INCONEL alloy C-276 (UNS N10276/W.Nr. 2.4819) is known for its corrosion resistance in a wide range of aggressive media. The high molybdenum content imparts resistance to localized corrosion such as pitting. The low carbon minimizes carbide precipitation during welding to maintain resistance to intergranular attack in heat-affected zones of welded joints. It is used in chemical processing, pollution control, pulp and paper production, industrial and municipal waste treatment and the recovery of "sour" natural gas. Applications in air pollution control include stack liners, ducts, dampers, scrubbers, stack-gas re-heaters, fans and fan housings. In chemical processing, the alloy is used for components including heat exchangers, reaction vessels, evaporators and transfer piping.

Physical Properties

Table 2 - Physical Properties

Temp	Thermal Conductivity	Coeff. of Expansion[a]	Electrical Resistivity	Young's Modulus
°F	Btu•in./ft²•h°F	10^{-6} in/in•°F	ohm•cmil/ft	10^3 ksi
-270	50	-	-	-
-100	60	-	0	-
0	65	-	-	-
77	-	-	739.2	29.8
100	71	-	-	-
200	77	6.8	743.8	29.5
400	90	7.0	749.3	28.6
600	104	7.2	757.7	27.8
800	117	7.4	760.3	26.7
1000	132	7.5	772.5	25.7
1200	145	7.7	781.5	24.8
1400	159	8.1	773.9	23.5
1600	173	8.5	768.3	22.0
1800	185	-	766.2	20.6
2000	195	-	757.7	19.1
°C	W/m•°C	µm/m•°C	µΩ•cm	GPa
-168	7.2	-	-	-
-73	8.7	-	-	-
20	9.8	-	-	-
25	-	-	122.9	205
100	11.2	12.2	123.7	203
200	12.8	12.4	124.5	198
300	14.7	12.9	125.7	192
400	16.4	13.2	126.0	186
500	18.2	13.5	127.7	180
600	20.0	13.6	129.9	178
700	21.9	14.1	129.7	167
800	23.7	14.8	128.2	159
900	25.4	-	127.4	150
1000	27.0	-	127.1	141
1100	28.3	-	-	-

[a]Mean coefficient of linear expansion between 77°F (25°C) and temperature shown.

Table 1 - Limiting Chemical Composition, %

Nickel	Balance
Molybdenum	15.0-17.0
Chromium	14.5-16.5
Iron	4.0-7.0
Tungsten	3.0-4.5
Cobalt	2.5 max.
Manganese	1.0 max.
Carbon	0.01 max.
Vanadium	0.35 max.
Phosphorus	0.04 max.
Sulfur	0.03 max.
Silicon	0.08 max.

Table 4 - Elevated Temperature Dynamic Modulus Properties

Temperature	Young's Modulus	Shear Modulus	Poisson's Ratio
°F	10^3 ksi	10^3 ksi	
70	31.30	11.81	0.33
100	31.18	11.75	0.33
200	30.77	11.57	0.33
300	30.35	11.40	0.33
400	29.92	11.23	0.33
500	29.42	11.05	0.33

Table 3 - Physical Constants

Density, lb/in³	0.321
g/cm³	8.89
Melting Range, °F	2415-2500
°C	1325-1370
Thermal Conductivity, Btu•in/ft²•h•°F	67.9
W/m•°C	9.8
Specific Heat, Btu•lb•°F	0.102
J/kg•°C	427
Young's Modulus, 10^3 ksi	29.8
GPa	205
Shear Modulus, 10^3 ksi	11.4
GPa	79
Permeability at 200 oersted (15.9 kA/m)	1.0002
Poisson's Ratio	0.307

INCONEL® alloy C-276

Mechanical Properties

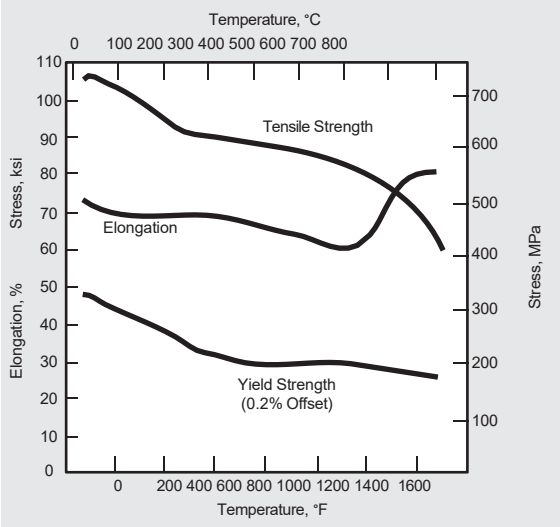

Figure 1. Tensile properties of annealed plate.

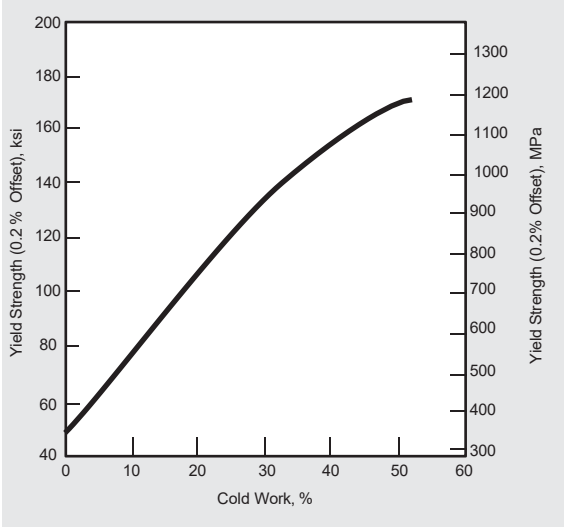

Figure 2. Effect of cold work on the yield strength of annealed plate.

Table 4 - Typical Room-Temperature Tensile Properties of Annealed Material

Product Form	Tensile Strength		Yield Strength (0.2% Offset)		Elongation	Hardness
	ksi	MPa	ksi	MPa	%	Rb
Tubing	105.4	727	45.4	313	70	92
Plate	107.4	741	50.3	347	67	89
Bar	110.0	758	52.6	363	62	88
Sheet	115.5	796	54.6	376	60	86

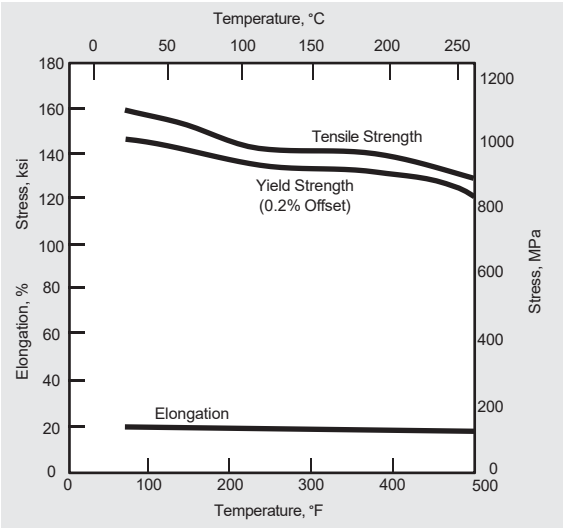

Figure 3. Tensile properties of 33.5% cold-worked tubing.

Corrosion Resistance

INCONEL alloy C-276 is resistant to general corrosion, stress-corrosion cracking, pitting and crevice corrosion in a broad range of severe environments. Its resistance to carbide precipitation during welding maintains corrosion resistance in the heat-affected zones of welded joints.

It has exceptional resistance to sulfuric acid and hydrochloric acid. It resists many of the most severe media encountered in chemical processing, including reducing and oxidizing acids, highly oxidizing, neutral, and acid chlorides, solvents, formic and acetic acids, acetic anhydride, wet chlorine gas, hypochlorites, and chlorine solutions. It has excellent resistance to phosphoric acid. At all temperatures below the boiling point and at concentrations lower than 65 wt %, tests have shown corrosion rates of less than 5 mpy (0.13 mm/y).

INCONEL alloy C-276 exhibits excellent resistance to corrosion by seawater especially under crevice conditions which induce attack in other commonly used materials such as 316 stainless steel, MONEL® alloy 400, and INCONEL alloy 625.

See Special Metals publication SMC-026, "Resistance to Aqueous Corrosion" on the website www.yttzhj.com, for more corrosion data.

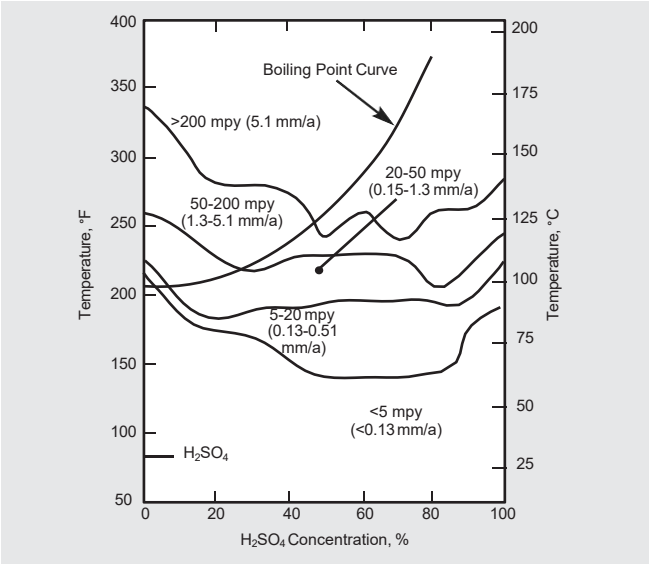

Figure 4. Corrosion rates in sulfuric acid.

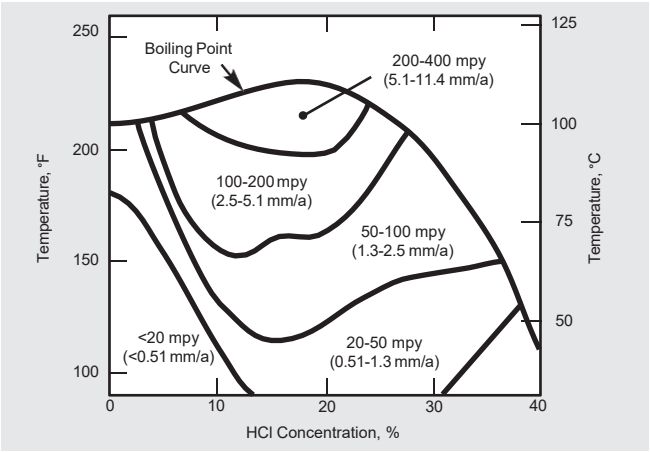

Figure 5. Corrosion rates in oxygen-saturated hydrochloric acid.

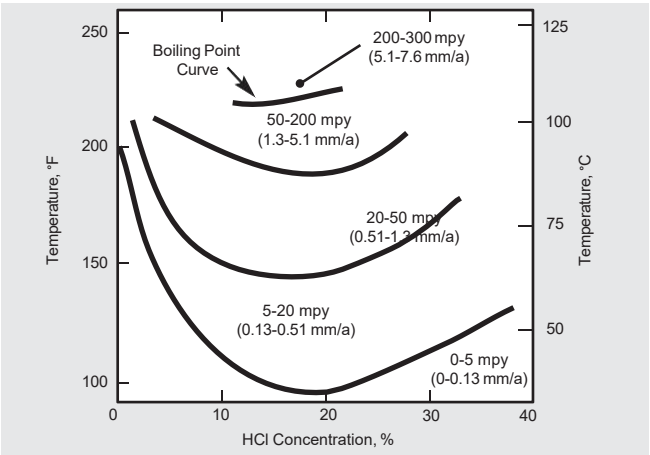

Figure 6. Corrosion rates in hydrochloric acid.

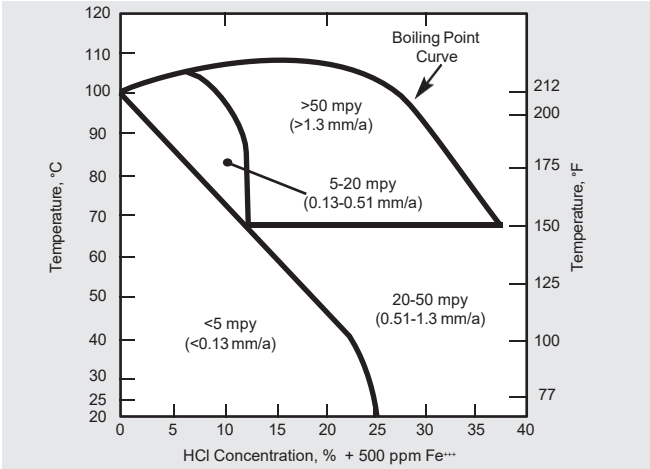

Figure 7. Corrosion rates in hydrochloric acid + 500 ppm Fe^{+++}

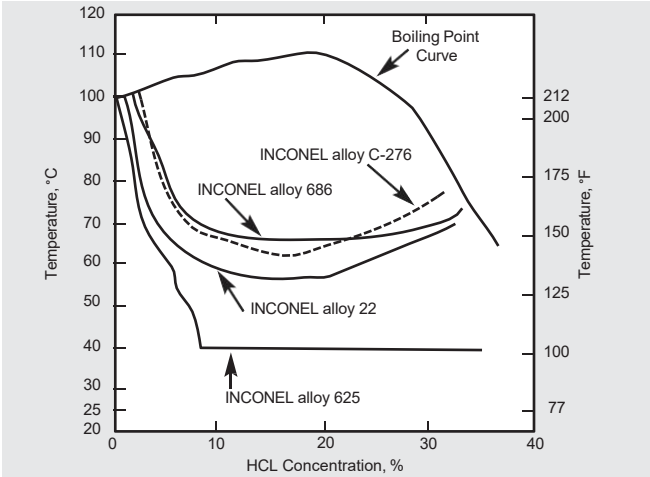

Figure 8. Corrosion resistance in hydrochloric acid. The isocorrosion curves show temperatures and concentrations above which the corrosion rate exceeds 0.5 mm/a (20 mpy).

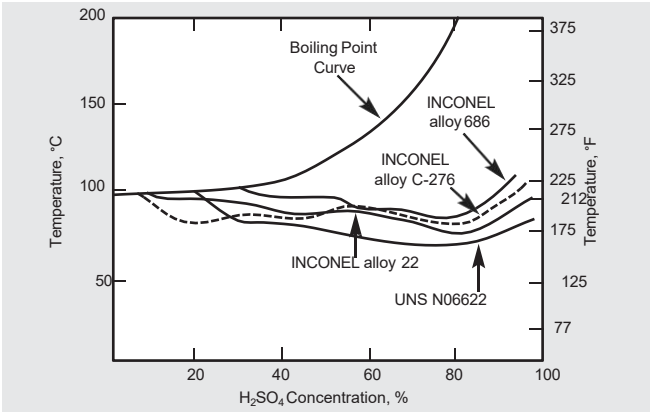

Figure 9. Comparative behavior of several nickel base alloys in sulfuric acid. The isocorrosion curves show temperatures and concentrations above which the corrosion rate exceeds 0.5 mm/a (20 mpy).

Table 5 - Corrosion Rates in Acid Solutions[a]

Solution	Temperature		Corrosion Rate, mpy (mm/a)			
	°F	°C	INCONEL alloy C-276	INCONEL alloy 22	INCONEL alloy 625	INCONEL alloy 686
10% H_2SO_4	Boiling	Boiling	20 (0.51)	22 (0.56)	17 (0.43)	3 (0.08)
20% H_2SO_4	176	80	3 (0.08)	1 (0.03)	1 (0.03)	-
40% H_2SO_4	176	80	5 (0.13)	10 (0.25)	5 (0.13)	-
80% H_2SO_4	176	80	4 (0.10)	9 (0.23)	6 (0.15)	4 (0.10)
95% H_2SO_4	122	50	0.1 (0.003)	-	48 (1.2)	-
5% H_2SO_4 + 0.1% HCl	Boiling	Boiling	22 (0.56)	24 (0.61)	-	-
10% H_2SO_4 + 1% HCl	Boiling	Boiling	70 (1.78)	201 (5.11)	465 (11.68)	-
10% H_2SO_4 + 2% HCl	Boiling	Boiling	138 (3.51)	281 (7.14)	-	132 (3.35)
10% H_2SO_4 + 2% HCl	122	50	0.2 (0.005)	0.1 (0.003)	0.1 (0.003)	0 (0)
10% H_2SO_4 + 5% HCl	Boiling	Boiling	256 (6.50)	456 (11.58)	-	-
40% H_2SO_4 + 10% HCl	176	80	26 (0.66)	32 (0.81)	-	-
2% HCl	Boiling	Boiling	43 (1.09)	52 (1.32)	-	6 (0.15)
5% HCl	140	60	10 (0.25)	-	46 (1.17)	1.2 (0.30)
20% HCl	212	100	154 (3.91)	269 (6.83)	385 (9.78)	-
5% HCl + 2% HF	158	70	18 (0.46)	40 (1.02)	102 (2.59)	-
85% H_3PO_4	Boiling	Boiling	10 (0.25)	13 (0.33)	>180 (>4.57)	16 (0.41)
10% HNO_3 + 3% HF	Boiling	Boiling	95 (2.41)	23 (0.61)	28 (0.71)	-

[a]168 h tests.

Table 6 - Corrosion Rates in Hydrochloric, Phosphoric and Acetic Acids[a]

Solution	Temperature		Corrosion Rate, mpy (mm/a)				
	°F	°C	INCONEL alloy C-276	INCOLOY® alloy 25-6MO	INCOLOY alloy 27-7MO	INCONEL alloy 22	INCONEL alloy 686
0.2% HCl	Boiling	Boiling	0.60 (0.02)	<0.1 (<0.003)	1.3 (0.03)	<0.1 (<0.003)	0.20 (0.005)
1% HCl	Boiling	Boiling	6.5 (0.17)	119 (3.02)	<0.1 (<0.003)	2.7 (0.07)	2.0 (0.05)
	194	90	3.5 (0.09)	37.0 (0.94)	<0.1 (<0.003)	-	-
	158	70	0.74 (0.02)	0.02 (<0.001)	<0.1 (<0.003)	-	-
5% HCl	158	70	13.2 (0.34)	142 (3.61)	150 (3.8)	18.8 (0.48)	9.8 (0.25)
	122	50	0.5 (0.01)	43.4 (1.10)	5 (0.13)	1 (0.03)	0 (0)
85% H_3PO_4	Boiling	Boiling	10.4 (0.26)	114 (2.90)	27 (0.69)	13.0 (0.33)	16.2 (0.41)
	194	90	0.20 (0.005)	10.6 (0.27)	<0.1 (<0.003)	0.21 (0.005)	0.18 (0.005)
80% CH_3COOH	Boiling	Boiling	0.15 (0.004)	<0.1 (<0.003)	<1 (<0.03)	<0.1 (<0.003)	<0.1 (<0.003)

[a]192 h tests.

Table 7 - Corrosion Rates in Various Media[a]

Solution	Temperature		Corrosion Rate	
	°F	°C	mpy	mm/a
10% HNO_3	Boiling	Boiling	15[b]	0.38[b]
10% HNO_3 + 2% HCl	180	82	6.5	0.17
15% HNO_3 + 3% HF	140	60	179	4.55
20% HNO_3 + 2% HF	140	60	215	5.46
3% HF	176	80	53	1.35
10% HF	75	24	2	0.05
10% HF	176	80	28	0.71
Concentrated HF	75	24	1	0.03
Concentrated HF	176	80	34	0.86
20% H_3PO_4	Boiling	Boiling	<1	<0.03
60% H_3PO_4	Boiling	Boiling	1	0.03
85% H_3PO_4	212	100	<1	<0.03
85% H_3PO_4	Boiling	Boiling	10	0.25
99.9% CH_3COOH + 0.1% NaCl	Boiling	Boiling	<1	<0.03
50% NaOH	Boiling	Boiling	1	0.03
10% HBr	176	80	<1	<0.03
10% HBr	Boiling	Boiling	<1	<0.03
10% NH_3Br	176	80	0	0.00
10% NH_3Br	Boiling	Boiling	0	0.00

[a]Test duration of 168 h except as noted.
[b]Test duration of 24 h.

Table 9 - Critical Crevice and Critical Pitting Temperatures in an Acidified 6% Ferric Chloride Solution (ASTM G 48, Methods C & D)

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
INCONEL alloy C-276	50	122	>85	>185
INCOLOY alloy 27-7MO	45	122	>85	>185
INCONEL alloy 625	35	95	>85	>185
INCOLOY alloy 25-6MO	35	86	70	158
INCOLOY alloy 825	5	41	30	86
AISI Stainless Steel	<0	<32	20	68

Table 10 - Corrosion Rates[a] in Simulated FGD Mixed-Gas Condensate Solutions

Solution	Temperature		Corrosion Rate, mpy (mm/a)		
	°F	°C	INCONEL alloy C-276	INCONEL alloy 22	INCONEL alloy 625
Solution 1[b]	185	85	82 (2.08)	20 (0.51)	14 (0.36)
Solution 2[c]	176	80	42 (1.07)	50 (1.27)	126 (3.20)

[a]168 h test.
[b]60% H_2SO_4 + 0.5% HCl + 0.1% HF + 0.1% HNO_3.
[c]60% H_2SO_4 + 2.5% HCl + 0.2% HF + 0.5% fly ash.

The performance of INCONEL alloy C-276 in a severe test for susceptibility to intergranular attack (ASTM G 28) is shown below in Table 8. The base corrosion rates listed are representative of typical production material. Rates significantly higher than these indicate susceptibility to intergranular attack. This test is designed to verify mill production only and not to compare alloys for use in applications such as flue gas desulfurization.

Table 8 - ASTM G28 Tests for Intergranular Attack

Alloy	Method A[a] Corrosion Rate		Method B[b] Corrosion Rate	
	mpy	mm/a	mpy	mm/a
INCONEL alloy C-276	175	4.45	30	0.76

[a]Boiling ferric sulfate/50% sulfuric acid.
[b]Boiling 23% H_2SO_4 + 1.2% HCl + 1% $FeCl_3$ + 1% $CuCl_2$.

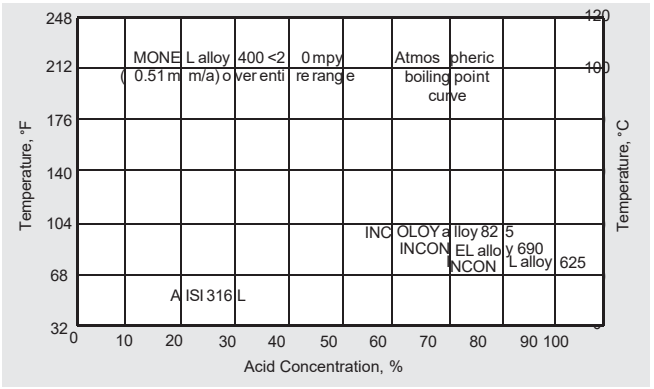

Figure 10. A summary iso-corrosion chart for 20 mpy (0.51 mm/a) data in hydrofluoric acid.

Corrosion Resistance - Flue Gas Desulfurization

INCONEL alloy C-276 is useful for flue gas desulfurization (FGD) systems to control air pollution from electric power plants. The alloy is used for various applications including scrubbers, ducting and stack liners.

Scrubber liquors and gas condensates generally contain chlorides and the chloride level often determines the corrosion behavior of the materials. INCONEL alloy C-276 has been shown to withstand higher chloride content than other alloys before the onset of localized corrosion in a simulated scrubber environment.

Table 11 - Maximum Pitting or Crevice Attack, mils (mm), in FGD Scrubber Slurry[a]

Alloy	Quencher	Absorber	Absorber Outlet	Outlet Duct	Bypass Duct
AISI 316L	22 (0.56)	21 (0.53)	35 (0.89)[b]	35 (0.89)[b]	12 (0.30)
AISI 317LM	20 (0.51)	22 (0.56)	29 (0.74)	33 (0.84)	29 (0.74)
INCOLOY alloy 825	15 (0.38)	33 (0.84)	39 (0.99)	50 (1.27)[b]	10 (0.25)
INCONEL alloy 625	<2 (<0.05)	10 (0.25)	11 (0.28)	7 (0.18)	nil
INCONEL alloy C-276	nil	nil	<2 (<0.05)	nil	nil

[a]6-month exposure at 126°F (52°C), pH 5.5, 5000 ppm chlorides.
[b]Perforated.

Table 12 - Maximum Pitting or Crevice Attack, mils (mm), in Scrubber Slurry[a]

Alloy	Scrubber Bottom	Under Spray Nozzles	Scrubber Outlet	Hold Tank
AISI 316	5 (0.13)	7 (0.18)	49 (1.24)[b]	2 (0.05)
INCOLOY alloy 825	<2 (<0.05)	1.2 (0.03)	49 (1.24)[b]	nil
INCONEL alloy 625	nil	nil	26 (0.66)	nil
INCONEL alloy C-276	nil	nil	nil	nil

[a]3-month exposure at 120°F (49°C), pH 5.8-6.1, 10,000 ppm chlorides.
[b]Perforated.

Corrosion Resistance - Oilfield Applications

INCONEL alloy C-276 is one of the premier materials for recovery and handling of "sour" natural gas, which contains hydrogen sulfide and usually carbon dioxide and chlorides. The gas can be extremely corrosive to carbon and alloy steels, and may cause brittle failure of many alloys by sulfide stress cracking (hydrogen embrittlement) or stress-corrosion cracking. The high levels of nickel, chromium, and molybdenum in INCONEL alloy C-276 make the alloy resistant to sour environments even at high temperatures in deep wells. The alloy is used for tubing and a variety of other downhole and surface components.

Table 13 - C-Ring Tests in NACE Solution[a]

Material Condition	Simulated Well Age	Yield Strength (0.2% Offset)		Hardness, Rockwell C	Duration, Days	Sulfide Stress Cracking
		ksi	MPa			
Cold Worked	600°F (315°C)/1000 h	126.6	873	32	43	No
Cold Worked	600°F (315°C)/1000 h	155.1	1069	38	43	No
Cold Worked	600°F (315°C)/1000 h	166.8	1150	35	43	No
Cold Worked	600°F (315°C)/1000 h	188.7	1301	43	43	No

[a]Room-temperature tests at 100% of yield strength in 5% NaCl plus 0.5% acetic acid saturated with H_2S. All specimens were coupled to carbon steel.

Heat Treatments

Hot forming should be between 1600 and 2250°F (870 and 1230°C), with all heavy forming above 2000°F (1090°C). INCONEL alloy C-276 is normally annealed at 2100-2150°F (1150-1175°C) and rapidly cooled such as by water quenching.

Joining

INCONEL alloy C-276 has good weldability and can be used as-welded for most applications. INCO-WELD® filler metal and welding electrode 686CPT® can be used to "overmatch" INCONEL alloy C-276 where enhanced corrosion resistance is required.

Information on joining is available in the Special Metals publication "Joining" on the website, www.yttzhj.com.

Table 14 - Recommended Welding Products

Shielded Metal Arc Welding	Gas Tungsten Arc Welding, Gas Metal Arc Welding
INCONEL welding electrode C-276	INCONEL filler metal C-276
INCO-WELD welding electrode 686CPT	INCO-WELD filler metal 686CPT

Table 15 - Corrosion Resistance of Weldments in INCONEL alloy C-276

Environment	Base Metal Alloy (5-6 mm thickness)	Weld Filler Metal	Maximum Pitting Depth of Attack, mm Average Results for Duplicate Specimens			
			GTAW Process		GMAW Pulsed Process	
			Base Metal	Weld Metal	Base Metal	Weld Metal
Green Death*	INCONEL alloy C-276	INCONEL filler metal C-276	0	6.2	0	3.4
	INCONEL alloy C-276	INCO-WELD filler metal 686CPT	0	0	0	0
ASTM G48C	INCONEL alloy C-276	INCONEL filler metal C-276	0	0	0	0
	INCONEL alloy C-276	INCO-WELD filler metal 686CPT	0	0	0	0

*11.9% H_2SO_4 + 1.3% HCl + 1% $FeCl_3$ + 1% $CuCl_2$ boiling at 103°C for 72 h.

Machining

Information on machining is available in the Special Metals publication "Machining" on the website, www.yttzhj.com.

Fabricating

Information on fabricating is available in the Special Metals publication "Fabricating" on the website, www.yttzhj.com.

Available Products and Specifications

INCONEL alloy C-276 is designated as UNS N10276 and Werkstoff Nr. 2.4819. It is listed in NACE MR0175 for oil and gas service. Alloy C-276 is available as pipe, tube, sheet, strip, plate, round bar, flat bar, forging stock, hexagon and wire.

INCONEL alloy C-276 is approved as a material of construction by the ASME Boiler and Pressure Vessel Code. Allowable stresses for Section III construction up to 800°F, Section VIII, Division 1 construction up to 1250°F, and Section VIII, Division 2 construction up to 800°F are contained in Tables 1B and 2B of ASME Code Case Section II, Part D.

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), ISO 9723 (Rod and Bar), ISO 9724 (Wire), ISO 9725 (Forgings), DIN 17752, DIN 17753, DIN 17754, VdTÜV 400/12.98

Plate, Sheet and Strip - ASTM B 575/B 906 & ASME SB 575/SB 906, ISO 6208, DIN 17750, VdTÜV 400/12.98

Pipe and Tube - ASTM B 622/B 829 & ASME SB 622/SB 829 (Seamless Tube), ASTM B 626/B 751 & ASME SB 626/SB 751 (Welded Tube), ASTM B 619/B 775 & ASME SB 619/SB 775 (Welded Pipe), ISO 6207 (Seamless Tube), DIN 17751, VdTÜV 400/12.98

Welding Products - INCONEL Filler Metal C-276 - AWS A5.14 / ERNiCrMo-4, INCONEL Welding Electrode C-276 - AWS A5.11 / ENiCrMo-4

Others - ASTM B 366 & ASME SB 366 (Fittings), DIN 17744 (chemical composition)

Publication Number SMC-019