INCONEL® alloy 22

INCONEL® alloy 22 (UNS N06022; W. Nr. 2.4602; NiCr21Mo14W) is a fully austenitic advanced corrosion-resistant alloy that offers resistance to both aqueous corrosion and attack at elevated temperatures. This alloy provides exceptional resistance to general corrosion, pitting, crevice corrosion, intergranular attack, and stress corrosion cracking. Alloy 22 has found numerous applications in the chemical/petrochemical processing, pollution control (flue gas desulfurization), power, marine, pulp and paper processing, and waste disposal industries.

Alloy 22 is nickel-base and typically contains 22% chromium, 14% molybdenum, and 3% tungsten. Iron is normally limited to less than 3%. The alloy's high content of chromium gives it good resistance to wet corrosion by oxidizing media (e.g., nitric acid and ferric and cupric salts). Its contents of molybdenum and tungsten give the alloy resistance to wet reducing media (e.g., sulfuric and hydrochloric acids). Alloy 22 exhibits excellent resistance to corrosive attack by seawater under stagnant and flowing conditions.

At elevated temperatures, the high chromium level of INCONEL alloy 22 helps it resist oxidation, carburization, and sulfidation. Since it is nickel-base, alloy 22 resists high temperature attack by halides (e.g., chlorides and fluorides). With these attributes, the alloy is widely used to protect steel tubes and other components in coal-fired and waste-to-energy boilers.

INCONEL alloy 22 products are covered by ASTM, ASME and ISO specifications. Alloy 22 is approved for construction of pressure vessels and components under the ASME Boiler and Pressure Vessel Code Section VIII, Division 1 for service up to 1250°F (677°C). The alloy is also approved by VdTÜV under Werkstoffblatt 479. The alloy is equivalent to and directly competes with Hastelloy® C-22® and Nicrofer® 5621hMoW alloys.

The limiting chemical composition ranges for alloy 22 are presented in Table 1. Table 2 compares the combined alloying content (Cr+Mo+W+Nb) of INCONEL alloy 22 with other similarly alloyed materials. Physical properties are presented in Table 3; mechanical properties at room temperature are found in Table 4; thermal conductivity in Table 5. Mechanical properties at elevated temperatures are seen in Figure 1.

Table 1 - Limiting Chemical Composition, %, of INCONEL alloy 22 (ASTM B 574, B 575, etc.)

Nickel	Balance*
Chromium	20.0-22.5
Molybdenum	12.5-14.5
Iron	2.0-6.0
Tungsten	2.5-3.5
Cobalt	2.5 max.
Vanadium	0.35 max.
Carbon	0.015 max.
Manganese	0.50 max.
Sulfur	0.02 max.
Silicon	0.08 max.
Phosphorus	0.02 max.

*Reference to the 'balance' of a composition does not guarantee this is exclusively of the element mentioned but that it predominates and others are present only in minimal quantities.

Table 2- Typical Compositions of the Ni-Cr-Mo-W corrosion resistant alloys

Alloy	UNS Number	Werkstoff Number	Fe	Ni	Cr	Mo	W or Nb	PREN*
686	N06686	2.4606	1	57	20.5	16.3	3.9	50.8
22	N06022	2.4602	2.5	59	21.5	14.1	3.1	47.3
C-276	N10276	2.4819	6	57	15.5	16	3.9	45.4
625	N06625	2.4856	3	62	22	9	3.6Nb	40.8
C-4	N06455	2.4611	2	66	16	16	-	40.0

*PREN= %Cr + 1.5(%Mo + %W + %Nb)

Publication Number SMC-049

Table 3 - Physical Properties of INCONEL alloy 22

Property	Value
Density	
lb/in^3	0.311
g/cm^3	8.61
Melting Range	
°F	2464-2529
°C	1351-1387
Specific Heat	
Btu/lb•°F	0.091
J/kg•°C	381
Permeability	
at 200 oersted (15.9 kA/m)	≤1.001
Electrical Resistivity	
ohm•circ mil/ft	730.7
microhm•m	1.215
Young's Modulus (Dynamic)	
10^3 ksi	30.3
GPa	209
Coefficient of Expansion	
70-200°F,10^6 in/in•°F	6.90
21-193°C, µm/m•°C	12.42

Table 4 -

Typical Room-Temperature Mechanical Properties of INCONEL alloy 22

Form	Material Thickness or Diameter		Tensile Strength		Yield Strength (0.2% Offset)		Elongation	Hardness
	in	mm	ksi	MPa	ksi	MPa	%	Rb
Plate	0.25-1.75	6.35-44.45	112	772	53	365	62	89
Sheet	0.038-0.15	0.97-3.81	122	841	63	434	54	93
Bar	0.50-5.50	12.7-139.7	115	793	55	379	60	89

ASTM Limiting Mechanical Properties of INCONEL alloy 22

Form	Tensile Strength		Yield Strength (0.2% Offset)		Elongation
	ksi	MPa	ksi	MPa	%
ASTM B 574, B 575 Bar, Plate, Sheet, Strip	100	690	45	310	45

Table 5 - Thermal Conductivity of INCONEL alloy 22

Temperature °C	Conductivity W/cm K	Temperature °F	Conductivity BTU in/ft^2 h °F
23	0.07995	73	55.47
50	0.08911	122	61.83
100	0.10148	212	70.41
200	0.12328	392	85.54
300	0.14089	572	97.75
400	0.15274	752	105.97
500	0.16400	932	113.78

Temperature °C	Conductivity W/cm K	Temperature °F	Conductivity BTU in/ft^2 h °F
600	0.17919	1112	124.32
700	0.22733	1292	157.72
800	0.24579	1472	170.53
900	0.23696	1652	164.41
1000	0.25484	1832	176.81
1100	0.27560	2012	191.21
1150	0.28479	2102	197.59

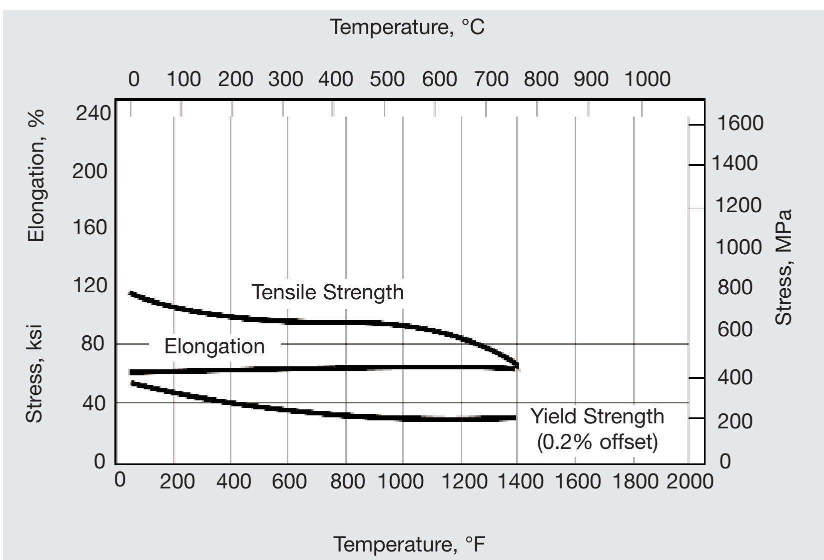


Figure 1 - Typical mechanical properties of INCONEL alloy 22 at elevated temperatures.

General Corrosion Resistance

The major attribute of INCONEL alloy 22 is outstanding resistance to a broad range of corrosive media. It resists oxidizing acids as well as reducing acids such as sulfuric and hydrochloric. Some other corrosive chemicals to which the alloy has high resistance are oxidizing acid chlorides, wet chlorine, formic and acetic acids, ferric and cupric chlorides, sea water, brines and many mixed or contaminated chemical solutions, both organic and inorganic.

Table 6 - General Corrosion Resistance in acid solutions (mpy)

Test Medium	Temp °C	C-4	C-276	22	686
1% HCl	Boiling	36	10	3	0.4
2% HCl	Boiling	85	43	52	6
5% HCl	70	–	13	19	10
10% H_2SO_4	Boiling	25	23	22	3
80% H_2SO_4	93	–	24	68	29
90% H_2SO_4	93	–	18	–	8
85% H_3PO_4	Boiling	61	10	13	16
65% HNO_3	Boiling	217	888	76	231
10% H_2SO_4 +2% HCl	Boiling	–	138	279	132
10% H_2SO_4 +5% HCl	80	–	–	82	34
3% HF	80	–	16	–	17
10% HF	80	–	28	–	26
40% HF +10% H_2SO_4	80	–	23	18	22

- No data available
Note: To convert mpy to mm/a, multiply by 0.0254

Figure 2 - A summary iso-corrosion chart for 20 mpy (0.51 mm/a) data in hydrofluoric acid.

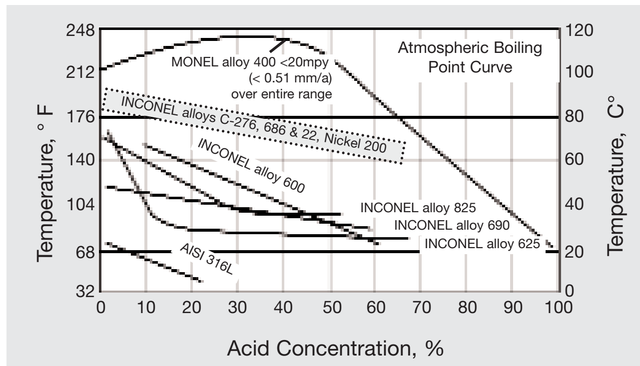


Figure 3 - Iso-corrosion chart for INCONEL alloy 22 in sulfuric acid.

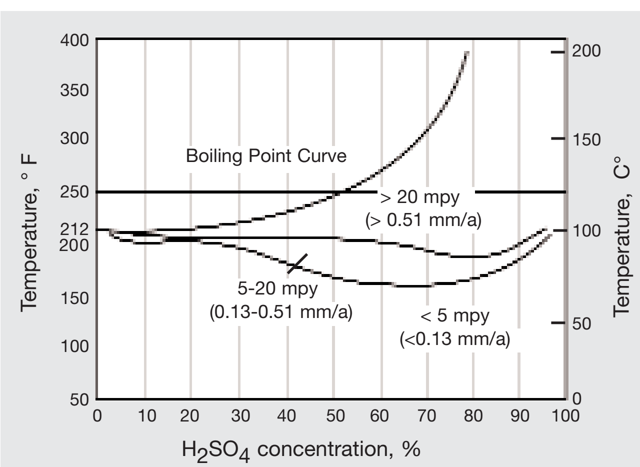
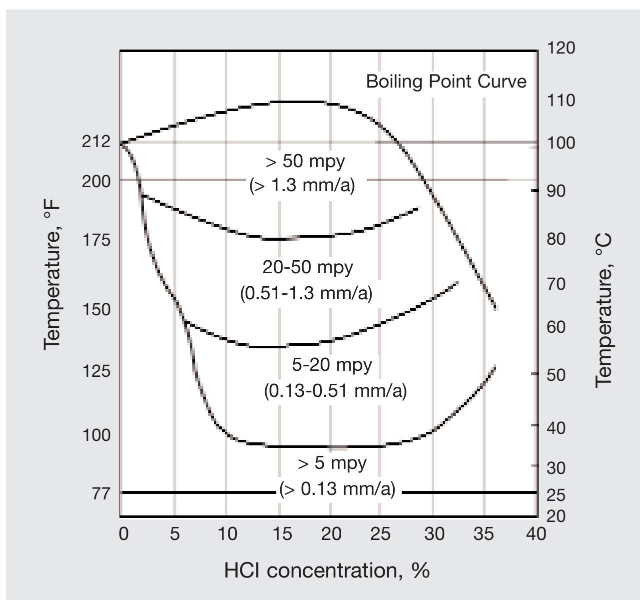


Figure 4 - Iso-corrosion chart for INCONEL alloy 22 in hydrochloric acid.



Localized Corrosion Resistance

Pitting and crevice corrosion are often evaluated by measurement of the minimum, or critical, temperature at which attack will occur. Critical pitting temperatures (CPT) and critical crevice temperatures (CCT) were determined in 6 wt. % ferric chloride + 1 wt. % hydrochloric acid at a maximum test temperature 85°C (185°F), Table 7. The relatively high molybdenum and tungsten and low iron content of INCONEL alloy 22 provide superior pitting resistance in this acid chloride environment.

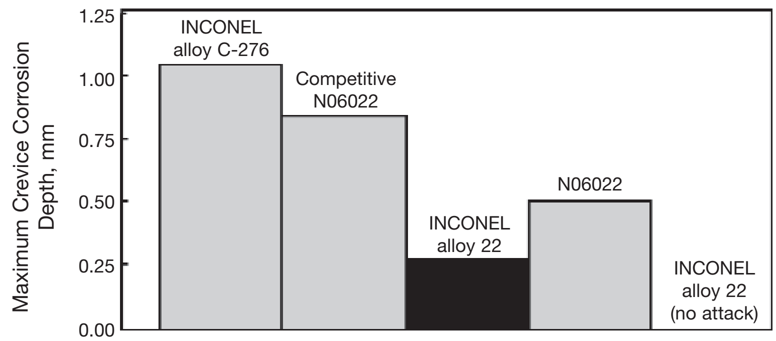


Figure 6 - Relative resistance of nickel-base alloys to crevice corrosion in 11.9% H_2SO_4 + 1.3% HCl + 1% $FeCl_3$ + 1% $CuCl_2$ at 125 °C.

Table 7- Critical crevice (CCT) and critical pitting (CPT) temperatures following testing in the ASTM G48 C and D environments of 6% $FeCl_3$ + 1% HCl for 72 hours.

Alloy	Critical Crevice Temperature		Critical Pitting Temperature	
	°C	°F	°C	°F
INCONEL alloy 686	>85	>185	>85	>185
INCONEL alloy 22	75	167	>85	>185
UNS N06022	58	136	>85	>185
UNS N10276	50	122	>85	>185
INCOLOY alloy 27-7MO	50	122	>85	>185
INCOLOY alloy 25-6MO	30	86	70	158
Type 316 stainless steel	20	68	<0	<32

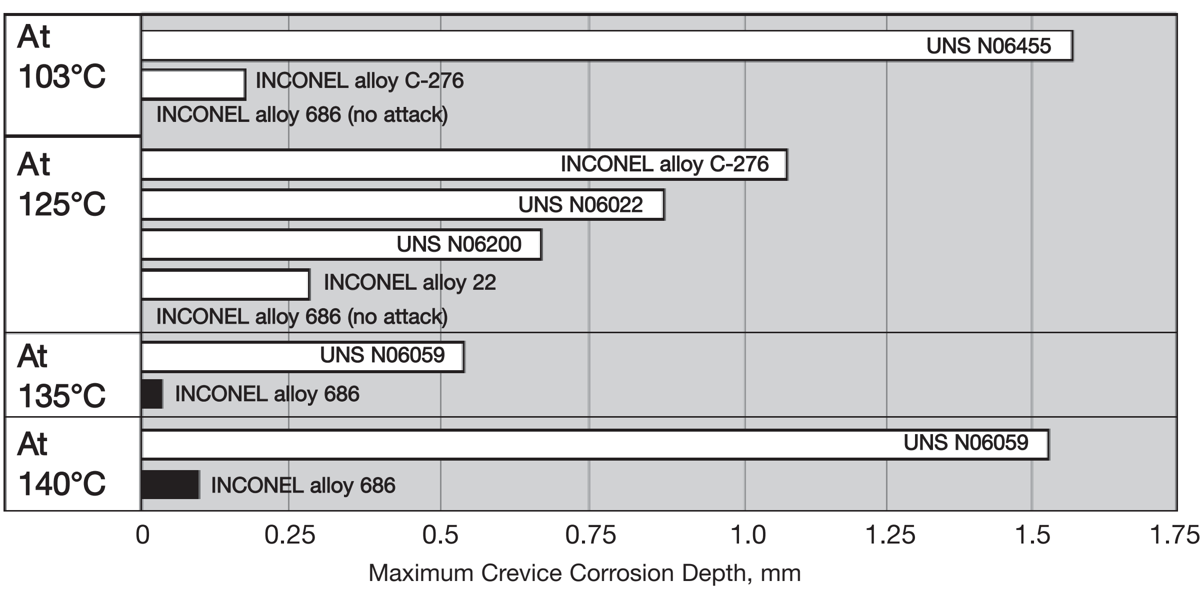


Figure 5 - Relative Resistance of nickel-base alloys to crevice corrosion as a function of temperature in 11.9% H_2SO_4 + 1.3% HCl + 1% $FeCl_3$ + 1% $CuCl_2$.

Table 8 - Crevice Corrosion Resistance at 125°C, 24 Hours Exposure, in 11.9% H_2SO_4+1.3% HCl+1% $FeCl_3$+1% $CuCl_2$. Average Result for 2 or More Multiple Crevice Specimens

Product Form	Alloy	% Crevices Attacked	Max. Attack Depth	
			mils	mm
Sheet	INCONEL alloy 22* 1/16” (1.6mm) sheet	13	24.5	0.65
Plate	INCONEL alloy 22 1/4” (6.4mm) plate	9	11	0.3

*Average of duplicate tests.

Intergranular Corrosion

Intergranular attack (IGA) is a localized corrosive attack along the grain boundaries of an alloy product. While IGA can occur due to several mechanisms, precipitation of phases in the grain boundaries (sensitization) is the most common cause. Susceptibility to sensitization varies from alloy to alloy. INCONEL alloy 22 has been shown to be resistant to sensitization when compared to most other corrosion-resistant alloys.

The ASTM G28 tests are commonly used to verify the resistance of an alloy product to IGA. Corrosion data generated by test methods A and B are presented in Table 9. The method A procedure is the Streicher test while the method B test utilizes a modified "Green Death" medium. It is seen that alloy 22 offers resistance equivalent to a competitive N06022 alloy.

Table 9 - Intergranular Corrosion Rates (ASTM G28 Methods A & B)

Alloy	ASTM G28 Test	Corrosion Rate (mpy)
INCONEL alloy 22	Method A	35
	Method B	6
UNS N06022	Method A	34
	Method B	6

Applications at Elevated Temperatures

While INCONEL alloy 22 is widely used for its excellent resistance to aqueous corrosion, the alloy is also resistant to many process environments at elevated temperatures up to 1250°F (677°C). Alloy 22 has been found to be especially effective for protection of boiler tubes, waterwalls, and other components in coal-fired electric power generation boilers. The alloy has given superior service in low NOx boilers as well. Alloy 22 is resistant to attack at elevated temperatures by halides (especially chlorides) and sulfur, which are often present in the grades of coal used for power generation. INCONEL alloy 22 also offers excellent resistance to aggressive corrosion by metal chloride and sulfate salts found in power generation boilers fired by municipal solid waste. Alloy steel components are commonly overlaid with alloy 22 by welding. Weld deposits fabricated using the Ni-Cr-Mo-W alloy 22 do not exhibit the segregation tendencies shown by Ni-Cr-Mo-Nb alloy systems. This affords significant enhancements in corrosion resistance and excellent resistance to the corrosion-fatigue cracking which is commonly observed in low NOx boiler waterwall overlays applied using Ni-Cr-Mo-Nb materials. In addition, solid components are used and alloy 22 clad steel tubes are also available.

To meet stringent emission limits, fossil fuel and waste-fired power generation boilers are being redesigned to add burners to limit the formation of oxides of nitrogen (NOx). Improved protection of the boiler tubes and waterwalls for service in these more aggressive environments is required. INCONEL Filler Metal 625 weld overlays have long been used for protection of such boiler components, but a recent study determined that these overlays can suffer from circumferential cracking due to stress-accelerated sulfidation of the dendrite centers of the weld overlays in as little as 18 months of service. The study also indicated that INCONEL Filler Metal 622 overlays should offer significantly better resistance to this attack and, thus, extended service life. This superior performance is attributed to the higher molybdenum content and the absence of niobium, which has been blamed for elemental segregation problems in alloy 625 weld overlays. As a result, INCONEL alloy 622 welding products are preferred over alloy 625 products for overlay of boiler components.

Forming and Welding

INCONEL alloy 22 is readily fabricated by standard procedures for nickel alloys. Its high ductility aids cold forming, although work hardening may require intermediate annealing. Welding can be by gas tungsten-arc, gas metal-arc, and shielded metal-arc processes. Matched composition welding products, INCONEL Welding Electrode 122 and Filler Metal 622, are available. Overmatching composition welds may be deposited with INCO-WELD® Filler Metal 686 CPT® or INCO-WELD Welding Electrode 686CPT.

INCONEL Welding Electrode 122 and INCONEL Filler Metal 622 welding products are also used to join high nitrogen super-duplex and super-austenitic stainless steels when the use of niobium-bearing welding products may result in the undesireable formation of niobium nitride particles. Alloy 622 welding products are also used for weld overlay of boiler tubes, waterwalls, and hardware in electric power generation boilers fired by high sulfur coal or oil and waste-to-energy incineration systems fired by municipal and industrial waste.

Information on fabrication, joining and machining is available in the Special Metals publications "Fabricating," "Joining" and "Machining," respectively, on the website, www.specialmetals.com.

Available Products and Specifications

INCONEL alloy 22 is designated as UNS N06022 and Werkstoff Nr. 2.4602. Standard product forms include sheet, strip, plate, round bar, flat bar, forging stock, hexagon, and wire. The products are available in a wide range of sizes.

Rod, Bar, Wire and Forging Stock -ASTM B 462 (Rod, Bar and Forging Stock), ASTM B 564 & ASME SB 564 (Forgings), ASTM B 574 & ASME SB 574 (Rod, Bar and Wire), ASME Code Case 2226, ASME Code Case N-621, ISO 9723, ISO 9724, DIN 17752 (Rod & Bar), DIN 17753 (Wire), DIN 17754 (Forgings)

Plate, Sheet and Strip - ASTM B 575/B 906 & ASME SB 575/SB 906, ASME Code Case 2226, ASME Code Case N-621, ISO 6208, DIN 17750

Pipe and Tube - ASTM B 619/B 775 & ASME SB 619/SB 775 (Welded Pipe), ASTM B 622/B 829 & ASME SB 622/SB 829 (Seamless Tube), ASTM B 626/B 751 & ASME SB 626/SB 751 (Welded Tube), ASME Code Case 2226, ASME Code Case N-621, ISO 6207, DIN 17751

Welding Products - INCONEL Filler Metal 622 - AWS A5.14 / ERNiCrMo-10, INCONEL Welding Electrode 622 - AWS A5.11 / ENiCrMo-10

Other Product Forms - ASTM B 366 & ASME SB-366 (Fittings)

Composition - DIN 17744

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