ALLOY C-22

ALLOY C-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 C-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 C-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 C-22 exhibits excellent resistance to corrosive attack by seawater under stagnant and flowing conditions.

At elevated temperatures, the high chromium level of ALLOY C-22 helps it resist oxidation, carburization, and sulfidation. Since it is nickel-base, ALLOY C-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.

ALLOY C-22 products are covered by ASTM, ASME and ISO specifications. ALLOY C-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 limiting chemical composition ranges for ALLOY C-22 are presented in Table 1. Table 2 compares the combined alloying content (Cr+Mo+W+Nb) of ALLOY C-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.

General Corrosion Resistance

The major attribute of ALLOY C-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.

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 ALLOY C-22 provide superior pitting resistance in this acid chloride environment.

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.
ALLOY C-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 C-22 offers resistance equivalent to a competitive N06022 alloy.

Applications at Elevated Temperatures
While ALLOY C-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 C-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 C-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. ALLOY C-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 C-22 by welding. Weld deposits fabricated using the Ni-Cr-Mo-W ALLOY C-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 C-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. ALLOY 625 Filler Metal 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 ALLOY 622 Filler Metal 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, ALLOY 622 welding products are preferred over ALLOY 625 products for overlay of boiler components.

Forming and Welding
ALLOY C-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.

Table 1 - Limiting Chemical Composition, %, of Alloy C-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)

Table 3 - Physical Properties of Alloy C-22

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 Alloy C-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 Alloy C-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 Alloy C-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

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

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
alloy 686	>85	>185	>85	>185
alloy 22	75	167	>85	>185
UNS N06022	58	136	>85	>185
UNS N10276	50	122	>85	>185
alloy 27-7MO	50	122	>85	>185
alloy 25-6MO	30	86	70	158
Type 316 stainless steel	20	68	<0	<32

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	alloy 22* 1/16" (1.6mm) sheet	13	24.5	0.65
Plate	alloy 22 1/4" (6.4mm) plate	9	11	0.3

*Average of duplicate tests.

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

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

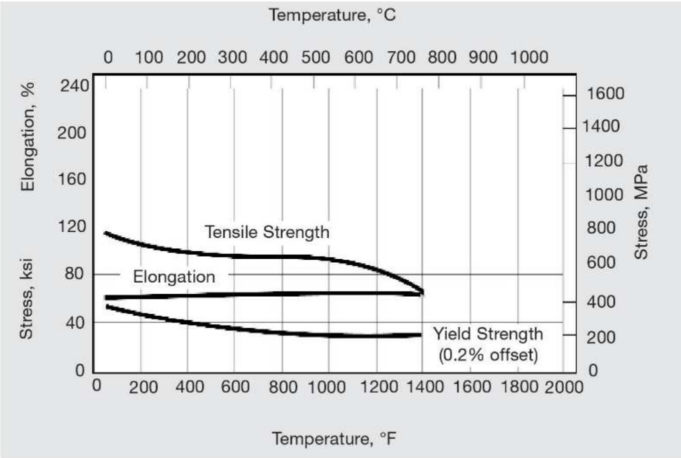

Figure 1 - Typical mechanical properties of **Alloy C-22** at elevated temperatures.

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

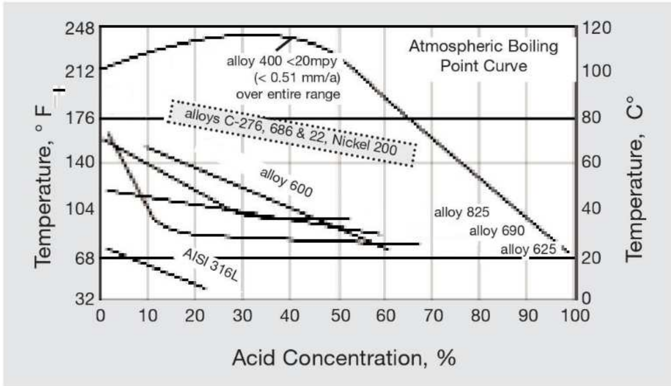

Figure 3 - Iso-corrosion chart for **Alloy C-22** in sulfuric acid.

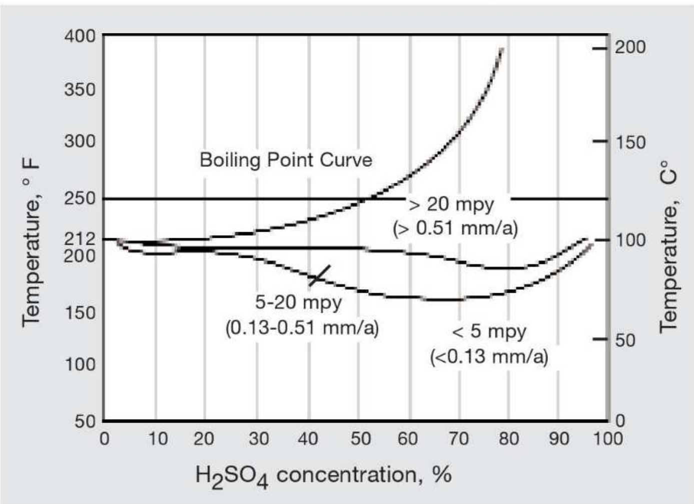

Figure 4 - Iso-corrosion chart for **Alloy C-22** in hydrochloric acid.

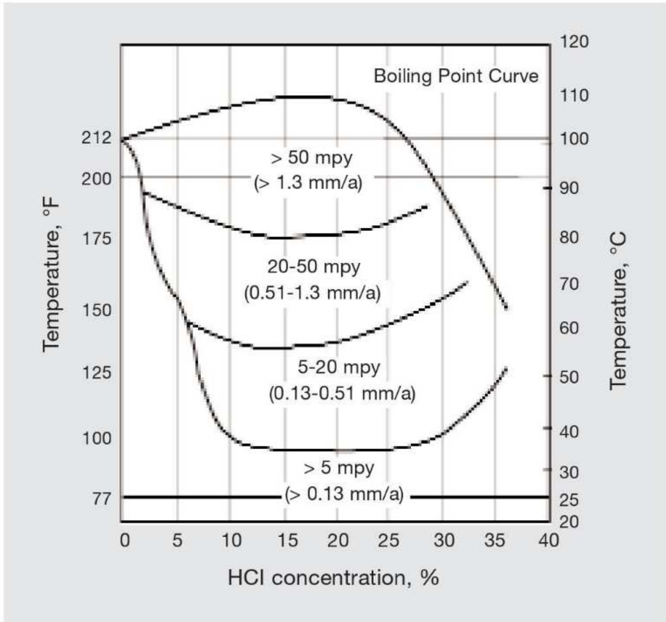

Figure 5 - Relative Resistance of nickel-base alloys to crevice corrosion as a function of temperature in 11.9% H_2SO_4 + 1.3% HCl + 1% $FeCl_3$ + 1% $CuCl_2$.

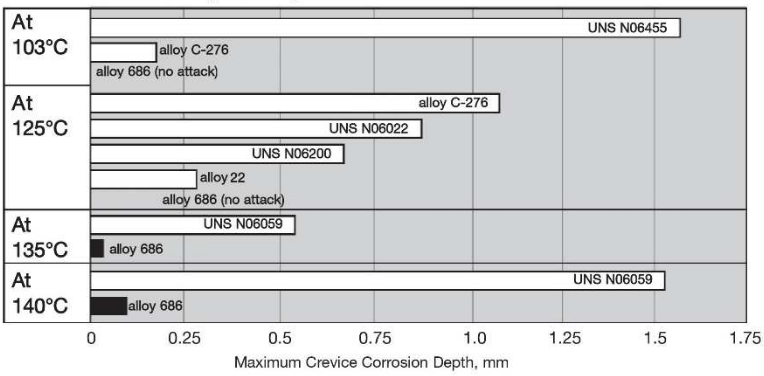

Figure 6 - Relative resistance of nickel-base alloys to crevice corrosion in 11.9% H_2SO_4 + 1.3% HCl + 1% $FeCl_3$ + 1% $CuCl_2$ at 125 °C.