

HASTELLOY® C-22HS® - Oil & Gas

Principal Features

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.

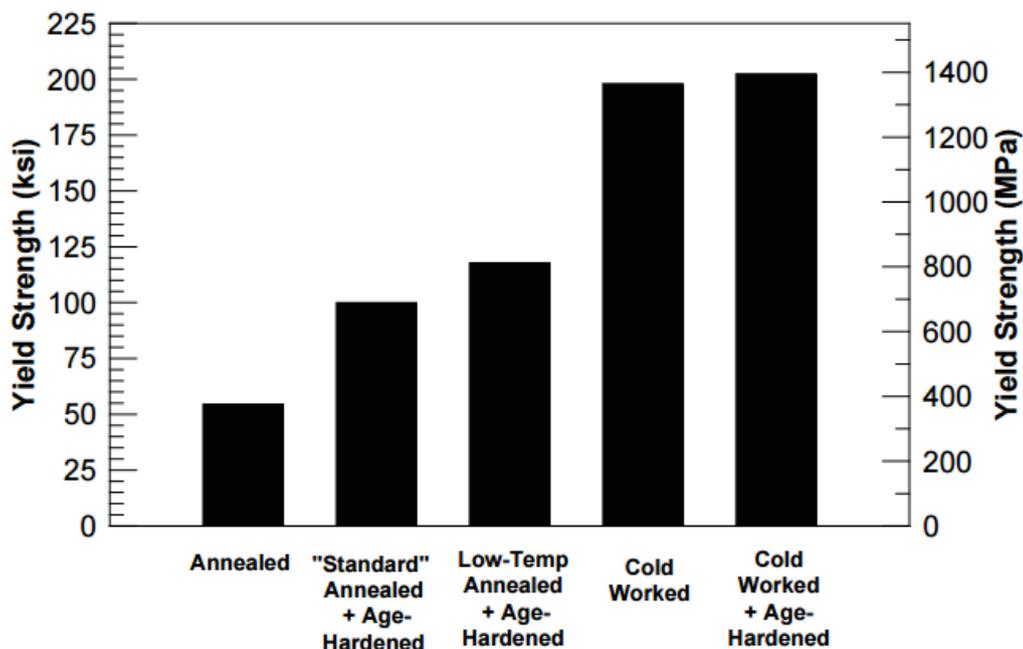
Available in Three Very High-Strength Conditions

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

^A1125°F (607°C)/10h/AC ^B1850°F (1010°C) ^C1300°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. Haynes does not recommend use of highly cold worked and aged material because the increase in yield strengths is minimal and the susceptibility to hydrogen embrittlement in severe oil well conditions is increased.



Nominal Composition

Weight %

Nickel:	Balance
Chromium:	21
Molybdenum:	17
Iron:	2 max.
Tungsten:	1 max.
Manganese:	0.8 max.
Aluminum:	0.5 max.
Silicon:	0.08 max.
Carbon:	0.01 max.
Boron:	0.006 max.

Sour Gas Testing

Standard NACE Test

NACE TM0177 Test Levels II and III, Method A, Solution 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 Continued

SSR Tensile

Material Condition	Environment	Time to Failure	Elong.	R. A.	Time to Failure Ratio	Elong. Ratio	R. A. Ratio	Secondary Cracking
-	-	h	%	%	h	%	%	-
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	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

R.A. = Reduction of Area

Elong. = Elongation

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

Material Condition	Environment	Time to Failure	Elong.	R. A.	Time to Failure Ratio	Elong. Ratio	R. A. Ratio	Secondary Cracking
-	-	h	%	%	h	%	%	-
LT Annealed + Age-Hardened	Air	26.8	38.6	54.1	-	-	-	-
	Level VII w/S	25.6	36.8	54	0.95	0.95	1	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	0.9	No

R.A. = Reduction of Area

Elong. = Elongation

Resistance to Pitting and Crevice Corrosion

Critical Crevice and Pitting Temperatures in 6% FeCl + 1% HCl

Alloy	Critical Pitting Temperature		Critical Crevice Temperature	
	°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

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

Physical Properties

Physical Property	British Units		Metric Units	
Density (annealed)	-	0.306 lb/in. ³	-	8.47 g/cm. ³
Density (Age-Hardened)	-	0.312 lb/in. ³	-	8.64 g/cm. ³
Melting Range	2380-2495°F	-	1304-1368°C	-
Electrical Resistivity	RT	38.4 μohm.in	RT	98.0 μohm.m
	200°F	39.3 μohm.in	100°C	100 μohm.m
	400°F	41.1 μohm.in	200°C	104 μohm.m
	600°F	42.8 μohm.in	300°C	108 μohm.m
	800°F	44.3 μohm.in	400°C	112 μohm.m
	1000°F	45.5 μohm.in	500°C	115 μohm.m
	1100°F	46.0 μohm.in	600°C	117 μohm.m
Thermal Conductivity	RT	82 Btu.in/h.ft ² .°F	RT	11.8 W/m.°C
	200°F	93 Btu.in/h.ft ² .°F	100°C	13.5 W/m.°C
	400°F	107 Btu.in/h.ft ² .°F	200°C	15.4 W/m.°C
	600°F	120 Btu.in/h.ft ² .°F	300°C	17.1 W/m.°C
	800°F	132 Btu.in/h.ft ² .°F	400°C	18.6 W/m.°C
	1000°F	147 Btu.in/h.ft ² .°F	500°C	20.5 W/m.°C
	1100°F	154 Btu.in/h.ft ² .°F	600°C	22.4 W/m.°C
Thermal Diffusivity	RT	0.129 ft ² /h	RT	0.0344 cm ² /s
	200°F	0.139 ft ² /h	100°C	0.0362 cm ² /s
	400°F	0.155 ft ² /h	200°C	0.0398 cm ² /s
	600°F	0.167 ft ² /h	300°C	0.0427 cm ² /s
	800°F	0.180 ft ² /h	400°C	0.0454 cm ² /s
	1000°F	0.194 ft ² /h	500°C	0.0489 cm ² /s
	1100°F	0.200 ft ² /h	600°C	0.0517 cm ² /s

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

RT= Room Temperature

Physical Properties Continued

Physical Property	Metric Units		British Units	
Specific Heat	RT	0.098 Btu/lb.°F	RT	412 J/kg.°C
	200°F	0.103 Btu/lb.°F	100°C	434 J/kg.°C
	400°F	0.108 Btu/lb.°F	200°C	451 J/kg.°C
	600°F	0.112 Btu/lb.°F	300°C	465 J/kg.°C
	800°F	0.115 Btu/lb.°F	400°C	577 J/kg.°C
	1000°F	0.118 Btu/lb.°F	500°C	488 J/kg.°C
	1100°F	0.120 Btu/lb.°F	600°C	504 J/kg.°C
Mean Coefficient of Thermal Expansion	RT	-	RT	-
	200°F	6.4 µin/in.°F	100°C	11.6 µm/m-°C
	400°F	6.7 µin/in.°F	200°C	12.0 µm/m-°C
	600°F	6.9 µin/in.°F	300°C	12.4 µm/m-°C
	800°F	7.1 µin/in.°F	400°C	12.7 µm/m-°C
	1000°F	7.3 µin/in.°F	500°C	13.1 µm/m-°C
	1100°F	7.4 µin/in.°F	600°C	13.3 µm/m-°C
Dynamic Modulus of Elasticity	RT	32.3 x 10 ⁶ psi	RT	223 GPa
	200°F	31.6 x 10 ⁶ psi	100°C	218 GPa
	400°F	30.5 x 10 ⁶ psi	200°C	211 GPa
	600°F	30.2 x 10 ⁶ psi	300°C	209 GPa
	800°F	29.5 x 10 ⁶ psi	400°C	205 GPa
	1000°F	27.6 x 10 ⁶ psi	500°C	195 GPa
	1100°F	26.4 x 10 ⁶ psi	600°C	181 GPa

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

RT= Room Temperature

Impact Strength

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

Temperature		Charpy V-Notch Impact Strength					
		LT Anneal + Age-Hardened		Cold-Worked		Cold-Worked + Age-Hardened	
°F	°C	ft.-lb.	J	ft.-lb.	J	ft.-lb.	J
RT	RT	75	102	146	198	125	168
-75	-59	67	92	153	207	125	169
-320	-196	54	73	113	153	102	138

*Average of two tests, all samples were longitudinal

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

Temperature		Sample Orientation	Charpy V-Notch Impact Strength Cold-Worked		Cold-Worked + Age-Hardened	
°F	°C		ft.-lb.	J	ft.-lb.	J
		-				
RT	RT	Longitudinal	148	201	108	146
		Transverse (Notch: Longitudinal)	60	81	56	76
		Transverse (Notch: Transverse)	54	73	49	66
-75	-59	Longitudinal	141	191	106	144
		Transverse (Notch: Longitudinal)	63	85	54	73
		Transverse (Notch: Transverse)	52	71	49	66

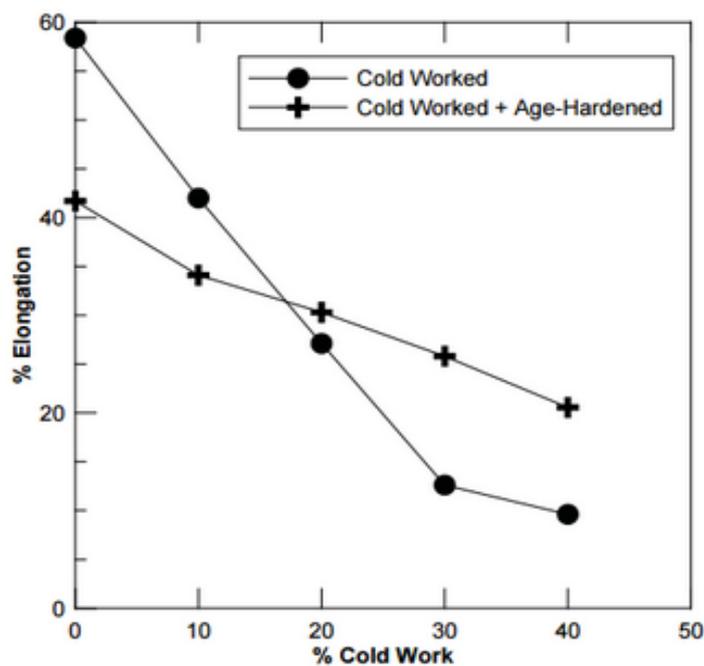
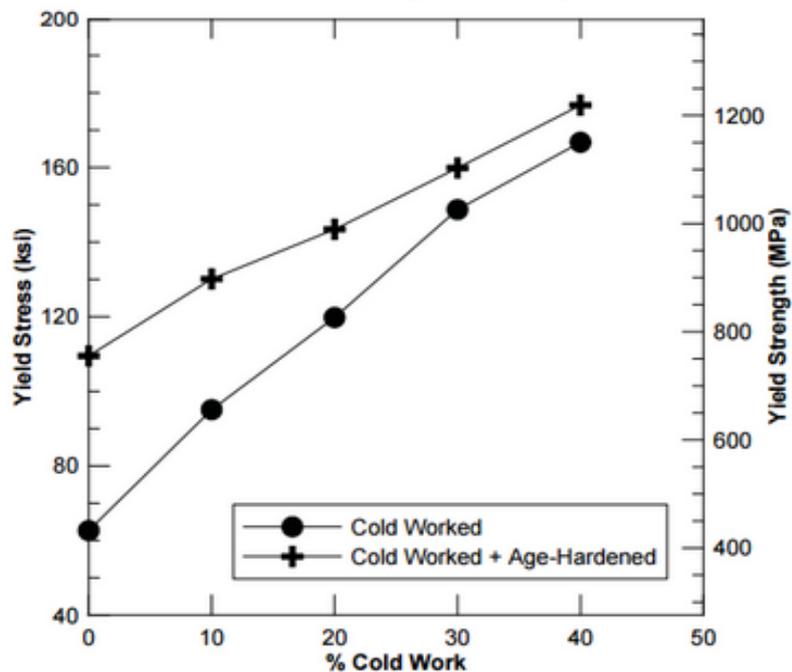
*Average of two tests

RT= Room Temperature

Tensile Data

Room Temperature Tensile Properties, Sheet

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.

Tensile Data Continued

Cold Forming

Average Room-Temperature Tensile Properties of Annealed* HASTELLOY® C-22HS® Alloy						
From	0.2% Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
	ksi	MPa	ksi	MPa		
-					%	%
Sheet	63.6	439	121.4	837	57.3	-
Plate & Bar	54.4	376	117	806	62.3	77.5

*1975°F (1079°C) anneal

Average Room Temperature Tensile Properties, Bar

Material Condition	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
	ksi	MPa	ksi	MPa		
-					%	-
Cold-Worked	198	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	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
	ksi	MPa	ksi	MPa	
-					%
Cold-Worked	187.3	1291	195	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

Tensile Data Continued

Room and Elevated Temperature Tensile Properties - 0.5" (12.7mm) Diameter Bar

Material Condition	Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
	°F	°C	ksi	MPa	ksi	MPa		
-							%	-
Cold-Worked	RT	RT	195.1	1345	200.4	1382	18	65.2
Cold-Worked	400	204	181.8	1254	182.6	1259	14.6	63.1
Cold-Worked	500	260	181	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

Transverse Tensile Properties, Cold-Worked Bar

Material Condition	Temperature	Orientation	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
			ksi	MPa	ksi	MPa		
-	°F	-					%	-
As Cold-Worked	RT	Longitudinal	181.4	1251	190.5	1313	21.2	71.1
		Transverse	156.6	1080	183	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	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
		Transverse	149.7	1032	174.8	1205	25.4	58.1

RT= Room Temperature

Hardness

Average Hardness Data

Form	Annealed	“Standard” Annealed ^B + Age-Hardened	LT Anneal ^C +Age-Hardened	Cold- Worked ^D	Cold-Worked ^E + Age-Hardened
Sheet	90 HRB	30 HRC	-	-	-
Plate	92 HRB	30 HRC	-	-	-
Bar	92 HRB	30 HRC	37 HRC	42 HRC	46 HRC
Tube	-	-	38 HRC	42 HRC	47 HRC

^AAnnealed at 1975°F (1079°C)

^B1975°F (1079°C) + 1300°F (704°C)/16h/FC to 1125°F (607°C)/32h/AC

^C1850°F (1010°C) + 1300°F (704°C)/16h/FC to 1125°F (607°C)/32h/AC

^DAs 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

HRB = Hardness Rockwell “B”.

HRC = Hardness Rockwell “C”.

Hardness Effects of Cold-Work and Age-Hardening Time

Effects of Cold-Work Level and Age-Hardening Treatment (Sheet)						
Age-Hardening Time*	Hardness (HRC) for % Cold Work Level					
	0%	10%	20%	30%	40%	50%
h						
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 1125°F (607°C) for the indicated time

HRC = Hardness Rockwell “C”.

90-Day Autoclave Testing

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

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