INCOLOY® alloy 800

The story of the "INCOLOY® alloys series," from 800 through 800H, 800HT®

The INCOLOY® 800 series of alloys, invented by the Special Metals Corporation Group of Companies, is the result of years of monitoring and maintaining the ultimate chemical properties for high-temperature strength and resistance to oxidation, carburization and other types of high-temperature corrosion.

Each one a refinement of the one before, these alloys have set the industry standard in high-temperature applications requiring optimum creep and rupture properties.

INCOLOY nickel-iron-chromium alloy 800 was introduced to the market in the 1950s to fill the need for a heat- and corrosion-resistant alloy with a relatively low nickel content since nickel was, at the time, designated a "strategic" metal. Over the past forty years it has been widely used for its strength at high temperatures and its ability to resist oxidation, carburization, and other types of high-temperature corrosion. Applications include furnace components and equipment, petrochemical furnace cracker tubes, pigtails and headers, and sheathing for electrical heating elements.

In 1963, the alloy was approved by the ASME Boiler and Pressure Vessel Committee, and the design stresses were published in Code Case 1325. For the first time, aluminum and titanium were listed as purposeful additions (at 0.15 to 0.60% each), and annealed material was differentiated from solution-annealed material. The new terms "Grade 1, annealed at approximately 1800°F (980°C)" and "Grade 2, annealed at approximately 2100°F (1150°C)" came into use. The Code Case covered Sections I and VIII, and listed design stresses for Grade 1 to 1100°F (593°C) and for Grade 2 to 1500°F (816°C).

Over the next few years, the Committee made several revisions. In 1965, extruded tube was accepted as Grade 2 material without heat treatment. By the following year, ASTM specifications had been approved for INCOLOY alloy 800, and these were listed to replace those covering INCONEL alloy 600. In 1967, an external pressure vessel chart for Grade 1 was added, and the following year the same addition was made for Grade 2.

In 1969, design stresses were increased as a result of changes in the criteria to determine those stresses. The minimum tensile strength curve was increased 10% and the rupture criterion was increased from 62.5 to 67% of the extrapolated 100,000 hour rupture strength. Six months later, the Case was changed from covering Sections I and VIII to Section I only since the design stresses for Section VIII had been included in Table UNF-23. There were also two sets of design stresses listed for each grade, one giving the values when the two-thirds yield strength criterion was used, the other when 90% of yield strength was used.

INCOLOY® alloy 800H (UNS N08810)

It had been known for some time that higher carbon alloy 800 had higher creep and rupture properties than low-carbon material. For that reason, Special Metals had melted to a carbon range of 0.05 to 0.10% except for special orders where customers specified a lower carbon content. The carbon range of 0.05 to 0.10% is within the ASTM and ASME specification limits for alloy 800 and is in the upper portion of that range.

Special Metals generated data for this material and presented them to the ASME Code. The Code approved higher design stresses for Section I and Divisions 1 and 2 of Section VIII, which appeared in Code Case 1325-7. Note that alloy 800H required not only a carbon range of 0.05 to 0.10% but also an average grain size of ASTM 5, or coarser.

With the issuance of Code Case 1325-7 and the common use of the term "800H", there was no longer a need to refer to "Grade 2" because it was replaced by 800H, and the material that had been called Grade 1 became, simply, INCOLOY alloy 800.

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INCOLOY® alloy 800HT® (UNS N08811)

Several other alloy manufacturers entered the alloy 800H (UNS N08810) market and additional creep and rupture data became available. The Metals Property Council for ASME gathered this data and made a new analysis using parametric procedures, involving 87 heats and 1,052 data points. The additional data, from other manufacturers, included results with considerably lower strength, and the new analysis, which reflected the results of all the available data, resulted in a recommendation that the design stresses be revised. These revised values were lower for temperatures of 1100 through 1500°F (593-816°C), and about the same for 1600 and 1650°F (871 and 899°C).

Special Metals knew the importance of maintaining the aluminum and titanium contents in the upper portion of the specified material range. This resulted in higher creep and stress rupture properties than competitive alloy 800H. Therefore, to maintain higher allowable design stresses, the company introduced a variation of INCOLOY alloy 800H which is called INCOLOY alloy 800HT (UNS N08811). INCOLOY alloy 800HT has a restricted chemistry, within the limits of alloy 800H, and requires a heat treatment of 2100°F (1149°C) minimum. The carbon is 0.06 to 0.10% (alloy 800H is 0.05 to 0.10%), the Al + Ti is 0.85 to 1.20% (alloy 800H is 0.30 to 1.20% Al + Ti).

The maximum allowable stresses for INCOLOY alloy 800HT (UNS N08811) are contained in ASME Code Case 1987 – latest revision. The alloy meets all the requirements for UNS N08811 *and* N08810 (alloy 800H) and can be certified to either or both UNS numbers. It is important to note that INCOLOY alloy 800HT (UNS N08811) has higher maximum allowable design stresses than UNS N08810. Therefore, other materials produced to UNS N08810 (alloy 800H) cannot be certified as UNS N08811 unless they meet the additional requirements for this designation. INCOLOY alloy 800HT is the result of years of monitoring and maintaining the ultimate properties in this series of alloys by The Special Metals Corporation group of companies, the inventor of all the INCOLOY 800 series alloys.

Information describing INCOLOY alloys 800H and 800HT is available in the Special Metals publication for alloys 800 and 800HT on the website www.yttzhj.com.

Limiting chemical composition of all three alloys are given in Table 1.

Note that the designation "800HT" is a trademark of the Special Metals Corporation group of companies.

Table 1 - Limiting Chemical Compositions, %, for INCOLOY alloys 800, 800H, and 800HT

General Requirements			
UNS designation	N08800	N08810	N08811
INCOLOY alloys	800	800H	800HT
Nickel	30.0-35.0	30.0-35.0	30.0-35.0
Chromium	19.0-23.0	19.0-23.0	19.0-23.0
Iron	39.5 min.	39.5 min.	39.5 min.
Carbon	0.10 max.	0.05-0.10	0.06-0.10
Aluminum	0.15-0.60	0.15-0.60	0.25-0.60
Titanium	0.15-0.60	0.15-0.60	0.25-0.60
Aluminum + Titanium	0.30-1.20	0.30-1.20	0.85-1.20
ASTM grain size	Not specified	5 or coarser	5 or coarser

Note: These alloys can be specified to more restrictive compositions on a specific order basis.

INCOLOY alloy 800H, special requirements*	
Carbon	0.08 max.
Aluminum + Titanium	0.4-0.7
ASTM grain size	Special

*As agreed for specific orders.

Special grain size requirements* INCOLOY alloys 800H and 800HT	
Plate	ASTM 1-5
Tube/Pipe	ASTM 1-5
Sheet	ASTM 2-5

*As agreed for specific orders.

INCOLOY® alloy 800

INCOLOY alloy 800 (UNS N08800/W. Nr. 1.4876) is a widely used material for construction of equipment requiring corrosion resistance, heat resistance, strength, and stability for service up to 1500°F (816°C). Alloy 800 offers general corrosion resistance to many aqueous media and, by virtue of its content of nickel, resists stress corrosion cracking. At elevated temperatures it offers resistance to oxidation, carburization, and sulfidation along with rupture and creep strength. For applications requiring greater resistance to stress rupture and creep, especially at temperatures above 1500°F (816°C), INCOLOY alloys 800H and 800HT are used.

The limiting chemical composition of alloy 800 is shown in Table 2. The chromium in the alloy imparts both aqueous and heat resistance. Iron provides resistance to internal oxidation. The nickel content maintains a ductile, austenitic structure. Thus, alloy 800 is readily formed, welded, and machined.

INCOLOY alloy 800 is used in a variety of applications involving exposure to corrosive environments and high temperatures. It is used for heat-treating equipment such as baskets, trays, and fixtures. In chemical and petrochemical processing, the alloy is used for heat exchangers and other piping systems in nitric acid media especially where resistance to chloride stress-corrosion cracking is required. In nuclear power plants, it is used for steam-generator tubing. The alloy is often used in domestic appliances for sheathing of electric heating elements. In the production of paper pulp, digester-liquor heaters are often made of alloy 800. In petroleum processing, the alloy is used for heat exchangers that air cool the process stream.

Table 2 - Limiting Chemical Composition, %

Nickel	30.0-35.0
Chromium	19.0-23.0
Iron	39.5 min.
Carbon	0.10 max.
Manganese	1.50 max.
Sulfur	0.015 max.
Silicon	1.0 max.
Copper	0.75 max.
Aluminum	0.15-0.60
Titanium	0.15-0.60

Physical Constants and Thermal Properties

Some physical constants for INCOLOY alloy 800 are listed in Table 3. Values for modulus of elasticity and Poisson's ratio of annealed material at various temperatures are given in Table 4. The modulus data were determined by the dynamic method; values for Poisson's ratio were calculated from moduli of elasticity. Thermal and electrical properties of annealed material are given for a range of temperatures in Table 5. Magnetic permeability of the alloy at low temperatures is shown in Figure 1.

Table 3 - Physical Constants

Density, lb/in³	0.287
g/cm³	7.94
Melting Range, °F	2475-2525
°C	1357-1385
Specific Heat, (32-212°F), Btu/lb•°F	0.11
(0-100°C), J/kg•°C	460
Permeability at 70°F (21°C) and 200 oersted (15.9 kA/m)	
Annealed	1.014
Hot-Rolled	1.009
Curie Temperature, °F	-175
°C	-115

Table 4 - Modulus of Elasticity[a]

Temperature	Tensile Modulus	Shear Modulus	Poisson's Ratio[b]
°F	10³ ksi	10³ ksi	
-310	30.55	11.45	0.334
75	28.50	10.64	0.339
200	27.82	10.37	0.341
400	26.81	9.91	0.353
600	25.71	9.47	0.357
800	24.64	9.04	0.363
1000	23.52	8.60	0.367
1200	22.37	8.12	0.377
1400	21.06	7.58	0.389
1600	19.20	6.82	0.408
°C	GPa	GPa	Poisson's Ratio
-190	210.6	78.9	0.334
20	196.5	73.4	0.339
100	191.3	71.2	0.343
200	184.8	68.5	0.349
300	178.3	66.1	0.357
400	171.6	63.0	0.362
500	165.0	60.3	0.367
600	157.7	57.4	0.373
700	150.1	54.3	0.381
800	141.3	50.7	0.394

[a]Determined by dynamic method.
[b]Calculated from moduli of elasticity.

Table 5 - Electrical and Thermal Properties

Temperature	Electrical Resistivity	Thermal Conductivity	Coefficient of Expansion[a]
°F	ohm•circ mil/ft	Btu•in/ft²•h°F	10^{-6} in/in/°F
70	595	80	-
100	600	83	-
200	620	89	7.9
400	657	103	8.8
600	682	115	9.0
800	704	127	9.2
1000	722	139	9.4
1200	746	152	9.6
1400	758	166	9.9
1600	770	181	10.2
1800	776	214	-
2000	788	-	-
°C	µΩ•m	W/m°C	µm/m/°C
20	0.989	11.5	-
100	1.035	13.0	14.4
200	1.089	14.7	15.9
300	1.127	16.3	16.2
400	1.157	17.9	16.5
500	1.191	19.5	16.8
600	1.223	21.1	17.1
700	1.251	22.8	17.5
800	1.266	24.7	18.0
900	1.283	27.1	-
1000	1.291	31.9	-

[a]Between 70°F (21°C) and temperature shown.

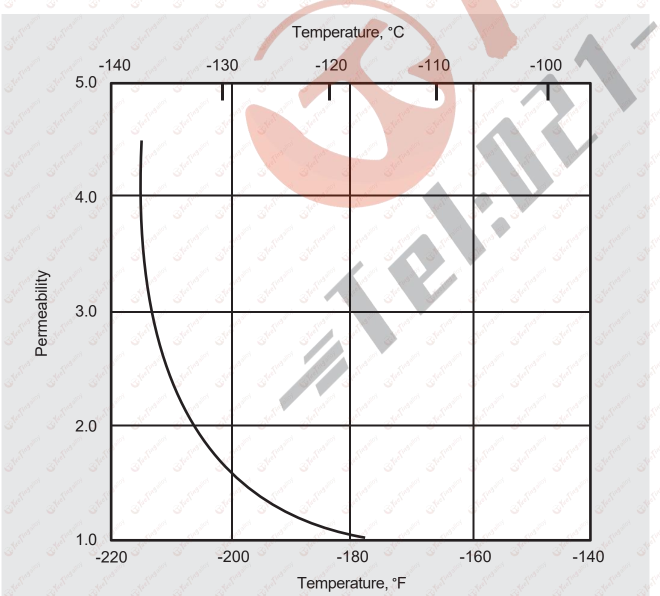

Figure 1. Permeability of annealed INCOLOY alloy 800 at low temperatures.

Mechanical Properties

INCOLOY alloy 800 has high mechanical strength over a broad temperature range. In general, alloy 800 is used for its strength characteristics at service temperatures up to about 1500°F (816°C). At those temperatures, equipment design is usually based on tensile properties. For applications that require high creep or rupture strength, INCOLOY alloys 800H and 800HT are used.

Tensile Properties

INCOLOY alloy 800 exhibits high tensile properties at room and elevated temperatures. Figures 2 and 3 show tensile properties at temperatures to 1500°F (815°C) of hot-rolled rod in the as-rolled and the annealed conditions. Tensile properties at room temperature and from 1200°F (650°C) to 1800°F (980°C) of as-extruded tubing are given in Table 6.

Cold work substantially increases the tensile properties of the alloy. Properties of cold-drawn rod in the as-drawn condition are given in Table 7.

High-temperature hardness and tensile properties of annealed and hot-rolled material are shown in Table 8.

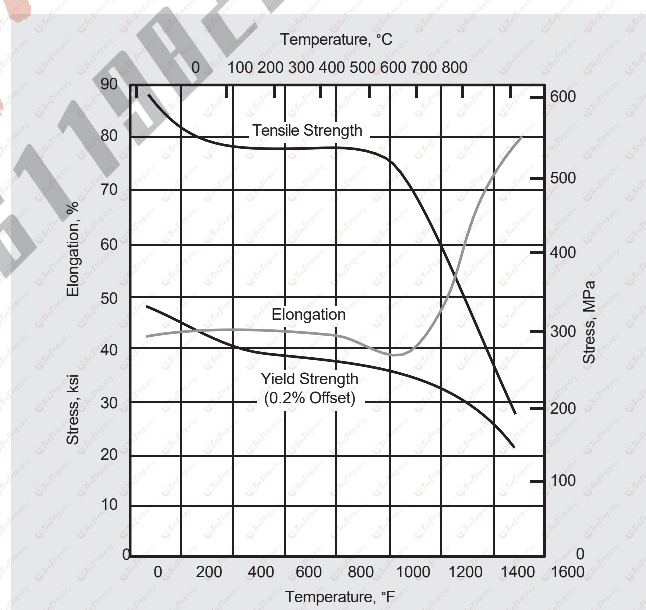

Figure 2. High-temperature tensile properties of INCOLOY alloy 800 hot-rolled rod.

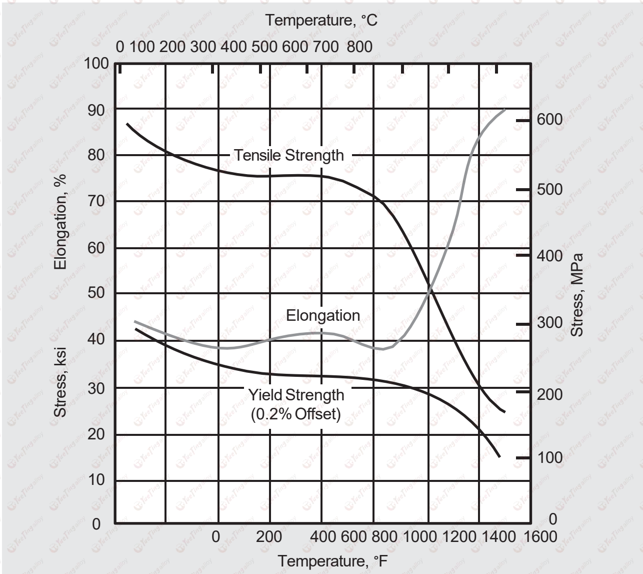

Figure 3. High-temperature tensile properties of INCOLOY alloy 800 hot-rolled rod, annealed 1800°F (980°C)/15 min.

Table 6 - Tensile Properties of INCOLOY alloy 800 As-extruded Tubing[a]

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Reduction of Area, %
°F	°C	ksi	MPa	ksi	MPa		
85	30	76.0	524	26.6	183	60.0	–
1200	650	52.5	362	18.0	124	47.0	59.0
1400	760	30.3	209	15.7	108	85.0	73.0
1500	815	23.6	163	17.3	119	98.0	79.5
1600	870	16.0	110	13.5	93	109.5	92.5
1700	925	11.8	81	9.2	63	111.5	93.0
1800	980	8.9	61	7.2	50	131.5	94.0

[a]5-in (127-mm) O.D., 0.50-in (12.7-mm) wall. Full-wall specimens.

Table 7 - Tensile Properties of INCOLOY alloy 800 Cold-Drawn Rod[a]

Temperature		Tensile Strength		Yield Strength (0.2% Offset)		Elongation, %	Reduction of Area, %
°F	°C	ksi	MPa	ksi	MPa		
85	30	111.8	771	100.0	690	17.0	64.0
200	95	107.5	741	95.0	655	16.0	63.3
400	205	102.5	707	94.2	650	13.0	58.8
600	315	99.5	686	93.0	641	12.0	56.6
700	370	96.3	664	91.5	631	15.0	53.2
900	480	96.3	664	90.0	621	15.0	52.5
1000	540	93.0	641	86.3	595	16.5	54.0
1100	595	87.3	602	80.7	556	15.0	50.0
1200	650	78.5	541	66.8	461	19.5	44.5
1300	705	64.4	444	61.4	423	28.0	42.5

[a]1-in (25-mm) diameter.

Table 8 - Hardness and Tensile Properties of INCOLOY alloy 800 at High Temperatures

Condition	Temperature		Hardness BHN	Tensile Strength		Yield Strength (0.2% Offset)	
	°F	°C		ksi	MPa	ksi	MPa
Annealed[a]	80	25	138	85.5	590	36.2	250
	800	425	120	74.1	511	24.9	172
	1000	540	119	73.7	508	25.8	178
	1200	650	110	58.7	405	25.5	176
	1300	705	97	46.3	319	25.3	174
	1400	760	66	34.5	238	21.6	149
Hot-rolled	80	25	198	96.4	665	64.6	445
	800	425	170	84.5	583	52.0	359
	1000	540	161	84.0	579	52.4	361
	1200	650	145	65.3	450	48.3	333
	1300	705	120	53.5	369	46.8	323
	1400	760	91	44.5	307	41.2	284

[a]1800°F (980°C).

Impact Strength

Alloy 800 has high impact strength at room temperature and remains tough at cryogenic temperatures. The results of Charpy keyhole tests performed at room and low temperatures on annealed plate are listed in Table 9. Table 10 shows the impact strength of annealed material after exposure to 1400°F (760°C) for up to 1500 hours.

Compressive Properties

The compressive yield strength of INCOLOY alloy 800 is essentially the same as the tensile yield strength. Compressive and tensile data for the alloy in two conditions are given in Table 11.

Fatigue Strength

The room-temperature fatigue strength of alloy 800 rod in various conditions is shown in Table 12. The data are from rotating-beam tests on polished specimens. Rotating-beam fatigue strength at temperatures to 1600°F (870°C) of annealed, cold-drawn rod is shown in Table 13. The room temperature tensile strength of the material tested was 86.5 ksi (596 MPa).

Data on low-cycle fatigue properties of INCOLOY alloy 800 are included in Figures 4, 5 and 6.

Table 9 - Impact Strength of INCOLOY alloy 800 Annealed Plate[a]

Temperature		Specimen Orientation	Charpy Keyhole Impact Strength	
°F	°C		ft•lbf	J
70	21	Longitudinal	89.8	122
		Transverse	82.7	112
-110	-79	Longitudinal	89.8	122
		Transverse	85.0	115
-320	-196	Longitudinal	78.3	106
		Transverse	69.5	94
-423	-253	Longitudinal	73.0	99
		Transverse	64.3	87

[a]0.8-in (20-mm) thick plate, annealed 1800°F (980°C). Each value is the average of three tests.

Table 10 - Room-Temperature Impact Strength of Cold-Rolled, Annealed INCOLOY alloy 800 After Long-Time Exposure at 1400°F (760°C)

Exposure Time, h	Charpy V-Notch Impact Strength	
	ft•lbf	J
0	106, 107, 108	144, 145, 146
500	96, 99, 100	130, 134, 136
1000	99, 99, 101	134, 134, 137
1500	96, 99, 100	130, 134, 136

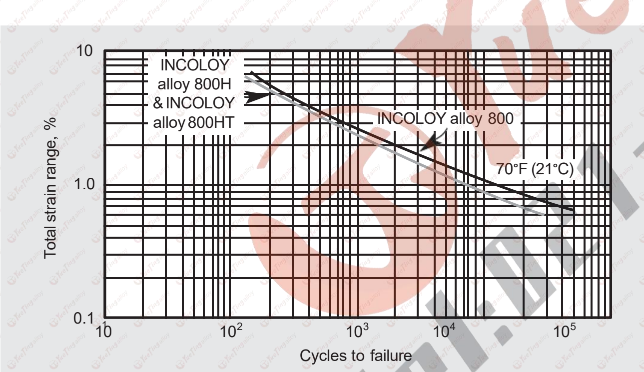

Figure 4. Low-cycle fatigue strength of alloys 800, 800H and 800HT. Bending strain was used for alloy 800; axial strain was used for alloys 800H and 800HT.

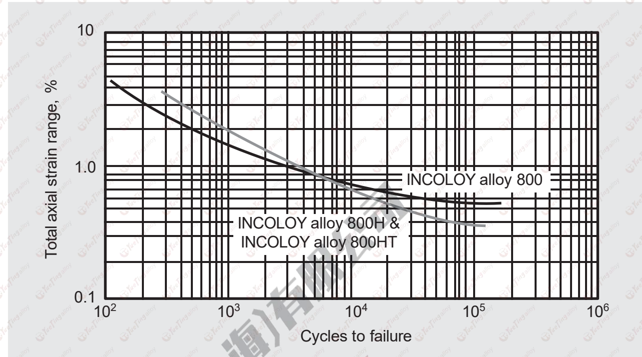

Figure 5. Low-cycle fatigue strength of alloys 800, 800H and 800HT at 1000°F (540°C).

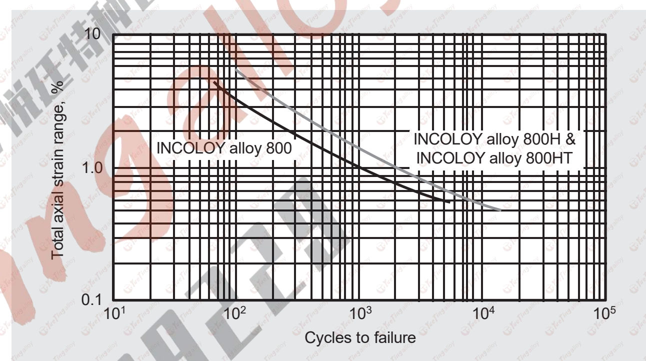

Figure 6. Low-cycle fatigue strength of alloys 800, 800H and 800HT at 1200°F (650°C).

Table 11 - Compressive Strength of INCOLOY alloy 800 Rod

Condition	Compression				Tension					
	Yield Strength (0.02% Offset)		Yield Strength (0.2% Offset)		Yield Strength (0.02% Offset)		Yield Strength (0.2% Offset)		Tensile Strength	
	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
Hot-Rolled Annealed	39.0	269	41.6	287	38.8	268	41.1	283	89.3	616
As-Extruded	21.0	145	25.4	175	21.0	145	27.5	190	69.5	479

Table 12 - Room-Temperature Fatigue Strength[a] of INCOLOY alloy 800 Rod

Material Condition	Tensile Strength		10^4 Cycles		10^5 Cycles		10^6 Cycles		10^7 Cycles		10^8 Cycles	
	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
Hot-Rolled	92	634	57	393	54	372	53	365	52	359	51	352
Hot-Rolled Annealed[b]	82	565	47	324	43	296	38	262	35	241	31	214
Cold-Drawn	114	786	–	–	65	448	49	338	37	255	33	228
Cold-Drawn Annealed[b]	82	565	48	331	43	296	39	269	36	248	32	221

[a]Rotating-beam tests on polished specimens.
[b]Annealed 1950°F (1065°C) /10 min, air cool.

Table 13 - Fatigue Strength[a] of Cold-Drawn, Annealed INCOLOY alloy 800 Rod

Temperature		10^5 Cycles		10^6 Cycles		10^7 Cycles		10^8 Cycles	
°F	°C	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
85	30	47.0	324	43.0	296	42.5	293	42.0	290
800	425	47.0	324	43.0	296	42.5	293	42.0	290
1000	540	40.0	276	39.0	269	38.5	265	38.0	262
1400	760	-	-	29.5	203	25.5	176	22.0	152
1600	870	–	–	20.0	138	16.5	141	13.5	93

[a]Rotating-beam tests on polished specimens, annealed 1600°F (870°C) /30 min, air cool.

Creep and Rupture Properties

Creep and rupture properties of INCOLOY alloy 800 in the annealed condition are shown in Figures 7 and 8. Alloy 800 is not normally used for applications that require optimum creep-rupture properties. In those cases, INCOLOY alloys 800H or 800HT should be used.

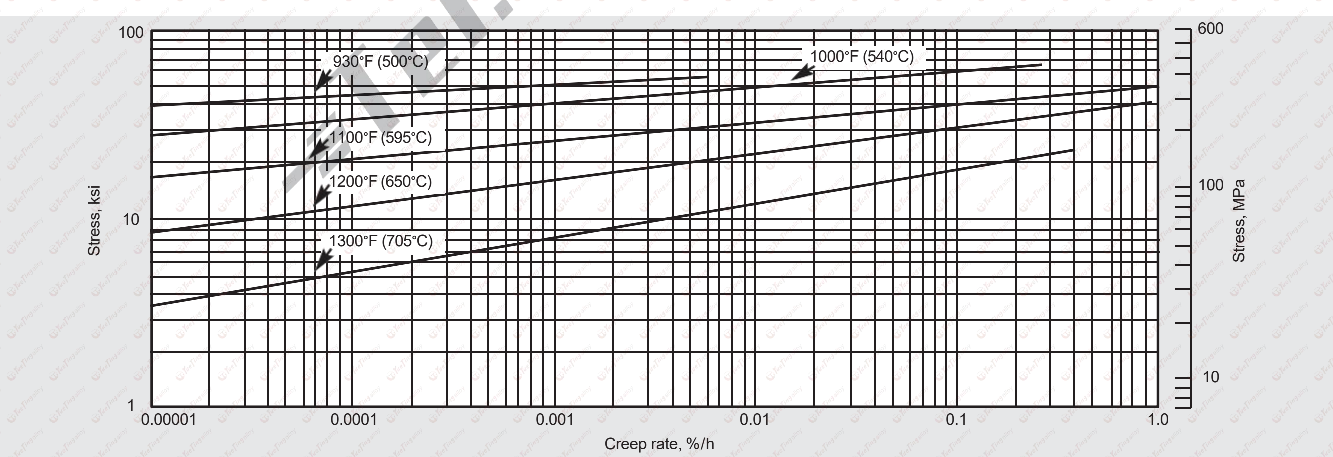

Figure 7. Typical creep strength of annealed INCOLOY alloy 800.

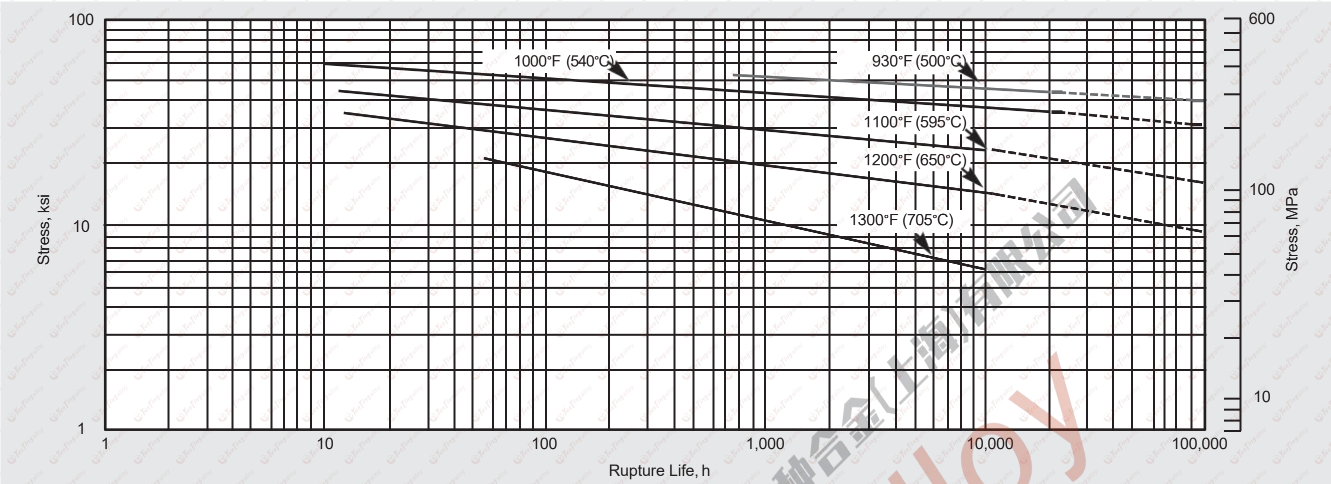

Figure 8. Typical rupture strength of annealed INCOLOY alloy 800.

ASME Boiler and Pressure Vessel Code

INCOLOY alloy 800 (UNS N08800) is approved under the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME). Rules for construction of power boilers are defined under Section I, and those for pressure vessels under Section VIII, Divisions 1 and 2.

Design stress values for alloy 800 for Section I and Section VIII, Division 1 construction are listed in Table 1B of section II (Materials), Part D (Properties). Construction is permitted for service up to 1500°F (816°C).

Design stress values for alloy 800 for Section VIII, Division 2 construction are listed in Table 2B of Section II (Materials), Part D (Properties). Section VIII, Division 2 construction is allowed for service up to 800°F (427°C).

The use of alloy 800 for nuclear construction is addressed under Section III of the ASME Code and by Code Cases N-20 and N-253. The design stress values for Section III, Class 1 construction are found in Table 2B of Section II (Materials), Part D (Properties). Design stress values for Section III, Class 2 construction are found in Table 1B of Section II (Materials), Part D (Properties).

Because of the extensive quality assurance and testing required for material for nuclear construction, the designer or fabricator is cautioned to be fully aware of the requirements of Section III before beginning such construction.

Microstructure and Metallurgy

INCOLOY alloy 800 is an austenitic, solid-solution alloy. Titanium nitrides, titanium carbides, and chromium carbides normally appear in the alloy's microstructure. The nitrides are stable at all temperatures below the melting point and are therefore unaffected by heat treatment.

Chromium carbides precipitate in the alloy at temperatures between 1000 and 2000°F (540 and 1095°C). Consequently, alloy 800 is similar to other austenitic alloys in that it can be rendered susceptible to intergranular corrosion (sensitized) in certain aggressive environments by exposure to temperatures of 1000 to 1400°F (540-760°C).

An important property of alloy 800 is its relative freedom from chloride stress-corrosion cracking. Extensive studies of stress-corrosion cracking of austenitic alloys in chloride solutions have shown that the tendency to crack decreases with increasing nickel content of alloy. For example, INCONEL alloy 600, with a nickel content of 76%, is considered to be immune to chloride-ion stress-corrosion cracking. INCOLOY alloy 800 (32.5% Ni) can be made to crack in severe laboratory tests, but it has such high resistance that it is commonly used to replace materials that have failed in service from stress-corrosion cracking.

Corrosion Resistance

INCOLOY alloy 800, like many austenitic stainless steels, can be sensitized, or made susceptible to intergranular attack in some aggressive media, by exposure to the temperature range of 1000 to 1400°F (540–760°C). The Huey test determines susceptibility to sensitization. The test involves exposure of a specimen to boiling 65% nitric acid for five consecutive 48-hour periods. An average corrosion rate for the five periods of substantially over about 24 mils penetration per year (0.61 mm/yr) indicates that the specimen is sensitized to some degree. The time-temperature-sensitization diagrams in Figures 12 and 13 show Huey test rates for alloy 800 annealed at two different temperatures and exposed to a range of sensitizing treatments.

When INCOLOY alloy 800 is exposed to heat from welding or other operations, care should be taken to avoid sensitization if the material is to be pickled or subjected to other aggressive environments. Sensitization is not a problem in most high-temperature applications.

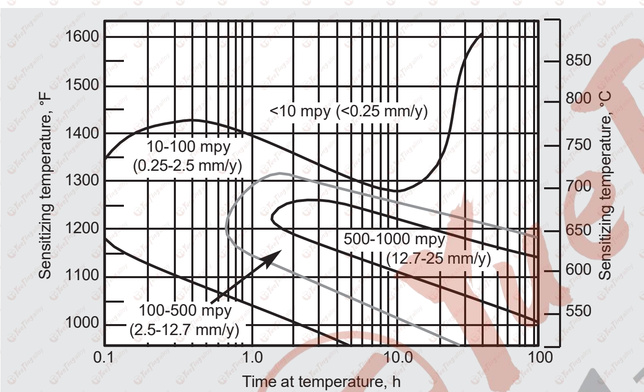

Figure 12. Time-temperature-sensitization diagram for INCOLOY alloy 800 annealed, 1750°F (955°C)/1h/waterquench.

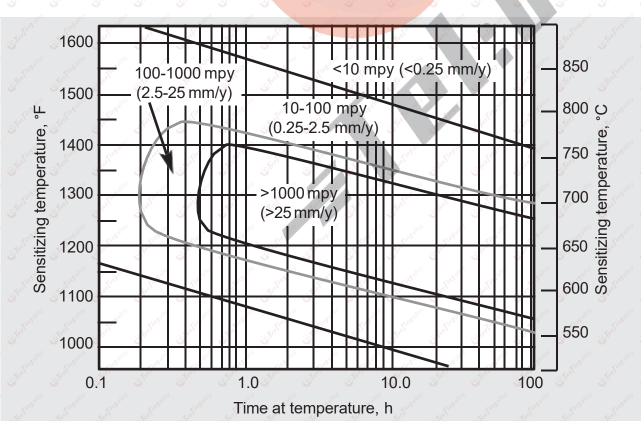

Figure 13. Time-temperature-sensitization diagram for INCOLOY alloy 800 annealed 2000°F (1095°C)/1 h/water quench.

Information on corrosion resistance is available in the Special Metals publication SMC-026, "Resistance to Aqueous Corrosion", on the website, www.yttzhj.com.

Working Instructions

The various mill forms of INCOLOY alloy 800 are fabricated into finished articles and equipment by standard procedures. The alloy is readily formed by either hot working or cold working, and it has good weldability and machinability.

Heating and Pickling

All material to be heated must be clean. Oil, paint, grease, shop soil and other foreign substances must be removed prior to the heating operation.

Heating must be performed in a low-sulfur atmosphere. Open heating must be done with low-sulfur fuel, and the furnace atmosphere must be maintained in a reducing condition to prevent excessive oxidation.

Because of the readiness with which chromium is oxidized into a refractory oxide by air, carbon dioxide or water vapor, alloy 800 cannot be bright annealed in the usual industrial annealing furnace. Under closely controlled conditions, the alloy can be bright annealed in dry, pure hydrogen (dew point of -73°F (-58°C) or lower, less than 0.004% by volume water, and less than 0.007% by volume air).

INCOLOY alloy 800 is normally annealed in box or muffle furnaces using prepared reducing atmospheres. A satisfactory atmosphere is formed by the products of combustion from low-sulfur natural gas burned with a deficiency of air. It produces a thin, adherent, green-black film of oxide on the material. Oxidizing atmospheres produce a heavy black scale that is difficult to remove. Removal of such scale often requires considerable grinding.

Specific annealing procedures depend on the amount of cold work and cross section of the material. The mechanical properties of heavily cold-worked material are only slightly affected by temperatures below 1000°F (540°C). Stress relief begins at about 1000°F (540°C) and is virtually complete after 1½ hours at 1600°F (870°C). Softening by annealing begins at about 1400°F (760°C) and is reasonably complete after 10 to 15 minutes at 1800°F (980°C). Appreciable grain growth may occur at temperatures over 1800°F (980°C). A satisfactory anneal, however, can usually be obtained by 2 to 5 minutes heating at 1900°F (1040°C).

The effects of annealing temperature on the grain size and room-temperature mechanical properties of a 1.2-in (30-

mm) diameter hot rolled rod are illustrated in Figure 14. The specimens were at temperature for 15 minutes and were air cooled before being tested. Oxide films and scales formed during heating can be removed by pickling. Because of the alloy's inherent resistance to chemical attack, specialized pickling procedures are needed. For additional information, refer to the Special Metals publication "Fabricating" on the Special Metals website at www.yttzhj.com.

Hot and Cold Forming

Hot forming of INCOLOY alloy 800 is done in the temperature range of 1600 to 2200°F (870 to 1200°C). Heavy forging should be done at temperatures from 1850°F to 2200°F (1010°C to 1200°C). Forming at temperatures between 1200 and 1600°F (650-870°C) can result in cracking of the workpiece.

The rate of cooling following hot forming is not critical with respect to thermal cracking. However, the alloy is subject to carbide precipitation in the 1000-1400°F (540-760°C) temperature range and should be cooled rapidly through that range to avoid sensitization.

Cold forming of alloy 800 is done by procedures similar to those used for INCONEL alloy 600 and stainless steel. The work-hardening rate for alloy 800, shown in Figure 15, is higher than the rate for mild steel but lower than that for Type 304 stainless steel. The work-hardening rate for INCOLOY alloy 800 is essentially the same as the rate for INCONEL alloy 600.

For additional information on hot and cold forming, refer to the Special Metals publication "Fabricating" on the Special Metals website at www.yttzhj.com.

Machining

Alloy 800 is readily machined by standard methods.

Turning operations can be performed with high metal-removal rates, good tool life, and good surface finish using coated carbide tools. Good results have also been obtained with high-speed-steel tools, which are better for interrupted cutting. Coated carbide tools have shown good life at cutting speeds of 110-190 sfpm (33.5-57.9 m/min) and a feed of 0.008-0.035 ipr (0.20-0.89 mm/rev.). High speed steel tools have been shown to have good life at cutting speeds of 35-95 sfpm (10.7-29.0 m/min) and a feed of 0.008-0.035 ipr (0.20-0.89 mm/rev.).

For additional information, refer to the Special Metals publication "Machining" on the Special Metals website at www.yttzhj.com.

Note: The same machining parameters apply to INCOLOY alloy 800H and 800HT.

Joining

INCOLOY alloy 800 has good weldability by all welding processes. Material to be welded must be thoroughly clean, and the proper joint designs must be used. Detailed information on surface preparation and joint designs as well as welding techniques is available from Special Metals.

For shielded metal-arc welding of alloy 800, the recommended welding product is INCO-WELD A Electrode. For gas-tungsten-arc, gas-metal-arc, and submerged-arc welding, INCONEL Filler Metal 82 is recommended. INCOFLUX 4 Submerged Arc Flux is used with the submerged-arc process. These products may be used for most dissimiliar welding requirements with alloy 800 as well.

High-temperature tensile properties of INCO-WELD A Electrode and INCONEL Filler Metal 82 are shown in Figures 16 and 17. Stress-rupture properties of the weldmetals are shown in Table 18.

For additional information, refer to the Special Metals publication "Joining" on the Special Metals website at www.yttzhj.com.

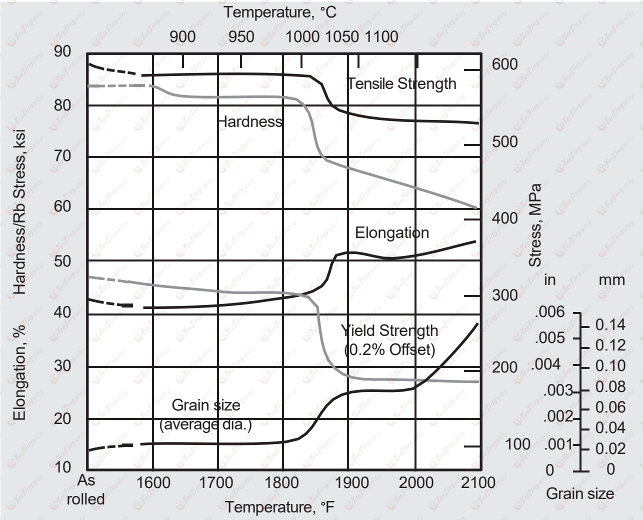

Figure 14. Effect of annealing temperature on properties of a 1.2-in. (30-mm) diameter INCOLOY alloy 800 hot-rolled rod.

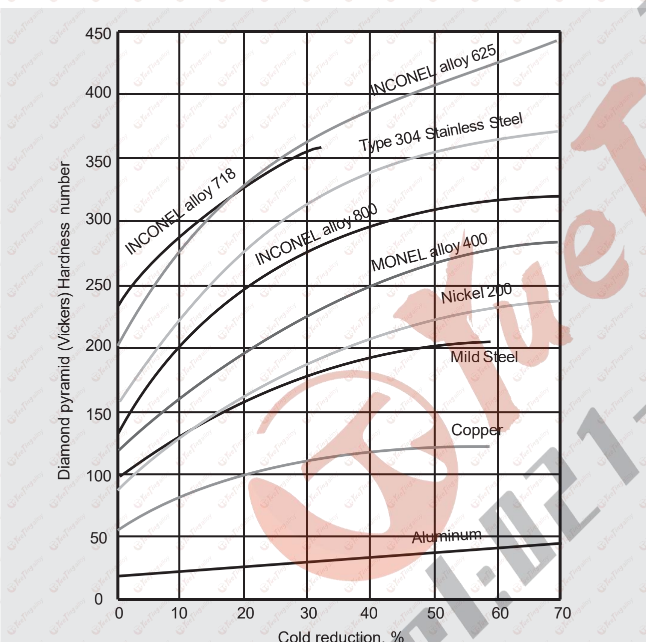

Figure 15. Effect of cold work on hardness of INCOLOY alloy 800 and other materials.

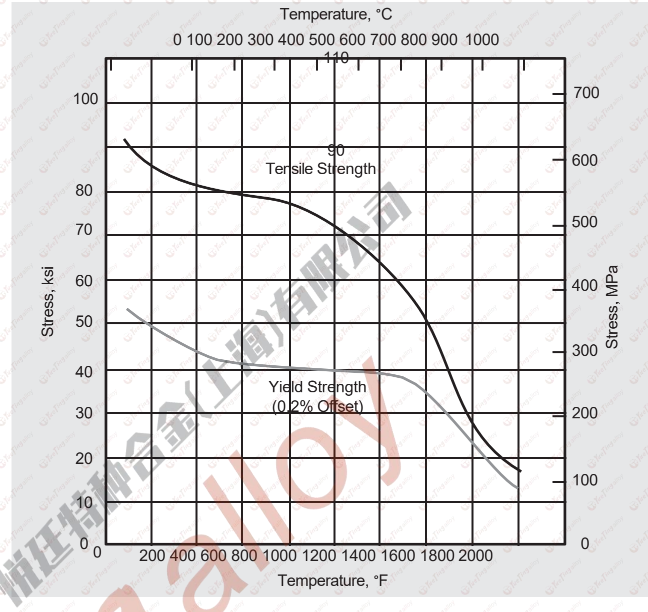

Figure 16. High-temperature tensile properties of INCO-WELD A Electrode (all-weld-metal specimens).

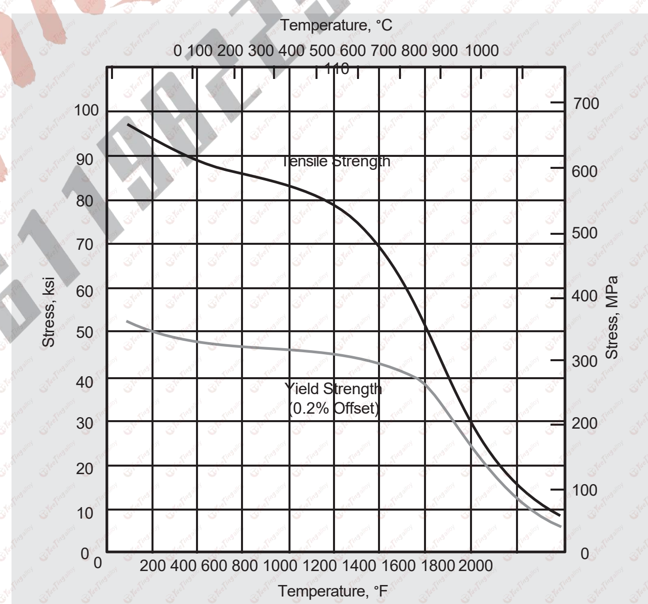

Figure 17. High-temperature tensile properties of INCONEL FIller Metal 82 (all-weld-metal specimens).