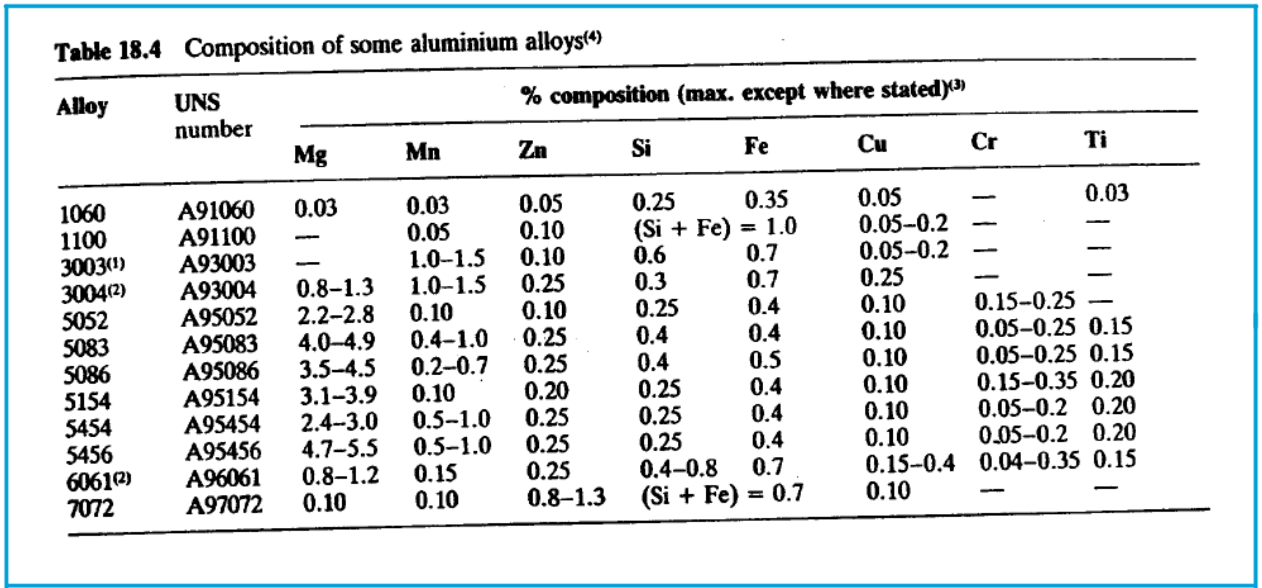


Table 18.4 Composition of some aluminium alloys(4)

Alloy	UNS number	% composition (max. except where stated)(3)							
		Mg	Mn	Zn	Si	Fe	Cu	Cr	Ti
1060	A91060	0.03	0.03	0.05	0.25	0.35	0.05	—	0.03
1100	A91100	—	0.05	0.10	(Si + Fe) = 1.0		0.05–0.2	—	—
3003(1)	A93003	—	1.0–1.5	0.10	0.6	0.7	0.05–0.2	—	—
3004(2)	A93004	0.8–1.3	1.0–1.5	0.25	0.3	0.7	0.25	—	—
5052	A95052	2.2–2.8	0.10	0.10	0.25	0.4	0.10	0.15–0.25	—
5083	A95083	4.0–4.9	0.4–1.0	0.25	0.4	0.4	0.10	0.05–0.25	0.15
5086	A95086	3.5–4.5	0.2–0.7	0.25	0.4	0.5	0.10	0.05–0.25	0.15
5154	A95154	3.1–3.9	0.10	0.20	0.25	0.4	0.10	0.15–0.35	0.20
5454	A95454	2.4–3.0	0.5–1.0	0.25	0.25	0.4	0.10	0.05–0.2	0.20
5456	A95456	4.7–5.5	0.5–1.0	0.25	0.25	0.4	0.10	0.05–0.2	0.20
6061(2)	A96061	0.8–1.2	0.15	0.25	0.4–0.8	0.7	0.15–0.4	0.04–0.35	0.15
7072	A97072	0.10	0.10	0.8–1.3	(Si + Fe) = 0.7		0.10	—	—

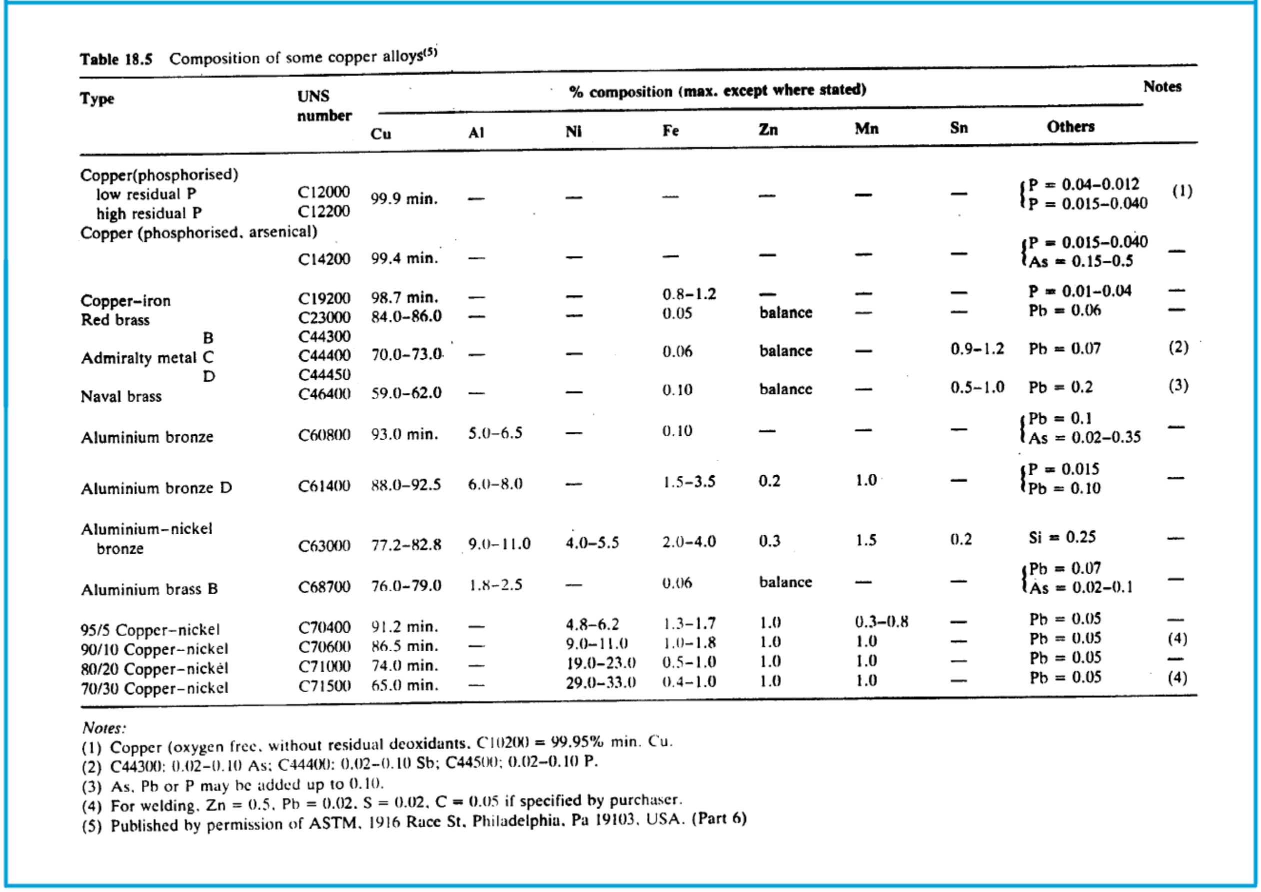


Table 18.5 Composition of some copper alloys(5)

Type	UNS number	% composition (max. except where stated)								Notes
		Cu	Al	Ni	Fe	Zn	Mn	Sn	Others	
Copper(phosphorised) low residual P high residual P	C12000 C12200	99.9 min.	—	—	—	—	—	—	P = 0.04–0.012 P = 0.015–0.040	(1)
Copper (phosphorised, arsenical)	C14200	99.4 min.	—	—	—	—	—	—	P = 0.015–0.040 As = 0.15–0.5	—
Copper–iron	C19200	98.7 min.	—	—	0.8–1.2	—	—	—	P = 0.01–0.04	—
Red brass	C23000	84.0–86.0	—	—	0.05	balance	—	—	Pb = 0.06	—
Admiralty metal B C D	C44300 C44400 C44450	70.0–73.0	—	—	0.06	balance	—	0.9–1.2	Pb = 0.07	(2)
Naval brass	C46400	59.0–62.0	—	—	0.10	balance	—	0.5–1.0	Pb = 0.2	(3)
Aluminium bronze	C60800	93.0 min.	5.0–6.5	—	0.10	—	—	—	Pb = 0.1 As = 0.02–0.35	—
Aluminium bronze D	C61400	88.0–92.5	6.0–8.0	—	1.5–3.5	0.2	1.0	—	P = 0.015 Pb = 0.10	—
Aluminium–nickel bronze	C63000	77.2–82.8	9.0–11.0	4.0–5.5	2.0–4.0	0.3	1.5	0.2	Si = 0.25	—
Aluminium brass B	C68700	76.0–79.0	1.8–2.5	—	0.06	balance	—	—	Pb = 0.07 As = 0.02–0.1	—
95/5 Copper–nickel	C70400	91.2 min.	—	4.8–6.2	1.3–1.7	1.0	0.3–0.8	—	Pb = 0.05	—
90/10 Copper–nickel	C70600	86.5 min.	—	9.0–11.0	1.0–1.8	1.0	1.0	—	Pb = 0.05	(4)
80/20 Copper–nickel	C71000	74.0 min.	—	19.0–23.0	0.5–1.0	1.0	1.0	—	Pb = 0.05	—
70/30 Copper–nickel	C71500	65.0 min.	—	29.0–33.0	0.4–1.0	1.0	1.0	—	Pb = 0.05	(4)

Notes:

(1) Copper (oxygen free, without residual deoxidants. C10200 = 99.95% min. Cu.

(2) C44300: 0.02–0.10 As; C44400: 0.02–0.10 Sb; C44500; 0.02–0.10 P.

(3) As, Pb or P may be added up to 0.10.

(4) For welding, Zn = 0.5, Pb = 0.02, S = 0.02, C = 0.05 if specified by purchaser.

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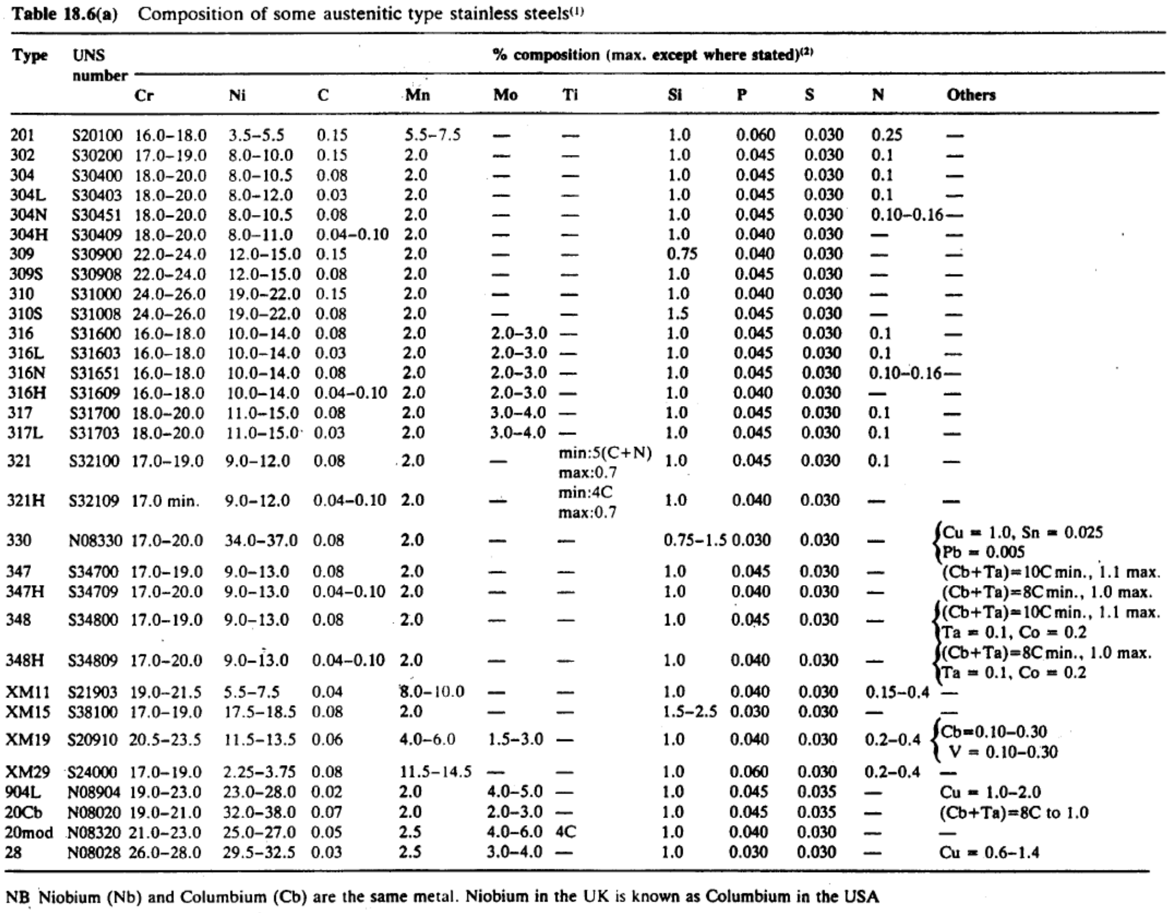

Table 18.6(a) Composition of some austenitic type stainless steels(1)

Type	UNS number	% composition (max. except where stated)(2)										
		Cr	Ni	C	Mn	Mo	Ti	Si	P	S	N	Others
201	S20100	16.0–18.0	3.5–5.5	0.15	5.5–7.5	—	—	1.0	0.060	0.030	0.25	—
302	S30200	17.0–19.0	8.0–10.0	0.15	2.0	—	—	1.0	0.045	0.030	0.1	—
304	S30400	18.0–20.0	8.0–10.5	0.08	2.0	—	—	1.0	0.045	0.030	0.1	—
304L	S30403	18.0–20.0	8.0–12.0	0.03	2.0	—	—	1.0	0.045	0.030	0.1	—
304N	S30451	18.0–20.0	8.0–10.5	0.08	2.0	—	—	1.0	0.045	0.030	0.10–0.16	—
304H	S30409	18.0–20.0	8.0–11.0	0.04–0.10	2.0	—	—	1.0	0.040	0.030	—	—
309	S30900	22.0–24.0	12.0–15.0	0.15	2.0	—	—	0.75	0.040	0.030	—	—
309S	S30908	22.0–24.0	12.0–15.0	0.08	2.0	—	—	1.0	0.045	0.030	—	—
310	S31000	24.0–26.0	19.0–22.0	0.15	2.0	—	—	1.0	0.040	0.030	—	—
310S	S31008	24.0–26.0	19.0–22.0	0.08	2.0	—	—	1.5	0.045	0.030	—	—
316	S31600	16.0–18.0	10.0–14.0	0.08	2.0	2.0–3.0	—	1.0	0.045	0.030	0.1	—
316L	S31603	16.0–18.0	10.0–14.0	0.03	2.0	2.0–3.0	—	1.0	0.045	0.030	0.1	—
316N	S31651	16.0–18.0	10.0–14.0	0.08	2.0	2.0–3.0	—	1.0	0.045	0.030	0.10–0.16	—
316H	S31609	16.0–18.0	10.0–14.0	0.04–0.10	2.0	2.0–3.0	—	1.0	0.040	0.030	—	—
317	S31700	18.0–20.0	11.0–15.0	0.08	2.0	3.0–4.0	—	1.0	0.045	0.030	0.1	—
317L	S31703	18.0–20.0	11.0–15.0	0.03	2.0	3.0–4.0	—	1.0	0.045	0.030	0.1	—
321	S32100	17.0–19.0	9.0–12.0	0.08	2.0	—	min:5(C+N) max:0.7	1.0	0.045	0.030	0.1	—
321H	S32109	17.0 min.	9.0–12.0	0.04–0.10	2.0	—	min:4C max:0.7	1.0	0.040	0.030	—	—
330	N08330	17.0–20.0	34.0–37.0	0.08	2.0	—	—	0.75–1.5	0.030	0.030	—	Cu = 1.0, Sn = 0.025 Pb = 0.005
347	S34700	17.0–19.0	9.0–13.0	0.08	2.0	—	—	1.0	0.045	0.030	—	(Cb+Ta)=10C min., 1.1 max.
347H	S34709	17.0–20.0	9.0–13.0	0.04–0.10	2.0	—	—	1.0	0.040	0.030	—	(Cb+Ta)=8C min., 1.0 max.
348	S34800	17.0–19.0	9.0–13.0	0.08	2.0	—	—	1.0	0.045	0.030	—	(Cb+Ta)=10C min., 1.1 max. Ta = 0.1, Co = 0.2
348H	S34809	17.0–20.0	9.0–13.0	0.04–0.10	2.0	—	—	1.0	0.040	0.030	—	(Cb+Ta)=8C min., 1.0 max. Ta = 0.1, Co = 0.2
XM11	S21903	19.0–21.5	5.5–7.5	0.04	8.0–10.0	—	—	1.0	0.040	0.030	0.15–0.4	—
XM15	S38100	17.0–19.0	17.5–18.5	0.08	2.0	—	—	1.5–2.5	0.030	0.030	—	—
XM19	S20910	20.5–23.5	11.5–13.5	0.06	4.0–6.0	1.5–3.0	—	1.0	0.040	0.030	0.2–0.4	Cb=0.10–0.30 V = 0.10–0.30
XM29	S24000	17.0–19.0	2.25–3.75	0.08	11.5–14.5	—	—	1.0	0.060	0.030	0.2–0.4	—
904L	N08904	19.0–23.0	23.0–28.0	0.02	2.0	4.0–5.0	—	1.0	0.045	0.035	—	Cu = 1.0–2.0
20Cb	N08020	19.0–21.0	32.0–38.0	0.07	2.0	2.0–3.0	—	1.0	0.045	0.035	—	(Cb+Ta)=8C to 1.0
20mod	N08320	21.0–23.0	25.0–27.0	0.05	2.5	4.0–6.0	4C	1.0	0.040	0.030	—	—
28	N08028	26.0–28.0	29.5–32.5	0.03	2.5	3.0–4.0	—	1.0	0.030	0.030	—	Cu = 0.6–1.4

NB Niobium (Nb) and Columbium (Cb) are the same metal. Niobium in the UK is known as Columbium in the USA

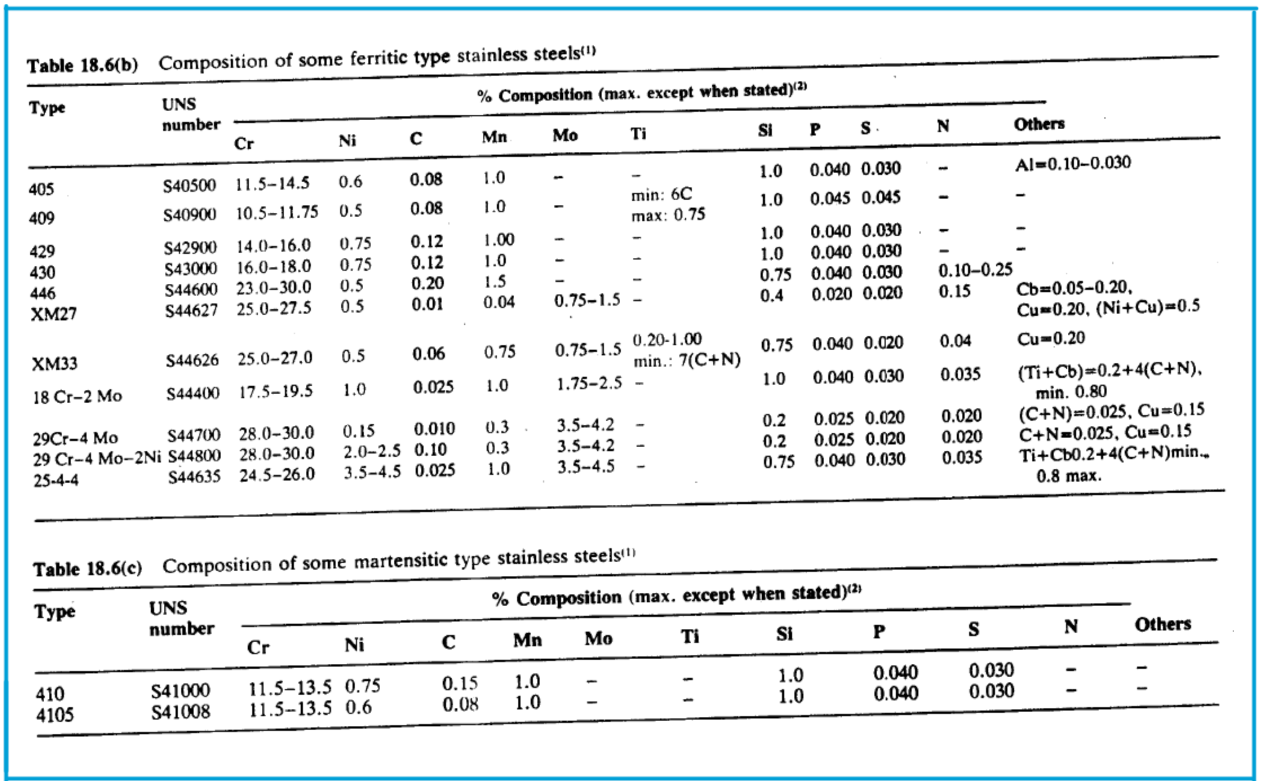

Table 18.6(b) Composition of some ferritic type stainless steels(1)

Type	UNS number	% Composition (max. except when stated)(2)										
		Cr	Ni	C	Mn	Mo	Ti	Si	P	S	N	Others
405	S40500	11.5–14.5	0.6	0.08	1.0	–	–	1.0	0.040	0.030	–	Al=0.10–0.030
409	S40900	10.5–11.75	0.5	0.08	1.0	–	min: 6C max: 0.75	1.0	0.045	0.045	–	–
429	S42900	14.0–16.0	0.75	0.12	1.00	–	–	1.0	0.040	0.030	–	–
430	S43000	16.0–18.0	0.75	0.12	1.0	–	–	1.0	0.040	0.030	–	–
446	S44600	23.0–30.0	0.5	0.20	1.5	–	–	0.75	0.040	0.030	0.10–0.25	
XM27	S44627	25.0–27.5	0.5	0.01	0.04	0.75–1.5	–	0.4	0.020	0.020	0.15	Cb=0.05–0.20, Cu=0.20, (Ni+Cu)=0.5
XM33	S44626	25.0–27.0	0.5	0.06	0.75	0.75–1.5	0.20-1.00 min.: 7(C+N)	0.75	0.040	0.020	0.04	Cu=0.20
18 Cr–2 Mo	S44400	17.5–19.5	1.0	0.025	1.0	1.75–2.5	–	1.0	0.040	0.030	0.035	(Ti+Cb)=0.2+4(C+N), min. 0.80
29Cr–4 Mo	S44700	28.0–30.0	0.15	0.010	0.3	3.5–4.2	–	0.2	0.025	0.020	0.020	(C+N)=0.025, Cu=0.15
29 Cr–4 Mo–2Ni	S44800	28.0–30.0	2.0–2.5	0.10	0.3	3.5–4.2	–	0.2	0.025	0.020	0.020	C+N=0.025, Cu=0.15
25-4-4	S44635	24.5–26.0	3.5–4.5	0.025	1.0	3.5–4.5	–	0.75	0.040	0.030	0.035	Ti+Cb0.2+4(C+N)min., 0.8 max.

Table 18.6(c) Composition of some martensitic type stainless steels(1)

Type	UNS number	% Composition (max. except when stated)(2)										
		Cr	Ni	C	Mn	Mo	Ti	Si	P	S	N	Others
410	S41000	11.5–13.5	0.75	0.15	1.0	–	–	1.0	0.040	0.030	–	–
4105	S41008	11.5–13.5	0.6	0.08	1.0	–	–	1.0	0.040	0.030	–	–

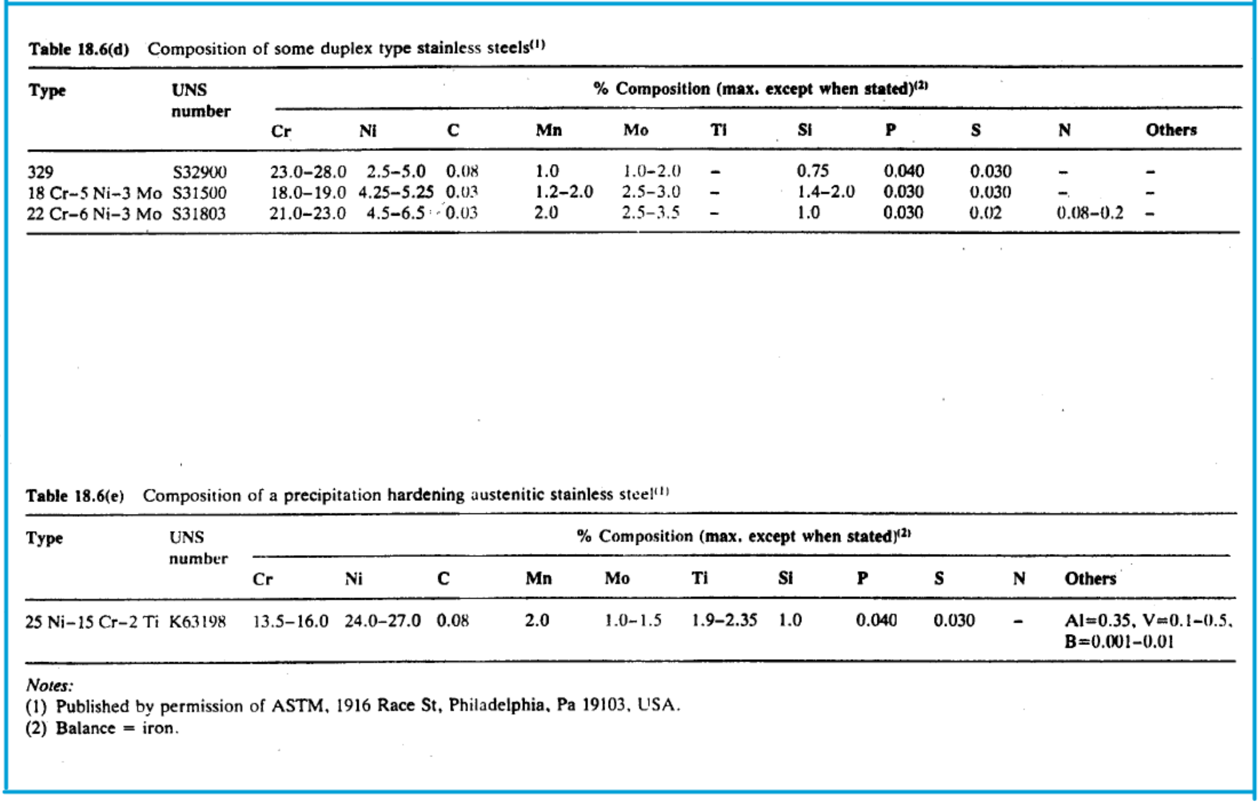

Table 18.6(d) Composition of some duplex type stainless steels(1)

Type	UNS number	% Composition (max. except when stated)(2)										
		Cr	Ni	C	Mn	Mo	Ti	Si	P	S	N	Others
329	S32900	23.0–28.0	2.5–5.0	0.08	1.0	1.0–2.0	–	0.75	0.040	0.030	–	–
18 Cr–5 Ni–3 Mo	S31500	18.0–19.0	4.25–5.25	0.03	1.2–2.0	2.5–3.0	–	1.4–2.0	0.030	0.030	–	–
22 Cr–6 Ni–3 Mo	S31803	21.0–23.0	4.5–6.5	0.03	2.0	2.5–3.5	–	1.0	0.030	0.02	0.08–0.2	–

Table 18.6(e) Composition of a precipitation hardening austenitic stainless steel(1)

Type	UNS number	% Composition (max. except when stated)(2)										
		Cr	Ni	C	Mn	Mo	Ti	Si	P	S	N	Others
25 Ni–15 Cr–2 Ti	K63198	13.5–16.0	24.0–27.0	0.08	2.0	1.0–1.5	1.9–2.35	1.0	0.040	0.030	–	Al=0.35, V=0.1–0.5, B=0.001–0.01

Notes:

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(2) Balance = iron.

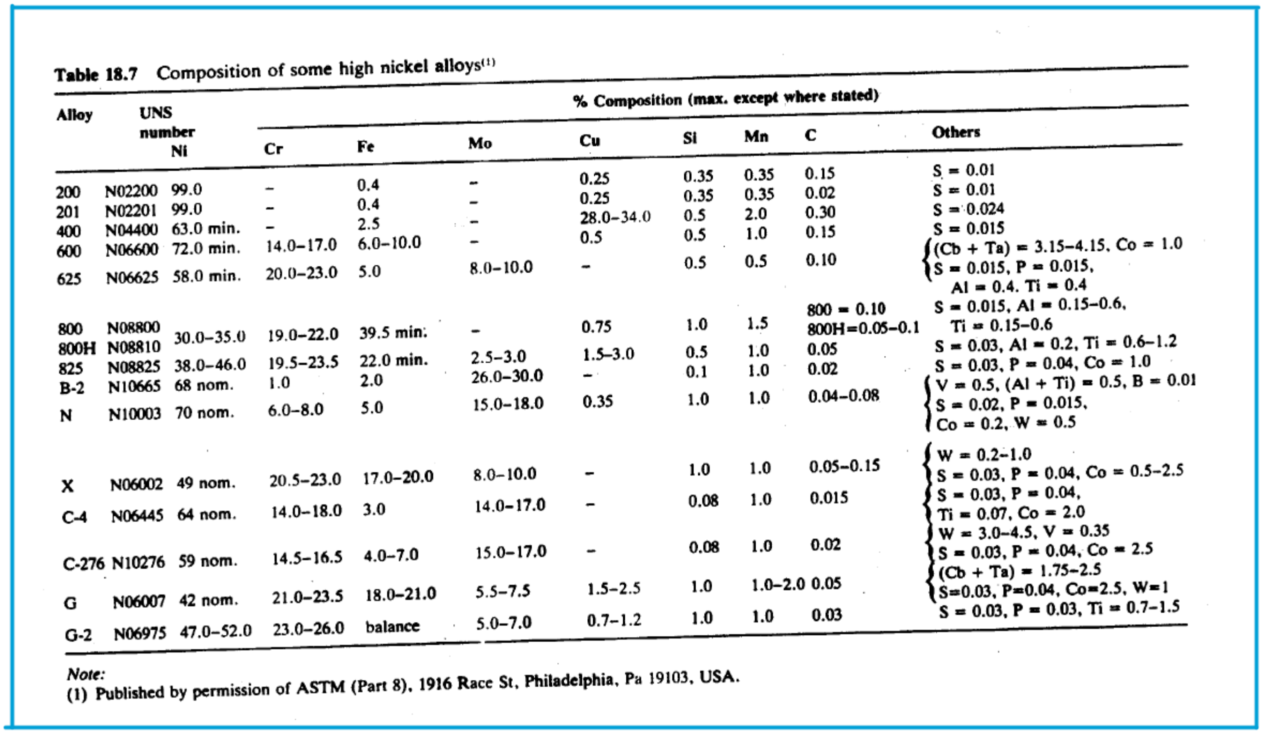

Table 18.7 Composition of some high nickel alloys[1]

Alloy	UNS number	% Composition (max. except where stated)								
		Ni	Cr	Fe	Mo	Cu	Si	Mn	C	Others
200	N02200	99.0	–	0.4	–	0.25	0.35	0.35	0.15	S = 0.01
201	N02201	99.0	–	0.4	–	0.25	0.35	0.35	0.02	S = 0.01
400	N04400	63.0 min.	–	2.5	–	28.0–34.0	0.5	2.0	0.30	S = 0.024
600	N06600	72.0 min.	14.0–17.0	6.0–10.0	–	0.5	0.5	1.0	0.15	S = 0.015
625	N06625	58.0 min.	20.0–23.0	5.0	8.0–10.0	–	0.5	0.5	0.10	(Cb + Ta) = 3.15–4.15, Co = 1.0 S = 0.015, P = 0.015, Al = 0.4, Ti = 0.4
800 800H	N08800 N08810	30.0–35.0	19.0–22.0	39.5 min.	–	0.75	1.0	1.5	800 = 0.10 800H=0.05–0.1	S = 0.015, Al = 0.15–0.6, Ti = 0.15–0.6
825	N08825	38.0–46.0	19.5–23.5	22.0 min.	2.5–3.0	1.5–3.0	0.5	1.0	0.05	S = 0.03, Al = 0.2, Ti = 0.6–1.2
B-2	N10665	68 nom.	1.0	2.0	26.0–30.0	–	0.1	1.0	0.02	S = 0.03, P = 0.04, Co = 1.0
N	N10003	70 nom.	6.0–8.0	5.0	15.0–18.0	0.35	1.0	1.0	0.04–0.08	V = 0.5, (Al + Ti) = 0.5, B = 0.01 S = 0.02, P = 0.015, Co = 0.2, W = 0.5
X	N06002	49 nom.	20.5–23.0	17.0–20.0	8.0–10.0	–	1.0	1.0	0.05–0.15	W = 0.2–1.0 S = 0.03, P = 0.04, Co = 0.5–2.5
C-4	N06445	64 nom.	14.0–18.0	3.0	14.0–17.0	–	0.08	1.0	0.015	S = 0.03, P = 0.04, Ti = 0.07, Co = 2.0
C-276	N10276	59 nom.	14.5–16.5	4.0–7.0	15.0–17.0	–	0.08	1.0	0.02	W = 3.0–4.5, V = 0.35 S = 0.03, P = 0.04, Co = 2.5
G	N06007	42 nom.	21.0–23.5	18.0–21.0	5.5–7.5	1.5–2.5	1.0	1.0–2.0	0.05	(Cb + Ta) = 1.75–2.5 S=0.03, P=0.04, Co=2.5, W=1
G-2	N06975	47.0–52.0	23.0–26.0	balance	5.0–7.0	0.7–1.2	1.0	1.0	0.03	S = 0.03, P = 0.03, Ti = 0.7–1.5

Note:

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