INCONEL alloy G-3 (UNS N06985/W. Nr. 2.4619) is a nickel-chromium-iron alloy with additions of molybdenum and copper. Some of the minor elements are controlled to yield increased resistance to heat-affected-zone (HAZ) corrosion and improved weldability. Alloy G-3 has excellent corrosion resistance to oxidizing chemicals and atmospheres. It is also resistant to reducing chemicals because of its nickel and copper contents. Nickel also provides the alloy with exceptional stress-corrosion-cracking resistance in chloride-containing environments. The high molybdenum provides very good resistance to pitting and crevice corrosion. The low carbon helps prevent sensitization, giving the alloy resistance to intergranular corrosion.

INCONEL alloy G-3 is particularly suitable for handling reducing acids such as phosphoric and sulfuric. It is used in flue gas desulfurization systems (scrubbers), especially in quencher, damper, and outlet ducting areas. It can be used in other air pollution control systems in the chemical and pulp and paper industries. It is a good candidate for evaporators, heat-exchangers, tank liners, and other equipment in phosphoric acid manufacturing plants.

Today's exploration for oil and gas leads to a range of highly corrosive environments that, in turn, require a range of corrosion-resistant high nickel content alloys. INCONEL® alloy G-3 is one of these alloys, providing an excellent combination of mechanical properties and strength. This alloy has been used extensively as OCTG (Oil Country Tubular Goods) in hot, sour environments.

Table 1 - Limiting Chemical Composition, %

Nickel	Balance*
Chromium	21.0-23.5
Iron	18.0-21.0
Molybdenum	6.0-8.0
Copper	1.5-2.5
Niobium (plus Tantalum)	0.50 max.
Carbon	0.015 max.
Tungsten	1.5 max.
Silicon	1.0 max.
Manganese	1.0 max.
Phosphorus	0.04 max.
Sulfur	0.03 max.
Cobalt	5.0 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.

Physical and Mechanical Properties

Some physical properties of INCONEL alloy G-3 are given in Table 2. Elastic modulus was determined by a dynamic method. Values for thermal properties of the alloy are listed for various temperatures in Table 3.

Table 2 - Physical Properties

Density, lb/in^3	0.294
g/cm^3	8.14
Melting Range, °F	2300-2450
°C	1260-1343
Modulus of Elasticity in Tension	
75°F (24°C) 10^3 ksi	28.9
GPa	199
1100°F (593°C), 10^3 ksi	24.0
GPa	165
Electrical Resistivity, ohm-circ mil/ft	675.97
μohm-cm	112.37

Table 3 - Thermal Properties

Temperature	Thermal Conductivity	Coefficient of Expansion[a]	Specific Heat
°F	Btu-in/ft^2-h-°F	10^{-6} in/in/°F	Btu/lb-°F
77	69	–	0.108
212	82	8.1	0.111
392	96	8.1	0.114
572	110	8.1	0.118
752	124	8.2	0.121
932	139	8.4	0.124
1112	151	8.4	0.130
°C	W/m-°C	μm/m/°C	J/kg-°C
25	10.0	–	453
100	11.8	14.6	464
200	13.8	14.6	478
300	15.9	14.6	493
400	17.9	14.8	507
500	20.0	15.1	521
600	21.8	15.1	543

[a]Average coefficient between 75°F (24°C) and temperature shown.

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INCONEL® alloy G-3

INCONEL alloy G-3 displays good mechanical properties. Minimum room-temperature tensile properties of the alloy in the annealed condition are shown in Table 4.

Results of standard double-shear tests on cold-drawn INCONEL alloy G-3 tubulars are shown in Table 5. The table also includes tensile test results on the same lot of material.

Table 4 - Minimum Room-Temperature Mechanical Properties of INCONEL alloy G-3

Product	Tensile Strength		Yield Strength (0.2% Offset)		Elongation
	ksi	MPa	ksi	MPa	%
Sheet & Plate (Annealed)	90	621	35	241	45
OCTG (Cold worked)	130	896	125	862	13

Table 5 - Typical Mechanical Properties of Cold-Worked INCONEL alloy G-3

Shear Strength		Tensile Strength		Shear/tensile Ratio
ksi	MPa	ksi	MPa	
82.5	568.8	133.9	923.2	0.61

Table 6 - Corrosion Test Data for INCONEL alloy G-3 and Alloy G 0.125-inch (3.2-mm) Sheet Evaluated in Various Commercially Significant Environments

Environment	Corrosion Rate, mpy (mm/a)	
	INCONEL alloy G-3	Alloy G
I. 10% HCl, 150°F (66°C)	87; 92 (2.2; 2.3)[1]	144 (3.66)
II. 10% H_2SO_4, boiling	20; 23 (0.51; 0.58)[1]	14 (0.36)
III. 50% H_2SO_4, boiling	49; 56 (1.2; 1.4)[1]	108 (2.74)
IV. 30% H_3PO_4, boiling	3; 3 (0.08; 0.08)[1]	4 (0.10)
V. 85% H_3PO_4, boiling	16; 17 (0.41; 0.43)[1]	20 (0.51)
VI. 158°F (70°C) (7 Vol.% H_2SO_4 + 3 Vol.% HCl + 1% $FeCl_3$ + 1% $CuCl_2$)	30; 40 (0.76; 1.02)[2]	1200 (30.5)
VII. 65% HNO_3, boiling	14; 16 (0.36; 0.41)[3]	22 (0.56)
VIII. Streicher test	12-17 (0.31-0.43)[4]	16-17 (0.41-0.69)

[1] Test duration 1 week; duplicate specimens.
[2] Test duration 24 hours; duplicate specimens.
[3] Huey test (ASTM Practice A-262-C) results; duplicate specimens, as-produced condition.
[4] ASTM Practice G-28, as-produced condition,

Corrosion Resistance

The combination of alloying elements in INCONEL alloy G-3 is designed to provide broad resistance to general and localized corrosion, as well as to stress corrosion cracking. The range of corrosive conditions withstood by INCONEL alloy G-3 is indicated by the alloy's ability to resist both acids and alkalies and both oxidizing and reducing media.

Table 6 contains corrosion data for INCONEL alloy G-3 sheet tested in a selection of important corrosion tests to characterize the alloy's resistance to environments of interest to the chemical, power, and pulp and paper industries.

INCONEL alloy G-3 exhibited better corrosion resistance than Alloy G in the 10% HCl; 50% H_2SO_4; 85% H_3PO_4; 7% H_2SO_4 + 3% HCl + 1% $FeCl_3$ + 1% $CuCl_2$; 65% HNO_3, and Streicher test environments. Alloy G showed slightly better resistance in the 10% H_2SO_4 test. Both alloys showed similar corrosion resistance in the 30% H_3PO_4 test.

Figure 1 is a plot of Streicher test corrosion rate data versus heat-treatment temperature for INCONEL alloy G-3 and Alloy G. Specimens were evaluated for 24 hours in boiling 50% H_2SO_4 with 42 grams per liter of ferric sulfate (ASTM G-28).

The test is used to detect Alloy G sensitivity to intergranular corrosion after an aging heat treatment, at 1400°-1800°F (760-982°C) for 1 hour. Maximum sensitivity occurs at 1600°F (871°C). INCONEL alloy G-3, however, shows much greater resistance to sensitization than Alloy G. Therefore, INCONEL alloy G-3 is expected to be significantly more resistant to heat-affected-zone (HAZ) corrosion due to the effects of welding.

Table 7 contains crevice corrosion data for INCONEL alloy G-3 and Alloy G evaluated in a simulated SO_2 scrubber environment of 35,000 ppm Cl, pH 5.0, 135°F (57°C). In this moderately aggressive acid-chloride environment, Alloys G-3 and G behaved similarly; i.e., approximately one-third of their creviced area sustained attack withless than 2 mils (0.05 mm) penetration. This was not expected, as the alloy G-3 heat contained 1% more molybdenum that the alloy G heat. Perhaps the higher niobium content of the alloy G enhanced its pitting resistance. Niobium and molybdenum have been shown to have a synergistic effect on the pitting resistance of INCONEL alloy 625.

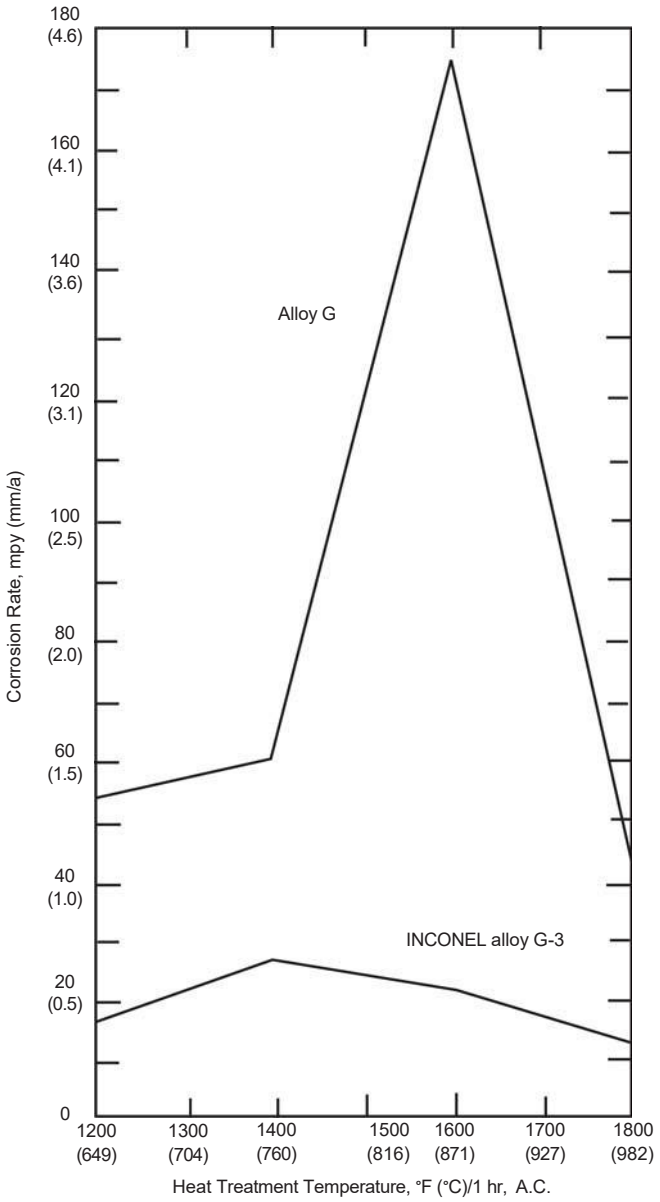

Figure 1 - Streicher test results

Table 7 - Crevice Corrosion Data for INCONEL alloy G-3 and Alloy G 0.125-inch (3.18 mm) Sheet, Evaluated in a 35,000-ppm Chloride (as NaCl), pH 5.0, 135°F (58°C) Simulated SO_2 Scrubber Environment for 30 Days.

Alloy	Corrosion Rate **m**py (mm/a)	**%** of Crevice **A**rea Attacked[a]	**M**aximum **C**revice Pit **D**epth mils (mm)
G-3[b]	<1 (<0.025)	33	<2 (<0.05)
G[b]	<1 (<0.025)	26	<2 (<0.05)

[a]40 crevices per specimen, i.e. 20 crevices per side, 80 for duplicates.
[b]Duplicate specimens, data averaged due to similar behavior.

Fabrication

INCONEL alloy G-3 is readily fabricated by all common methods. Forming operations are performed by standard procedures for nickel alloys. The alloy is machinable with either carbide or high speed steel tools; carbide tools are recommended for high cutting speeds and feeds. Tools should have positive rake angles and should be operated with continuous cutting to avoid work-hardening of the material.

INCONEL alloy G-3 has good weldability and needs no post-weld heat treatment to restore corrosion resistance. Recommended welding products are INCONEL welding electrode G-3 for shielded-metal-arc welding and INCONEL filler metal G-3 for gas-shielded-arc welding. Those weld metals exhibit corrosion resistance equivalent to that of base metal.

Available Products and Specifications

INCONEL alloy G-3 is designated UNS N06985 and W. Nr. 2.4619, and is available in a wide range of wrought mill forms including rod, bar, plate, sheet, strip and tubular products. Mill products may be obtained to the specifications listed below.

INCONEL alloy G-3 is approved as a material of construction for pressure vessels under Section VIII of the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers.

INCONEL alloy G-3 is stated in NACE Standard MR0175.

Rod and bar: ASTM B 581, ASME SB-581, DIN 17752
Plate, sheet and strip: ASTM B 582, ASME SB-582, DIN 17750, ISO 6208
Welded pipe: ASTM B 619, ASME SB-619, ASTM B 775, ASME SB 775
Seamless pipe and tube: ASTM B 622, ASME SB-622, ASTM B 829, ASME SB 829, DIN 17751
Welded tube: ASTM B 626, ASME SB-626, ASTM B 751, ASME SB 751
Other: DIN 17744, ISO 9724, ASTM B 366, ASME SB 366