HAYNES International

HIGH-TEMPERATURE ALLOYS

HAYNES® 556™ alloy

An iron-nickel-chromium-cobalt alloy that combines effective resistance to sulfidizing, carburizing and chlorine-bearing environments with good oxidation resistance, fabricability and excellent high-temperature strength.

Contents

H-3013E

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PRINCIPAL FEATURES

High Strength and Resistance to High-Temperature Corrosion

HAYNES® 556™ alloy is an iron-nickel-chromium-cobalt alloy that combines effective resistance to sulfidizing, carburizing and chlorine-bearing environments at high temperatures with good oxidation resistance, fabricability, and excellent high-temperature strength. It has also been found to resist corrosion by molten chloride salts and other salts, and is resistant to corrosion from molten zinc.

Ease of Fabrication

HAYNES 556 alloy has excellent forming and welding characteristics. It may be forged or otherwise hot-worked, providing that it is held at 2150°F (1175°C) for a time sufficient to bring the entire piece to temperature. As a consequence of its good ductility, 556 alloy is also readily formed by cold working. All hot- or cold-worked parts should be annealed and rapidly cooled in order to restore the best balance of properties.

The alloy can be welded by a variety of techniques, including gas tungsten arc (GTAW), gas metal arc (GMAW), shielded metal arc (coated electrode), and resistance welding.

Heat-Treatment

HAYNES 556 alloy is furnished in the solution heat-treated condition, unless otherwise specified. The alloy is normally solution heat-treated at 2150°F (1175°C) and rapidly cooled or water-quenched for optimum properties. Heat treatments at temperatures lower than the solution heat-treating temperature may cause precipitation of secondary phases.

Available in Practical Product Forms

HAYNES 556 alloy is available in the form of plate, sheet, strip, billet, bar, wire, pipe and tubing.

Applicable Specifications

HAYNES 556 alloy is covered by ASME Section VIII, Division 1, up to 1650°F (900°C) and ASME Section I, (Code Case 2010) up to 1200°F (650°C). ASTM specifications include B-435 (plate/sheet), B-572 (rod/bar), B-619 (welded pipe), B-622 (seamless pipe and tubing), and B-626 (welded tubing). AMS specifications are AMS 5874 (sheet/strip/plate), AMS 5877 (bar/forgings) and AMS 5831 (wire). 556 weld wire is covered by AWS specification A5.9 (ER3556). The UNS number for HAYNES 556 alloy is R30556.

Applications

HAYNES 556 alloy combines properties which make it highly useful for service at elevated-temperature in moderately to severely corrosive environments. Applications can include tubing and structural members in municipal and industrial waste incinerators, rotary calciners and kilns for minerals processing, and non-rotating components in land-based gas turbines burning low-grade fuels.

In the chemical process industry, 556 alloy is used for applications in rotary calciners, carbon regenerators, and in processes involving high-sulfur petroleum feedstocks.

In the metallurgical process industry, 556 alloy is widely used for hot-dip galvanizing fixtures, spinners and baskets, and for high speed furnace fans. 556 alloy is also employed in air preheaters of diesel engines, the inner covers of coil annealing furnaces, and in various high-temperature applications in the aerospace industry.

Nominal Chemical Composition, Weight Percent

Fe	Ni	Co	Cr	Mo	W	Ta	N	Si	Mn	Al	C	La	Zr
31[a]	20	18	22	3	2.5	0.6	0.20	0.4	1	0.2	0.10	0.02	0.02

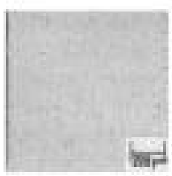
[a] As Balance

SULFIDATION RESISTANCE

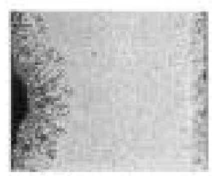
HAYNES® 556™ alloy is second in resistance only to HAYNES HR-160® alloy to the types of sulfur-bearing environments that are present in many high-temperature industrial processes. This is due partly to its comparatively low nickel content coupled with the important addition of cobalt, the high chromium level, and the carefully balanced minor elements. For comparison, data illustrating the relative sulfidation resistance of INCONEL® alloy 601, HASTELLOY® X alloy, alloys 600 and 800H, and Type 310 stainless steel are shown in the accompanying photomicrographs. 556 alloy had little sulfide penetration or wastage after 215 hours of exposure in an Ar+5%H_2+5%CO+1%CO_2+ 0.15%H_2S+0.1%H_2O test gas at 1800°F (980°C). By contrast, alloys such as INCONEL alloy 601 were completely destroyed, while other materials suffered severe wastage and sulfide penetration or pitting.

Comparative Sulfidation Resistance at 1800°F (980°C) for 215 Hours

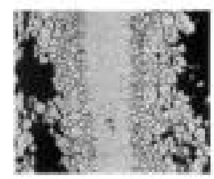
(Width of Micros Indicates Original Sample Thickness)



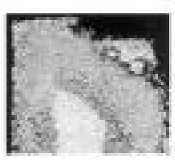
HAYNES 556 alloy
Average Metal Affected = 2.0 Mils (50 µm)/Side



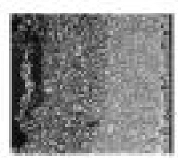
Type 310 stainless steel
Average Metal Affected = 7.4 Mils (190 µm)/Side



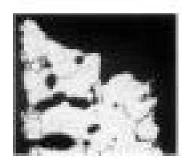
Alloy 800H
Average Metal Affected = 23.2 Mils (590 µm)/Side



HASTELLOY X alloy
Average Metal Affected = >22 Mils (560 µm)/Side



INCONEL alloy 601
Average Metal Affected = >22 Mils (560 µm)/Side



Alloy 600
Average Metal Affected = >22 Mils (560 µm)/Side

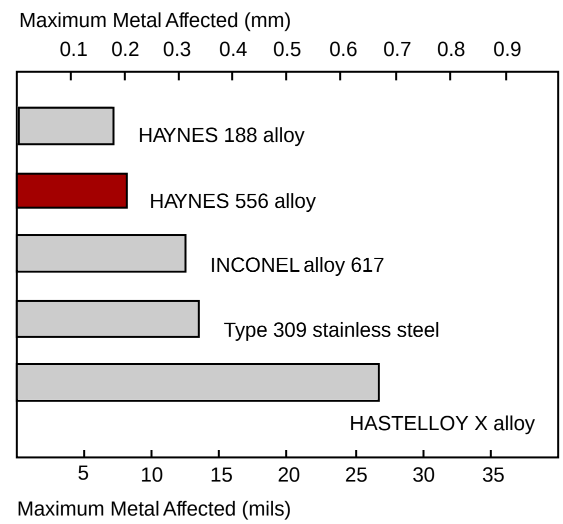
Sulfidation Resistance at Other Temperatures

	1400°F (760°C)*				1600°F (871°C)*			
	Metal Loss		Average Metal Affected**		Metal Loss		Average Metal Affected	
Material	Mils	µm	Mils	µm	Mils	µm	Mils	µm
HR-160® alloy	0.2	5	1.1	30	0.1	3	3.8	95
556 alloy	2.5	65	3.8	95	5.2	130	11.7	295
Type 310	6.2	155	9.1	230	9.5	240	13.5	345
alloy 800H	7.1	180	11.2	285	11.7	295	19.2	490
X alloy	>29.5	>750	Perforated		>21.7	>550	Consumed	
alloy 600	>21.7	>560	Perforated		>21.7	>550	Consumed	
alloy 601	>29.5	>750	Perforated		>21.7	>550	Perforated	

*215 Hour Exposure in Ar+5% H_2+5%CO+1% CO_2+0.15%H_2S+0.10%H_2O
**Metal Loss + Average Internal Penetration

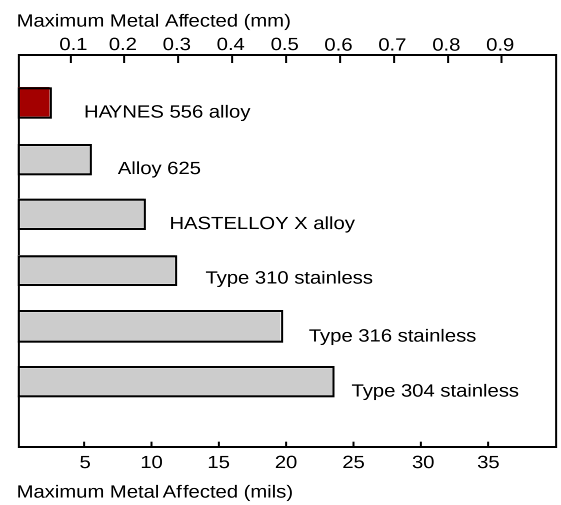
Field Experience - Municipal Waste Incinerator

Samples were exposed for 950 hours in the superheater section of a municipal waste incinerator. Combustion gas temperatures were about 1475°F (800°C) with excursions to 1740°F (950°C). The mode of corrosion observed was oxidation/sulfidation, although alkali chloride compounds were known to be present. HAYNES® 556™ alloy was found to be one of the best alloys for resisting this highly corrosive environment.



Field Experience - Aluminum Remelting Furnace

Samples of tubing were exposed for 1150 hours in the recuperator of an aluminum remelting furnace producing 1250°F (675°C) flue gases. The tube samples were internally cooled by combustion preheat air the same as the operating recuperator tubes. The mode of corrosion observed was combined attack by alkali sulfates and chlorides together with oxidation. HAYNES 556 alloy exhibited outstanding resistance to corrosion in this environment.



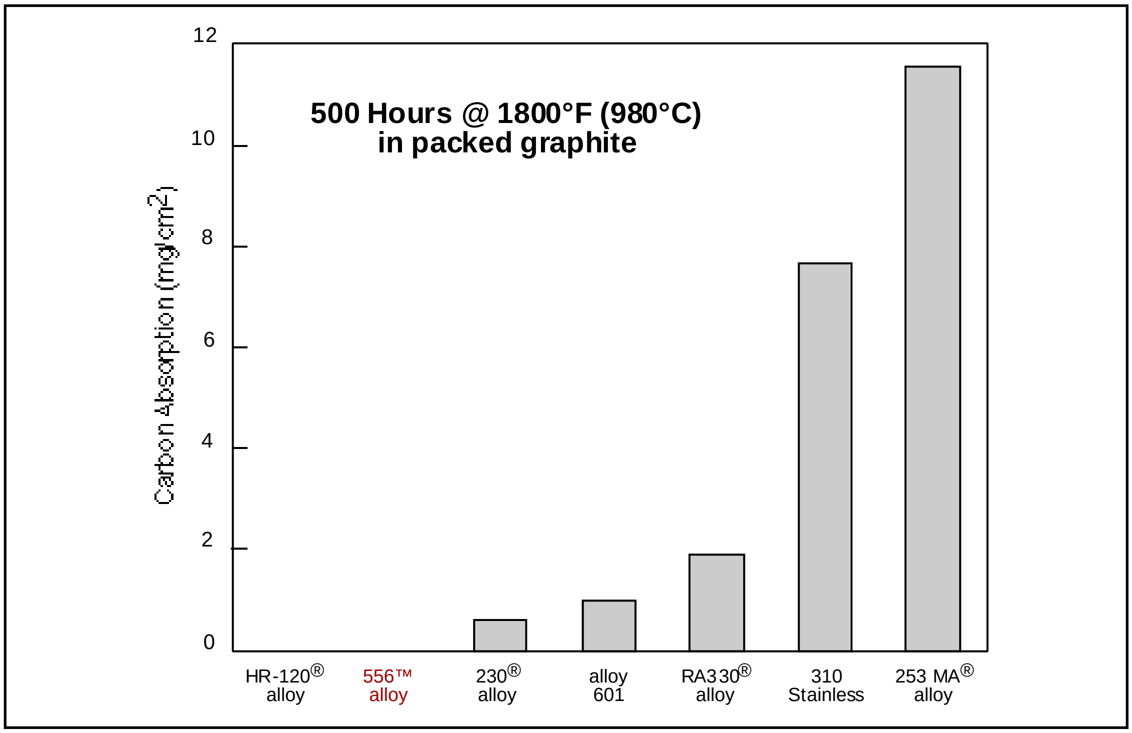
CARBURIZATION RESISTANCE

HAYNES® 556™ alloy has excellent resistance to carburization, as measured in both mixed gas exposure tests and packed graphite exposure tests. Results for these tests are presented in the following pages.

All results are presented in terms of the mass of carbon absorption per unit area, which was obtained from the equation M = C(W/A) where M = the mass of carbon absorption per unit area (mg/cm^2). C = difference in carbon (weight fraction) before and after exposure , W = weight of the unexposed specimen (mg) and A = surface area of the specimen exposed to the test environment (cm^2).

Packed Carburization Resistance

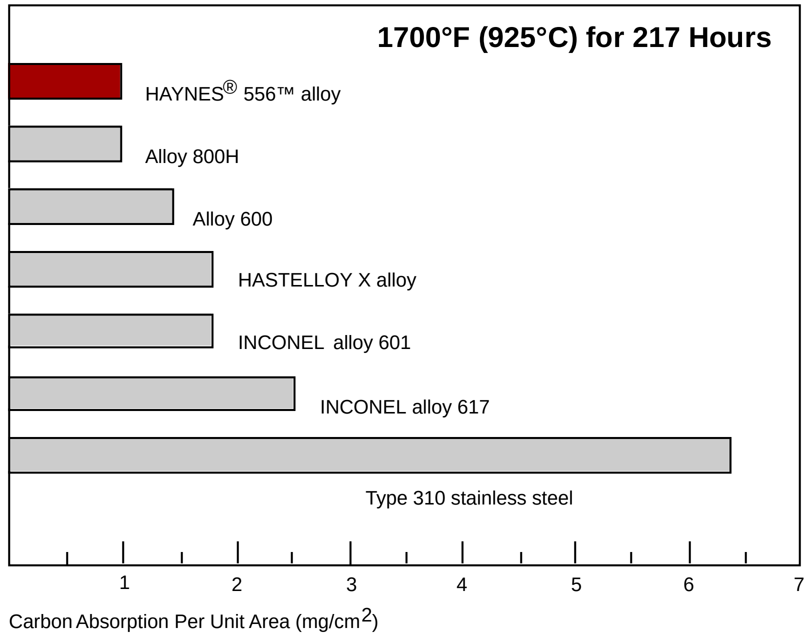
Carbon absorption observed for 556 alloy following 500 hour exposure in packed graphite at 1800°F (980°C) was negligible, as shown below. Similar resistance was exhibited by HAYNES HR-120® alloy. This is in contrast to other alloys tested, all of which exhibited measurable carbon absorption. In particular, the resistance to carburization of 556 alloy was significantly better than that for the stainless steel type materials.



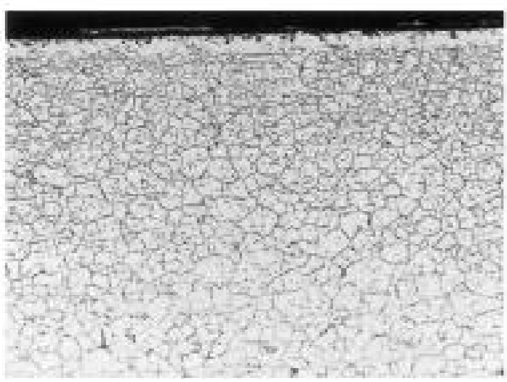
Mixed Gas Carburization Tests

Carbon absorption observed for 556 alloy following exposure at both 1700°F (925°C) and 1800°F (980°C) to a carburizing gas mixture was significantly lower than that for most other materials tested. This is shown in the graphs on the following pages. For these tests, the exposure was performed in a gas environment consisting of (by volume %) 5.0% H_2, 5.0% CO, 5.0% CH_4 and the balance argon. The calculated equilibrium composition (volume %) at 1800°F (980°C) and one atm was 14.2% H_2, 4.8%CO, 0.003% CO_2, 0.026% CH_4, 0.011% H_2O and the balance argon. The activity of carbon was 1.0 and the partial pressure of oxygen was 9 x 10^{-22} atm at 1800°F (980°C).

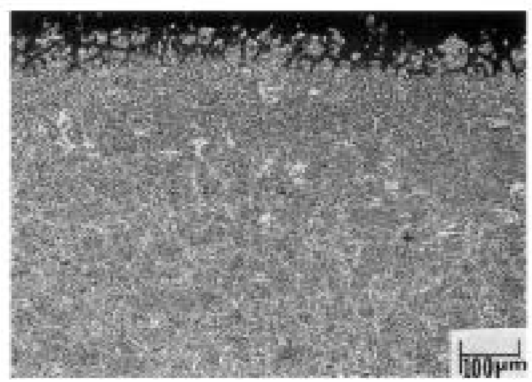
Comparative 1700°F (925°C) Mix Gas Carburization Tests



Typical Carburized Microstructures (Unetched) After Exposure For 215 Hours At 1700°F (925°C)

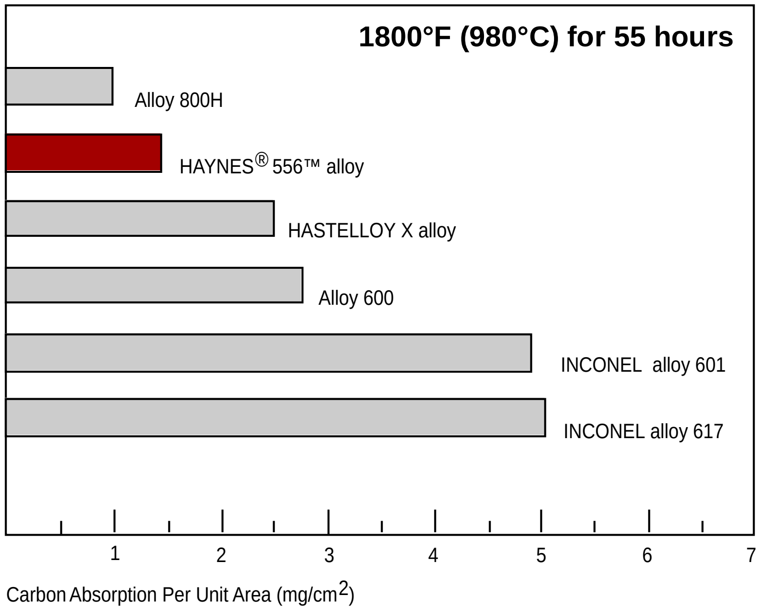


HAYNES 556 alloy

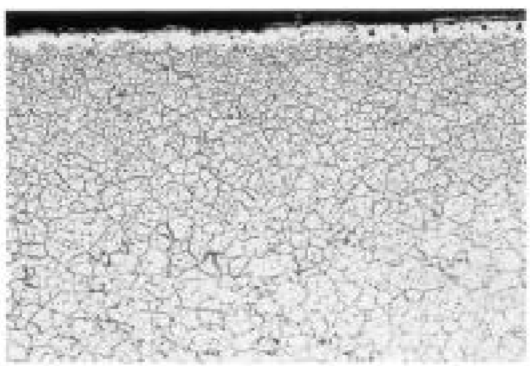


Type 310 Stainless Steel

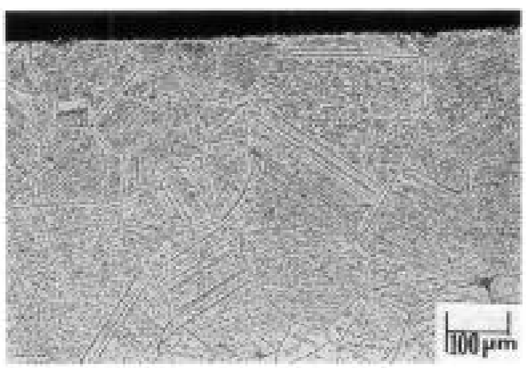
Comparative 1800°F (980°C) Mixed Gas Carburization Tests



Typical Carburized Microstructures (Unetched) After Exposure For 55 Hours At 1800°F (980°C)



HAYNES 556 alloy



INCONEL alloy 617

Note: Alloy 617 is carburized to the center of the sample.

OXIDATION RESISTANCE

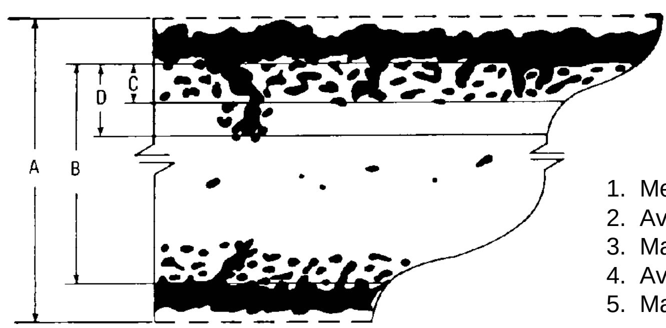
HAYNES® 556™ alloy exhibits good resistance to both air and combustion gas oxidizing environments, and can be used for long-term exposure at temperatures up to 2000°F (1095°C). For exposures of short duration, 556 alloy can be used at higher temperatures.

Comparative Oxidation Resistance in Flowing Air*

	1800°F (980°C) - 1008 Hours				2000°F (1095°C) - 1008 Hours			
	Metal Loss		Average Metal Affected**		Metal Loss		Average Metal Affected	
Material	Mils	µm	Mils	µm	Mils	µm	Mils	µm
X alloy	0.3	8	0.9	25	1.5	40	2.7	70
556™ alloy	0.4	10	1.1	30	1.0	25	2.6	65
alloy 601	0.5	15	1.3	35	1.2	30	2.6	65
alloy 800H	0.9	25	1.8	45	5.4	135	7.4	190
446 SS	1.3	35	2.3	60	13.1	335	14.5	370
316 SS	12.4	315	14.3	365	>69.0	>1750	Consumed	

Samples cycled to room temperature once-a-week
* Flowing air at a velocity of 7.0 feet/minute (212.0 cm/minute) past the samples.
** Metal Loss + Average Internal Penetration

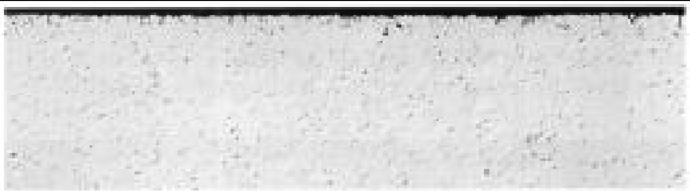
Metallographic Technique used for Evaluating Environmental Tests



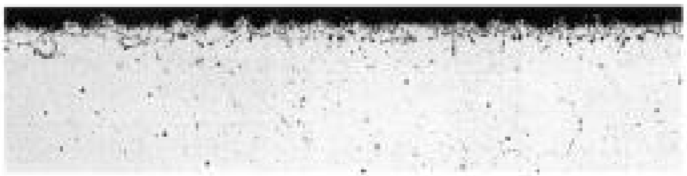
1. Metal Loss = (A - B)/2
2. Average Internal Penetration = C
3. Maximum Internal Penetration = D
4. Average Metal Affected = ((A - B)/2) + C
5. Maximum Metal Affected = ((A - B)/2) + D

Comparative Oxidation in Flowing Air 1800°F (980°C) for 1008 Hours

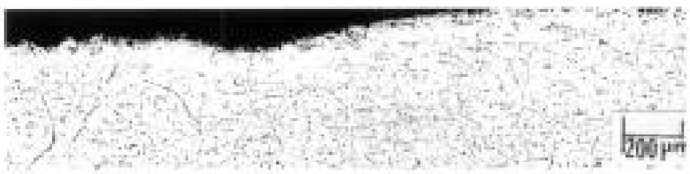
Microstructures shown are for coupons exposed for 1008 hours at 1800°F (980°C) in air flowing 7.0 feet/minute (212.0 cm/minute) past the samples. Samples were descaled by cathodically charging the coupons while they were immersed in a molten salt solution. The black area shown at the top of each picture represents actual metal loss due to oxidation. The data clearly show HAYNES® 556™ alloy to be superior to both RA330® alloy and Type 304 stainless steel as well as the other iron-base alloys shown in the table on the previous page.



HAYNES 556 alloy
Average Metal Affected =
1.1 mils (20 µm)



RA330 alloy
Average Metal Affected =
4.3 mils (110 µm)



Type 304 Stainless Steel
Average Metal Affected =
8.1 mils (205 µm)

Comparative Burner Rig Oxidation Resistance 1000 Hour Exposure at 1800°F (980°C)

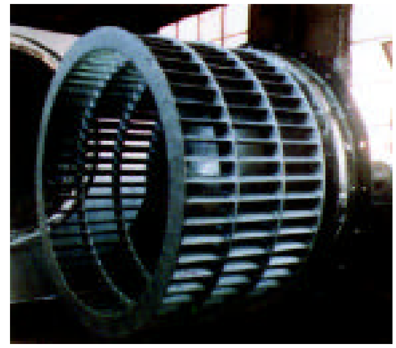
Material	Metal Loss		Average Metal Affected*	
	Mils	µm	Mils	µm
230® alloy	0.8	0.02	3.5	0.09
556 alloy	1.7	0.04	6.2	0.16
RA330 alloy	7.8	0.20	11.8	0.30
MULTIMET® alloy	11.8	0.30	14.8	0.38
alloy 800H	12.3	0.31	15.3	0.39
Type 310 Stainless Steel	13.7	0.35	16.5	0.42
alloy 600	12.3	0.31	17.8**	0.45**
alloy 601	3.0	0.08	20.0	0.51

*Metal Loss + Maximum Internal Penetration **Extrapolated from 917 hours

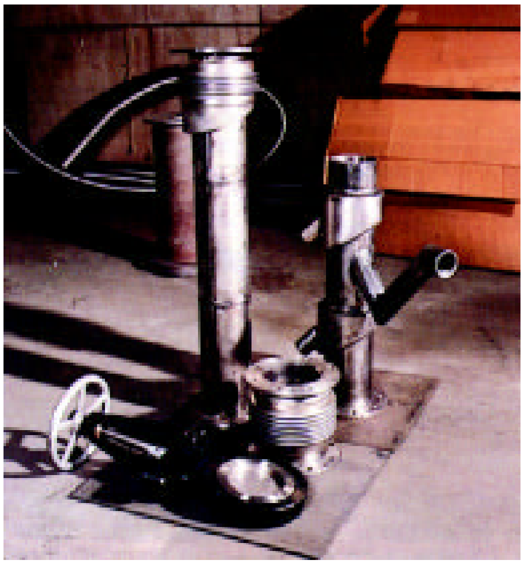
Oxidation Test Parameters

Burner rig oxidation tests were conducted by exposing, in a rotating holder, samples 0.375 inch x 2.5 inches x thickness (9.5mm x 64mm x thickness) to the products of combustion of fuel oil (2 parts No. 1 and 1 part No. 2) burned at a ratio of air to fuel of about 50:1. (Gas velocity was about 0.3 mach). Samples were automatically removed from the gas stream every 30 minutes and fan cooled to less than 500°F (260°C) and then reinserted into the flame tunnel.

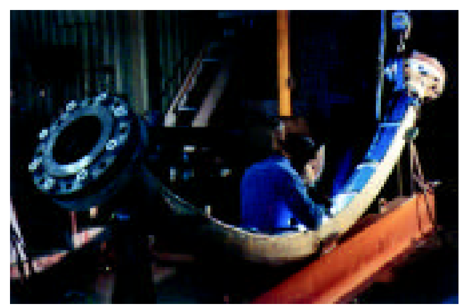
APPLICATIONS



This high-temperature fan for a heat-treat furnace of HAYNES 556 alloy was selected to resist a number of atmospheres at 1700 to 1800°F (925 to 980°C).



HAYNES® 556™ alloy was chosen for components of this waste ash handling system operating at 1650°F (900°C). It has more than doubled the life of previously used stainless steel.

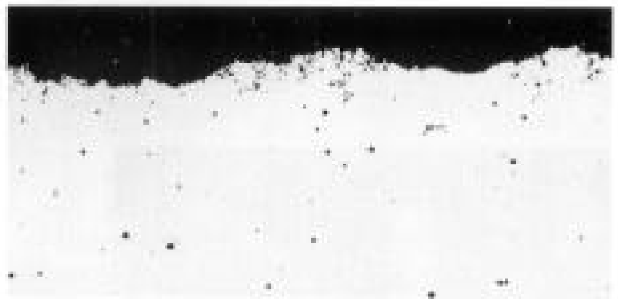


A deposit of HAYNES 556 alloy protects elbows in a piping system at a titanium dioxide plant. The elbows, coated with 556 alloy has lasted over hour times as long as those hardfaced with a cobalt-base alloy. The inside of the elbow is scoured by abrasive TiO_2 and corrosive Cl_2 at temperatures to 1600°F (870°C).

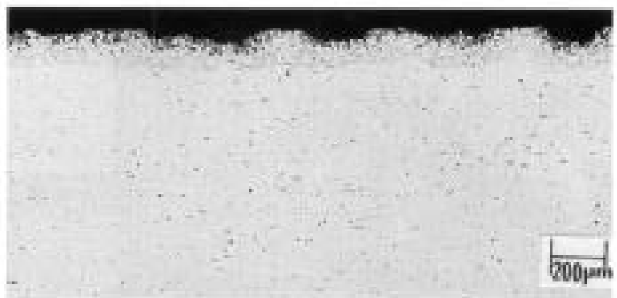
HAYNES 556 refractory anchors have outperformed other alloys in this tailgas burner which removes high-sulfur gases from effluent of refining operations.

RESISTANCE TO CHLORINE-BEARING ENVIRONMENTS

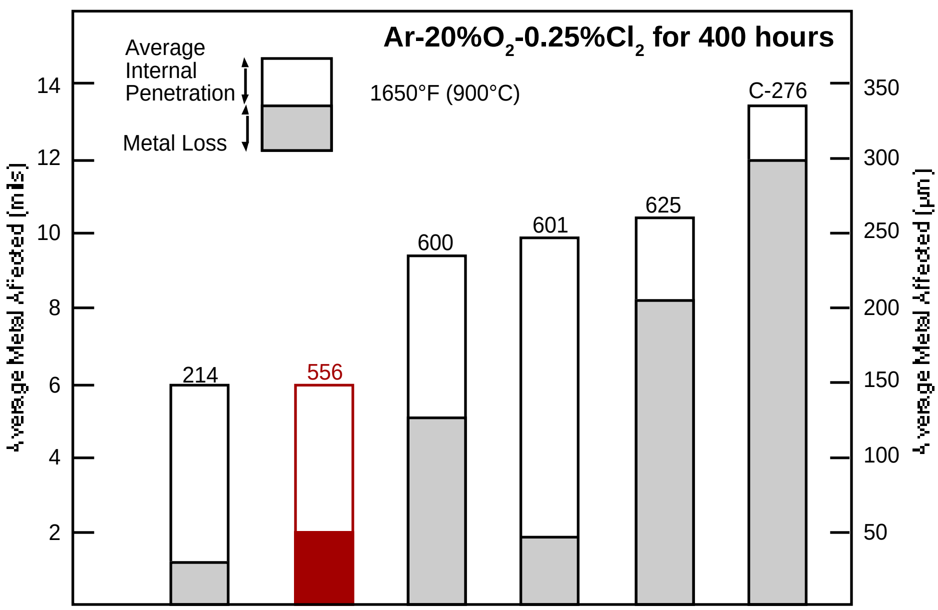
HAYNES® 556™ alloy can be considered resistant to high-temperature oxidizing environments containing chlorine. Although not as resistant as HAYNES 214™ alloy at temperatures above 1650°F (900°C), 556 alloy has resistance comparable to that of 214 alloy at temperatures at or below 1650°F (900°C). This is shown by the test results given for 400 hour exposures at 1650°F (900°C) in a flowing gas mixture of Ar+20%O_2+0.25% Cl_2. Note that 556 alloy shows very low metal loss compared to most of the alloys tested, which included alloys 600, 625, INCONEL alloy 601 and HASTELLOY C-276 alloy.



Alloy 600



HAYNES 556 alloy



OTHER HIGH TEMPERATURE ENVIRONMENTS

Molten Chloride Salts

HAYNES® 556™ alloy exhibits reasonable resistance to neutral NaCl-KCl-$BaCl_2$-type heat-treating salts at temperatures up to 1550°F (845°C) based upon actual field tests in a molten salt pot heat treating facility. Coupons were exposed for 30 days.

Material	Average Metal Affected	
	Mils	mm
HAYNES 188 alloy	28	0.7
HASTELLOY X alloy	38	1.0
HAYNES 556 alloy	42	1.1
Type 304 stainless steel	74	1.9
Type 310 stainless steel	79	2.0
Alloy 600	94	2.4
INCONEL alloy 601	115	2.9

Phosphorus-Bearing Combustion Environment

Based upon field tests performed in the combustion chamber of a fluid bed dryer used to dry sodium tripolyphosphate compounds, HAYNES 556 alloy exhibits very good resistance to corrosion caused by formation of low-melting point eutectics involving phosphorus. Samples were exposed 30 days at a temperature of about 1475°F (800°C).

Material	Maximum Metal Affected	
	Mils	μm
HASTELLOY X alloy	3.0	75
HAYNES 556 alloy	6.0	150
HAYNES 214 alloy	8.0	205
HASTELLOY S alloy	9.0	230
HAYNES 188 alloy	9.0	230
Alloy 800H	11.0	280
Type 304 stainless steel	15.0	380

Molten Zinc

Resistance to molten zinc is an important consideration for structural components in galvanizing operations. Laboratory tests were performed at 850°F (455°C) for 50 hours in molten zinc to determine suitability for such operations. Results are given below:

Material	Metal Loss* mils	(μm)
HAYNES 556 alloy	1.6	41
HAYNES 25 alloy	2.3	58
HAYNES 188 alloy	2.5	64
1010 Carbon Steel	9.2	234
446 Stainless Steel	9.3	236

*no internal attack noted for any of the alloys tested

Material	Metal Loss* mils	(μm)
Alloy 800H	11.0	280
304 Stainless Steel	14.1	358
HAYNES 625 alloy	>24.0**	>610**
HASTELLOY X alloy	>24.0**	>610**

**dissolved

TYPICAL PHYSICAL PROPERTIES

	Temp., °F	British Units	Temp., °C	Metric Units
Density	Room	0.297 lb/in.^{3}	Room	8.23 g/cm.^{3}
Melting Temperature	2425-2580		1330-1415	
Electrical Resistivity	Room	37.5 microhm-in.	Room	95.2 microhm-cm
	200	38.7 microhm-in.	100	98.6 microhm-cm
	400	40.5 microhm-in.	200	102.6 microhm-cm
	600	42.1 microhm-in.	300	106.5 microhm-cm
	800	43.5 microhm-in.	400	109.5 microhm-cm
	1000	44.7 microhm-in.	500	112.5 microhm-cm
	1200	45.7 microhm-in.	600	115.1 microhm-cm
	1400	46.6 microhm-in.	700	117.2 microhm-cm
	1600	47.3 microhm-in.	800	119.0 microhm-cm
	1800	48.0 microhm-in.	900	120.7 microhm-cm
	2000	48.6 microhm-in.	1000	122.3 microhm-cm
			1100	123.7 microhm-cm
Thermal Diffusivity	Room	4.5 x 10^{-3} in.^{2}/sec.	Room	28.7 x 10^{-3} cm^2/sec.
	200	4.8 x 10^{-3} in.^{2}/sec.	100	31.2 x 10^{-3} cm^2/sec.
	400	5.3 x 10^{-3} in.^{2}/sec.	200	34.2 x 10^{-3} cm^2/sec.
	600	5.8 x 10^{-3} in.^{2}/sec.	300	37.0 x 10^{-3} cm^2/sec.
	800	6.3 x 10^{-3} in.^{2}/sec.	400	39.7 x 10^{-3} cm^2/sec.
	1000	6.7 x 10^{-3} in.^{2}/sec.	500	42.3 x 10^{-3} cm^2/sec.
	1200	7.1 x 10^{-3} in.^{2}/sec.	600	44.8 x 10^{-3} cm^2/sec.
	1400	7.5 x 10^{-3} in.^{2}/sec.	700	47.0 x 10^{-3} cm^2/sec.
	1600	7.7 x 10^{-3} in.^{2}/sec.	800	48.8 x 10^{-3} cm^2/sec.
	1800	8.0 x 10^{-3} in.^{2}/sec.	900	50.3 x 10^{-3} cm^2/sec.
	2000	8.2 x 10^{-3} in.^{2}/sec.	1000	51.6 x 10^{-3} cm^2/sec.
			1100	52.8 x 10^{-3} cm^2/sec.
Thermal Conductivity	Room	77 Btu-in./ft.^{2} hr.-°F	Room	11.1 W/m-K
	200	90 Btu-in./ft.^{2} hr.-°F	100	13.1 W/m-K
	400	107 Btu-in./ft.^{2} hr.-°F	200	15.4 W/m-K
	600	122 Btu-in./ft.^{2} hr.-°F	300	17.3 W/m-K
	800	135 Btu-in./ft.^{2} hr.-°F	400	19.0 W/m-K
	1000	148 Btu-in./ft.^{2} hr.-°F	500	20.8 W/m-K
	1200	160 Btu-in./ft.^{2} hr.-°F	600	22.4 W/m-K
	1400	173 Btu-in./ft.^{2} hr.-°F	700	24.0 W/m-K
	1600	185 Btu-in./ft.^{2} hr.-°F	800	25.5 W/m-K
	1800	197 Btu-in./ft.^{2} hr.-°F	900	27.2 W/m-K
	2000	210 Btu-in./ft.^{2} hr.-°F	1000	28.9 W/m-K
			1100	30.4 W/m-K

Typical Physical Properties (continued)

	Temp., °F	British Units	Temp., °C	Metric Units
Specific Heat	Room	0.111 Btu/lb.-°F	Room	464 J/Kg-K
	200	0.113 Btu/lb.-°F	100	475 J/Kg-K
	400	0.118 Btu/lb.-°F	200	493 J/Kg-K
	600	0.122 Btu/lb.-°F	300	508 J/Kg-K
	800	0.126 Btu/lb.-°F	400	523 J/Kg-K
	1000	0.130 Btu/lb.-°F	500	538 J/Kg-K
	1200	0.133 Btu/lb.-°F	600	552 J/Kg-K
	1400	0.135 Btu/lb.-°F	700	561 J/Kg-K
	1600	0.140 Btu/lb.-°F	800	570 J/Kg-K
	1800	0.147 Btu/lb.-°F	900	595 J/Kg-K
	2000	0.152 Btu/lb.-°F	1000	618 J/Kg-K
			1100	638 J/Kg-K
Mean Coefficient of Thermal Expansion	70-200	8.1 microinches/in.-°F	25-100	14.7 10^{-6}m/m-°C
	70-400	8.2 microinches/in.-°F	25-200	14.9 10^{-6}m/m-°C
	70-600	8.4 microinches/in.-°F	25-300	15.1 10^{-6}m/m-°C
	70-800	8.6 microinches/in.-°F	25-400	15.4 10^{-6}m/m-°C
	70-1000	8.8 microinches/in.-°F	25-500	15.7 10^{-6}m/m-°C
	70-1200	9.0 microinches/in.-°F	25-600	16.1 10^{-6}m/m-°C
	70-1400	9.2 microinches/in.-°F	25-700	16.4 10^{-6}m/m-°C
	70-1600	9.4 microinches/in.-°F	25-800	16.7 10^{-6}m/m-°C
	70-1800	9.5 microinches/in.-°F	25-900	17.0 10^{-6}m/m-°C
	70-2000	9.6 microinches/in.-°F	25-1000	17.1 10^{-6}m/m-°C
			25-1100	17.1 10^{-6}m/m-°C

DYNAMIC MODULUS OF ELASTICITY

Temp., °F	Dynamic Modulus of Elasticity, 10^6 psi	Temp., °C	Dynamic Modulus of Elasticity, GPa
Room	29.7 x 10^6 psi	Room	205 GPa
200	29.1 x 10^6 psi	100	200 GPa
400	28.2 x 10^6 psi	200	195 GPa
600	26.9 x 10^6 psi	300	187 GPa
800	25.6 x 10^6 psi	400	179 GPa
1000	24.4 x 10^6 psi	500	172 GPa
1200	23.1 x 10^6 psi	600	164 GPa
1400	21.8 x 10^6 psi	700	155 GPa
1600	20.9 x 10^6 psi	800	148 GPa
1800	20.1 x 10^6 psi	900	143 GPa
		1000	138 GPa

APPLICATIONS

HAYNES® 556™ spinner baskets are continually cycled through molten zinc at 850°F (455°C) for hot dip galvanizing. After 16 months of operation the 556 baskets showed no measureable metal loss from the molten zinc exposure.

This salt pot heat-treat basket of HAYNES 556 alloy for heat treating aircraft components at 1600°F to 600°F (870°C to 315°C) in molten salt has outperformed stainless steels 3 times because of 556 alloys excellent ductility, thermal fatigue resistance and improved strength levels at 1600°F (870°C).

556 alloy vacuum carburizing furnace retort.

556 alloy upgrades MULTIMET® alloy stator vanes in industrial turbines.

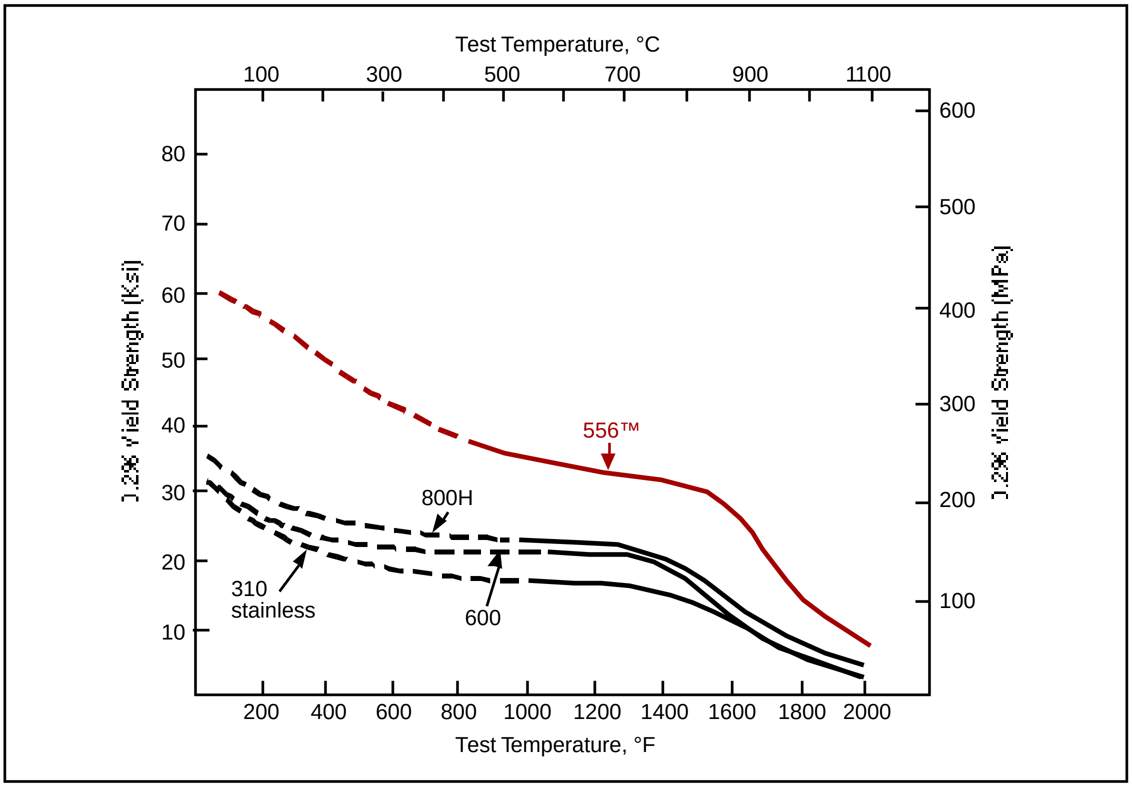
TYPICAL TENSILE PROPERTIES

Cold-Rolled and Solution Annealed Sheet, 0.033 to 0.109 Inches (0.8 to 2.8 mm) Thick*

Test Temperature		Ultimate Tensile Strength		Yield Strength at 0.2% Offset		Elongation in 2 in. (50.8 mm)
°F	°C	Ksi	MPa	Ksi	MPa	%
Room	Room	118.1	815	59.5	410	47.7
1000	540	93.4	645	34.9	240	54.4
1200	650	85.4	590	32.8	225	52.4
1400	760	68.5	470	32.0	220	49.1
1600	870	47.6	330	28.6	195	52.6
1800	980	28.0	195	15.5	105	63.3
2000	1095	14.8	100	8.0	55	55.4

* Based upon 10 or more Tests per condition

Comparative Yield Strengths (Sheet)



Typical Tensile Properties (continued)

Hot-Rolled and Solution Annealed Plate, 0.250 to 0.500 Inches (6.4 to 12.7 mm) Thick*

Test Temperature		Ultimate Tensile Strength		Yield Strength at 0.2% Offset		Elongation in 2 in. (50.8 mm)
°F	°C	Ksi	MPa	Ksi	MPa	%
Room	Room	116.4	805	54.6	375	51.4
1000	540	90.3	625	30.6	210	60.3
1200	650	83.1	575	30.6	210	57.4
1400	760	68.5	470	29.3	200	52.6
1600	870	49.3	340	27.9	190	69.1
1800	980	30.7	210	18.5	130	83.9
2000	1095	16.1	110	8.7	60	95.2

* Based upon 56 Tests

ASME VESSEL CODE ALLOWABLE STRESSES

HAYNES® 556™ alloy is approved for ASME Vessel Code Section I construction to 1200°F (650°C) under Code Case No. 2010 and Section VIII Division 1 construction to 1650°F (900°C). Allowable stresses are reprinted here by permission of the ASME.

ASME Vessel Code Allowable Stresses

Metal Temperatures Not Exceeding		Maximum Allowable Stress Values			
		Standard		Note [1]	
°F	°C	Ksi	(MPa)	Ksi	(MPa)
100	37	25.0	(172)	25.0	(172)
200	93	25.0	(172)	25.0	(172)
300	149	23.1	(159)	24.5	(168)
400	204	21.3	(146)	23.7	(163)
500	260	20.1	(138)	23.1	(159)
600	315	19.3	(133)	22.8	(157)
650	343	19.0	(131)	22.7	(156)
700	371	18.7	(129)	22.5	(155)
750	398	18.5	(127)	22.4	(154)
800	426	18.2	(125)	22.3	(153)
850	454	18.0	(124)	22.2	(153)
900	482	17.8	(122)	22.1	(152)
950	510	17.6	(121)	21.8	(150)
1000	537	17.4	(120)	21.6	(148)
1050	565	17.2	(118)	21.4	(147)
1100	593	17.1	(118)	20.8	(143)
1150	621	16.9	(116)	16.9	(116)
1200	648	13.6	(93)	13.6	(93)
1250	676	10.9	(75)	10.9	(75)
1300	704	8.8	(60)	8.8	(60)
1350	732	7.0	(48)	7.0	(48)
1400	760	5.6	(38)	5.6	(38)
1450	787	4.5	(31)	4.5	(31)
1500	815	3.6	(25)	3.6	(25)
1550	843	2.8	(19)	2.8	(19)
1600	871	2.2	(15)	2.2	(15)
1650	898	1.8	(12)	1.8	(12)

NOTE (1)
Due to the relatively low yield strength of this material, these higher stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 67%, but do not exceed 90% of the yield strength at temperature. Use of these stress may result in dimensional changes due to permanent strain. These stress values are not recommended for flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

TYPICAL CREEP AND STRESS-RUPTURE PROPERTIES

Solution Annealed Sheet, Plate and Bar

Temperature °F	Temperature °C	Creep, Percent	Average Initial Stress, Ksi (MPa)* to Produce Specified Creep and Rupture: 10 Hours		100 Hours		1,000 Hours		10,000 Hours	
1200	650	0.5	44.0	(305)	32.0	(220)	24.0	(165)	-	-
		1.0	49.0	(340)	35.0	(240)	25.5	(175)	18.5	(130)
		Rupture	-	-	53.0	(365)	38.0	(260)	27.5	(190)
1300	705	0.5	29.0	(200)	21.0	(145)	15.0	(105)	-	-
		1.0	33.0	(230)	24.0	(165)	17.5	(120)	12.5	(86)
		Rupture	52.0	(360)	37.0	(255)	26.0	(180)	17.0	(115)
1400	760	0.5	19.0	(130)	13.5	(93)	9.4	(65)	-	-
		1.0	22.0	(150)	16.0	(110)	11.5	(79)	8.5	(59)
		Rupture	35.0	(240)	25.0	(170)	17.5	(120)	11.9	(82)
1500	815	0.5	13.0	(90)	9.0	(62)	6.5	(45)	-	-
		1.0	15.0	(105)	11.0	(76)	8.2	(57)	6.0	(41)
		Rupture	25.0	(170)	17.0	(115)	11.8	(81)	7.6	(52)
1600	870	0.5	8.9	(61)	6.4	(44)	4.6	(32)	-	-
		1.0	10.0	(69)	7.5	(52)	5.5	(38)	4.1	(28)
		Rupture	17.0	(115)	11.5	(79)	7.5	(52)	4.9	(34)
1700	925	0.5	6.2	(43)	4.5	(31)	3.2	(22)	-	-
		1.0	7.2	(50)	5.0	(34)	3.5	(24)	2.5	(17)
		Rupture	12.0	(83)	7.6	(52)	4.8	(33)	3.0	(21)
1800	980	0.5	4.4	(30)	3.0	(21)	2.0	(14)	-	-
		1.0	5.0	(34)	3.4	(23)	2.3	(16)	1.6	(11)
		Rupture	7.5	(52)	4.8	(33)	3.0	(21)	1.9	(13)

TYPICAL IMPACT PROPERTIES

Material	V-Notch Impact Strength[1] Room Temperature: ft.-lb.	Joules
alloy 800H	239[2]	324[2]
alloy 600	180	244
556™ alloy	177[2]	240[2]
188 alloy	143	194
S alloy	140	190
alloy 625	81	110
X alloy	54	73

[1] Average of 4 or more tests
[2] Samples did not break

THERMAL STABILITY

HAYNES® 556™ exhibits reasonable retained ductility after long term thermal exposure at intermediate temperatures. It does not exhibit significant sigma phase formation even after 16,000 hours exposure at 1000 to 1600°F (540 to 870°C). Principal phases precipitated from solid solution are carbides and carbonitrides.

Room-Temperature Tensile Properties of Bar Following Thermal Exposure*

Exposure Temperature °F	Exposure Temperature °C	Hours	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength MPa	Yield Strength at 0.2% Offset Ksi	Yield Strength at 0.2% Offset MPa	Elongation in 2 in. (50.8 mm) %
1200	650	0	113.4	780	62.5	430	46.5
		1000	120.5	830	59.7	410	36.0
		4000	121.2	835	57.4	395	33.0
		8000	127.3	880	59.8	410	29.4
1400	760	0	113.4	780	62.5	430	46.5
		1000	128.7	885	60.8	420	24.8
		4000	127.1	875	57.4	395	25.8
		8000	125.1	865	54.6	375	24.7
1600	870	0	113.4	780	62.5	430	46.5
		1000	112.9	780	52.3	360	32.8
		4000	111.5	770	42.8	295	29.0
		8000	108.1	745	43.9	305	29.5

* Average of three tests for each condition

Elevated-Temperature Tensile Properties of Bar Following 16,000-Hour Thermal Eexposures*

Test Temperature °F	Test Temperature °C	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength MPa	Yield Strength at 0.2% Offset Ksi	Yield Strength at 0.2% Offset MPa	Elongation in 2 in. (50.8 mm) %
1000	537	95.7	660	37.4	260	48.0
1200	648	88.8	610	37.8	260	23.4
1400	760	72.3	500	35.1	240	25.3
1600	871	42.1	290	21.9	150	29.5

Thermal Stability (continued)

Room-Temperature Tensile Properties of Sheet Following1000-Hour Thermal Exposures*

Test Temperature °F	Test Temperature °C	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength MPa	Yield Strength at 0.2% Offset Ksi	Yield Strength at 0.2% Offset MPa	Elongation in 2 in. (50.8 mm) %
Room	Room	118.1	815	59.5	410	47.7
1200	648	118.4	815	53.4	370	37.9
1400	760	118.8	820	53.8	370	17.0
1600	871	111.0	765	46.6	320	20.4

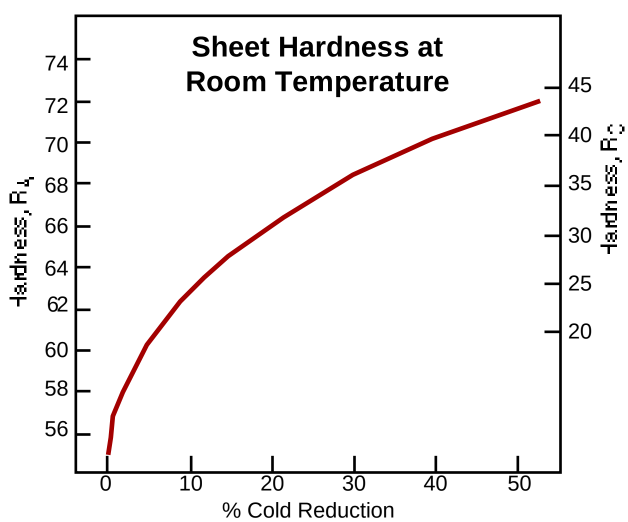
* Average of two or more tests

FABRICATION CHARACTERISTICS

Heat Treatment

HAYNES® 556™ alloy is normally final solution heat-treated at 2150°F (1175°C) for a time commensurate with section thickness. Solution heat-treating can be performed at temperatures as low as about 2125°F (1165°C), but resulting material properties will be altered accordingly. Annealing during fabrication can be performed at even lower temperatures, but a final, subsequent solution heat treatment is needed to produce optimum properties and structure. Please refer to following sections and publication H-3159 for additional information.

Typical Hardness Properties



Solution Annealed Room Temperature Hardness

Form	R_B
Sheet	91.0
Plate	96.5

Fabrication Characteristics (continued)

Effect of Cold Reduction upon Room-Temperature Tensile Properties*

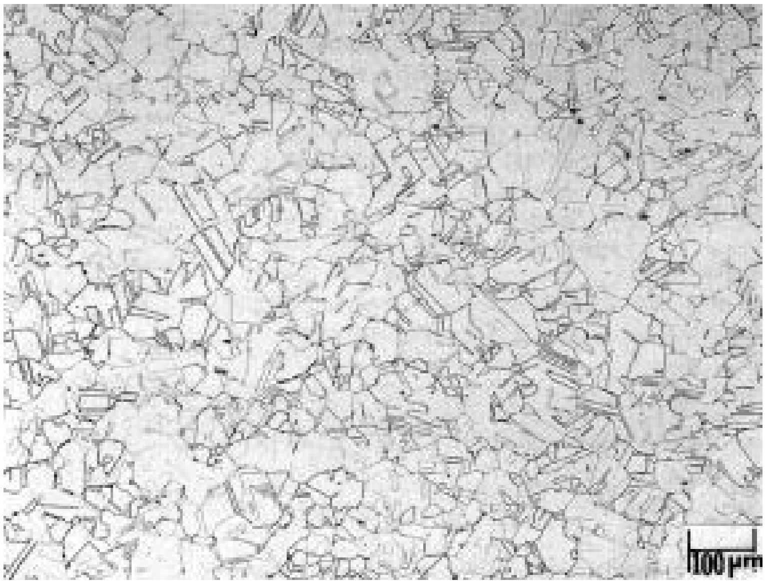
Percent Cold Reduction	Subsequent Anneal Temperature	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength MPa	Yield Strength at 0.2% Offset Ksi	Yield Strength at 0.2% Offset MPa	Elongation in 2 in. (50.8 mm) %
0	None	115.0	795	52.9	365	50.7
10		127.8	880	93.3	645	34.8
20		142.1	980	113.3	780	23.5
30		172.6	1190	144.1	995	12.0
40		189.3	1305	155.8	1075	10.1
50		204.2	1410	169.7	1170	8.0
0	1850°F (1010°C) for 5 min.	114.7	790	52.6	365	44.8
10		121.6	840	76.9	530	34.3
20		127.0	875	88.8	610	30.3
30		135.2	930	92.7	640	26.6
40		133.3	920	80.0	550	30.6
50		135.0	930	83.0	570	31.7
0	1950°F (1065°C) for 5 min.	115.8	800	52.9	365	45.2
10		122.2	845	76.8	530	36.9
20		124.7	860	76.8	530	34.8
30		125.1	865	66.0	455	38.3
40		128.1	885	71.4	490	36.7
50		131.0	905	77.9	535	33.4
0	2050°F (1121°C) for 5 min.	117.0	805	54.3	375	47.0
10		117.4	810	55.3	380	48.0
20		120.1	830	58.4	405	45.4
30		123.6	850	63.5	440	43.0
40		124.7	860	66.9	460	42.4
50		126.6	875	70.8	485	35.0

* Based upon rolling reductions taken upon 0.120-inch (3.0mm) thick sheet.
Duplicate tests

Fabrication Characteristics (continued)

Typical Microstructure

(ASTM 5 grain size) Annealed at 2150°F (1175°C)



Etchant: 95ml HCl plus 5gm oxalic acid, 4 volts

WELDING

HAYNES® 556™ alloy is readily welded by gas tungsten arc (GTAW), gas metal arc (GMAW), shielded metal arc (coated electrode), and resistance welding techniques. Submerged arc welding is not recommended as this process is characterized by high heat input to the base metal and slow cooling of the weld. These factors can increase weld restraint and promote cracking.

Base Metal Preparation

The joint surface and adjacent area should be thoroughly cleaned before welding. All grease, oil, crayon marks, sulfur compounds and other foreign matter should be removed. It is preferable, but not necessary, that the alloy be in the solution-annealed condition when welded.

Filler Metal Selection

Matching composition filler metal is recommended for joining 556 alloy. For shielded metal-arc welding, MULTIMET electrodes (AMS 5795) are suggested. For dissimilar metal joining of 556 alloy to nickel- or cobalt-base materials, 556 filler metal will generally be a good selection, but HASTELLOY S alloy (AMS 5838A) or HASTELLOY W alloy (AMS 5786B, 5787A) welding products may be used. For dissimilar welding to iron-base materials, 556 filler metal is recommended. Please see publication H-3159.

Preheating, Interpass Temperatures and Post-Weld Heat Treatment

Preheat is not usually required so long as base metal to be welded is above 32°F (0°C). Interpass temperatures generally should be low. Auxiliary cooling methods may be used between weld passes, as needed, providing that such methods do not introduce contaminants. Post-weld heat treatment is not normally required for 556 alloys.

Nominal Welding Parameters

Nominal welding parameters are provided as a guide for performing typical operations. These are based upon welding conditions used in Haynes International, Inc. laboratories. For further information, please consult Haynes publication H-3159.

Automatic Gas Tungsten Arc Welding

Square Butt Joint - No Filler Metal Added

	Material Thickness		
	0.040" (1.0mm)	0.062" (1.6mm)	0.125" (3.2mm)
Current (DCEN), amperes	45	75	110
Voltage	8	8.5	9.5
Travel Speed, in/min. (mm/min)	10 (254)	12 (305)	12 (305)
Electrode Size-EWTH-2, in (mm)	1/16 (1.6)	3/32 (2.4)	1/8 (3.2)
Electrode Shape	45° inc	45° inc	45° inc
Cup Size	#8	#8	#8
Shielding Gas Flow, CFH (l/min.)	30 (14.2)	30 (14.2)	30 (14.2)
Gas Type	Argon	Argon	Argon
Backing Gas, CFH (l/min.)	10 (4.7)	10 (4.7)	10 (4.7)
Gas Type	Argon	Argon	Argon

Manual Gas Tungsten Arc Welding

V-or U-Groove - All Thicknesses 1/8" (3.2 mm) or greater

Technique	-	Stringer Bead
Current (DCEN), amperes	-	120 root, 140-150 Fill
Voltage	-	11 to 14
Filler Metal	-	1/8" diameter (3.2 mm) 556™ alloy
Travel Speed, ipm (mm/min)	-	4 to 6 (102-152)
Electrode Size-EWTH-2, in (mm)	-	1/8" diameter (3.2 mm)
Electrode Shape	-	30° included
Cup Size	-	#6 or larger
Gas Type	-	Argon
Shielding Gas Flow, CFH (l/min.)	-	30 to 35 (14.2 to 16.5)
Backing Gas Flow, CFH (l/min.)	-	10 (4.7) or back-gouge to sound metal and fill from root side
Preheat	-	Ambient
Interpass Temperature Maximum	-	200°F (93°C)

Gas Metal Arc Welding

	Short Circuiting Transfer Mode All Thicknesses 0.090" and greater (2.3mm)	**Spray Transfer Mode All Thicknesses 0.156" and greater (4.0mm)**
Wire Type	556 alloy	556 alloy
Wire Diameter, in (mm)	0.045 (1.1)	0.062 (1.6)
Feed Speed, ipm (m/min)	170 to 190 (4.3 to 4.8)	160 to 170 (4.0 to 4.3)
Current (DCEP), amperes	100 to 110	210 to 230
Voltage	20 to 22	28 to 30
Stickout, in (mm)	1/2-3/4 (12.7 to 19.1)	3/4 (19.1)
Travel Speed, ipm (mm/min)	8 to 10 (203 to 254)	9 to 12 (229 to 305)
Torch Gas Flow, CFH (l.min.)	40 (18.9)	40 (18.9)
Gas Type	A1025 (90% He, 7.5% Ar, 2.5% CO_2) or 75% Ar + 25% He)	Argon

Shielded Metal Arc Welding

No matching chemistry SMAW electrodes are currently available for 556™ alloy. MULTIMET electrodes (AMS 5795) have been successfully used to join 556 alloy. Typical parameters for MULTIMET electrodes (flat position) are given below.

Electrode Diameter		**Voltage**	**Current (DCEP)**	**Travel Speed**	
in	**(mm)**		**amperes**	**ipm**	**(mm/min)**
3/32	(2.4)	22 - 24	45 - 75	3 - 5	(76 - 127)
1/8	(3.2)	22 - 24	70 - 110	4 - 6	(102 - 152)
5/32	(4.0)	23 - 25	110 - 140	4 - 6	(102 - 152)

Typical Tensile Properties, All-Weld Metal (GTAW)

Test Temperature		Ultimate Tensile Strength		Yield Strength at 0.2% Offset		Elongation in 2 in. (50.8 mm)
°F	°C	Ksi	MPa	Ksi	MPa	%
Room	Room	107.3	740	67.3	465	43.1
1200	648	71.4	490	44.6	310	39.4
1400	760	55.2	380	42.4	290	38.9
1600	871	32.8	225	29.0	200	51.9
1800	982	29.2	200	20.7	145	125.7

Typical crack-free face and root bends for welded 556™ alloy 0.5 inch (13 mm) plate and matching filler metal. Bend radius was 0.75 inch (19 mm).

HEALTH AND SAFETY

Welding can be a safe occupation. Those in the welding industry, however, should be aware of the potential hazards associated with welding fumes, gases, radiation, electric shock, heat, eye injuries, burns, etc. Also, local, municipal, state, and federal regulations (such as those issued by OSHA) relative to welding and cutting processes should be considered.

Nickel-, cobalt-, and iron-base alloy products may contain, in varying concentration, the following elemental constituents: aluminum, cobalt, chromium, copper, iron, manganese, molybdenum, nickel and tungsten. For specific concentrations of these and other elements present, refer to the Material Safety Data Sheets (MSDS) available from Haynes International, Inc.

Inhalation of metal dust or fumes generated from welding, cutting, grinding, melting, or dross handling of these alloys may cause adverse health effects such as reduced lung function, nasal and mucous membrane irritation. Exposure to dust or fumes which may be generated in working with these alloys may also cause eye irritation, skin rash and effects on other organ systems.

The operation and maintenance of welding and cutting equipment should conform to the provision of American National Standard ANSI/AWS Z49.1, "Safety in Welding and Cutting". Attention is especially called to Section 4 (Protection of Personnel) and 5 (Health Protection and Ventilation) of ANSI/AWS Z49.1. Mechanical ventilation is advisable and, under certain conditions such as a very confined space, is necessary during welding or cutting operations, or both, to prevent possible exposure to hazardous fumes, gases, or dust that may occur.

Acknowledgements:

INCONEL is a registered trademark of Inco Family of Companies.
RA330 is a registered trademarks of Rolled Alloys, Inc.
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MACHINING

HAYNES® 556™ alloy is similar in machining characteristics to other solid-solution-strengthened nickel-base alloys. These alloys as a group are classified as moderate to difficult to machine; however, it should be emphasized that they can be machined using conventional methods at satisfactory rates. As these alloys will work-harden rapidly, the keys to successful machining are to use lower speeds and feeds, and to take heavier cuts than would be used for machining stainless steels. See Haynes International publication H-3159 for more detailed information.

Normal Roughing (Turning / Facing)

Use carbide C-2 / C-3 grade tool

Speed: 90 surface feet / minute
Feed: 0.010 in. / revolution
Depth of cut: 0.150 in.

Negative rake square insert, 45° SCEA' 1/32 in. nose radius. Tool holder: 5° negative back and side rakes.

Lubricant: Dry[2], oil[3] or water-base[4,5].

Finishing (Turning / Facing)

Use carbide C-2 / C-3 grade tool

Speed: 95-110 surface feet / minute
Feed: 0.005-0.007 in. / revolution
Depth of cut: 0.040 in.

Positive rake square insert, if possible, 45° SCEA' 1/32 in. nose radius. Tool holder: 5° positive back and side rakes.

Lubricant: Dry or water-base.

Drilling

Use high speed steel M-33 / M-40 series[6]/ or T-15 grades*

Speed: 10-15 surface feet / minute (200 RPM maximum for 1/4 in. diameter or smaller)

Lubricant: oil or water-base. Use coolant feed drills if possible.

Short, heavy-web drills with 135° crank shaft point. Thinning of web at point may reduce thrust.

Feed:
0.001 in. rev. 1/8 in. dia.
0.002 in. rev. 1/4 in. dia.
0.003 in. rev. 1/2 in. dia.
0.005 in. rev. 3/4 in. dia.
0.007 in. rev. 1 in. dia.

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*Carbide drills not recommended, but may be used in some set-ups. See Haynes International publication H-3159 for details.

Notes:
1 SCEA - Side cutting edge angle, or lead angle of the tool.

2 At any point where dry cutting is recommended, an air jet directed on the tool may provide substantial tool life increases. A water-base coolant mist may also be effective.

3 Oil coolant should be a premium quality, sulfochlorinated oil with extreme pressure additives. A viscosity at 100°F of from 50 to 125 SSU is standard.

4 Water-base coolant should be a 15:1 mix of water with either a premium quality, sulfochlorinated water soluble oil or a chemical emulsion with extreme pressure additives.

5 Water-base coolants may cause chipping or rapid failure of carbide tools in interrupted cuts.

6 M-40 series High Speed Steels include M-41 through M-46 at time of writing, others may be added, and should be equally suitable.

STANDARD PRODUCTS

By Brand or Alloy Designation:

HAYNES International

HASTELLOY® Family of Corrosion-Resistant Alloys

B-2, B-3®, C-4, C-22®, C-276, C-2000®, D-205™, G-3, G-30®, G-50® and N

HASTELLOY Family of Heat-Resistant Alloys

S, W, and X

HAYNES® Family of Heat-Resistant Alloys

25, R-41, 75, HR-120®, 150, HR-160®, 188, 214™, 230®, 230-W™, 242™, 263, 556™, 625, 718, X-750, MULTIMET® and WASPALOY

Corrosion-Wear Resistant Alloy

ULTIMET®

Wear-Resistant Alloy

6B

HAYNES Titanium Alloy Tubular

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Standard Forms:

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Properties Data:

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