HAYNES International

HIGH-TEMPERATURE ALLOYS

HAYNES® 25 alloy

A Co-Ni-Cr-W alloy that combines excellent high-temperature strength with good oxidation resistance.

Contents

H-3057D

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PRINCIPAL FEATURES

Excellent High-Temperature Strength and Good Oxidation Resistance

HAYNES® 25 alloy is a cobalt-nickel-chromium-tungsten alloy that combines excellent high-temperature strength with good resistance to oxidizing environments up to 1800°F (980°C) for prolonged exposures, and excellent resistance to sulfidation. It can be fabricated and formed by conventional techniques, and has been used for cast components. Other attractive features include excellent resistance to metal galling.

Fabrication

HAYNES 25 alloy has good forming and welding characteristics. It may be forged or otherwise hot-worked, providing that it is held at 2200°F (1205°C) for a time sufficient to bring the entire piece to temperature. The alloy has good ductility, and thus also may be formed by cold working. The alloy does work-harden very rapidly, however, so frequent intermediate annealing treatments will be needed for complex component forming operations. 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 both manual and automatic welding methods, including gas tungsten arc (GTAW), gas metal arc (GMAW), shielded metal arc, electron beam and resistance welding. It exhibits good restraint welding characteristics.

Heat Treatment

Wrought HAYNES 25 alloy is furnished in the solution heat-treated condition, unless otherwise specified. The alloy is normally solution heat-treated at 2150 to 2250°F (1175 to 1230°C) and rapidly cooled or water-quenched for optimal properties. Annealing at temperatures less than the solution heat-treating temperature will produce some carbide precipitation in 25 alloy, which may affect the alloy's properties.

Available in Convenient Forms

HAYNES 25 alloy is produced in the form of plate, sheet, strip, billet, bar, wire, coated electrodes, pipe and tubing.

Applications

HAYNES 25 alloy combines properties which make it suitable for a number of component applications in the aerospace industry, including parts in established military and commercial gas turbine engines. In modern engines, it has largely been replaced by newer materials such as HAYNES 188 alloy, and, most recently, 230® alloy, which possess improved properties. Another area of significant usage for 25 alloy is as a bearing material, for both balls and races.

Applicable Specifications

HAYNES 25 alloy is covered by the following specifications: AMS 5537 (sheet, strip and plate), AMS 5759 (bar, rings and forgings), AMS 5796 (welding wire), and AMS 5797 (coated welding electrodes). The UNS number for this material is R30605.

Nominal Chemical Composition, Weight Percent

Co[a]	Ni	Cr	W	Fe	Mn	Si	C
51	10	20	15	3*	1.5	0.4*	0.10

*Maximum [a] As balance

CREEP AND STRESS-RUPTURE STRENGTH

HAYNES 25 alloy is a solid-solution-strengthened material which possesses excellent high-temperature strength. It is particularly effective for very long-term applications at temperatures of 1200 to 1800°F (650 to 980°C). It is stronger than nickel-base solid-solution-strengthened alloys, and is the strongest of the cobalt-base materials which still have good fabrication characteristics.

Cold-Rolled and 2200°F (1205°C) Solution-Annealed Sheet*

Test Temperature °F (°C)	Creep %	Approximate Initial Stress, Ksi (MPa) to Produce Specified Creep in: 10 Hrs.	100 Hrs.	1,000 Hrs.
1200 (650)	0.5	62.0 (425)	47.5 (330)	33.5 (230)
	1.0	71.0 (490)	54.0 (370)	39.0 (270)
	Rupture	82.0 (565)	69.0 (475)	57.0 (395)
1300 (705)	0.5	43.0 (295)	30.0 (205)	21.0 (145)
	1.0	49.5 (340)	35.0 (210)	23.2 (160)
	Rupture	64.0 (440)	50.0 (345)	38.0 (260)
1400 (760)	0.5	28.0 (195)	19.5 (135)	14.8 (100)
	1.0	32.0 (220)	21.5 (150)	16.2 (110)
	Rupture	47.0 (325)	36.0 (250)	26.0 (180)
1500 (815)	0.5	18.5 (130)	14.0 (97)	10.2 (70)
	1.0	20.2 (140)	15.5 (105)	12.3 (85)
	Rupture	34.0 (235)	24.7 (170)	18.1 (125)
1600 (870)	0.5	13.7 (94)	9.9 (68)	6.9 (48)
	1.0	15.2 (105)	12.0 (83)	8.9 (61)
	Rupture	24.0 (165)	17.5 (120)	12.0 (83)
1700 (925)	0.5	9.7 (67)	6.8 (47)	4.5 (31)
	1.0	12.0 (83)	8.8 (61)	5.6 (39)
	Rupture	17.3 (120)	11.8 (81)	7.2 (50)
1800 (980)	0.5	6.8 (47)	4.5 (31)	2.6 (18)
	1.0	8.8 (61)	5.6 (39)	3.0 (21)
	Rupture	11.8 (81)	7.2 (50)	4.0 (28)

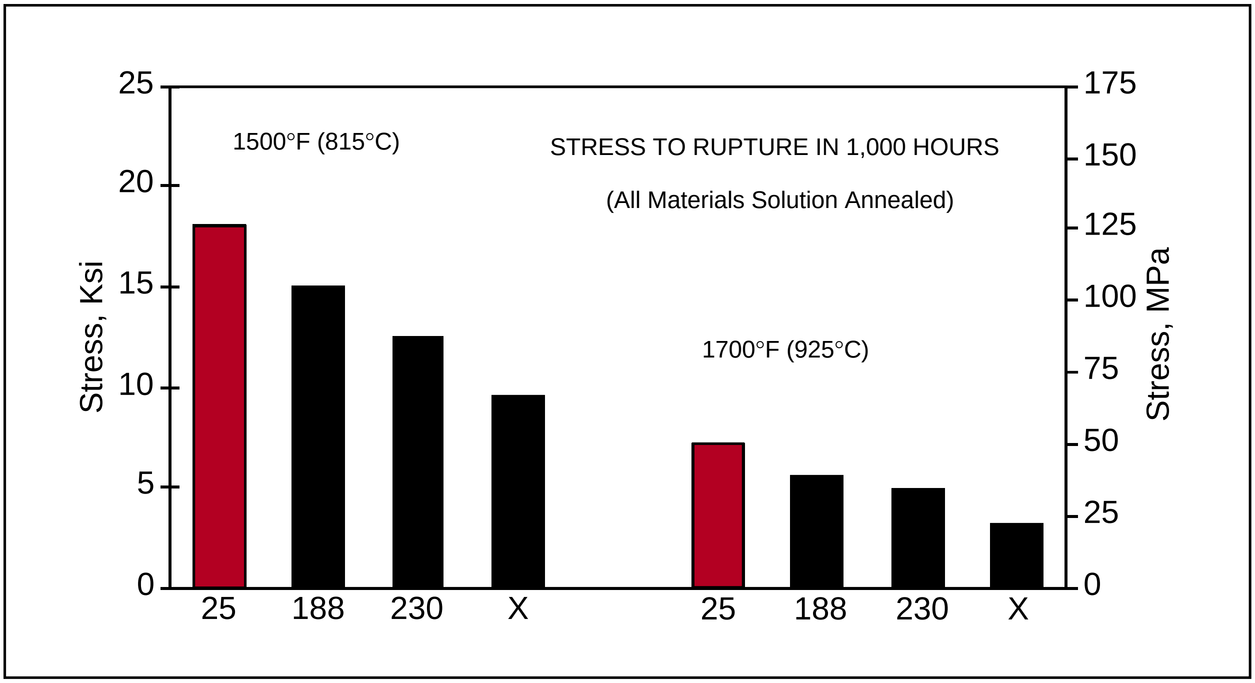
*Based upon limited data.

CREEP AND STRESS-RUPTURE STRENGTH

Hot-Rolled and 2250°F (1230°C) Solution-Annealed Bar

Test Temperature °F (°C)	Creep %	Approximate Initial Stress, Ksi (MPa) to Produce Specified Creep in: 10 Hrs.	100 Hrs.	1,000 Hrs.
1350 (730)	0.5			
	1.0			
	Rupture	42.5 (295)	36.5 (250)	30.3 (210)
1500 (815)	0.5			
	1.0			
	Rupture	30.0 (205)	22.0 (150)	17.0 (115)
1600 (870)	0.5			
	1.0			
	Rupture	23.0 (160)	16.5 (115)	12.0 (83)
1700 (925)	0.5			
	1.0			
	Rupture	17.0 (115)	12.0 (83)	8.4 (58)
1800 (980)	0.5			
	1.0			
	Rupture	11.5 (79)	7.5 (52)	5.0 (34)

Comparative Rupture Strength, Sheet



TYPICAL TENSILE PROPERTIES

Cold-Rolled and 2200°F (1205°C) Solution-Annealed Sheet*

Test Temperature		Ultimate Tensile Strength		0.2% Yield Strength		Elongation in 2 in. (51 mm)
°F	°C	Ksi	MPa	Ksi	MPa	%
Room	Room	146	1005	69	475	51
1000	540	112	770	48	330	60
1200	650	108	745	48	330	60
1400	760	93	640	41	285	42
1600	870	60	415	36	250	45
1800	980	34	235	18	125	36
2000	1095	23	160	11	76	48

*Limited data

Hot-Rolled and 2250°F (1230°C) Solution-Annealed Bar*

Test Temperature		Ultimate Tensile Strength		0.2% Yield Strength		Elongation in 2 in. (51 mm)
°F	°C	Ksi	MPa	Ksi	MPa	%
Room	Room	147	1015	73	505	60
1000	540	113	780	43	295	63
1200	650	105	725	43	295	49
1400	760	90	620	41	285	29
1600	870	54	370	34	235	29
1800	980	28	195	19	130	41

*Limited data

Vacuum Investment Castings — Solution Treated*

Test Temperature		Ultimate Tensile Strength		0.2% Yield Strength		Elongation in 5D	Reduction in Area
°F	°C	Ksi	MPa	Ksi	MPa	%	%
Room	Room	98	675	60	415	25	33
800	425	81	560	30	205	42	35
1200	650	74	510	27	185	30	34
1400	760	46	315	25	170	24	29
1600	870	43	295	24	165	25	31
1800	980	28	195	23	160	24	34

*Limited data

COLD-WORKED PROPERTIES

HAYNES 25 alloy has excellent strength and hardness characteristics in the cold-worked condition. These high property levels are also evident at elevated temperature, making 25 alloy quite suitable for applications such as ball bearings and bearing races. A modest additional increase in hardness and strength can be achieved through aging of the cold-worked material.

Typical Tensile Properties, Cold-Worked Sheet*

Cold Reduction	Test Temperature		Ultimate Tensile Strength		0.2% Yield Strength		Elongation in 2 in. (51 mm)
	°F	°C	Ksi	MPa	Ksi	MPa	%
10	70	20	155	1070	105	725	41
	1000	540	114	785	78	540	48
	1200	650	115	795	80	550	37
	1400	760	87	600	67	460	8
	1600	870	62	425	47	325	13
	1800	980	39	270	27	185	15
15	70	20	166	1145	124	855	30
	1000	540	134	925	107	740	29
	1200	650	129	890	111	765	15
	1400	760	104	715	86	595	5
	1600	870	70	485	52	360	9
	1800	980	40	275	30	205	5
20	70	20	183	1260	141	970	19
	1000	540	156	1075	133	915	18
	1200	650	137	945	120	825	2
	1400	760	107	740	96	660	3
	1800	980	41	285	30	205	4

*Limited data for cold-rolled 0.050-inch (1.3 mm) thick sheet

COLD-WORKED PROPERTIES

Typical Tensile Properties, Cold-Worked and Aged Sheet*

Condition	Test Temperature °F	Test Temperature °C	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength MPa	0.2% Yield Strength Ksi	0.2% Yield Strength MPa	Elongation in 2 in. (51 mm) %
15% CW + Age A	70	20	168	1160	136	940	31
	1200	650	128	885	104	715	23
20% CW + Age A	70	20	181	1250	152	1050	17
	1000	540	151	1040	129	890	19
	1200	650	144	995	128	885	8
	1400	760	108	745	97	670	2
	1600	870	74	510	59	405	6
	1800	980	43	295	33	230	5
20% CW + Age B	70	20	191	1315	162	1115	16
	600	315	165	1140	132	910	28
	1000	540	149	1025	124	855	23
	1200	650	140	965	119	820	13
	1400	760	116	800	92	635	7
	1600	870	71	490	50	345	9
	1800	980	42	290	31	215	12

*Limited data for cold-rolled 0.050-inch (1.3 mm) thick sheet.

Age A = 700°F (370°C)/1 hour
Age B = 1100°F (595°C)/2 hours

Typical Hardness at 70°F (20°C), Cold-Worked and Aged Sheet*

Cold-Work %	Hardness, Rockwell C, After Indicated Level of Cold Work and Subsequent Aging Treatment: None	900°F (480°C) 5 Hours	1100°F (595°C) 5 Hours
None	24	25	25
5	31	33	31
10	37	39	39
15	40	44	43
20	44	44	47

*Limited data for cold-rolled 0.070-inch (1.8 mm) thick sheet.

IMPACT STRENGTH PROPERTIES, PLATE

Test Temperature °F (°C)	Typical Charpy V-Notch Impact Resistance Ft.-lbs.	Joules
-321 (-196)	109	148
-216 (-138)	134	182
-108 (-78)	156	212
-20 (-29)	179	243
Room	193	262
500 (260)	219	297
1000 (540)	201	273
1200 (650)	170	230
1400 (760)	143	194
1600 (870)	120	163
1800 (980)	106	144

THERMAL STABILITY

When exposed for prolonged periods at intermediate temperatures, HAYNES 25 alloy exhibits a loss of room temperature ductility in much the same fashion as some other solid-solution-strengthened superalloys, such as HASTELLOY® X alloy or alloy 625. This behavior occurs as a consequence of the precipitation of deleterious phases. In the case of a 25 alloy, the phase in question is Co_2W laves phase. HAYNES 188 alloy is significantly better in this regard than 25 alloy; however, for applications where thermal stability is important, 230® alloy is an even better selection.

Room-Temperature Properties of Sheet After Thermal Exposure*

Exposure Temperature °F (°C)	Hours	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength MPa	0.2% Yield Strength Ksi	0.2% Yield Strength MPa	Elongation %
None	0	135.0	930	66.8	460	48.7
1200 (650)	500	123.6	850	70.3	485	39.2
	1000	140.0	965	92.3	635	24.8
	2500	130.7	900	95.1	655	12.0
1400 (760)	100	115.3	795	68.9	475	18.1
1600 (870)	100	113.6	785	72.1	495	9.1
	500	126.1	870	77.3	535	3.5
	1000	142.0	980	81.7	565	5.0

*Composite of multiple sheet lot tests.

TYPICAL PHYSICAL PROPERTIES

	Temp., °F	British Units	Temp., °C	Metric Units
Density	Room	0.330 lb/in³	Room	9.13 g/cm³
Melting Range	2425-2570		1330-1410	
Electrical Resistivity	Room	34.9 µohm-in	Room	88.6 µohm-cm
	200	35.9 µohm-in	100	91.8 µohm-cm
	400	37.6 µohm-in	200	95.6 µohm-cm
	600	38.5 µohm-in	300	97.6 µohm-cm
	800	39.1 µohm-in	400	98.5 µohm-cm
	1000	40.4 µohm-in	500	100.8 µohm-cm
	1200	41.8 µohm-in	600	104.3 µohm-cm
	1400	42.3 µohm-in	700	106.6 µohm-cm
	1600	40.6 µohm-in	800	107.8 µohm-cm
	1800	37.7 µohm-in	900	101.1 µohm-cm
			1000	95.0 µohm-cm
Thermal Conductivity	Room	65 BTU-in/ft² hr-°F	Room	9.4 W/m-K
	200	75 BTU-in/ft² hr-°F	100	10.9 W/m-K
	400	90 BTU-in/ft² hr-°F	200	12.9 W/m-K
	600	105 BTU-in/ft² hr-°F	300	14.8 W/m-K
	800	120 BTU-in/ft² hr-°F	400	16.8 W/m-K
	1000	135 BTU-in/ft² hr-°F	500	18.7 W/m-K
	1200	150 BTU-in/ft² hr-°F	600	20.7 W/m-K
	1400	165 BTU-in/ft² hr-°F	700	22.6 W/m-K
	1600	182 BTU-in/ft² hr-°F	800	24.7 W/m-K
	1800	200 BTU-in/ft² hr-°F	900	26.9 W/m-K
			1000	29.2 W/m-K

TYPICAL PHYSICAL PROPERTIES (continued)

	Temp., °F	British Units		Temp., °C	Metric Units	
Mean Coefficient of Thermal Expansion	70-200	6.8	microinches/in-°F	25-100	12.3	µm/m-°C
	70-400	7.2	microinches/in-°F	25-200	12.9	µm/m-°C
	70-600	7.6	microinches/in-°F	25-300	13.6	µm/m-°C
	70-800	7.8	microinches/in-°F	25-400	14.0	µm/m-°C
	70-1000	8.0	microinches/in-°F	25-500	14.3	µm/m-°C
	70-1200	8.2	microinches/in-°F	25-600	14.6	µm/m-°C
	70-1400	8.6	microinches/in-°F	25-700	15.1	µm/m-°C
	70-1600	9.1	microinches/in-°F	25-800	15.8	µm/m-°C
	70-1800	9.4	microinches/in-°F	25-900	16.5	µm/m-°C
	70-2000	9.8	microinches/in-°F	25-1000	17.0	µm/m-°C
				25-1100	17.6	µm/m-°C

DYNAMIC MODULUS OF ELASTICITY

Temp, °F	Dynamic Modulus of Elasticity, 10^6 psi	Temp.,°C	Dynamic Modulus of Elasticity, GPa
Room	32.6	Room	225
200	32.3	100	222
400	31.0	200	214
600	29.4	300	204
800	28.3	400	197
1000	26.9	500	188
1200	25.8	600	181
1400	24.3	700	174
1600	22.8	800	163
1800	21.4	900	154
		1000	146

METAL-TO-METAL GALLING RESISTANCE

HAYNES 25 alloy exhibits excellent resistance to metal galling. Wear results shown below were generated for standard matching material room-temperature pin on disc tests. Wear depths are given as a function of applied load. The results indicate that 25 alloy is superior in galling resistance to many materials, and is surpassed only by ULTIMET® alloy and HAYNES 6B alloy. Both of these materials were specifically designed to have excellent wear resistance.

	Room-Temperature Wear Depth For Various Applied Loads					
	3,000 lbs. (1,365 Kg)		6,000 lbs. (2,725 Kg)		9,000 lbs. (4,090 Kg)	
Material	**mils**	**µm**	**mils**	**µm**	**mils**	**µm**
6B alloy	0.02	0.6	0.03	0.7	0.02	0.5
ULTIMET alloy	0.11	2.9	0.11	2.7	0.08	2.0
25 alloy	**0.23**	**5.9**	**0.17**	**4.2**	**0.17**	**4.2**
188 alloy	1.54	39.2	3.83	97.3	3.65	92.6
HR-160® alloy	1.73	43.9	4.33	109.9	3.81	96.8
214™ alloy	2.32	59.0	3.96	100.5	5.55	141.0
556™ alloy	3.72	94.4	5.02	127.6	5.48	139.3
230® alloy	4.44	112.7	7.71	195.8	8.48	215.5
HR-120™ alloy	6.15	156.2	7.05	179.0	10.01	254.2

HIGH-TEMPERATURE HARDNESS PROPERTIES

The following are results from standard vacuum furnace hot hardness tests. Values are given in originally measured DPH (Vickers) units and conversions to Rockwell C/B scale in parentheses.

	Vickers Diamond Pyramid Hardness (Rockwell C/B Hardness)				
	70°F (20°C)	**800°F (425°C)**	**1000°F (540°C)**	**1200°F (650°C)**	**1400°F (760°C)**
Solution Treated	251 (R_C22)	171 (R_B87)	160 (R_B83)	150 (R_B80)	134 (R_B74)
15% Cold Work	348 (R_C35)	254 (R_C23)	234 (R_B97)	218 (R_B95)	-
20% Cold Work	401 (R_C41)	318 (R_C32)	284 (R_C27)	268 (R_C25)	-
25% Cold Work	482 (R_C48)	318 (R_C32)	300 (R_C30)	286 (R_C28)	-

AQUEOUS CORROSION RESISTANCE

HAYNES 25 alloy was not designed for resistance to corrosive aqueous media. Representative average corrosion data are given for comparison. For applications requiring corrosion resistance in aqueous environments, ULTIMET alloy and HASTELLOY® corrosion-resistant alloys should be considered.

	Average Corrosion Rate, mils per year (mm per year)					
	1% HCl (Boiling)		**10% H_2SO_4 (Boiling)**		**65% HNO_3 (Boiling)**	
ULTIMET alloy	<1	(<0.03)	99	(2.51)	6	(0.15)
C-22® alloy	3	(0.08)	12	(0.30)	134	(3.40)
25 alloy	**226**	**(5.74)**	**131**	**(3.33)**	**31**	**(0.79)**
Type 316L	524	(13.31)	1868	(47.45)	9	(0.23)

OXIDATION RESISTANCE

HAYNES® 25 alloy exhibits good resistance to both air and combustion gas oxidizing environments, and can be used for long-term continuous exposure at temperatures up to 1800°F (980°C). For exposures of short duration, 25 alloy can be used at higher temperatures. Applications for which oxidation resistance is a serious consideration normally call for newer, more capable materials such as 230® alloy or HAYNES 188 alloy. This is particularly important at temperatures above 1800°F (980°C).

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

	Metal Loss		Average Metal Affected		Maximum Metal Affected	
Material	**Mils**	**μm**	**Mils**	**μm**	**Mils**	**μm**
230 alloy	0.8	20	2.8	71	3.5	89
HAYNES 188 alloy	1.1	28	3.5	89	4.2	107
HASTELLOY® X alloy	2.7	69	5.6	142	6.4	153
Alloy 625	4.9	124	7.1	180	7.6	193
25 alloy	**6.2**	**157**	**8.3**	**211**	**8.7**	**221**
Alloy 617	2.7	69	9.8	249	10.7	272
Alloy 800H	12.3	312	14.5	368	15.3	389
Type 310 Stainless Steel	13.7	348	16.2	411	16.5	419
Alloy 600	12.3	312	14.4	366	17.8	452

Oxidation Test Parameters

Burner rig oxidation tests were conducted by exposing samples 3/8 in. x 2.5 in. x thickness (9 mm x 64 mm x thickness), in a rotating holder, to products of combustion of No. 2 fuel oil 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 near ambient temperature and then reinserted into the flame tunnel.

Comparative Oxidation Resistance in Flowing Air*

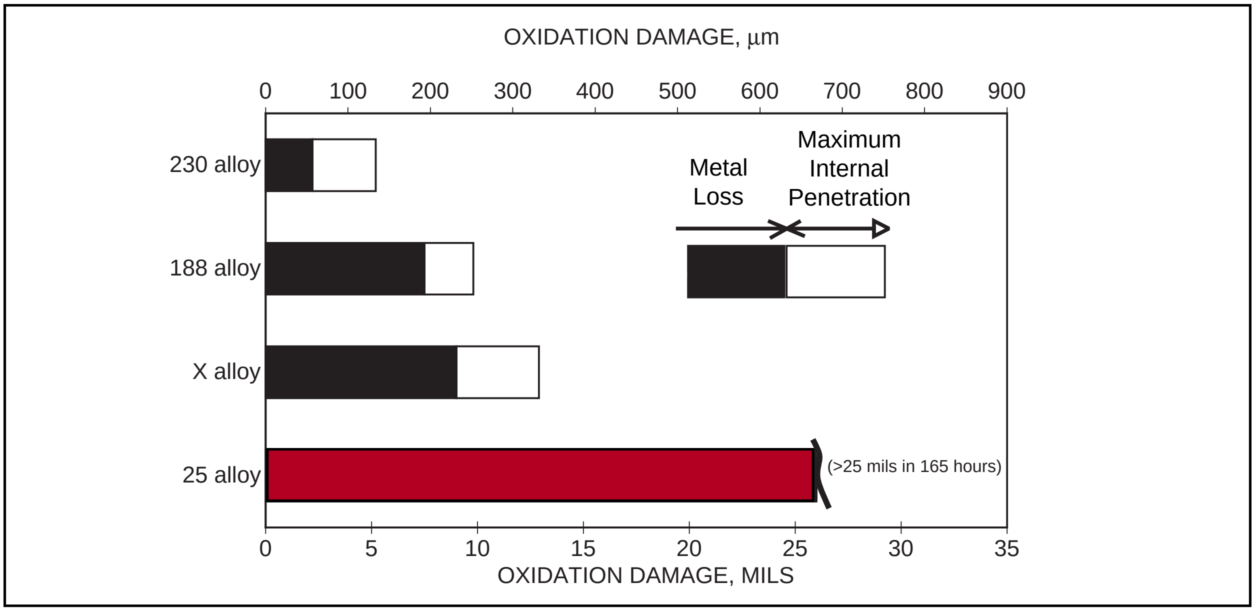
	Average Metal Affected in 1008 Hours**					
	1800°F (980°C)		2000°F (1095°C)		2100°F (1150°C)	
Material	**Mils**	**μm**	**Mils**	**μm**	**Mils**	**μm**
HAYNES 188 alloy	0.6	15	1.3	33	8.0	203
230 alloy	0.7	18	1.3	33	3.4	86
25 alloy	**0.7**	**18**	**10.2**	**259**	**19.2**	**488**
Alloy 625	0.7	18	4.8	122	18.2	462
X alloy	0.9	23	2.7	69	5.8	147
Alloy 617	1.3	33	1.8	46	3.4	86

* Flowing air at a velocity of 7.0 ft./min. (213.4 cm/min.) past the samples. Samples cycled to room temperature once-a-week.

** Metal Loss + Average Internal Penetration.

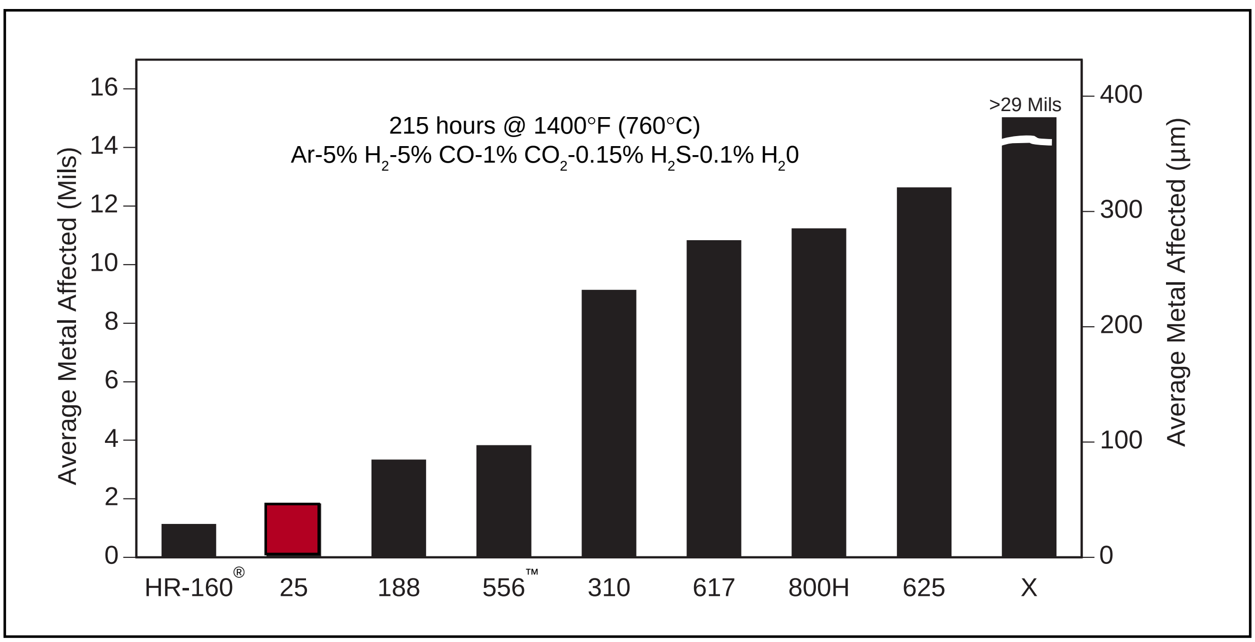
OXIDATION RESISTANCE

Comparative Burner Rig Oxidation Resistance at 2000°F (1095°C) for 500 Hours

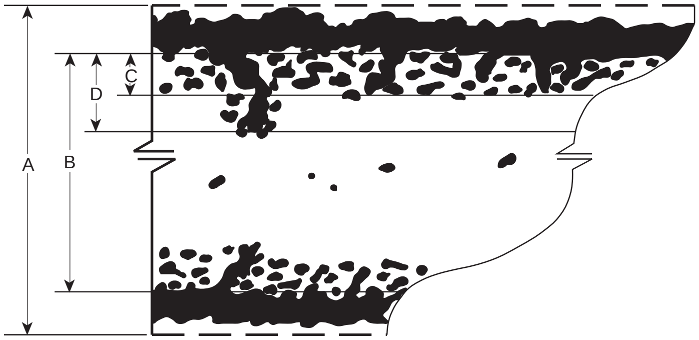


SULFIDATION RESISTANCE AT 1400°F (760°C)

HAYNES® 25 alloy has very good resistance to gaseous sulfidation environments encountered in various industrial applications. Tests were conducted at 1400°F (760°C) in a gas mixture consisting of 5 percent H_2, 5 percent CO, 1 percent CO_2, 0.15 percent H_2S and 0.1 percent H_2O, balance Ar. Coupons were exposed for 215 hours. This is a severe test, with equilibrium sulfur partial pressure of 10^{-6} to 10^{-7} and oxygen partial pressures less than that needed to produce protective chromium oxide scales.



Schematic Representation of 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

FABRICATION CHARACTERISTICS

Heat Treatment

HAYNES® 25 alloy is normaly final solution heat-treated at 2150 to 2250°F (1175 to 1230°C) for a time commensurated with section thickness. 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 call Haynes International for further information.

Effect of Cold Reduction Upon Room-Temperature Properties*

% Cold Reduction	Subsequent Anneal	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength MPa	0.2% Yield Strength Ksi	0.2% Yield Strength MPa	Elongation in 2 in. (51 mm) %	Hardness
0	None	144.0	995	68.4	470	58.5	R_C24
10		181.9	1255	123.6	850	37.1	R_C36
15		178.2	1230	148.5	1025	27.7	R_C40
20		193.5	1335	150.9	1040	18.2	R_C42
25		232.5	1605	183.9	1270	14.6	R_C44
10	1950°F (1065°C) for 5 min.	163.0	1125	97.9	675	39.3	R_C32
15		167.1	1150	91.2	630	43.8	R_C30
20		170.7	1175	96.5	665	40.8	R_C32
25		169.5	1170	88.9	615	44.3	R_C32
10	2050°F (1120°C) for 5 min.	156.6	1080	74.0	510	53.4	R_C27
15		161.2	1110	78.6	540	51.9	R_C28
20		164.8	1135	82.0	565	47.6	R_C31
25		165.6	1140	82.9	570	48.0	R_C30
10	2150°F (1175°C) for 5 min.	148.1	1020	66.9	460	62.6	R_C21
15		156.1	1075	73.6	505	55.4	R_C26
20		154.0	1060	72.1	495	59.3	R_C26
25		149.3	1030	68.5	470	61.7	R_C25

*Based upon cold reductions taken upon 0.110-inch (2.8 mm) thick sheet. Duplicate tests.

FABRICATION CHARACTERISTICS

Effect of Cold Reduction and Annealing Upon Grain Size

% Cold Reduction	Subsequent Anneal	% Recrystallization	ASTM Grain Size Range
0	None	N/A	3 1/2 - 4*
10	1950°F (1065°C) for 5 min.	<10	-
15		95	7
20		95	7 - 8
25		100	7 1/2 - 8
10	2050°F (1120°C) for 5 min.	<10	-
15		95	6 - 7
20		100	7 - 8
25		100	7 1/2 - 8
10	2150°F (1175°C) for 5 min.	100	4 - 4 1/2*
15		100	5 - 7
20		100	4 1/2 - 7*
25		100	4

*Some larger grains near surface.

Effect of Small Cold Reductions on Grain Growth*

% Strain Induced**	Subsequent Anneal	ASTM Grain Size Range	Comments
1	2050°F (1120°C) for 5 min.	2 - 4 1/2	Larger at Surface
2		3 1/2 - 4	Larger at Surface
3		3 1/2 - 4	
4		3 1/2 - 5	
8		4 - 5 1/2	Recrystallized at Surface
1	2150°F (1175°C) for 5 min.	2 - 4 1/2	Larger at Surface
2		3 1/2 - 4	Larger at Surface
3		3 1/2 - 5 1/2	Larger at Surface
4		3 1/2 - 5	
8		4 1/2 - 6	Fully Recrystallized
1	2250°F (1230°C) for 5 min.	1 - 1 1/2	Larger at Surface
2		1 1/2 - 2 1/2	Larger at Surface
3		2 - 4	
4		2 - 2 1/2	
8		3 - 3 1/2	Fully Recrystallized

* Initial grain size ASTM 3 1/2 - 4 with a few larger at surface.

** Samples prestrained in a tensile testing machine.

WELDING

HAYNES® 25 alloy is readily welded by Gas Tungsten Arc (GTAW), Gas Metal Arc (GMAW), Shielded Metal Arc (coated electrodes), electron beam welding and resistance welding techniques. Its welding characteristics are similar to those for HAYNES 188 alloy. 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. Contact with copper or copper-bearing materials in the joint area should be avoided. 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 25 alloy. For shielded metal arc welding, HAYNES 25 alloy electrodes (AMS 5797) are available. For dissimilar metal joining of 25 alloy to nickel-, cobalt- or iron-base materials, 25 alloy itself, 230-W™ filler wire, 556® alloy, HASTELLOY S alloy (AMS 5838) or HASTELLOY W alloy (AMS 5786, 5787) welding products are suggested, depending upon the particular case.

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 25 alloy. For further information, please contact Haynes International.

HEALTH & SAFETY INFORMATION

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 concentrations, 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) H3095 and H1072 for the product.

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 provisions of American National Standard ANSI/AWS Z49.1, (Safely in Welding and Cutting). Attention is especially called to Section 7 (Protection of Personnel) and 8 (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.

MACHINING

Operation	High Speed Steel Tools	Carbide Tools
Roughing, with sever interruptions; Turning or Facing	M-40 series,[1] M-2, M-33, T-4, T-8 and T-15. 45° SCEA[2],-10° Back Rake, + 10° Side Rake, 1/16" nose radius 1/4" depth of cut max., 0.012" feed max., 15 sfm cutting speed Water base coolant[3]	C-1 or C-2 grade square insert, 45° SCEA, -5° Back Rake, -5° Side Rake, 1/16" nose radius, 1/4" depth of cut max. 40 sfm, .012 feed max. Dry, oil, or water base coolant[6]
Normal roughing; Turning or Facing	Same tool grades 45° SCEA, 0° Back Rake, + 10° Side Rake, 1/16" nose radius 1/4" depth of cut max., .015 feed max. 20 sfm cutting speed Water base coolant	Same tool grades Same tool geometry 1/4" depth of cut max., .015 feed max., 40-60 sfm depending on rigidity of setup. Dry, [4,5] oil or water base coolant[6]
Finishing; Turning or Facing	M-40 series, M-33, M-3, T-8 and T-15 15-45°SCEA, + 10° Back Rake, + 15° Side Rake, 1/32-1/16" nose radius, .040-.010" depth of cut, .005-007" feed, 25-30 sfm Water base coolant	C-2 or C-3 grade square insert, if popssible 15-45° SCEA, + 5° Side Rake,[7] + 5° Back Rake, 1/32-1/16" nose radius .040-.010" depth of cut, .005-.007" feed, 60-90 sfm Dry or water base coolant[6]
Rough Boring	M-40 series, M-2, T-1 and T-4 Same tool geometry as Normal Rough Turning with extra clearance as needed, 1/8" depth of cut max., .012 feed max., 15-20 sfm Water base coolant	C-1 or C-2 grade If insert type boring bar, use standard negative rake tools with largest possible SCEA and 1/16" nose radius. if brazed tool bar, grind 0° Back Rake, -5° Side Rake, 1/16" nose radius and largest possible SCEA, 1/8" depth of cut max., .012 feed max., 30-50 sfm depending on rigidity of setup Dry, oil or water base coolant[6]
Finish Boring	Same tool grades, geometry and cutting conditions as Finish Turning and Facing except Back Rake may be best at 0° Water base coolant	C-2 or C-3 grade Use standard positive rake tools[7] on insert type bars—grind brazed tools as for finish turning and facing except back rake may be best at 0°. 50-90 sfm Water base coolant
Face Milling	M-2, M-7, or M-40 series Radial and Axial Rake 0 to + 10°, 45° Corner angle, 10° Relief angle, Feed .005-.009"/tooth, 15-20 sfm Oil or water base coolant	Carbide not generally successful C-1 or C-2 grade may work Use negative axial and radial rake, 45° corner angle, 10° relief angle, .005-.008"/tooth feed, 30-60 sfm Dry, oil base coolant or water base mist will reduce thermal shock damage of carbide cutter teeth

MACHINING (continued)

Operation	High Speed Steel Tools	Carbide Tools
End Milling	M-40 series or T-15 If possible, use short mills with 4 or more flutes for rigidity. For 1/2" dia. mills, feed .002"/tooth, for 1" and larger, feed .005"/tooth, 15-20 sfm Oil or water base coolant	Not recommended, but C-2 grades may be successful on good setups. Feed same as high speed steel 30-60 sfm Dry; oil, or water base mist will reduce thermal shock damage.
Drilling	M-33, M-40 series or T-15 Feed .001"/Rev 1/16" dia. .002"/ Rev 1/4" dia .003"/Rev 1/2" dia .004"/Rev 1" dia Use short drills, heavy webs, 135° crankshaft grind points wherever possible. Speed 10-15 sfm Oil or water coolant Use coolant feed drills if possible	C-2 grade not recommended, but solid or tipped drills may be successful on rigid setups. The web must be thinned to reduce thrust. Use 135° included angle on point. 20-40 sfm Coolant-feed carbide tipped drills may be economical in some setups. Oil or water base coolant
Reaming	M-33, M-40 series or T-15 Use 45° corner angle, narrow primary land and 10° relief angle, 1/2" dia. feed .003"/tooth, 2" dia. feed .004"/tooth, Oil or water base coolant 10-20 sfm	C-2 or C-3 grade Tipped reamers recom-mended Solid carbide reamers require very good setup. Tool geom-etry and feed same as High Speed Steel 30-50 sfm
Tapping	M-1, M-7, M-10 2 Flute, spiral point, plug tap 0 to 10° hook angle nitrided surface may be helpful by increasing wear resistance but may cause chipping or breakage 5 sfm cutting speed, Tap drill for 60-65% thread, if possible, to increase tool life Use best possible tapping compound, sulfochlorinated oil base preferred.	Not recommended

NOTES:

1. M-40 series High Speed Steels include M-41, M-42, M-43, M-44, M-45 and M-46 at the time of writing. Others may be added and should be equally suitable.
2. SCEA-Side cutting edge angle or lead angle of the tool.
3. Water base coolant should be premium quality, sulfochlorinated water soluble oil or chemical emulsion with extreme pressure additives. Dilute with water to make 15:1 mix.
4. 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.
5. Oil coolant should be a premium quality, sulfochlorinated oil with extreme pressure additives. Viscosity at 100°F from 50 to 125 SSU.
6. Water base coolant may cause chipping and rapid failure of carbide tools in interrupted cuts.
7. Negative rake tools should be used in interrupted cuts.

STANDARD PRODUCTS

By Brand or Alloy Designation:

HAYNES International

HASTELLOY® Corrosion-Resistant Alloys

B-3®, C-4, C-22®, C-22HS®, C-276, C-2000®, G-30®, G-35®, G-50®, HYBRID-BC1™, and N

HASTELLOY® High-Temperature Alloys

S, W, and X

HAYNES® High-Temperature Alloys

25, R-41, 75, HR-120®, HR-160®, HR-224™, 188, 214®, 230®, 230-W®, 242®, 263, 282®, 556®, 617, 625, 625SQ®, 718, X-750, MULTIMET®, NS-163™, and Waspaloy

Corrosion-Wear Resistant Alloy

ULTIMET®

Wear-Resistant Alloy

6B

HAYNES® Titanium Alloy Tubular

Ti-3Al-2.5V

Standard Forms: Bar, Billet, Plate, Sheet, Strip, Coils, Seamless or Welded Pipe & Tubing, Pipe Fittings, Flanges, Fittings, Welding Wire, and Coated Electrodes

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