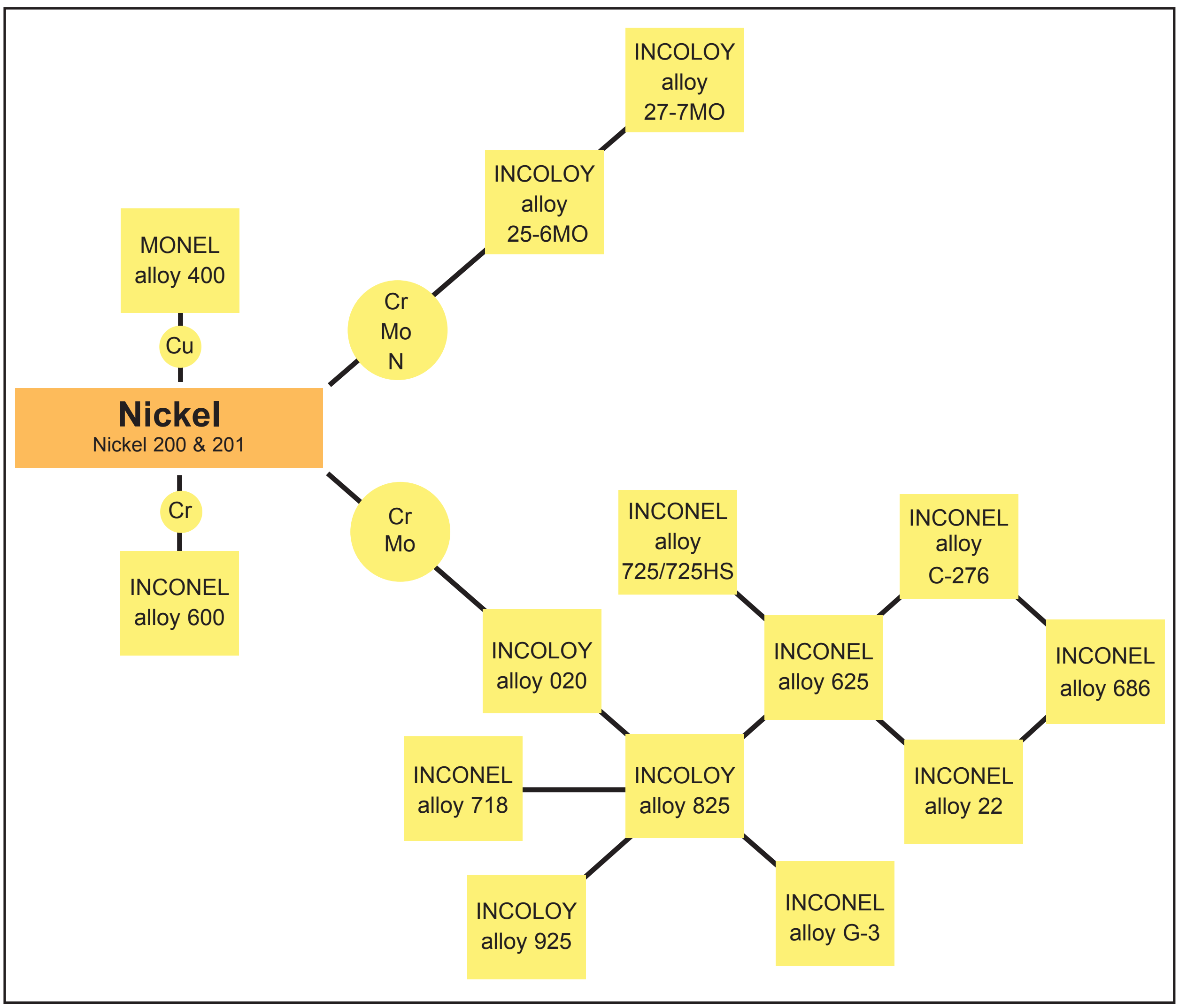
Corrosion-Resistant Alloys from Special Metals Corporation

Special Metals Corporation - With major manufacturing operations in Huntington, WV, Newton, NC, and New Hartford, NY in the USA and Hereford and Stratford-upon-Avon in the UK and sales offices and distribution centers around the world, Special Metals Corporation (SMC) is the world's leading producer of high performance, corrosion-resistant nickel-base alloys. SMC offers a complete line of corrosion-resistant alloy (CRA) products to meet the service requirements of the aggressive environments encountered in today's processing industry. These products are available through the SMC worldwide manufacturing, supply, and distribution network. The company also offers world class technical support to help the potential user choose the optimum product for the application. Information on all the alloy products manufactured by Special Metals is available on the SMC website, www.specialmetals.com. Information on Special Metals welding products may be found at www.specialmetalswelding.com. Or, contact any of the Special Metals offices listed on the last page of this brochure.

The Special Metals Families of Corrosion-Resistant Alloys

SMC offers a complete range of corrosion-resistant alloys ranging from super austenitic stainless steels to the most highly alloyed CRA currently in production, INCONEL® alloy 686. To help the potential user better compare these products, they have been divided into alloy families in this brochure.



Corrosion-Resistant Alloys

Super-Austenitic Stainless Steels (SASS)

The 300 series chromium-nickel austenitic stainless steels have been used for most of the 20th century to resist corrosion. During the last decades of the 20th century, stainless steel technology took a giant leap forward with the development of higher nickel stainless steels enhanced by the addition of nitrogen for improved strength and corrosion resistance. These alloys normally contain about 6% molybdenum, so they offer excellent resistance to localized corrosion in reducing and mixed acid environments. They contain sufficient chromium for resistance to oxidizing environments as well.

INCOLOY® alloy 25-6MO (UNS N08926) is a SASS that offers excellent resistance to corrosion, especially in seawater and acid/halide environments.

SMC just recently completed the development of an advanced-grade SASS commercially designated INCOLOY alloy 27-7MO (UNS S31277). With special thermal mechanical processing and increased contents of nickel, chromium, nitrogen, and molybdenum, alloy 27-7MO offers significantly improved corrosion resistance and strength often equivalent to that of much more costly nickel-chromium-molybdenum alloys but at a very economical price. In some applications, INCOLOY alloy 27-7MO can be used in place of more costly materials such as alloys 625 and C-276.

Mid-Range Corrosion-Resistant Alloys

The members of this family of products are nickel-base and contain up to 9% molybdenum. With their contents of chromium and molybdenum they provide resistance to both oxidizing and reducing acid environments. They are moderately priced and provide good value for applications for which they provide adequate resistance.

INCOLOY alloy 825 contains over 3% molybdenum and is stabilized to resist sensitization by an addition of titanium. The performance of alloy 825 in sulfuric acid is enhanced by an addition of copper. With its high nickel content (42%), alloy 825 provides excellent resistance to stress-corrosion cracking in chloride-bearing media.

INCOLOY alloy 020 is similar in composition to alloy 825, but contains a lower nickel content of approximately 35% and is stabilized by additions of niobium.

INCONEL alloy G-3 contains 6% molybdenum which gives it improved resistance to general and localized corrosion in reducing acids. Like alloy 825, alloy G-3 contains enough nickel (48%) so that it is resistant to stress corrosion cracking.

INCONEL alloy 625 is the most highly alloyed material in this family and is most versatile in its applications. With 9% molybdenum and 4% niobium, alloy 625 offers corrosion resistance approaching that of alloys C-276 and 22. It offers excellent strength and exceptional resistance to fatigue. Alloy 625 is widely used in aerospace and marine construction as well as for processing components.

Advanced Corrosion-Resistant Alloys

SMC manufactures three nickel-base nickel-chromium-molybdenum alloys that offer exceptional resistance to a variety of corrosive media. With their high contents of chromium, molybdenum, and tungsten, the members of this alloy family offer the best resistance attainable with nickel alloys in acidic (reducing, oxidizing, and mixed) and halide (chloride and fluoride salts) environments.

INCONEL alloy C-276 is a well-established alloy that has been popular in the process industries for over 30 years. Alloy C-276 is the "workhorse" of the air pollution control (flue gas desulfurization – FGD) industry, providing corrosion resistance to all but the most aggressive environments encountered.

INCONEL alloy 22 (formerly marketed under the designation INCONEL alloy 622) is similar to alloy C-276 but offers improved resistance to localized corrosion and attack by oxidizing media.

With high contents of chromium, molybdenum, and tungsten, INCONEL alloy 686 offers superior corrosion resistance to both alloys C-276 and 22. Alloy 686 is the most highly alloyed corrosion-resistant alloy commercially available.

High-Strength Corrosion-Resistant Alloys

SMC offers corrosion-resistant alloys that are essentially precipitation-hardenable (age-hardenable) versions of their solid-solution counterparts. These products offer the corrosion resistance of the standard alloys but more than twice the strength. In addition, precipitation-hardenable alloys can be fabricated prior to heat treatment when they are relatively soft and ductile and then heat treated afterward to develop high strength.

INCOLOY alloy 925™ is an age-hardenable version of INCOLOY alloy 825; INCONEL alloy 725™ is an age-hardenable version of INCONEL alloy 625.

INCONEL alloy 718 provides good resistance to aqueous corrosion in seawater and is widely used for fasteners and hardware in marine construction. INCONEL alloy 725 and its even higher strength derivative, INCONEL alloy 725HS, are gaining popularity for this type of application. Alloys 725 and 725HS offer fracture toughness considerably improved over that of alloy 718.

Solid-solution alloys can also be cold worked to increase their strength. INCONEL alloy 686 is used in the cold-worked condition for high strength (110 to 140 ksi yield strength) marine fasteners.

High Nickel Materials & Alloys

Commercially pure Nickel 200 and Nickel 201 are widely used in chemical and process plants for caustic soda, chlorine, organic acids and synthetic fiber production. Nickel is also useful to provide metallurgical stability, improve thermal stability, fabricability and weldability.

MONEL® alloy 400 is a nickel-copper alloy that provides excellent strength, and resistance to a wide range of media including seawater, dilute hydrofluoric, hydrochloric and sulfuric acids and alkalies. The material is used in salt production, hydrocarbon processing, marine and offshore applications.

INCONEL alloy 600 is a nickel-chromium-iron alloy with resistance to chloride and fluoride attack, chloride stress-corrosion cracking and caustic corrosion. Alloy 600 offers high strength and oxidation resistance at elevated temperatures.

Resistance to Localized Corrosion

The Pitting Resistance Equivalency Number (PREN) is a means of comparing the relative resistance of alloys to localized corrosion. The PREN values reported in Table 1 were calculated using the typical composition values in the table and an equation developed to be applicable to the range of corrosion-resistant alloys reported in the table.

The relative resistance of alloys to localized corrosion can also be compared by their critical crevice temperature (CCT) and critical pitting temperature (CPT), determined in the ASTM G48 test using methods C and D, respectively. Test samples are exposed to an acidified solution of 6% ferric chloride for 72 hours. CCT tests utilize a crevice device while pitting tests do not. The CCT and CPT are defined as the lowest temperatures at which measurable corrosion occurs. The test is limited to a maximum test temperature of 85°C, as the test solution becomes unstable at higher temperatures. Therefore, the CCT and CPT values for alloys that do not corrode at 85°C are reported as ">85°C". Values for some corrosion-resistant alloys are reported in Table 2.

Table 2 – CCT & CPT Values for Corrosion-Resistant Alloys, Determined per ASTM G48, Methods C & D

Alloy	316SS	825	25-6MO	625	27-7MO	C-276	22	686
CCT (°C)	<0	5	30	35	45	50	85	>85
CPT (°C)	20	30	70	>85	>85	>85	>85	>85

Chemical Composition

The typical chemical compositions of the SMC corrosion resistant alloys are reported in Table 1. Limiting chemical compositions for purchasing purposes will be found in the appropriate society specifications (e.g., ASTM, ASME, BS, SAE/AMS, VdTÜV, etc.).

Table 1 – Typical Chemical Composition of SMC Corrosion-Resistant Alloys

Alloy	UNS No.	Ni	Cr	Mo	Cu	W	Nb	N	PREN[a]
25-6MO	N08926	25	20	6.5	1	–	–	0.20	35.8
27-7MO	S31277	27	22	7.2	1	–	–	0.34	43.0
825	N08825	42	21	3	2	–	–	–	25.5
G-3	N06985	48	22	7	2	1	–	–	34.0
625	N06625	62	22	9	–	–	3.5	–	40.8
C-276	N10276	58	16	16	–	3.5	–	–	45.3
22	N06022	57	22	14	–	3.2	–	–	47.8
686	N06686	58	21	16.3	–	3.9	–	–	51.3
718[b]	N07718	53	20	3	–	–	5	–	32.0
725[b]	N07725	56	22	9	–	–	3.5	–	40.8
925[b]	N09925	44	21	3	2	–	–	–	25.5

[a] PREN = %Cr + 1.5(%Mo + %W + %Nb) + 30(%N)
[b] Age-hardenable alloys also contain aluminum and titanium for phase precipitation

Resistance to General Corrosion

General corrosion is the most commonly encountered form of attack in processing applications. In this form of corrosion, the surface of the material is uniformly attacked such that the cross sectional thickness thins over time. The data presented in Tables 3 through 7 show the resistance of some alloys to general corrosion in various media.

Table 3 – Corrosion Rates in Hydrochloric Acid: 5% Concentration at 50°C Exposed for 1 Week

Alloy	Corrosion Rate (mpy)
INCOLOY alloy 25-6MO	46
INCOLOY alloy 27-7MO	22
INCONEL alloy 625	<0.1
INCONEL alloy C-276	0.5

Table 4 – Corrosion Rates in Sulfuric Acid: 95% Concentration at 50°C Exposed for 1 Week

Alloy	Corrosion Rate (mpy)
INCOLOY alloy 25-6MO	18
INCOLOY alloy 27-7MO	14
INCONEL alloy 625	48
INCONEL alloy C-276	0.1

Table 5 – Corrosion Rates in Sulfuric Acid

Test Medium	Temperature, °C	Alloy 25-6MO	Alloy 27-7MO	Alloy C-276
10% Sulfuric Acid	65	0	0	1
50% Sulfuric Acid	65	24	24	8
98% Sulfuric Acid	65	57	49	7
10% Sulfuric Acid	Boiling	59	58	34
50% Sulfuric Acid	Boiling	239	261	263
98% Sulfuric Acid	Boiling	1550	310	261

Table 6 – Corrosion Resistance in Various Acid Solutions

Test Medium	Temp., °C	Alloy 625	Alloy C-276	Alloy 22	Alloy 686
1.5% HCl	Boiling	–	32	14	2
2% HCl	Boiling	557	43	52	6
5% HCl	Boiling	–	146	–	185
10% H_2SO_4	Boiling	–	23	18	3
80% H_2SO_4	93°C	–	24	–	29
90% H_2SO_4	93°C	–	18	–	8
85% H_3PO_4	Boiling	–	10	13	16
65% HNO_3	Boiling	20	888	76	231
10% H_2SO_4+2% HCl	Boiling	–	138	279	132
10% H_2SO_4+5% HCl	80°C	–	–	82	34
50% Acetic+1% NaCl	Boiling	–	–	0.8	0.4
3% HF	80°C	38	16	–	17
10% HF	80°C	313	28	32	26
30% HF	80°C	–	–	–	24
10% H_2SO_4+40% HF	80°C	–	23	18	22

– indicates no data available for the alloy

Table 7 – Corrosion Rates in Environment Simulating a Wet Limestone Flue Gas Desulfurization Sulfur Dioxide Abatement System for a High-Sulfur Coal-Fired Electric Power Generating Station: 60% sulfuric acid + 2.5% hydrochloric acid + 0.2% hydrofluoric acid + 0.5% flyash at 80°C exposed for 1 week

Alloy	Corrosion Rate (mpy)
INCOLOY alloy 25-6MO	199
INCOLOY alloy 27-7MO	153
INCONEL alloy 625	187
INCONEL alloy C-276	51
INCONEL alloy 686	23

Resistance to Stress Corrosion

Alloys that are highly stressed (e.g, by cold forming or age hardening) are subject to stress corrosion cracking in some environments. It is generally accepted that an alloy's resistance to the effects of stress corrosion is a function of its nickel content. Alloys with higher nickel content are normally found to be more resistant to stress corrosion than those with lesser contents of nickel. The Copson curve (Figure 1) is often used to compare resistance to stress cracking in chloride-containing environments.

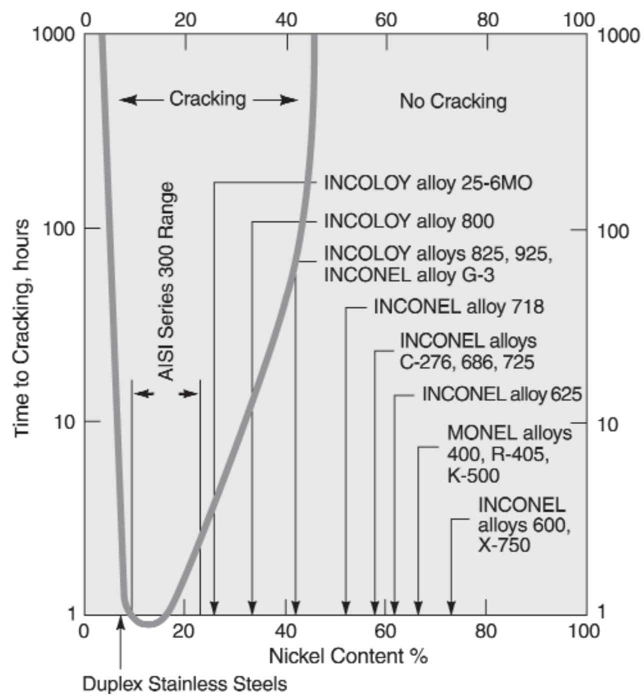


Figure 1. The classic indicator of susceptibility to chloride-ion stress-corrosion cracking is the boiling 42% magnesium chloride test. The test has shown that alloys containing more than about 45% nickel are resistant to chloride stress cracking.

Fabrication

Corrosion-resistant alloys are readily formed and joined using conventional techniques and equipment. Solid solution alloy products are normally used in the annealed condition. Age-hardenable alloys are best fabricated in the annealed condition and either directly aged or annealed and aged afterward to achieve high strength.

Corrosion-resistant alloys are normally formed at room temperature. If severe deformation is required, it may be necessary to either use multiple deformations with annealing performed between operations or the part may be heated to an elevated temperature at which greater deformation is possible. After hot forming, parts should be annealed to restore corrosion resistance. In most cases, cold-formed components may be placed in service without annealing. However, if the environment is such that it might induce stress corrosion cracking, the cold-formed parts should be annealed. Age-hardened alloys are not normally used in environments that can induce stress corrosion.

Corrosion-resistant alloys are best joined using overmatching composition welding products. Due to the rapid solidification of weldments, elemental segregation can result in composition gradients across the components of the weld. Thus, some areas will be enriched with alloying elements while others will be depleted. The corrosion resistance of the depleted areas will be compromised such that they will corrode preferentially to the base metal. Therefore, welds are best deposited with welding products of overmatching composition. For example, INCOLOY alloys 825 and 25-6MO are generally welded with INCONEL alloy 22 or 625 welding products. INCOLOY alloy 27-7MO may be joined with INCONEL alloy 22 or 686 welding products. INCONEL alloy C-276 and 22 may be joined with INCONEL alloy 686 welding products. Since there is no more highly alloyed product available, INCONEL alloy 686 products must be joined with matching composition welding products.

After fabrication, cleaning of the alloy surface may be required to prevent process contamination or to ensure alloy performance. Foreign materials which have become embedded into the alloy surface should be removed by grinding or pickling. Paints, markings, coating, etc. should be removed as they can act as a crevice and induce localized corrosion. Scratches, deep dents, and rough grinding burrs should be removed by grinding to blend them into the contour of the surface. Deep defects may require weld repair. Severe heat tint should be removed either by grinding or pickling. Welding slag should be removed from SMAW and SAW weldments by chipping and brushing with a stainless steel brush. It may be necessary to grind the surface of SMAW or SAW deposits to be placed in severe high-temperature service as any residual weld slag can cause molten slag attack at high temperatures.

Some stainless steels are passivated prior to service to optimize corrosion resistance. Exposure of these materials to passivating solutions (e.g, nitric acid) forms a passive film on the surface. Corrosion-resistant nickel alloys generally do not require passivation, as they form a passive surface film when exposed to air. The resistance of alloys to be exposed to a high-temperature reducing environment may be improved by a pre-oxidizing heat treatment.

Product Availability

Special Metals Corporation manufactures a complete line of corrosion-resistant alloys in most product forms. Commonly available forms are sheet, strip, plate, round, square and hexagonal rod and bar, solid and clad tubing, I.D. finned tubes, pipe, forging stock, extruded shapes, welding filler metals, weld strip, flux-covered electrodes, and welding fluxes. SMC CRA products are supplied to a variety of specifications worldwide including ASTM, ASME, BS, SAE/AMS and VdTÜV. For commercial information or to submit an inquiry, contact any of the SMC offices listed on the last page of this document or visit the SMC website, www.specialmetals.com.

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