INCOLOY® alloy MA956

INCOLOY® alloy MA956 (UNS S67956), first developed as an aerospace superalloy and now used in a range of industrial applications, combines excellent strength and fabricability with outstanding resistance to prolonged exposure up to 1300°C (2400°F). Its exceptional properties result from the mechanical alloying process by which it is made; a process which allows a fine distribution of yttrium oxide particles to be incorporated into a highly corrosion-resistant Fe-Cr-Al alloy.

The alloy has excellent oxidation resistance up to 1300°C (2400°F) and significant creep strength up to its unusually high melting point of 1482°C (2700°F). Thicker sections may be used up to 1370°C (2500°F). Typical industrial applications include hearth rollers, radiant tubes, furnace muffles, fluidized bed retorts, heat treatment baskets, mesh belts, heat shields, burner nozzles, sensor tubes for thermowells and combustion chamber components for diesel engines.

A full range of both hot and cold-worked mill products is available. The forming and machining characteristics are similar to those of conventional high-chromium ferritic steels and Fe-Cr-Al alloys.

Table 1. Limiting Chemical Composition, wt.%

Iron	Balance*
Chromium	18.5-21.5
Aluminum	3.75-5.75
Titanium	0.2-0.6
Carbon	0.1 max.
Yttrium oxide	0.3-0.7
Copper	0.15 max.
Manganese	0.30 max.
Cobalt	0.3 max.
Nickel	0.50 max.
Phosphorus	0.02 max.

*Reference to the 'balance' of an alloy's composition does not guarantee this is exclusively of the element mentioned, but that it predominates and others are present only in minimal quantities.

Physical Properties

Melting point 1480°C (2700°F)

The unusually high solidus is 100-200°C higher than for most high-temperature nickel-base superalloys. Even at these extremely high temperatures the dispersion of yttrium oxide provides dimensional and structural stability and prevents embrittlement due to grain growth.

Density 7.25 g/cm³ (0.262 lb/in³)

The low density is only 70% that of molybdenum allowing INCOLOY alloy MA956 to be economically substituted for similar size fixtures in vacuum furnaces.

The lower mass also reduces loading stresses. Unlike molybdenum, the alloy is completely immune to accidental exposure to air at elevated temperatures.

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Physical Properties, continued

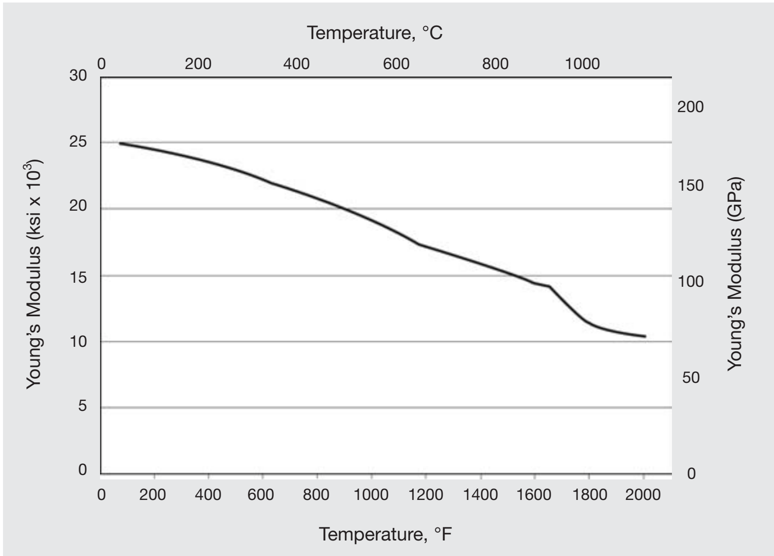

Figure 1. Young's modulus of INCOLOY alloy MA956

Thermal & Electrical Properties

Table 2- Thermal & Electrical Properties

Temp.	Expansion coefficient 10^{-6}•°C	Thermal conductivity W/m•°C	Electrical resistivity µΩ•m	Specific heat J/kg•°C
20	-	10.9	1.31	469
100	11.3	12.2	1.31	491
200	11.6	13.9	1.33	519
300	11.9	15.4	1.34	547
400	12.3	16.9	1.36	575
500	12.7	18.4	1.37	602
600	13.0	19.8	1.39	630
700	13.4	21.2	1.41	658
800	13.9	22.6	1.42	686
900	14.4	24.1	1.43	714
1000	14.9	25.5	1.43	741
1100	15.5	27.0	1.44	769

Thermal Expansion

Compared with nickel-base alloys and austenitic stainless steels, INCOLOY alloy MA956 has the advantage of a relatively low coefficient of thermal expansion.

Resistivity

The material has a high electrical resistance and is suitable for heating applications where the mechanical loading is high.

Thermal Conductivity

This property increases with temperature and is higher than for ceramics. This is of particular advantage in radiant tube and heat-exchanger applications.

Tensile Properties

Isotropy

INCOLOY alloy MA956 sheet and plate are rolled in both the longitudinal and transverse directions. After annealing, this results in large pancake shaped grains which minimize directionality in mechanical properties and facilitate the forming of complex shapes from sheet and plate. Tube and bar, mainly processed longitudinally, have a more elongated grain shape and have the highest strength in this direction.

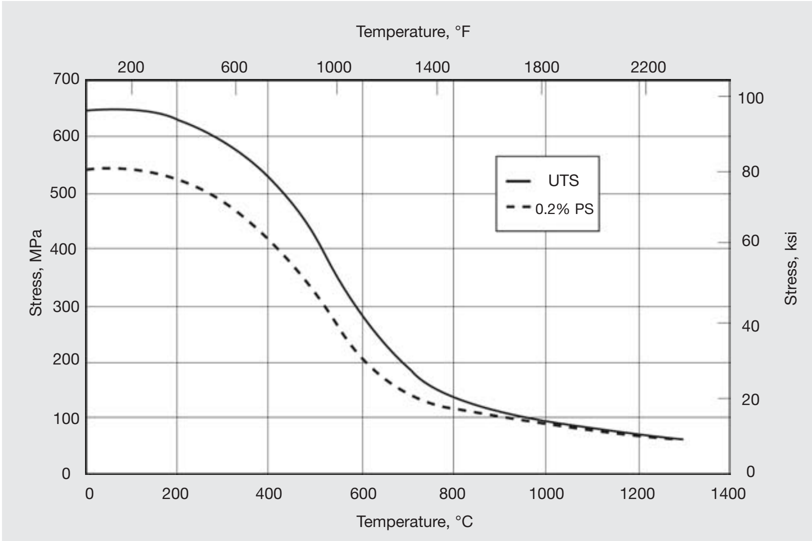

Figure 2. Tensile strength of cold-rolled sheet

Retention Of Strength

At the very highest temperatures, the alloy retains significant strength up to the melting point.

At temperatures above 1000°C (1830°F), the alloy is stronger than all conventional, wrought, nickel-base cold-rolled sheet superalloys.

Ductility

Like many ferritic steels in widespread use, INCOLOY alloy MA956 displays a different response to severe deformation below the Ductile-Brittle Transition Temperature (DBTT). The exact point depends on the product form but is generally in the range 0-100°C (32-212°F).

It is recommended that the usual practice is followed for such steels and pre-warming to 150-200°C (300-400°F) is carried out before forming the material. It may be necessary to warm any tools if chilling of the workpiece is likely.

Maximum ductility occurs at around 650°C (1200°F) and at this temperature the alloy may be readily formed to complex shapes. At temperatures up to 1300°C (2370°F) there is useful ductility which compares very favorably with alternative ceramic materials.

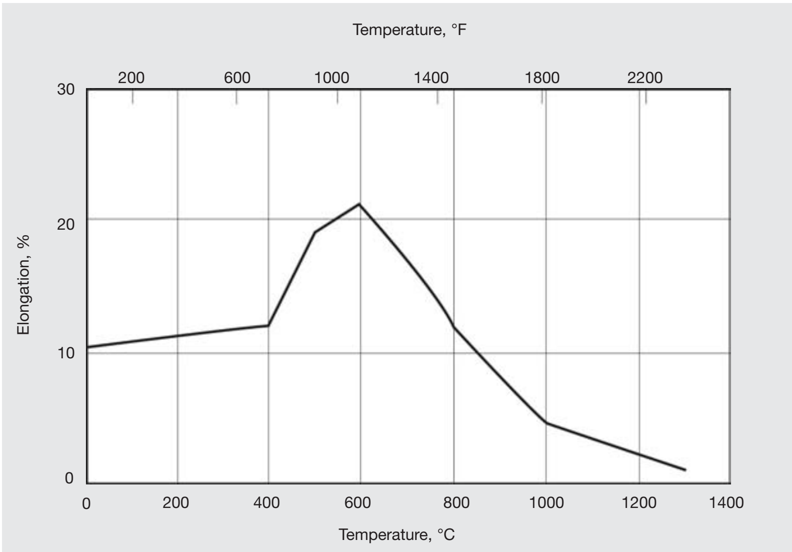

Figure 3. Tensile elongation of cold-rolled sheet

Creep Properties

INCOLOY alloy MA956 sheet is made by mechanical alloying. Unlike conventional melted alloys, this permits oxide dispersion strengthening (ODS) with microscopic particles of yttrium oxide. This is effective up to the alloy melting point. In addition to ODS, special processing and heat treatment results in a stable, coarse grain size which further enhances the alloy's high-temperature strength.

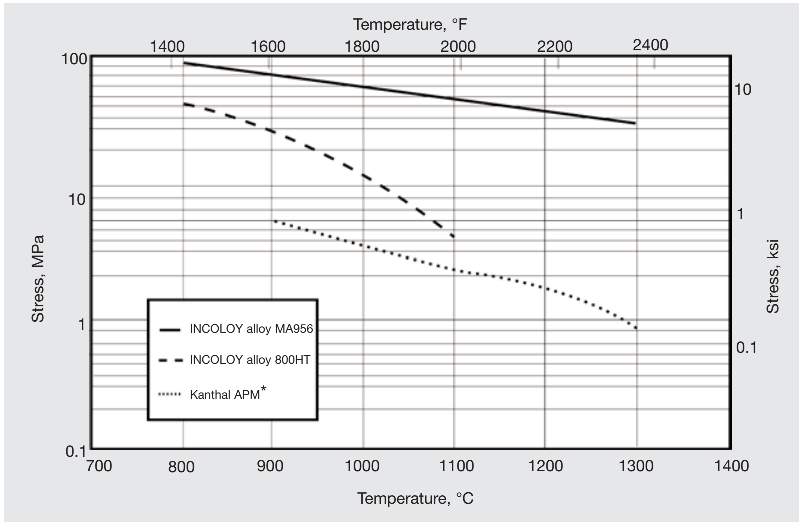

Figure 4. Comparison of 1000-hour creep-rupture strength

A unique feature of ODS alloys is their extreme long-term stability and resistance to creep. The reduction in strength is minimal over very long times compared with conventional Ni-Cr and Fe-Cr-Al alloys, the creep strength advantage above 1000°C (1830°F) being approximately 10-20 times. Using ODS alloys at moderate stresses, it is often possible to disregard the effects of creep.

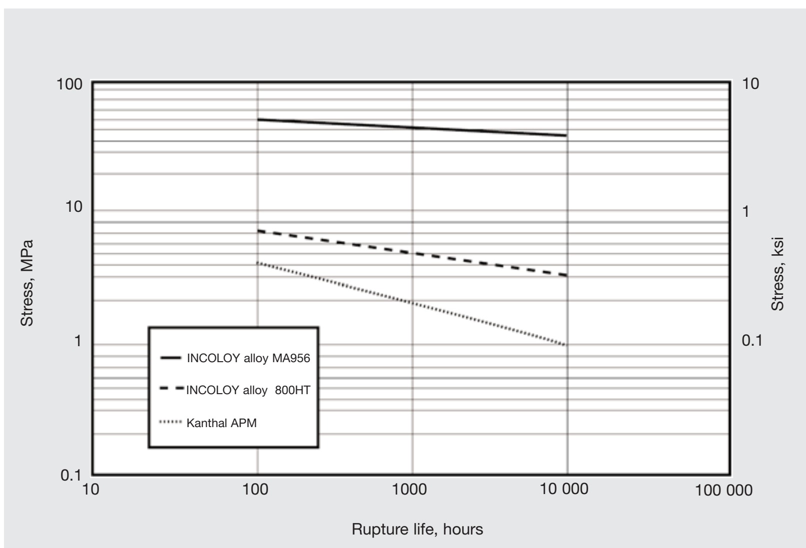

Figure 5. Comparison of creep-rupture life at 1100°C (2012°F)

*APM is a trademark of Kanthal AB

Corrosion Resistance

Oxidation

The high aluminum content of INCOLOY alloy MA956 allows the information of a thin, highly adherent and protective surface layer of alumina. This process occurs in a wide range of atmospheres, even when levels of oxygen are low. The layer is very effective in reducing the rates of further oxidation. Should the protective layer be mechanically damaged, the high aluminum content of the alloy allows the formation of fresh alumina which heals the affected area. INCOLOY alloy MA956 may be used under oxidizing conditions up to 1300°C (2370°F), much higher than conventional nickel-chromium alloys.

For optimum environmental resistance of machined or cut surfaces, particularly in reducing atmospheres, it is recommended that all traces of lubricants and other foreign matter are removed prior to pre-oxidizing for service in air for 2 hours at 1100°C (2012°F).

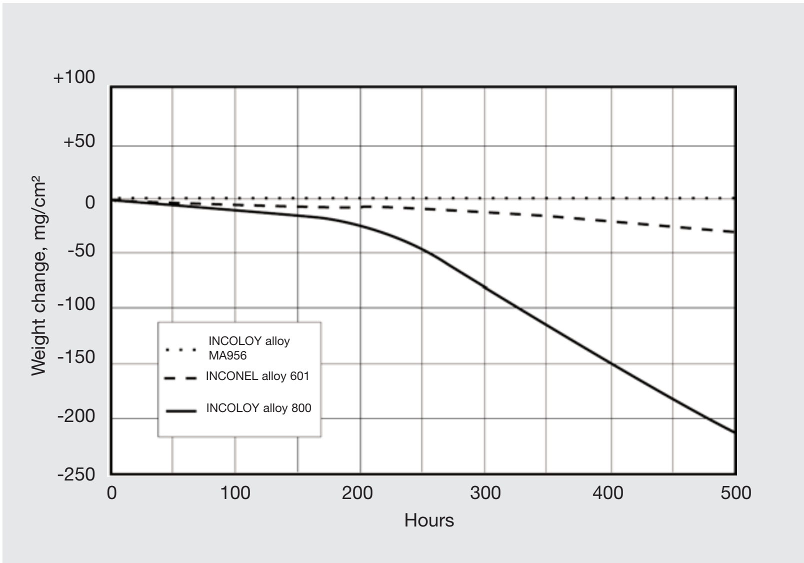

Figure 6. Oxidation resistance at 1205°C (2200°F)

Carburization

The alumina layer is also a barrier to carburization and sulfidation. Carbon diffusion rates into the base metal are greatly reduced, as is the adherence of carbon deposits on the oxide surface. The relatively clean surface under carburizing conditions also maintains excellent heat transfer rates in radiant heating and chemical processing applications, thus reducing the risk of damage to the alloy through overheating.

Sulfidation

The adherent aluminum oxide scale formed by the alloy provides a surface barrier to sulfur.

The complete absence of nickel in the alloy avoids the formation of harmful nickel sulfide.

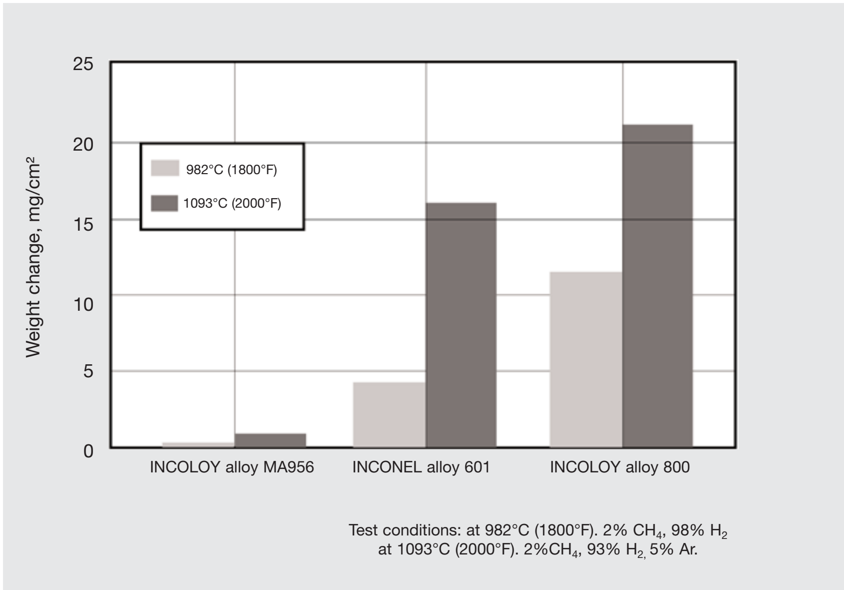

Figure 7. Comparison of carburization resistance

Working

Machining

INCOLOY alloy MA956 is readily machined by all conventional techniques. Its hardness is in the range HV 250-300 (Rc 25-30) and the work hardening rate is relatively low compared with nickel-base alloys. The general machining characteristics are similar to type 410 ferritic stainless steel. Although it is possible to use high-speed steel tools it is usually more economical to employ carbide-tipped tools.

Cutting with an abrasive saw requires care to avoid thermal shock which can cause cracking; if possible cooling fluid should be used. If electric discharge machining (EDM) is to be used, the recast surface layer must be subsequently removed by grinding.

Joining

Conventional TIG welding is possible but produces relatively low strength joints. This process is acceptable for positioning and fillet type welds. Suitable filler wires are INCONEL filler metal 82 for dissimilar metal joints to nickel-base alloys and matching composition wires for welding to austenitic stainless steels. For joining the alloy to itself a Fe-Cr-Al wire is recommended where high-temperature oxidation resistance is required in the weld. The strongest joints are produced by processes with high energy density such as laser and electron beam welding.

If it is impossible to avoid highly restrained joint designs, post-weld stress relieving should be carried out as soon as practicable to avoid delayed stress cracking. A treatment of 2 hours at 1100°C (2010°F) in air followed by air cooling is suggested. The same cycle may serve as a pre-oxidation treatment provided the surface is cleaned of lubricants and other contaminants.

Brazing, diffusion bonding and transient liquid phase bonding (TLP) are possible if extreme care is first taken to remove the protective alumina film by grinding.

For maximum strength at high temperatures, mechanical joints such as matching composition rivets, pins and threaded connections are often used.

Forming

The nature of INCOLOY alloy MA956 (a ferritic alloy) requires care in high strain rate forming operations such as bending, deep drawing, punching and shearing. For severe deformations it is recommended that the material and tooling is warmed to 150-200°C (300-400°F).

Product Forms

INCOLOY alloy MA 956 is available in the following forms and sizes:

Form	mm	inches
Cold-rolled sheet	0.7-2.0 thick	0.030-0.080
Hot-rolled plate	3-10 thick	0.120-0.400
Tube	10-110 OD	0.400-4.250
Hot-finished round bar	5.5-50 dia.	0.215-2.000
Cold-drawn wire	2.0-8.5 dia.	0.080-0.335
Flat bar from to	4 x 11 25 x 75	0.160 x 1.0450 1.000 x 3.000

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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