HAYNES International CORROSION-RESISTANT ALLOYS

HASTELLOY® C-22HS® ALLOY

Oil & Gas Applications

Contents

H-3180

HASTELLOY®C-22HS®- OIL & GAS APPLICATIONS

The data in this document is believed to be useful for applications in the oil & gas industry, or other industries which may require an alloy with excellent corrosion resistance and strength levels higher than "standard" HASTELLOY®C-22HS® alloy. Additional information on C-22HS alloy may be found in the alloy brochure H-2122 on the Haynes International website.

NOMINAL CHEMICAL WEIGHT %

Ni	Cr	Mo	Fe	W	Mn	Al	Si	C	B
57[a]	21	17	2*	1*	0.8*	0.5*	0.08*	0.01*	0.006*

[a] As Balance * Maximum

AVAILABLE IN THREE VERY HIGH-STRENGTH CONDITIONS

Early testing of C-22HS alloy was focused on material in the annealed + age-hardened condition where the material was annealed at 1975°F (1079°C) and age-hardened at 1300°F (704°C)/16h/Furnace cool (FC) to 1125°F (607°C)/32h/Air-cool (AC.) In this "standard condition" C-22HS alloy will typically have strengths around 100 ksi (690 MPa). While this strength level is almost double of "C-type" alloys in the annealed condition, many oil and gas applications require even greater strength. For this reason, a considerable development effort has been generated on C-22HS alloy in three other "very high strength" conditions:.

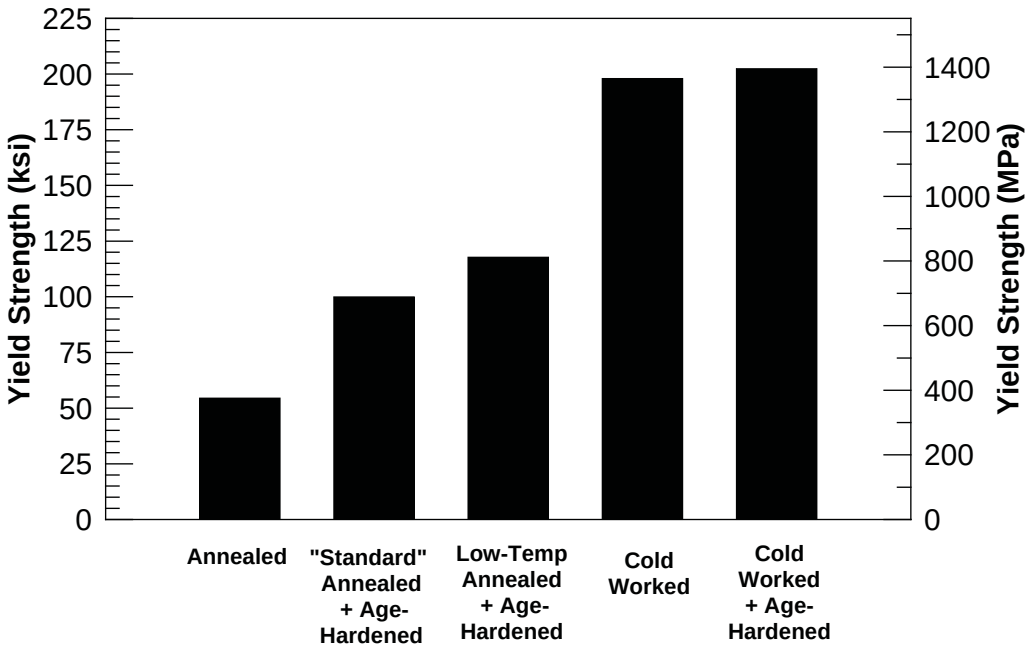
1) Cold Worked

2) Cold Worked + Age-Hardened[A]

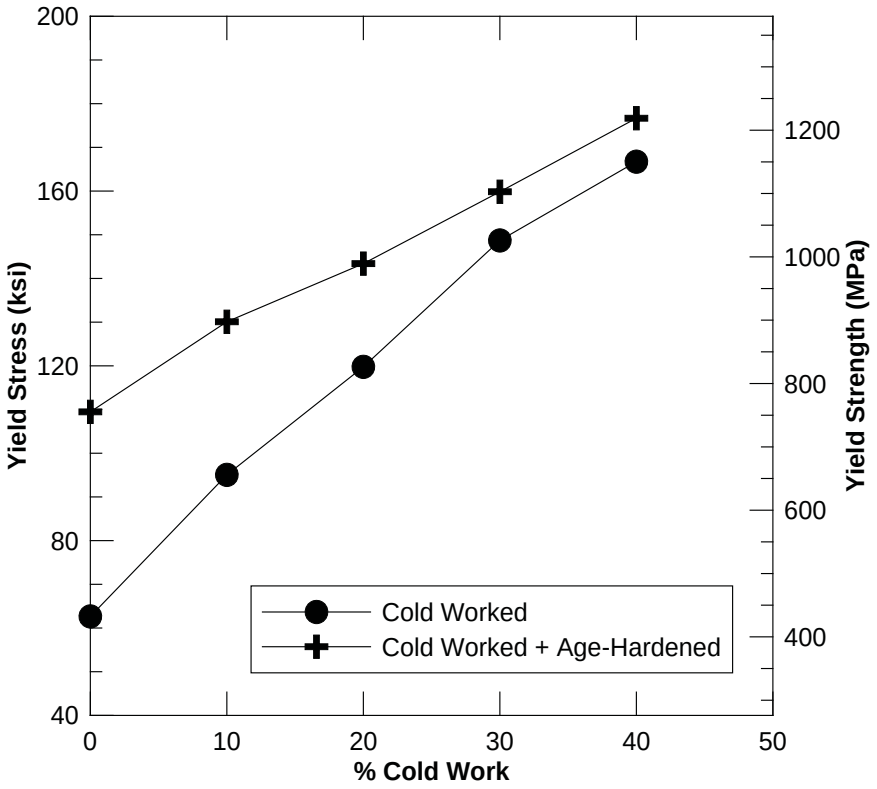
3) Low Temperature (LT) Annealed[B] + Age-Hardened[C]

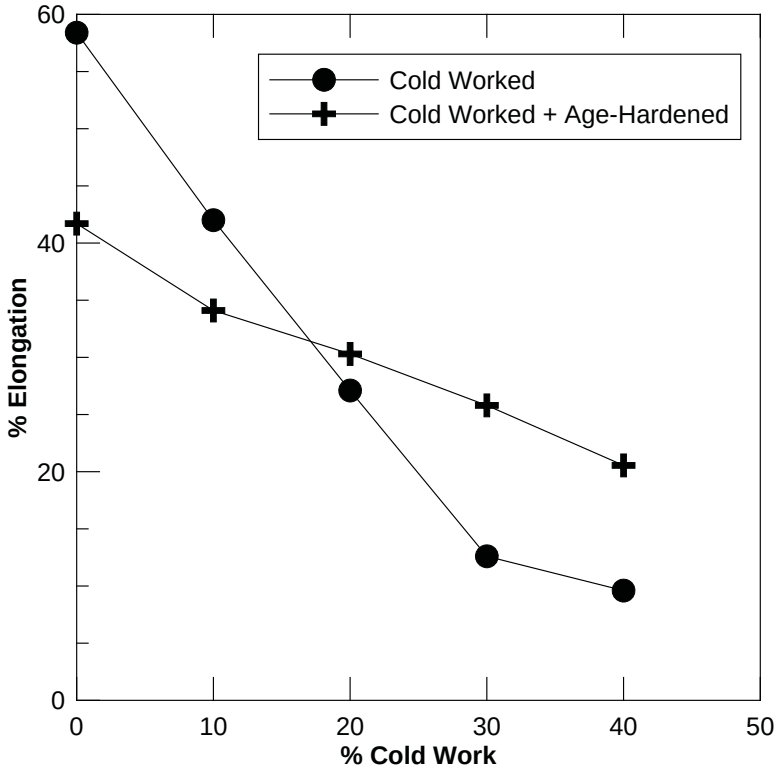
[A]1125°F (607°C)/10h/AC [B]1850°F (1010°C) [C]1300°F (704°C)/16h/FC to 1125°F (607°C)/32h/AC

A comparison of yield strengths for the three very high strength conditions is shown below along with that of the annealed and "standard" conditions.



Effects of Cold Work Level and Age-Hardening Treatment





Age-hardening treatment increases the yield strength, but the amount of increase is less at higher levels of cold work

Age-hardening treatment results in lower ductility at low levels of cold work, but increases ductility at higher cold work levels

AVERAGE ROOM TEMPERATURE TENSILE PROPERTIES - BAR

Material Condition	Yield Strength (ksi)	Yield Strength (MPa)	Ultimate Tensile Strength (ksi)	Ultimate Tensile Strength (MPa)	Elongation %	R.A %
Cold-Worked	198.0	1365	203.5	1403	16.7	64.2
Cold-Worked + Age-Hardened	202.4	1396	230.7	1591	19.9	48.7
LT Annealed + Age-Hardened	117.8	812	194.1	1338	32.9	45.7

Cold-worked condition: cold work levels ranged from 43 to 47%
Cold-Worked + Age-Hardened condition: cold work levels same as above, age-hardening treatment – 1125°F (607°C)/10h
LT Annealed + Age Hardened: anneal- 1850°F (1010°C), age-hardening- 1300°F (704°C)/16h/FC to 1125°F (607°C)/32h/AC

AVERAGE ROOM TEMPERATURE TENSILE PROPERTIES - TUBE

Material Condition	Yield Strength (ksi)	Yield Strength (MPa)	Ultimate Tensile Strength (ksi)	Ultimate Tensile Strength (MPa)	Elongation %
Cold-Worked	187.3	1291	195.0	1345	15.1
Cold-Worked + Age-Hardened	198.7	1370	222.6	1535	19.2
LT Annealed + Age-Hardened	120.8	833	191.3	1319	33.4

Cold-worked condition: cold work levels ranged from 52 to 53%
Cold-Worked + Age-Hardened condition: cold work levels same as above, age-hardening treatment –1125°F (607°C)/10h/AC
LT Annealed + Age Hardened: anneal- 1850°F (1010°C), age-hardening- 1300°F (704°C)/16h/FC to 1125°F (607°C)/32h/AC

ROOM AND ELEVATED TEMPERTURE TENSILE PROPERTIES

0.5" (12.7mm) Diameter Bar

Material Condition	Temperature (°F)	Temperature (°C)	Yield Strength (ksi)	Yield Strength (MPa)	Ultimate Tensile Strength (ksi)	Ultimate Tensile Strength (MPa)	Elongation %	R.A. %
Cold-Worked	RT	RT	195.1	1345	200.4	1382	18.0	65.2
Cold-Worked	400	204	181.8	1254	182.6	1259	14.6	63.1
Cold-Worked	500	260	181.0	1248	181.1	1249	14.1	60.8
Cold-Worked + Age-Hardened	RT	RT	203.1	1400	233.6	1611	21.4	57.5
Cold-Worked + Age-Hardened	400	204	185.9	1282	208.9	1440	20.9	58.7
Cold-Worked + Age-Hardened	500	260	183.1	1262	207.3	1429	20.9	57.5
LT Annealed + Age-Hardened	RT	RT	118.3	816	195.1	1345	32.3	43.4
LT Annealed + Age-Hardened	400	204	104.4	720	178.7	1232	38.4	53.4
LT Annealed + Age-Hardened	500	260	100.4	692	174.4	1202	37.2	51.2

Cold-worked condition: cold work level of 43%
Cold-worked + Age-hardened condition: cold work levels same as above, age-hardening treatment –1125°F (607°C)/10h/AC
LT Annealed + Age Hardened: anneal- 1850°F (1010°C), age-hardening- 1300°F (704°C)/16h/FC to 1125°F (607°C)/32h/AC

CHARPY IMPACT TESTING

1" (25.4mm) Diameter Bar, 44% Cold-Worked (CW)

	LT Anneal + Age-Hardened		Cold-Worked		Cold-Worked + Age-Hardened	
Temperature	(ft-lbf)	(J)	(ft-lbf)	(J)	(ft-lbf)	(J)
RT	75	102	146	198	124	168
-75ºF (-59ºC)	67	91	153	207	125	169
-320ºF (-196ºC)	54	73	113	153	102	138

*Average of two tests, all samples were longitudinal

AVERAGE HARDNESS DATA

Form	Annealed	"Standard" Annealed [B] + Age-Hardened	"LT" Annealed + [C] Age-Hardened	Cold-Worked [D]	Cold-Worked [E] + Age-Hardened
Sheet	90 Rb	30 Rc	--	--	--
Plate	92 Rb	30 Rc	--	--	--
Bar	92 Rb	30 Rc	37 Rc	42 Rc	46 Rc
Tube	--	--	38 Rc	42 Rc	47 Rc

[A]Annealed at 1975°F (1079°C)
[B]1975°F (1079°C) + 1300°F (704°C)/16h/FC to 1125°F (607°C)/32h/AC
[C]1850°F (1010°C) + 1300°F (704°C)/16h/FC to 1125°F (607°C)/32h/AC
[D]As cold-worked (43 to 47% bar, 52 to 53% tube)
[E]Cold -worked (43 to 47% bar, 52 to 53% tube) + 1125°F (607°C)/10h/AC

HARDNESS EFFECTS OF COLD WORK & AGE-HARDENING TIME

Effects of Cold Work Level and Age-Hardening Treatment (Sheet)

Age-Hardening Time*	Hardness (Rc) for % Cold Work Level					
Hours	0%	10%	20%	30%	40%	50%
0	<20	29	35	37	40	45
1	<20	27	33	38	41	47
4	<20	26	33	39	41	48
10	<20	35	40	41	45	51
24	<20	40	43	44	48	52

*Age-Hardening was performed at 1125ºF (607°C) for the indicated time

COLD-FORMING CHARACTERISTICS

Average Room-Temperature Tensile Properties of Annealed* HASTELLOY® C-22HS® Alloy

Form	0.2% Yield Strength		Ulitmate Tensile Strength		Elongation	R.A.
	(ksi)	(MPa)	(ksi)	(MPa)	%	%
Sheet	63.6	439	121.4	837	57.3	-
Plate & Bar	54.4	376	117.0	806	62.3	77.5

*1975ºF (1079ºC) anneal

SOUR GAS TESTING - STANDARD NACE TEST

NACE TM0177 Test Levels II and III, Method A, Soultion A, Applied Stress = 100% YS

Material Condition	Heat#	Coupling	Result
LT Annealed + Age-Hardened	1	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
	2	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
	3	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
Cold-Worked	1	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
	2	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
	3	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
Cold-Worked + Age-Hardened	1	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
	2	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
	3	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass

*Triplicate Samples

SOUR GAS TESTING - SSR TENSILE

Material Condition	Envrionment*	Time to Failure (h)	Elong. %	R.A. %	Time to Failure Ratio	Elong. Ratio	R.A Ratio	Secondary Cracking
LT Annealed + Age-Hardened	Air	26.8	38.6	54.1	--	--	--	--
	Level VII w/o S	25.5	36.7	52.8	0.95	0.95	0.98	No
Cold-Worked	Air	8.9	12.8	63.4	--	--	--	--
	Level VII w/o S	8.4	12.1	63.2	0.95	0.95	1.00	No
Cold-Worked + Age-Hardened	Air	14.4	20.7	56.8	--	--	--	--
	Level VII w/o S	14.1	20.3	53.8	0.98	0.98	0.95	No

NACE TM0198 Slow Strain Rate Tensile, Level VII, With Elemental Sulfer

Material Condition	Envrionment*	Time to Failure (h)	Elong. %	R.A. %	Time to Failure Ratio	Elong. Ratio	R.A Ratio	Secondary Cracking
LT Annealed + Age-Hardened	Air	26.8	38.6	54.1	--	--	--	--
	Level VII w/S	25.6	36.8	54.0	0.95	0.95	1.00	No
Cold-Worked	Air	8.9	12.8	63.4	--	--	--	--
	Level VII w/ S	8.2	11.7	62.4	0.92	0.91	0.98	No
Cold-Worked + Age-Hardened	Air	14.4	20.7	56.8	--	--	--	--
	Level VII w/ S	13.6	19.6	51.2	0.94	0.95	0.90	No

LOCALIZED CORROSION RESISTANCE

Critical Crevice and Pitting Temperatures in 6% $FeCl_3$ + 1% HCl

	Critical Pitting Temperature		Critical Crevice Temperature	
Alloy	(°F)	(°C)	(°F)	(°C)
C-22HS®(Annealed + Age -Hardened)	230	110	167	75
C-22HS® (Annealed)	>248	>120	212	100
C-22®	>248	>120	176	80
C-276	>248	>120	131	55
625	212	100	104	40
725 (Annealed + Age-Hardened)	185	85	77	25

MATERIAL PROPERTIES

Density (Annealed)	0.311 lb/in³	8.60 g/cm³
Density (Age-Hardened)	0.312 lb/in³	8.64 g/cm³
Melting Range	2380-2495°F	1304-1368°C

*Age-hardened 1300°F (704°C)/16h/AC + 1125°F (607°C)/32h/AC

Physical Properties of HASTELLOY® C-22HS® Alloy* – Standard Units

Temperature	Specific Heat	Thermal Conductivity	Thermal Diffusivity	Electrical Resistivity	Mean Coefficient of Thermal Expansion	Dynamic Modulus of Elasticity (Young's Modulus)
(°F)	(Btu/lb·°F)	(Btu·in/h·ft²·°F)	(ft²/h)	(microhms·in)	(µin/in · °F)	(msi)
RT	0.098	82	0.129	38.4	—	32.3
200	0.103	93	0.139	39.3	6.4	31.6
400	0.108	107	0.155	41.1	6.7	30.5
600	0.112	120	0.167	42.8	6.9	30.2
800	0.115	132	0.180	44.3	7.1	29.5
1000	0.118	147	0.194	45.5	7.3	27.6
1100	0.120	154	0.200	46.0	7.4	26.4

Physical Properties of HASTELLOY® C-22HS® Alloy* – Metric Units

Temperature	Specific Heat	Thermal Conductivity	Thermal Diffusivity	Electrical Resistivity	Mean Coefficient of Thermal Expansion	Dynamic Modulus of Elasticity (Young's Modulus)
(°C)	(J/kg · K)	(W/m · K)	(cm²/s)	(µohm · cm)	(µm/m · K)	(GPa)
RT	412	11.8	0.0344	98.0	—	223
100	434	13.5	0.0362	100	11.6	218
200	451	15.4	0.0398	104	12.0	211
300	465	17.1	0.0427	108	12.4	209
400	577	18.6	0.0454	112	12.7	205
500	488	20.5	0.0489	115	13.1	195
600	504	22.4	0.0517	117	13.3	181

*Properties are in the standard age-hardened condition unless otherwise noted

TRANSVERSE TENSILE PROPERTIES-COLD-WORKED BAR

Cold-Worked (54%) Bar - 2-3/8" (60mm) Diameter (Longitudinal and Transverse)

			Yield Strength		Ultimate Tensile Strength		Elongation	R.A
Material Condition	Temperature	Orientation	(ksi)	(MPa)	(ksi)	(MPa)	%	%
As-Cold-Worked	RT	Longitudinal	181.4	1251	190.5	1313	21.2	71.1
		Transverse	156.6	1080	183.0	1262	18.8	60.9
	350	Longitudinal	160.2	1105	166.6	1149	18.5	72.2
		Transverse	138.3	954	160.9	1109	16.1	59.6
	450	Longitudinal	156.1	1076	163.1	1125	18.3	72.2
		Transverse	139.0	958	156.7	1080	14.8	59.3
Cold-Worked + Age-Hardened	RT	Longitudinal	193.5	1334	210.6	1452	27.5	66.5
		Transverse	168.3	1160	197.8	1364	25.5	58.5
	350	Longitudinal	179.8	1240	193.5	1334	25.1	66.6
		Transverse	152.1	1049	177.1	1221	25.8	58.3
	450	Longitudinal	173.1	1194	193.4	1333	25.2	62.0
		Transverse	149.7	1032	174.8	1205	25.4	58.1

CHARPY IMPACT TESTING

2-3/8" (60mm) Diameter Bar, 54% Cold-Worked (CW)

		Impact Energy*			
		Cold-Worked		Cold-Worked + Age-Hardened	
Temperature	Sample Orientation	(ft-lbf)	(J)	(ft-lbf)	(J)
RT	Longitudinal	148	201	108	146
	Transverse (Notch: Longitudinal)	60	81	56	76
	Transverse (Notch: Transverse	54	73	49	66
-75ºF (-59ºC)	Longitudinal	141	191	106	144
	Transverse (Notch: Longitudinal)	63	85	54	73
	Transverse (Notch: Transverse	52	71	49	66

*Average of two tests

90-DAY AUTOCLAVE TEST

C-Ring, Test Level VII, 1 g/L Elemental Sulfur, Applied Stress = 100% YS

Material Condition	Heat#	Result
LT Annealed + Age-Hardened	1	Pass
	2	Pass
	3	Pass
Cold-Worked	1	Pass
	2	Pass
	3	Pass
Cold-Worked + Age-Hardened	1	Pass
	2	Pass
	3	Pass

WARNING: This product and fumes generated from the normal use of this product contain Manganese. The inhalation of welding rod fumes containing Manganese has been associated with the development of serious Parkinson's Disease-like symptoms, Parkinsonism, Manganism, and other central nervous system conditions. Such symptoms may include impaired speech, balance and movement. Avoid breathing fumes generated in the welding process by utilizing appropriate environmental controls, including but not limited to ventilation, exhaust and respirators.

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