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INCONEL alloy 686 (UNS N06686/WNr. 2.4606) is a single-phase, austenitic Ni-Cr-Mo-W alloy offering outstanding corrosion-resistance in a range of severe environments. Its high Ni and Mo provide good resistance in reducing conditions, and high Cr offers resistance to oxidizing media. Mo and W aid resistance to localized corrosion such as pitting. Low carbon helps minimize grain boundary precipitation to maintain corrosion-resistance in the heat-affected zones of welded joints. Resistance to general, pitting and crevice corrosion increases with the alloying (Cr+Mo+W) content, and INCONEL alloy 686 scores higher than competitive materials.

Alloy	Fe	Ni	Cr	Mo	W	Cr+Mo+W
UNS N06625	3	62	22	8.8	—	30.8
UNS N10276	6	57	15.5	16	3.9	35.4
UNS N06022	2	59.4	20.5	14.2	3.2	37.9
INCONEL alloy 686	1	57	20.5	16.3	3.9	40.7

INCONEL alloy 686 is covered by U.S. Patent 5,019,184.

Limiting Chemical Composition, wt %

Cr	19.0 - 23.0	Mn	0.75 max.
Mo	15.0 - 17.0	S	0.02 max.
W	3.0 - 4.4	Si	0.08 max.
Ti	0.02 - 0.25	P	0.04 max.
Fe	1.0 max.	Ni	Balance
C	0.01 max.		

Its matched composition welding products, designated INCO-WELD® filler metal or welding electrode 686CPT® also offer exceptional as-welded resistance to sulfuric or hydrochloric acids, to mixtures of the two, and to crevice or pitting corrosion in hot concentrated acid chloride solutions. These welding products are also used for dissimilar and overmatched welding applications (see pages 13 and 14).

INCONEL alloy 686 is used for resistance to aggressive media in chemical processing, pollution control, pulp and paper manufacture, and waste management applications.

Available Forms

Rod and/or Bar Products	Hot-Rolled Plate*	Cold-Rolled Sheet and/or Strip	Pipe and/or Tubing	Wire and/or Wire Rod
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*Alloy-clad steel plate is also available from specialist suppliers in North America, Europe and Asia. Inquire for further details.

Specifications

Form	ASTM	ASME	VdTUV**	DIN***
Rod and Bar	B 574	SB-574	515,12-98	17752
Wire	B 574	SB-574	—	17753
Plate, Sheet & Strip	B 575	SB-575	515,12-98	17750
Forgings	B 564	SB-564	—	17754
Seamless Tube & Pipe	B 622 B 829*	SB-622 SB-829*	515,12-98	17751
Welded Tube	B 626 B 751*	SB-626 SB-751*	—	—
Welded Pipe	B 619 B 775*	SB-619 SB-775*	—	—

* General Requirements

** VdTUV 515,12-98 covers the temperature range -196°C (-321°F) to 450°C (842°F).

*** DIN specifications, including 17744 (composition) are pending.

Physical Properties

Density		Melting Range		Electrical Resistivity,		Permeability at	
lb/in ³	0.315	°F	2440-2516	ohm•circ mil/ft	744.4	200 oersted (15.9 kA/m)	
g/cm ³	8.73	°C	1338-1380	μΩ•m	1.237	1.0001	

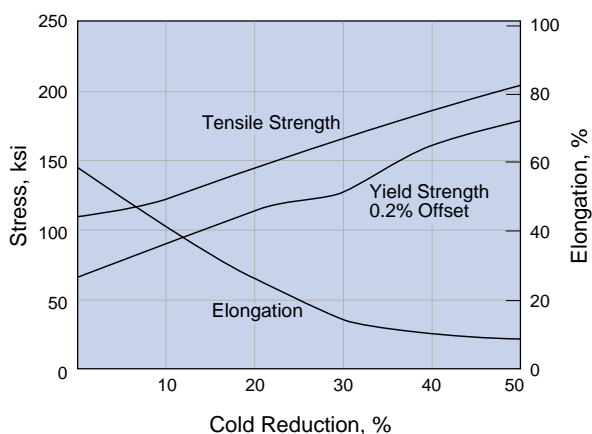
Thermal and Electrical Properties							
Temperature	Specific Heat	Coefficient of Expansion ^a	Electrical Resistivity	Temperature	Specific Heat	Coefficient of Expansion ^a	Electrical Resistivity
°F	Btu/lb • °F	10 ⁻⁶ in/in • °F	ohm • cmil/ft	°C	J/kg • °C	μm/m • °C	μΩ • cm
0	0.087	—	—	-15	364	—	—
70	0.089	—	744.4	20	373	—	123.7
200	0.092	6.67	749.2	100	389	11.97	124.6
400	0.098	6.81	756.7	200	410	12.22	125.7
600	0.104	7.00	760.9	300	431	12.56	126.3
800	0.110	7.17	765.6	400	456	12.87	127.2
1000	0.116	7.25	779.8	500	477	13.01	128.9
1200	0.122	7.49	776.1	600	498	13.18	129.5
				700	519	—	127.9

^a Mean coefficient of linear expansion between room temperature and temperature shown.

Moduli of Elasticity & Poisson's Ratio							
Temperature	Young's Modulus	Shear Modulus	Poisson's Ratio	Temperature	Young's Modulus	Shear Modulus	Poisson's Ratio
°F	10 ⁶ psi	10 ⁶ psi	μ	°C	GPa	GPa	μ
70	30.0	11.1	0.35	20	207	77	0.34
200	29.7	10.9	0.36	100	205	75	0.37
400	28.5	10.5	0.36	200	197	72	0.37
600	28.0	10.2	0.37	300	193	70	0.38
800	26.9	9.9	0.36	400	185	69	0.34
1000	26.0	9.5	0.37	500	183	67	0.37
1200	24.6	9.1	0.35	600	173	65	0.33
				700	165	61	0.35

Mechanical Properties

Room-Temperature Tensile Properties of Annealed Material							
Product Form	Thickness or Diameter		Tensile Strength		Yield Strength (0.2% offset)		Elongation
	in	mm	ksi	MPa	ksi	MPa	%
Plate	0.500	12.7	104.7	722	52.8	364	71
Plate	0.250	6.35	106.3	733	57.9	399	68
Sheet	0.125	3.18	116.5	803	61.1	421	59
Sheet	0.062	1.57	123.0	848	59.2	408	59
Rod	1.50	38.1	117.5	810	52.1	359	56



Effect of cold work on room temperature tensile properties.

High-Temperature Tensile Tests. Average of Three Heats, 0.25 in (6.4 mm) Plate

Temperature		Yield Strength		Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
75	24	57.5	396	107.3	740	60
200	93	46.8	323	100.2	691	69
400	204	42.1	290	92.1	635	67
600	316	41.7	288	87.3	602	60
800	427	32.5	224	82.6	570	69
1000	538	37.9	261	79.1	545	61

**Metallurgical
Stability**
Effect of 100-h High-Temperature Exposure on Room-Temperature Impact Strength

Exposure Temperature		Test Temperature		Impact Strength		Exposure Temperature		Test Temperature		Impact Strength	
°F	°C	°F	°C	ft-lbf	J	°F	°C	°F	°C	ft-lbf	J
As annealed		70	20	299	405	As annealed		-320	-196	298	404
1000	540	70	20	295	400	1000	540	-320	-196	299	405
1200	650	70	20	296	401	1200	650	-320	-196	297	403
1400	760	70	20	18.5	25.1	1400	760	-320	-196	9.0	12.2
1600	870	70	20	6.0	8.1	1600	870	-320	-196	2.5	3.4
1800	980	70	20	2.0	2.7	1800	980	-320	-196	2.0	2.7

Effect of Heat Treatment on IGA Resistance. ASTM G-28, B. 24-Hour Test

Alloy	Corrosion Rate, mpy (mm/y)			
	Annealed	Annealed + Reheated for 1h at:		
		1400°F (760°C)	1600°F (870°C)	1800°F (980°C)
INCONEL alloy 686	12 (0.30)	13 (0.33)	17 (0.43)	27 (0.69)
INCONEL alloy 622	7 (0.18)	2022 (51)	1982 (50)	75 (1.9)
UNS N06022	6 (0.15)	2283 (58)	2056 (52)	2306 (59)
INCONEL alloy C-276	45 (1.1)	>1000 (>25)	>1000 (>25)	>1000 (>25)

Corrosion Resistance

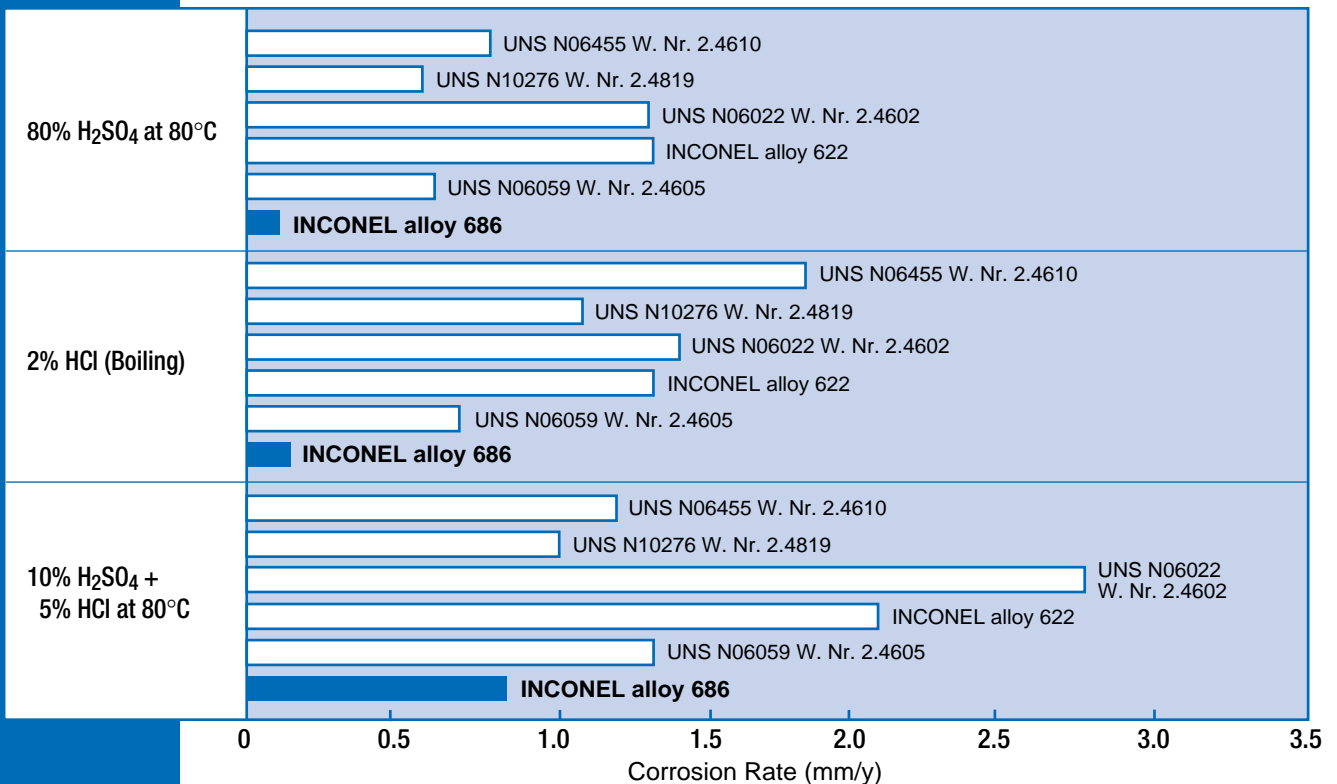
INCONEL alloy 686 offers outstanding resistance to general corrosion, to stress-corrosion cracking, and to pitting and crevice corrosion. Its resistance to intergranular precipitation during welding maintains its corrosion-resistance in the heat-affected zones of welded joints.

It offers resistance to both reducing and oxidizing acids and to mixed acid solutions. It is especially suited to handling mixed acids containing high concentrations of halides. It has shown good resistance to mixed acid media with pH levels of 1 or less, and chloride levels of over 100,000 ppm.

Alloy resistance to pitting corrosion is often compared by reference to the so-called "Pitting Resistance Equivalency Number" – the PREN.

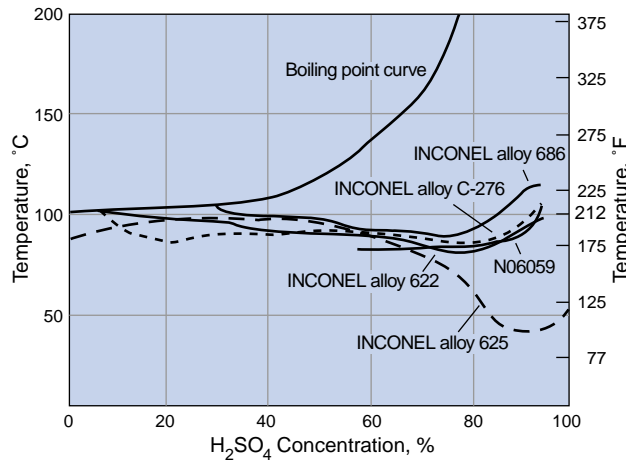
Performance and potential can be compared by the calculation $PREN = \%Cr + 1.5 (\%Mo + \%W + \%Nb)$. In ascending order of excellence, the highly alloyed INCONEL alloy 686 is proved as the optimum choice among commercially available, pit-resistant, Ni-Cr-Mo alloys:

INCONEL alloy 686	51
INCONEL alloy 622	47
UNS N06059	47
UNS N06200	47
UNS N06022	46
UNS N10276	45
UNS N06625	40

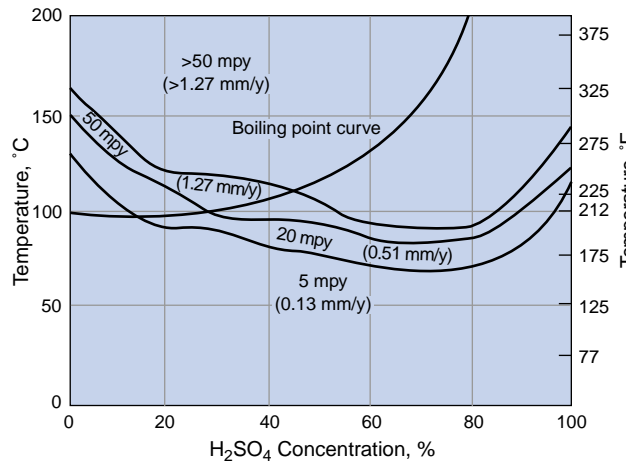


General corrosion-resistance of nickel base alloys in acid solutions. (Special Metals laboratory test data.)

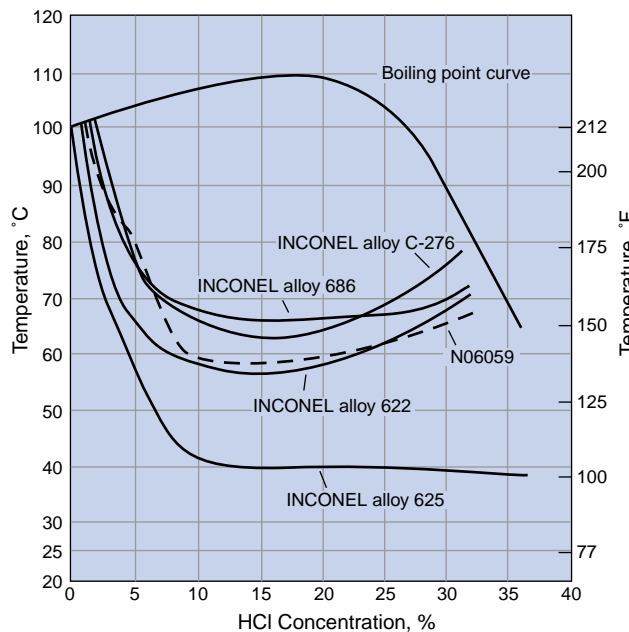
Corrosion Resistance
(continued)



Comparative behavior of several nickel base alloys in sulfuric acid. The iso-corrosion lines indicate a corrosion rate of 20 mpy.

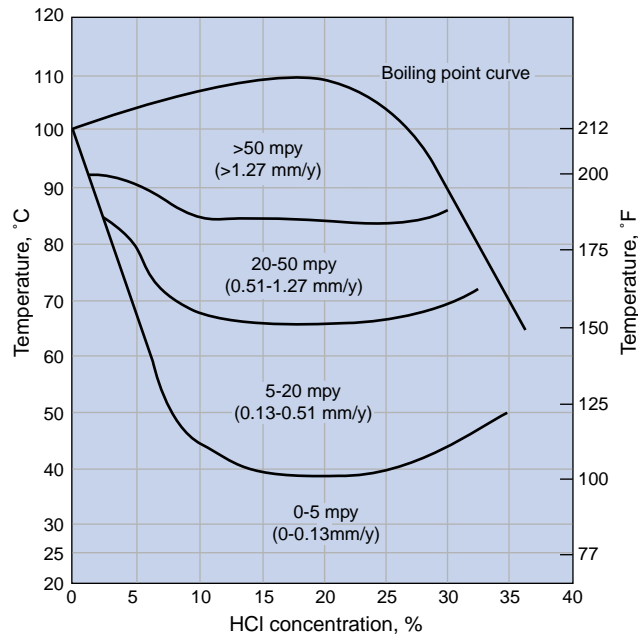


Iso-corrosion chart for INCONEL alloy 686 in sulfuric acid.

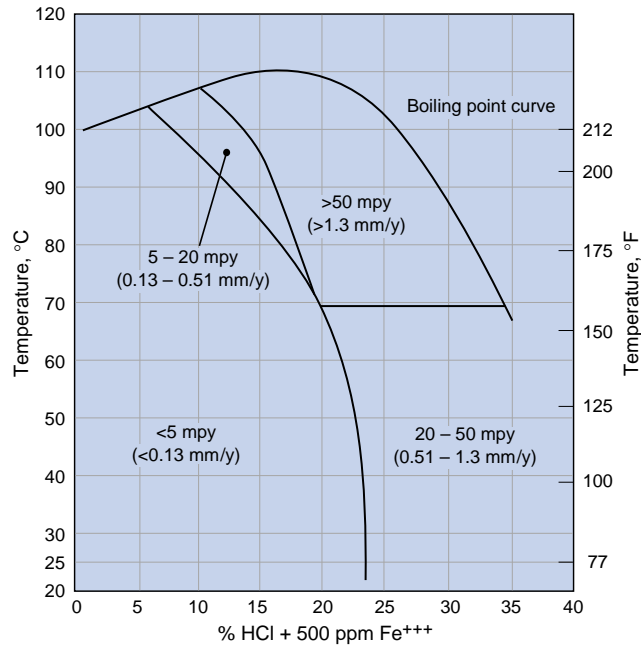


Comparative behavior of several nickel base alloys in hydrochloric acid. The iso-corrosion lines indicate a corrosion rate of 20 mpy.

Corrosion Resistance (continued)



Iso-corrosion chart for INCONEL alloy 686 in hydrochloric acid.



Corrosion resistance of INCONEL alloy 686 in hydrochloric acid + 500 ppm Fe⁺⁺⁺. The iso-corrosion curves show temperatures and concentrations that cover the corrosion rate range from <5 mpy (<0.13 mm/y) to >50 mpy (>1.3 mm/y).

Corrosion Rates in Acid Solutions^a

Alloy	Corrosion Rate, mpy (mm/y)			
	80% H ₂ SO ₄ 176°F (80°C)	2% HCl Boiling	10% H ₂ SO ₄ + 2% HCl Boiling	10% H ₂ SO ₄ + 5% HCl 176°F (80°C)
INCONEL alloy 686 ^b	4 (0.10)	6 (0.15)	132 (3.35)	34 (0.86)
UNS N10276	23 (0.58)	43 (1.09)	138 (3.51)	—
INCONEL alloy 622	52 (1.32)	52 (1.32)	279 (7.09)	82 (2.08)
UNS N06022	51 (1.30)	55 (1.40)	370 (9.40)	109 (2.77)

^a One week test duration. ^b Average of two tests.

Corrosion Resistance (continued)

Corrosion Rates in Hydrochloric and Phosphoric Acids^a

Solution	Temperature		Corrosion Rate, mpy (mm/y)			
	°C	°F	INCONEL alloy C-276	INCOLOY alloy 25-6MO	INCONEL alloy 622	INCONEL alloy 686
0.2% HCl	Boiling	Boiling	<1 (<0.025)	<1 (<0.025)	<1 (<0.025)	<1 (<0.025)
1% HCl	Boiling	Boiling	13 (0.33)	119 (3.02)	3 (0.08)	2 (0.05)
5% HCl	70 50	158 122	13 (0.33) 4 (0.10)	142 (3.61) 43 (1.09)	19 (0.48) 5 (0.13)	10 (0.25) 2 (0.05)
85% H ₃ PO ₄	Boiling 90	Boiling 194	10 (0.25) <1 (<0.025)	114 (2.90) 11 (0.30)	13 (0.33) <1 (<0.025)	16 (0.41) <1 (<0.025)

^a 192-h tests.

Corrosion Rates in Simulated FGD Outlet-Duct Environments^a

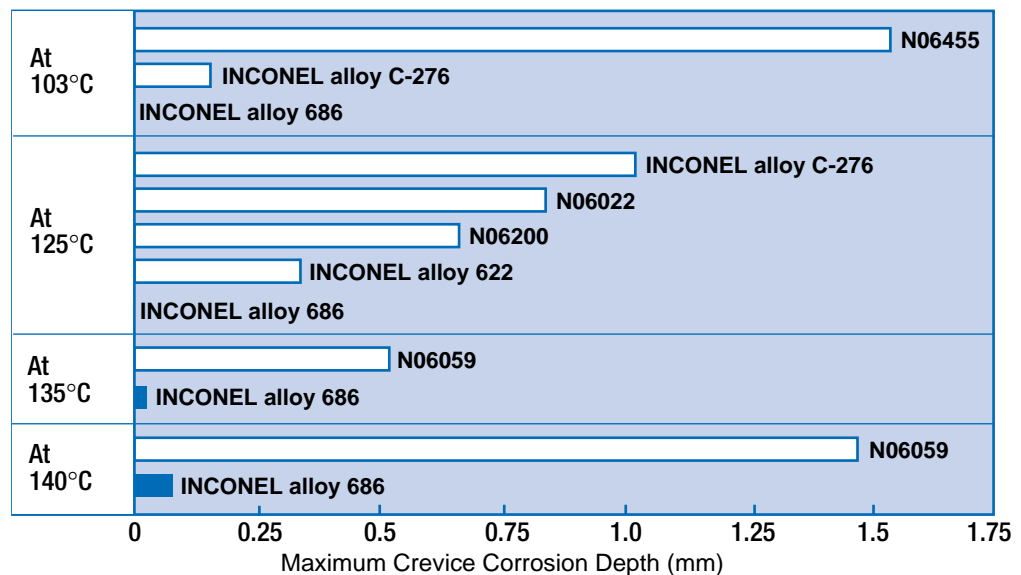
Alloy	Corrosion Rate, mpy (mm/y)		
	Solution One ^b	Solution Two ^c	Solution Three ^d
INCONEL alloy 686	14 (0.36)	23 (0.58)	274 (6.96)
UNS N10276	54 (1.37)	28 (0.71)	238 (6.05)
INCONEL alloy 622	12 (0.31)	40 (1.02)	279 (7.09)
UNS N06059	8 (0.21)	47 (1.20)	308 (7.82)

^a One week test duration.

^b 60% H₂SO₄ + 0.5% HCl + 0.1% HF + 0.1% HNO₃ at 85°C (185°F).

^c 60% H₂SO₄ + 2.5% HCl + 0.2% HF + 0.5% flyash at 80°C (176°F).

^d 70% H₂SO₄ + 2.5% HCl + 0.2% HF at 105°C (221°F).



Relative resistance of nickel base alloys to crevice corrosion as a function of temperature in 11.9% H₂SO₄ + 1.3% HCl + 1.0% FeCl₃ + 1.0% CuCl₂. (Special Metals laboratory test data.)

Corrosion Resistance
(continued)

Critical Crevice and Critical Pitting Temperatures in an Acidified 6% Ferric Chloride Solution

Alloy	Critical Crevice Temperature		Critical Pitting Temperature	
	°C	°F	°C	°F
INCONEL alloy 686	>85	>185	>85	>185
UNS N06059	>85	>185	>85	>185
INCONEL alloy 622	≥85	≥185	>85	>185
UNS N06022	58	136	>85	>185
UNS N10276	45	113	>85	>185
UNS N06625	35	95	>85	>185
INCOLOY alloy 25-6MO	30	86	70	158
INCOLOY alloy 825	5	41	30	86
AISI 316 stainless steel	<0	<32	20	68

Resistance to Crevice Corrosion in Solution Saturated with Sodium Chloride and Sulfur Dioxide at 80°C (176°F)^a

Alloy	Crevice Corrosion			Edge Pitting		
	Crevices Attacked, %	Maximum Attack		Number of Pits	Maximum Attack	
		mils	mm		mils	mm
Plate						
INCONEL alloy 686	1.3	<1	<0.025	0	0	0
INCONEL alloy 622 ^b	56.7	6	0.15	2	2	0.05
INCONEL alloy C-276 ^c	80.3	20	0.51	4	35	0.89
Sheet						
INCONEL alloy 686	36.3	8	0.20	1	<1	<0.025
INCONEL alloy 622 ^b	61.3	10	0.25	14	3	0.08
INCONEL alloy C-276 ^c	83.3	14	0.36	10	7	0.18

^a One week test duration. Each value is the average of three tests.

^b Contained shallow pits in random areas.

^c Contained deep pits in random areas.

Fabrication

INCONEL alloy 686 is readily fabricated. Forming operations can be by standard methods used for other high-nickel alloys such as INCONEL alloys C-276, 622 and 625. Work hardening during cold forming may make intermediate annealing necessary.

Hot forming should be between 1600 and 2500°F (870 and 1230°C), with all heavy forming above 2000°F (1090°C). INCONEL alloy 686 is normally annealed at 2150-2200°F (1180-1200°C), with rapid cooling.

Machining

Recommended Conditions for Turning with Single-Point Tools

Hardness	Depth of Cut		High Speed Steel				Tool	Carbide						Tool
			Surface Speed		Feed			Surface Speed				Feed		
	in	mm	fpm	m/min	ipr	mm/rev	Brazen Tool		Throw Away		Feed			
							fpm	m/min	fpm	m/min	ipr	m/rev		
85 R _b	0.25	6.35	12-18	3.7-5.5	1/100	1/4	T-5	30-40	10-12	40-60	12-18	1/100	1/4	C-2
45 R _c	0.05	1.27	15-20	4.6-6.1	2/250	1/5	M-36	40-50	12-15	50-100	15-30	2/250	1/5	C-2

Welding

INCONEL alloy 686 is readily weldable and needs no post-weld heat treatment to restore corrosion resistance. Recommended welding products are INCO-WELD welding electrode

686CPT for shielded-metal-arc welding and INCO-WELD filler metal 686CPT for gas-metal-arc and gas-tungsten-arc processes.

INCO-WELD 686CPT alloy products are used for joining nickel alloys such as INCONEL alloys 686, C-276 or 622, and UNS N06022, N06059 and N06920, as well as duplex, superduplex and super-austenitic stainless steels like INCOLOY alloy 25-6MO or UNS N08367. They are also useful for dissimilar metal welding, offering protection against preferential weld-metal attack when used for joining Mo-containing alloys or alloy-clad steels.

The corrosion-resistance of welds made in these materials, using the 686CPT consumables, is consistently greater than that of welds made using matched composition welding products; usually better than that of the base metals themselves. They are used in chemical and petro-

chemical processing, pollution control, oil and gas extraction, oil refining, and in marine environments.

INCO-WELD welding electrode 686CPT is an all-position shielded-metal-arc electrode. Filler metal 686CPT is used for gas-metal-arc and gas-tungsten-arc welding, and for submerged-arc welding using INCOFLUX NT120. Electroslag overlaying can also be carried out using INCO-WELD weldstrip 686CPT with INCOFLUX ESS1.

For more information on INCO-WELD 686CPT and other welding products, contact Inco Alloys International Welding Products, whose locations in the U.S., U.K. and Canada are listed on the back of this publication.

Corrosion Resistance

**General Corrosion Resistance in 10% H₂SO₄ + 2% HCl, at 80°C, for 7 days.
Average corrosion rates from 2 tests, mpy (mm/y).**

Base Metal / Filler Metal	GTAW sheet	GMAW-P sheet	SMAW plate
INCONEL alloy 686 / 686CPT	16 (0.4)	19 (0.5)	23 (0.6)
INCONEL alloy 622 / 686CPT	45 (1.1)	42 (1.1)	43 (1.1)
INCONEL alloy 622 / 622	54 (1.4)	46 (1.2)	49 (1.2)
UNS N06022 / 686CPT	49 (1.2)	45 (1.1)	61 (1.5)
UNS N06022 / N06022	49 (1.2)	50 (1.3)	70 (1.8)
INCONEL alloy C-276 / 686CPT	29 (0.7)*	24 (0.6)	33 (0.8)
INCONEL alloy C-276 / C-276	29 (0.7)	26 (0.7)	37 (0.9)

*Slight heat-affected zone attack.

Corrosion Resistance

(continued)

Pitting Test Results for Welded Plate Specimens. Saturated SO₂ + 26% NaCl, at 80°C for 336 hours.

Base Metal Alloy	Weld Filler Metal	Maximum Pitting Depth of Attack, mils (mm) Average Results for Duplicate Specimens					
		GTAW Process		GMAW-P Process		SMAW	
		Base Metal	Weld Metal	Base Metal	Weld Metal	Base Metal	Weld Metal
INCONEL alloy 686	INCO-WELD 686CPT	0	0	0	0	0	0
INCONEL alloy 622	INCO-WELD 686CPT	0	0	12 (0.3)	0	0	0
INCONEL alloy 622	INCONEL alloy 622	0	0	0	0	0	10 (0.3)
UNS N06022	INCO-WELD 686CPT	0	0	16 (0.4)	8 (0.2)	0	0
UNS N06022	N06022	29 (0.7)	54 (1.4)	49 (1.2)	45 (1.1)	33 (0.8)	48 (1.2)
INCONEL alloy C-276	INCO-WELD 686CPT	29 (0.7)	18 (0.5)	26 (0.7)	19 (0.5)	28 (0.7)	3 (0.08)
INCONEL alloy C-276	INCONEL alloy C-276	5 (0.1)	34 (0.9)	24 (0.6)	41 (1.0)	20 (0.5)	43 (1.1)

Pitting Test Results for Welded Specimens. 11.9% H₂SO₄ + 1.3% HCl + 1% FeCl₃ + 1% CuCl₂. Boiling at 103°C for 72 Hours.

Base Metal Alloy	Weld Filler Metal	Maximum Pitting Depth of Attack, inches (mm) Average Results for Duplicate Specimens			
		GTAW Process		GMAW-P Process	
		Base Metal	Weld Metal	Base Metal	Weld Metal
INCONEL alloy 686	INCO-WELD 686CPT	0	0	0	0
INCONEL alloy 622	INCO-WELD 686CPT	0	0	0	0
INCONEL alloy 622	INCONEL alloy 622	0	189 (4.8)	4 (0.1)	303 (7.7)
UNS N06022	INCO-WELD 686CPT	35 (0.9)	185 (4.7)	8 (0.2)	0
UNS N06022	UNS N06022	28 (0.7)	224 (5.7)	63 (1.6)	118 (3.0)
INCONEL alloy C-276	INCO-WELD 686CPT	0	0	0	0
INCONEL alloy C-276	INCONEL alloy C-276	0	244 (6.2)	0	134 (3.4)
UNS N06200	INCO-WELD 686CPT	0	0	—	—
UNS N06200	UNS N06200	0	94 (2.4)	—	—
UNS N06059	INCO-WELD 686CPT	0	0	—	—
UNS N06059	UNS N06059	0	51 (1.3)	—	—

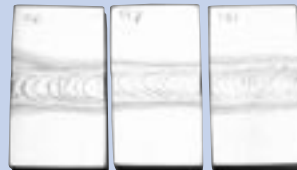
Overmatched Welding Products

There are many alloys capable of resisting corrosion but when they are welded, the corrosion-resistance of the welded structure can be compromised. The least expensive base metals with adequate strength and corrosion-resistance are usually selected with welding products that match the composition of the base metals. However, this can cause problems in service when the rapidly cooled as-cast structure of a weld shows lesser properties than those of the matched composition base metal.

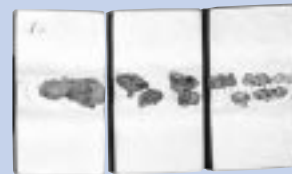
A weld where the consumable “overmatches” the base metal offers a more cost-effective performance. This can be of outstanding value, for example, where welds have to survive in rigorous pitting environments. INCO-WELD 686CPT products offer an overmatched performance capability for welding a range of materials, consistently greater than welds made using matched compositions, and typically even greater than the base metals themselves. Matching INCONEL alloy 686, the INCO-WELD 686CPT welding products overmatch all the other commercially available high-performance Ni-Cr-Mo corrosion-resistant alloys.

Pitting resistance in welded joints for a range of high-performance Ni-Cr-Mo alloys. GTAW welds of various sizes of plate and sheet, laboratory tested in a "Green Death" solution — 11.9% H₂SO₄ + 1.3% HCl + 1% FeCl₃ + 1% CuCl₂. Three days at boiling (103°C) temperature. Samples turned to show the most severe attack.

INCONEL alloy 686 (UNS N06686, WNr. 2.4606) welded with INCO-WELD filler metal 686CPT.

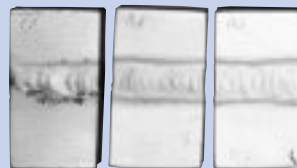


UNS N06022, (WNr. 2.4602) welded with INCO-WELD filler metal 686CPT.



UNS N06022, (WNr. 2.4602) welded with a matched composition welding product.

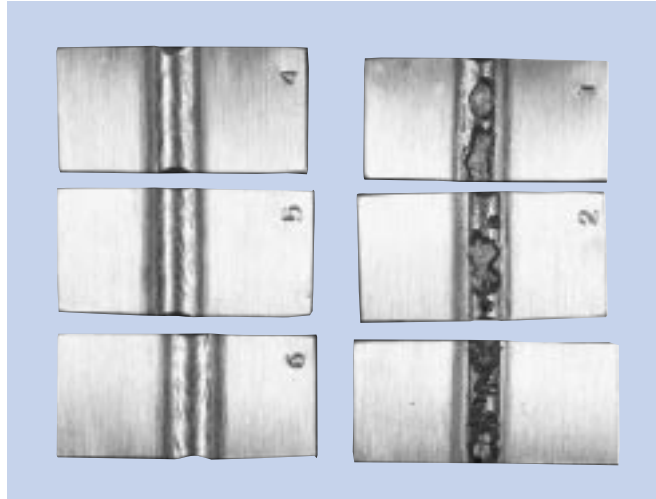
UNS N10276, (WNr. 2.4819) welded with INCO-WELD filler metal 686CPT.



UNS N10276, (WNr. 2.4819) welded with a matched composition welding product.

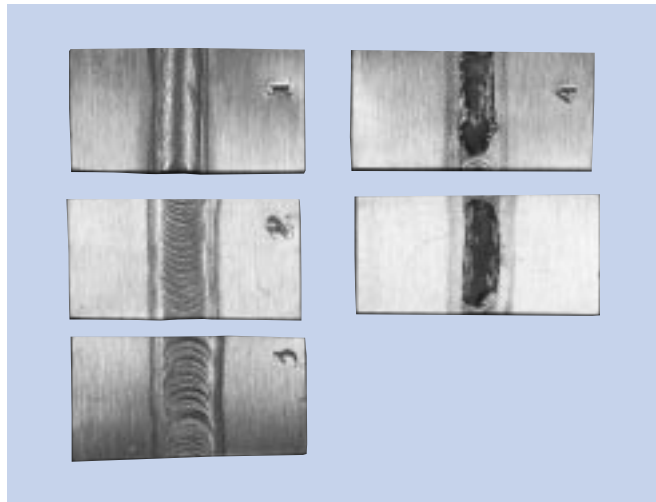
**Overmatched
Welding
Products**
(continued)

**UNS N06200,
welded with
INCO-WELD
filler metal 686CPT.**



**UNS N06200,
welded with
a matched
composition
welding product.**

**UNS N06059,
(W.Nr. 2.4605)
welded with
INCO-WELD
filler metal 686CPT.**



**UNS N06059,
(W.Nr. 2.4605)
welded with
a matched
composition
welding product.**



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