INCOLOY® alloy 909

INCOLOY® alloy 909 (UNS N19909) is a nickel-iron-cobalt alloy whose outstanding characteristics are a constant low coefficient of thermal expansion, a constant modulus of elasticity, and high strength. The alloy is strengthened by a precipitation-hardening heat treatment made possible by additions of niobium and titanium. The chemical composition of INCOLOY alloy 909 is given in Table 1.

The combination of low expansion and high strength makes INCOLOY alloy 909 especially useful for gas turbines. The low expansion enables closer control of clearances and tolerances for greater power output and fuel efficiency. The high strength increases strength-to-weight ratios for lower weight in aircraft engines. For those reasons, INCOLOY alloy 909 is used for gas-turbine vanes, casings, shafts, and shrouds.

The properties of INCOLOY alloy 909 are attractive also for rocket-engine thrust chambers, ordnance hardware, springs, steam-turbine bolts, gauge blocks, instrumentation, and glass-sealing applications.

Table 1 - Limiting Chemical Composition, %

Nickel	35.0-40.0
Cobalt	12.0-16.0
Niobium	4.3-5.2
Titanium	1.3-1.8
Iron	Balance*
Silicon	0.25-0.50
Aluminum	0.15 max.
Carbon	0.06 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.

In the continuing evolution of SMC-developed low coefficient of expansion superalloys, Special Metals Corporation has introduced INCONEL® alloy 783, offering these improvements over INCOLOY alloy 909:

- Excellent resistance to oxidation to 1300°F (704°C)

- Resistance to SAGBO comparable to that of INCONEL alloy 718

- 5% lower density than alloys 909 and 718

-Better impact resistance

-Processing characteristics comparable to alloy 718

Physical and Mechanical Properties

Values for some physical properties of INCOLOY alloy 909 are listed in Table 2. The values were determined for age-hardened material. Curie temperature varies within the range shown depending on specific chemical composition of the material.

Thermal and electrical properties of age-hardened material are given in Table 3.

INCOLOY alloy 909 maintains its rigidity over a wide temperature range. As shown by Table 4, the modulus of elasticity remains nearly constant from room temperature to 1200°F (650°C). Elastic modulus was determined for age-hardened material, and testing was by a dynamic method.

The composition of INCOLOY alloy 909 is designed to provide a low and constant coefficient of thermal expansion. The alloy's expansion rate is about half the rate of other alloys having comparable strength. Figure 1 compares thermal expansion of INCOLOY alloy 909 and other high-strength alloys. The coefficient of expansion of INCOLOY alloy 909 is approximately 4.3 x 10^{-6} in/in/°F (7.7 µm/m/°C) from room temperature to the inflection point (Curie temperature). At the inflection point, which is in the region of 800°F (425°C), the alloy changes from ferromagnetic to paramagnetic and displays higher expansion coefficients with increasing temperature.

The combination of low expansion and constant elastic modulus, in conjunction with relatively high thermal conductivity, makes INCOLOY alloy 909 highly resistant to thermal fatigue and thermal shock.

Table 2 - Physical Properties

Density, lb/in^3	0.296
g/cm^3	8.19
Melting Range, °F	2540-2610
°C	1395-1430
Curie Temperature, °F	750-850
°C	400-455
Young's Modulus, 10^3 ksi	23.0
GPa	159
Shear Modulus, 10^3 ksi	8.6
GPa	59

Table 3 - Thermal Properties of INCOLOY alloy 909

Temperature	Specific Heat	Electrical Resistivity	Thermal Conductivity
°F	Btu/lb-°F	ohm-circ mil/ft	Btu-in/ft^2-h-°F
70	0.102	438	102.9[a]
200	0.107	498	112.0
400	0.113	586	123.5
600	0.120	659	132.7
800	0.127	711	139.6
1000	0.134	738	147.2
1200	0.140	750	154.3
1400	0.147	748	159.0
1600	0.154	741	–
1800	0.161	749	–
2000	0.167	766	–
°C	J/kg-°C	µohm-m	W/m-°C
20	427	0.728	14.8[a]
100	450	0.840	16.3
200	473	0.968	17.8
300	494	1.081	18.9
400	525	1.165	19.8
500	551	1.217	20.8
600	576	1.242	21.8
700	599	1.247	22.5
800	626	1.238	23.3[a]
900	653	1.232	–
1000	678	1.248	–

[a] Extrapolated value.

Table 4 - Effect of Temperature on Elastic Properties of INCOLOY alloy 909

Temperature		% Change from Room-Temperature Value	
°F	°C	Young's Modulus	Shear Modulus
200	93	+ 0.6	+ 1.1
400	204	+ 1.4	+ 2.3
600	316	+ 2.7	+ 3.4
800	427	+ 3.3	+ 3.4
900	482	+ 3.5	+ 3.4
1000	538	+ 2.5	+ 1.1
1200	649	- 1.8	- 2.3
1400	760	- 7.7	- 9.2
1600	871	- 14.7	- 14.9
1800	982	- 22.0	- 23.0
2000	1093	- 34.0	- 37.0

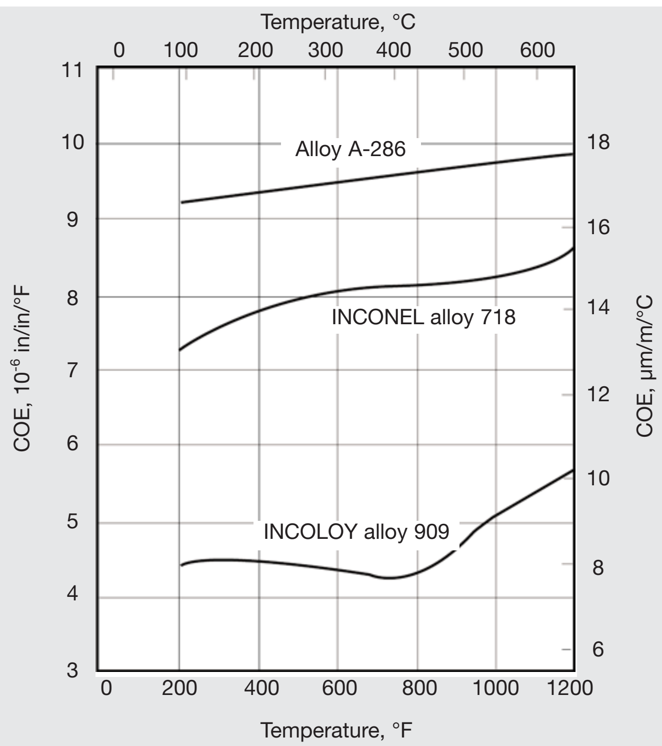

Figure 1 - Coefficients of expansion of INCOLOY alloy 909 and other high-strength alloys.

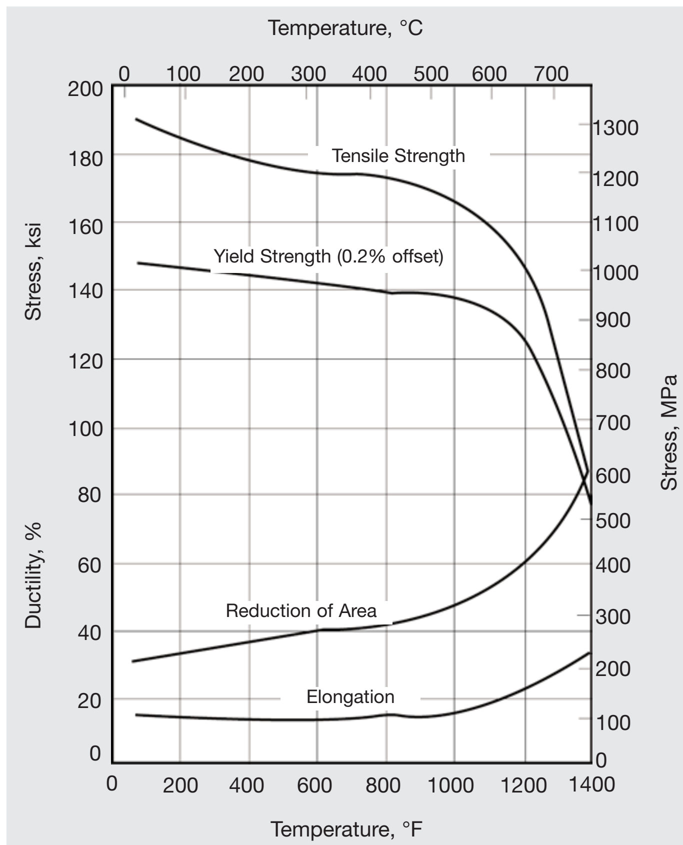

Figure 2 - High-temperature tensile properties of age-hardened INCOLOY alloy 909.

Mechanical Properties

In the age-hardened condition, INCOLOY alloy 909 has high mechanical properties at room temperature and retains much of its strength at temperatures to about 1200°F (650°C). All mechanical properties reported here are for material given the standard heat treatment:

Solution treat at 1800°F (980°C)/1 hr, air cool, plus age harden at 1325°F (720°C)/8 h, furnace cool at 100°F (55°C)/h to 1150°F (620°C)/8 h, air cool.

Table 5 gives tensile properties of INCOLOY alloy 909 at room temperature and at 1200°F (650°C). The effects of temperatures to 1400°F (760°C) on tensile properties are shown in Figure 2. Major decreases in strength do not occur until temperatures over 1200°F (650°C), where age hardening begins to lose its effectiveness.

Previously developed low-expansion superalloys may be susceptible to grain-boundary oxygen embrittlement at high temperatures and consequent poor notch-bar rupture strength. Special processing or long, over-aging heat treatments are needed to alleviate the problem. INCOLOY alloy 909 achieves, primarily through its silicon content, good notch-rupture properties with conventional processing and heat treatment. Typical rupture strength of INCOLOY alloy 909 is shown in Figure 3. The notch-bar tests, conducted at 1000°F (540°C), showed strength levels comparable to those obtained with smooth-bar tests.

An indication of the resistance of INCOLOY alloy 909 to stress-accelerated grain-boundary oxidation is shown in Figure 4, which compares creep crack-growth rates for INCOLOY alloy 909 and INCOLOY alloy 903. The tests were conducted with fatigue-precracked specimens in air at 1000°F (540°C). INCOLOY alloy 903 is another low-expansion superalloy similar in composition to INCOLOY alloy 909.

Stress-rupture test conditions can greatly affect the measured rupture strengths of low-expansion superalloys. Alignment of the specimen during testing is especially significant.

INCOLOY alloy 909 also offers improved low-cycle fatigue strength compared to INCOLOY alloy 903. Notched (K_t = 2.0) low-cycle fatigue tests were conducted in air at 1000°F (540°C) at 20 cpm under load control. The results, shown in Figure 5, illustrate the vastly improved notched LCF strength of INCOLOY alloy 909.

Room-temperature mechanical properties of INCOLOY alloy 909 after extended (1000-h) exposure to high temperatures are given in Table 6. The test results indicate that no deleterious phases were formed during the exposure period.

Table 5 - Typical Tensile Properties of Age-Hardened INCOLOY alloy 909

Temperature		Yield Strength (0.2% Offset)		Tensile Strength		Elongation (%)	Reduction of Area, %
°F	°C	ksi	MPa	ksi	MPa		
70	20	150	1034	185	1276	15	30
1200	650	125	862	150	1034	25	60

Table 6 - Room-Temperature Tensile Properties of Age-Hardened Material After 1000-h Exposure to Elevated Temperatures

Exposure Temperature		Yield Strength (0.2% Offset)		Tensile Strength		Elongation (%)	Reduction of Area, %
°F	°C	ksi	MPa	ksi	MPa		
No Exposure		148	1020	190	1310	16	32
1100	595	159	1096	195	1345	12	29
1200	650	146	1007	186	1282	14	30
1300	705	100	690	142	979	10	16

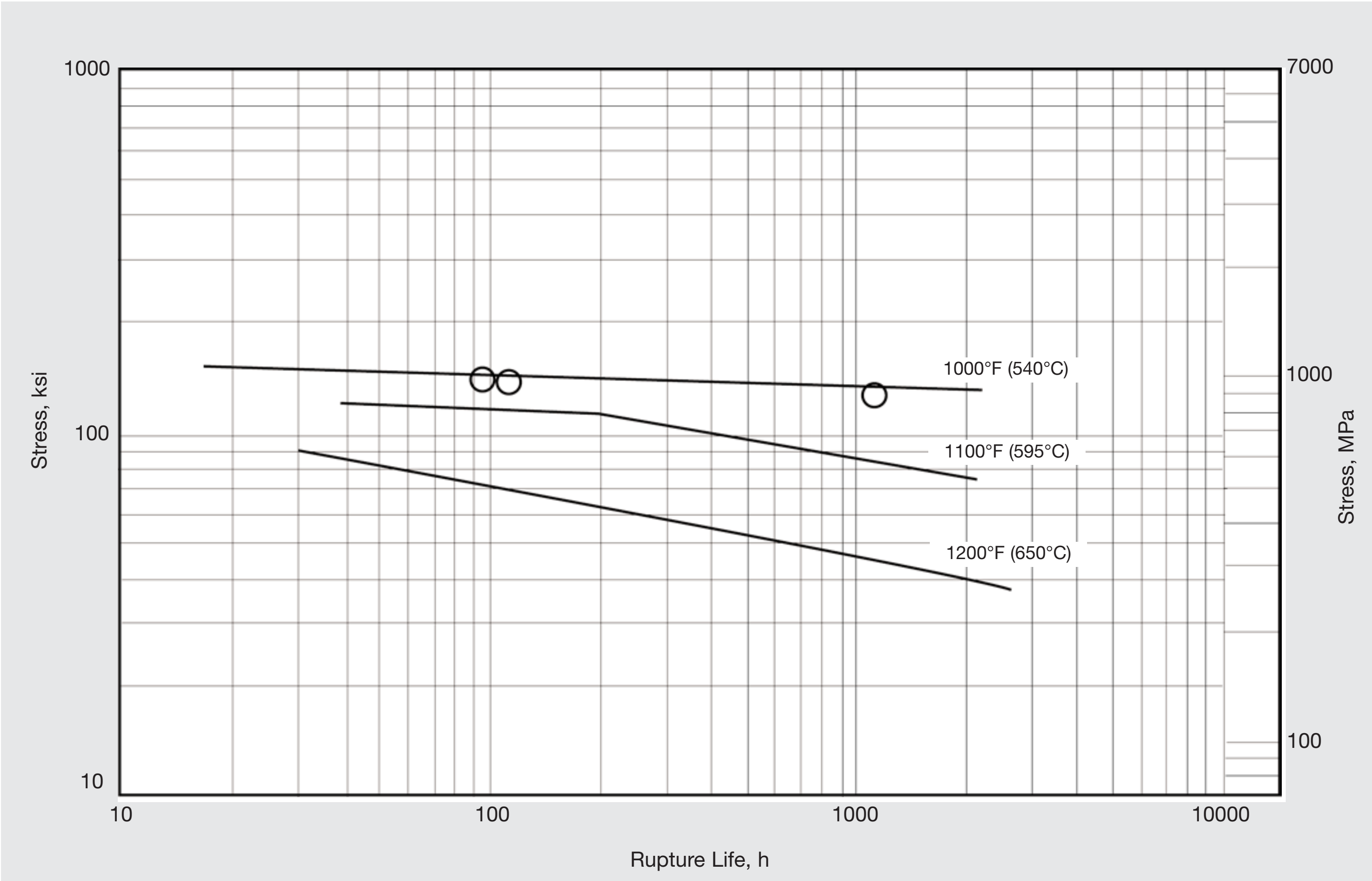

Figure 3 - Rupture Strength of age-hardened INCOLOY alloy 909. Curves represent smooth-bar tests. Symbols at 1000°F (540°C) indicate notch-bar tests.

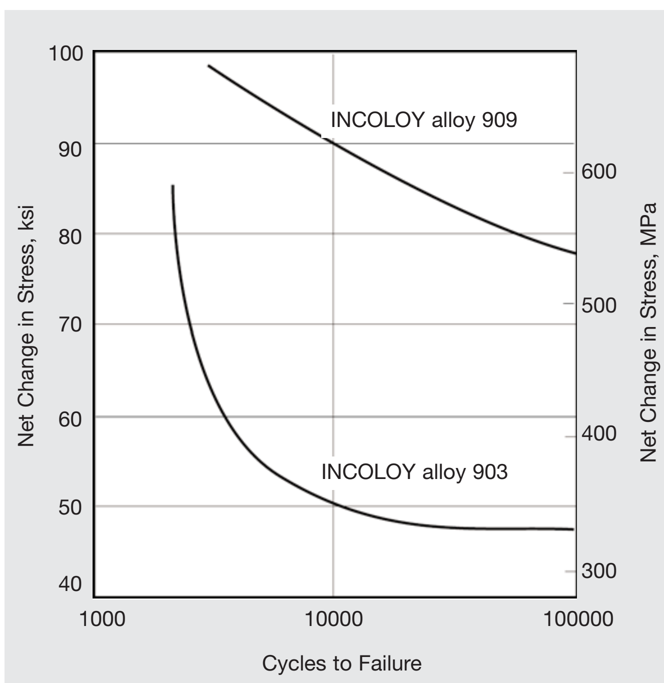

Figure 5 - Low-cycle fatigue strengths of INCOLOY alloys 909 and 903 at 1000°F (540°C).

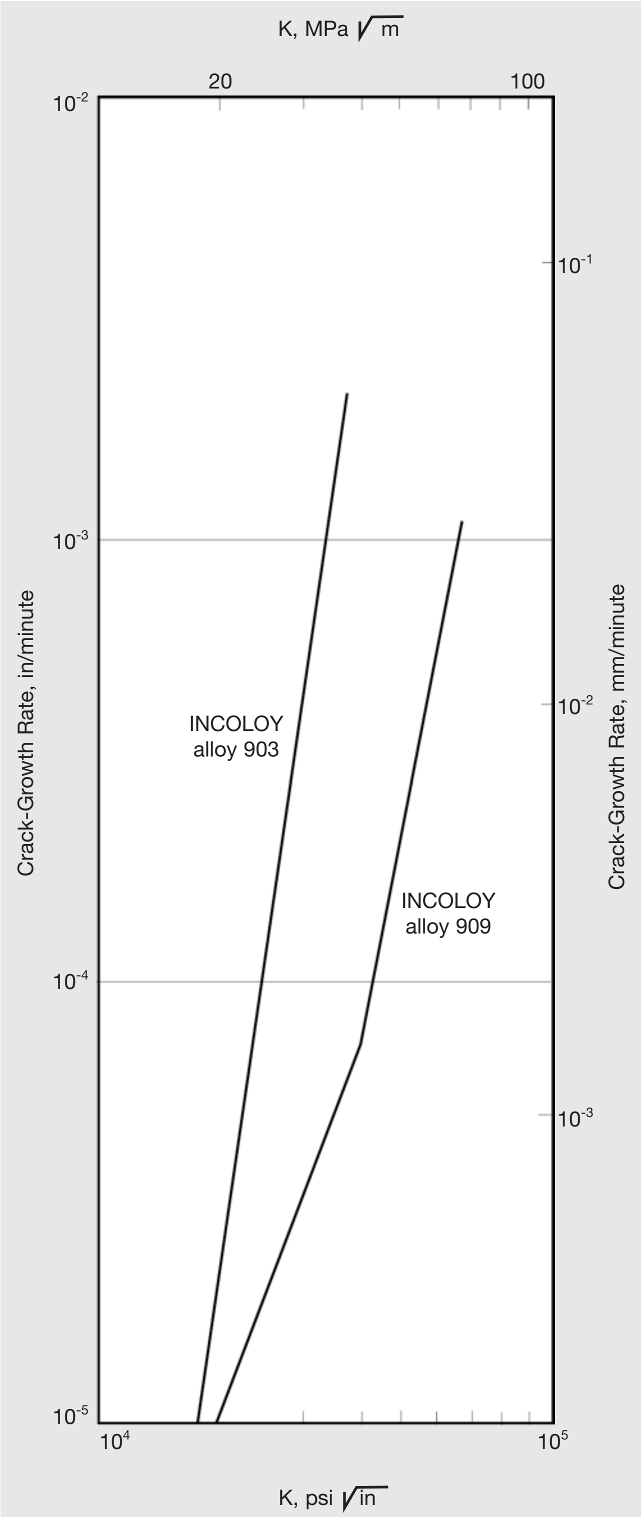

Figure 4 - Creep crack-growth rates of age-hardened material at 1000°F (540°C) in air.

Corrosion Resistance

INCOLOY alloy 909 contains no chromium because the presence of that element would increase thermal expansion rate. The absence of chromium, however, makes the alloy more susceptible to oxidation in high-temperature atmospheres. In some applications, INCOLOY alloy 909 may require a protective coating to prevent excessive oxidation. Figure 6 compares INCOLOY alloy 909 with INCONEL alloy 718 (19% chromium) in a cyclic oxidation test at 1200°F (650°C).

A characteristic of INCOLOY alloy 909 is that, unlike other materials of comparable strength, it resists embrittlement by high-pressure hydrogen.

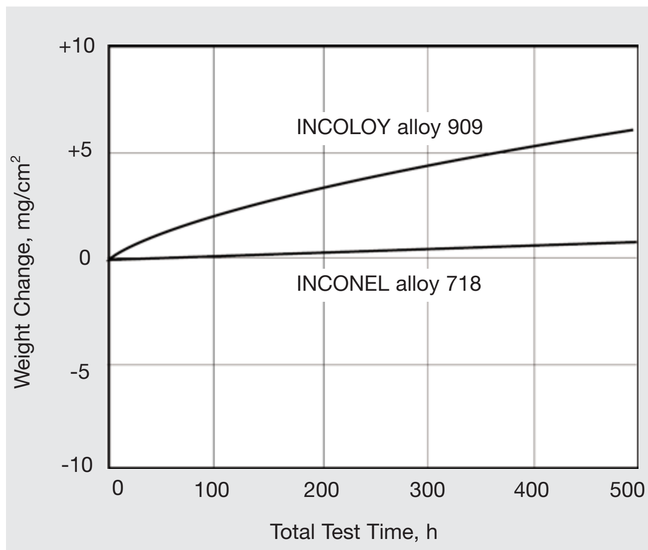

Figure 6 - Resistance to cyclic oxidation at 1200°F (650°C). Cycles consisted of 15 minutes of exposure to temperature and 5 minutes of cooling in air.

Fabrication

INCOLOY alloy 909 has good fabricability and can be formed, machined, and welded by conventional procedures for nickel alloys. In most operations, its behavior is similar to that of INCONEL alloy 718.

Hot Forming

The temperature range for hot forming of INCOLOY alloy 909 is 1600°F to 2050°F (870°C to 1120°C). The following sequence is recommended to achieve an optimum combination of tensile and rupture properties.

1. Initial forging after the metal has been heated to 1940°F to 2050°F (1060°C to 1120°C).
2. Intermediate forging with 25% reduction after a heating temperature of 1825°F to 1925°F (995°C to 1050°C). A warm-work and reheat sequence at this stage will produce grain refinement, a lower recrystallization temperature, and improved properties in the finished product.
3. Finish forging with 20% to 25% reduction after a heating temperature of 1800°F to 1875°F (980°C to 1025°C). The temperature of the workpiece should be lower than 1750°F (955°C) during most of the finishing operation.

Hot-formed material should not be cooled by water quenching. Air cooling is recommended. High stresses developed in the metal by water quenching may lead to unfavorable precipitate morphology and resultant lower tensile properties.

Machining

INCOLOY alloy 909 is machined by conventional practices for high-strength nickel alloys. The tooling and procedures given for Group D-2 alloys in the Special Metals publication “Machining” on the website, www.specialmetals.com, should be used. Rough machining should be done with the material in the annealed condition.

Welding

INCOLOY alloy 909 is readily welded by the gas-tungsten-arc process. General information on surface preparation, joint design and welding technique is available in the publication “Joining” on the Special Metals website, www.specialmetals.com.

Specific welding recommendations may be obtained from Special Metals.

Heat Treatment

Solution annealing before age hardening normally should be done at 1800°F (980°C). For optimum mechanical properties, the recommended age-hardening treatment is 1325°F (720°C)/8 h, furnace cool at 100°F (55°C)/h to 1150°F (620°C)/8 h, air cool.

Available Products and Specifications

INCOLOY alloy 909 is designated as UNS N19909. Standard product forms include sheet, plate, rod, bar, wire rod, forging stock and hot-rolled profile.

Billets - SAE AMS 5884

Bars and forgings - SAE AMS 5892

Sheet and strip - SAE AMS 5893.

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www.specialmetals.com

U.S.A.

Special Metals Corporation

Billet, rod & bar, flat & tubular products
3200 Riverside Drive
Huntington, WV 25705-1771
Phone +1 (304) 526-5100
+1 (800) 334-4626
Fax +1 (304) 526-5643

Billet & bar products
4317 Middle Settlement Road
New Hartford, NY 13413-5392
Phone +1 (315) 798-2900
+1 (800) 334-8351
Fax +1 (315)798-2016

Atomized powder products
100 Industry Lane
Princeton, KY 42445
Phone +1 (270) 365-9551
Fax +1 (270) 365-5910

Shape Memory Alloys
4317 Middle Settlement Road
New Hartford, NY 13413-5392
Phone +1 (315) 798-2939
Fax +1 (315) 798-6860

United Kingdom

Special Metals Wiggin Ltd.
Holmer Road
Hereford HR4 9SL
Phone +44 (0) 1432 382200
Fax +44 (0) 1432 264030

Special Metals Wire Products
Holmer Road
Hereford HR4 9SL
Phone +44 (0) 1432 382556
Fax +44 (0) 1432 352984

China

Special Metals Pacific Pte. Ltd.
Room 1802, Plaza 66
1266 West Nanjing Road
Shanghai 200040
Phone +86 21 3229 0011
Fax +86 21 6288 1811

Special Metals Pacific Pte. Ltd.
Room 910, Ke Lun Mansion
12A Guanghua Road
Chaoyang District
Beijing 100020
Phone +86 10 6581 8396
Fax +86 10 6581 8381

France

Special Metals Services SA
17 Rue des Frères Lumière
69680 Chassieu (Lyon)
Phone +33 (0) 4 72 47 46 46
Fax +33 (0) 4 72 47 46 59

Germany

Special Metals Deutschland Ltd.
Postfach 20 04 09
40102 Düsseldorf
Phone +49 (0) 211 38 63 40
Fax +49 (0) 211 37 98 64

Hong Kong

Special Metals Pacific Pte. Ltd.
Unit A, 17th Floor, On Hing Bldg
1 On Hing Terrace
Central, Hong Kong
Phone +852 2439 9336
Fax +852 2530 4511

India

Special Metals Services Ltd.
No. 60, First Main Road, First Block
Vasantha Vallabha Nagar
Subramanyapura Post
Bangalore 560 061
Phone +91 (0) 80 2666 9159
Fax +91 (0) 80 2666 8918

Italy

Special Metals Services SpA
Via Assunta 59
20054 Nova Milanese (MI)
Phone +390 362 4941
Fax +390 362 494224

The Netherlands

Special Metals Service BV
Postbus 8681
3009 AR Rotterdam
Phone +31 (0) 10 451 44 55
Fax +31 (0) 10 450 05 39

Singapore

Special Metals Pacific Pte. Ltd.
24 Raffles Place
#27-04 Clifford Centre
Singapore 048621
Phone +65 6532 3823
Fax +65 6532 3621

Affiliated Companies

Special Metals Welding Products
1401 Burris Road
Newton, NC 28658, U.S.A.
Phone +1 (828) 465-0352
+1 (800) 624-3411
Fax +1 (828) 464-8993

Canada House
Bidavon Industrial Estate
Waterloo Road
Bidford-On-Avon
Warwickshire B50 4JN, U.K.
Phone +44 (0) 1789 491780
Fax +44 (0) 1789 491781

Controlled Products Group
590 Seaman Street, Stoney Creek
Ontario L8E 4H1, Canada
Phone +1 (905) 643-6555
Fax +1 (905) 643-6614

A-1 Wire Tech, Inc.
A Special Metals Company
4550 Kishwaukee Street
Rockford, IL 61109, U.S.A.
Phone +1 (815) 226-0477
+1 (800) 426-6380
Fax +1 (815) 226-0537

Rescal SA
A Special Metals Company
200 Rue de la Couronne des Prés
78681 Epône Cédex, France
Phone +33 (0) 1 30 90 04 00
Fax +33 (0) 1 30 90 02 11

DAIDO-*SPECIAL METALS* Ltd.
A Joint Venture Company
Daido Shinagawa Building
6-35, Kohnan 1-chome
Minato-ku, Tokyo 108-0057, Japan
Phone +81 (0) 3 5495 7237
Fax +81 (0) 3 5495 1853