HASTELLOY® C-22HS® alloy

Principal Features

A high strength C-type alloy for the Oil and Gas Industries

HASTELLOY® C-22HS® alloy is the premier nickel-chromium-molybdenum, corrosion-resistant material for oil and gas industry use. Cold working of the alloy at levels between 30 and 65% result in high room temperature yield strengths. It exhibits exceptional resistance to sour gas environments and is NACE/ISO approved.

Product Forms

C-22HS® alloy is available in the form of plate, sheet, strip, billet, bar, wire, pipe, and tube. Round products in the form of solid bars are available up to 10" with various amounts of cold work to achieve high strength and toughness by simultaneously retaining the excellent corrosion resistance of the alloy.

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.

Principal Features Continued

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:

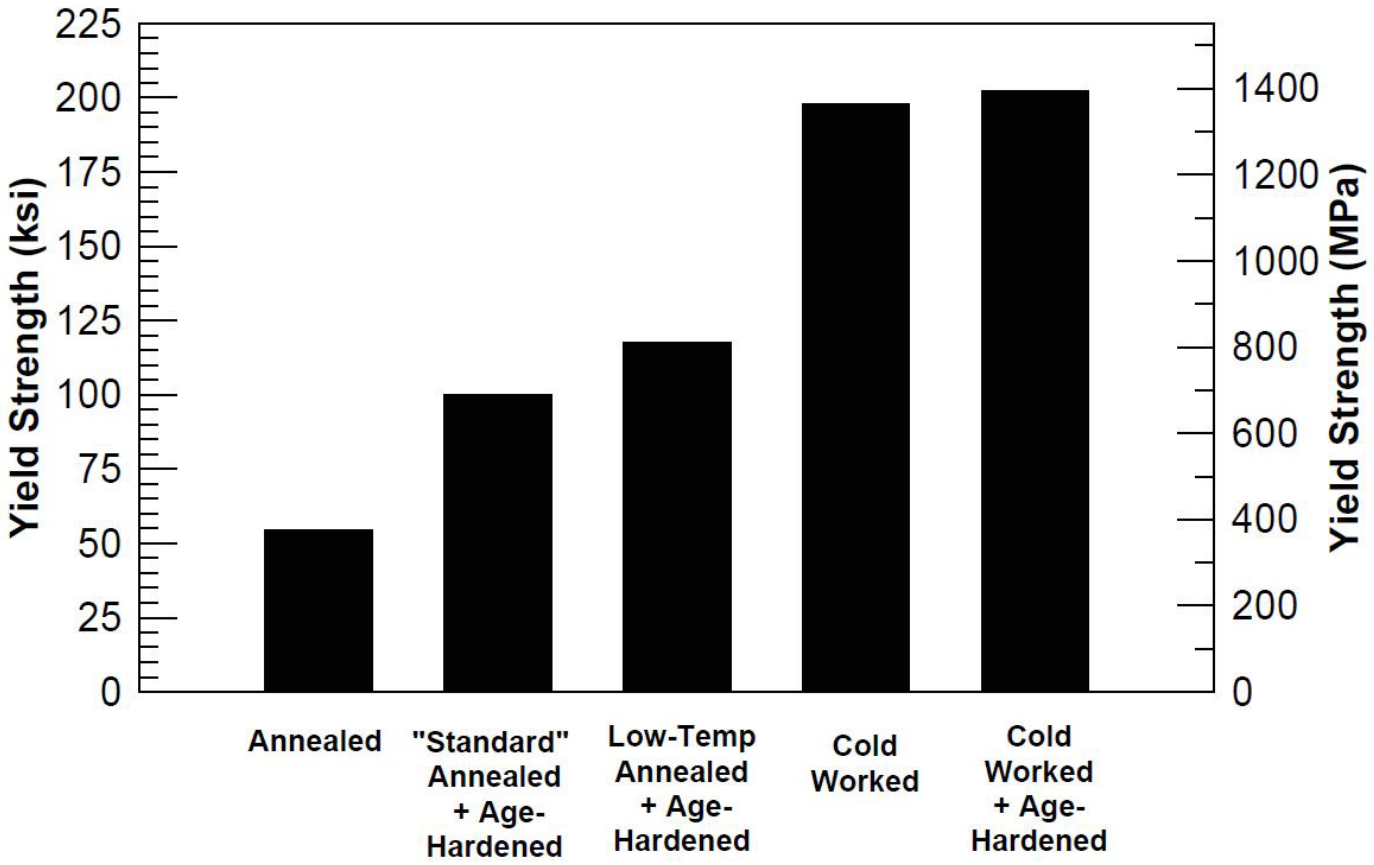
1) Cold Worked

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. 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:	61 Balance
Cobalt:	1 max.
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.
Copper:	0.5 max.

Tensile Properties of Cold-worked Material

Average Room Temperature Tensile Properties of Bar (Cold-worked in the Range 43-47%)

Condition	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
	ksi	MPa	ksi	MPa	%	%
Cold-worked Bar	198	1365	203.5	1403	16.7	64.2

Room Temperature Tensile Properties of Bar as a Function of Diameter and Percentage Cold-work

Bar Diameter*		Cold-work	Room Temperature Tensile Properties				
			0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
in	mm	%	ksi	MPa	ksi	MPa	%
0.5	12.7	43	191.1	1317	196.5	1355	18.2
0.75	19.1	44	204.7	1411	210	1448	15.5
1	25.4	44	188.3	1298	193.8	1336	17.6
1.25	31.8	46	205.2	1415	210.9	1454	15.4
1.567	39.8	37	184.2	1270	192.7	1329	17.4
2	50.8	47	207.5	1431	212	1462	13
2.375	60.3	54	181.4	1251	190.5	1313	21.2
2.5	63.5	49	180	1241	183.7	1267	18.2
3.62	91.9	42	192.3	1326	197.3	1360	14

*Averages from duplicate test samples

Tensile Properties of Cold-worked Material Continued

Room and Elevated Temperature Tensile Properties of 0.5 in Diameter Cold-worked (43%) Bar

Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
°F	°C	ksi	MPa	ksi	MPa	%	%
RT	RT	195.1	1345	200.4	1382	18	65.2
400	204	181.8	1254	182.6	1259	14.6	63.1
500	260	181	1248	181.1	1249	14.1	60.8

Room and Elevated Temperature Tensile Properties of 2.375 in Diameter Cold-worked (54%) Bar as a Function of Orientation (Longitudinal and Transverse)

Test Temperature		Orientation	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
°F	°C	-	ksi	MPa	ksi	MPa	%	%
RT	RT	Longitudinal	181.4	1251	190.5	1313	21.2	71.1
		Transverse	156.6	1080	183	1262	18.8	60.9
350	177	Longitudinal	160.2	1105	166.6	1149	18.5	72.2
		Transverse	138.3	954	160.9	1109	16.1	59.6
450	232	Longitudinal	156.1	1076	163.1	1125	18.3	72.2
		Transverse	139	958	156.7	1080	14.8	59.3

RT= Room Temperature

Average Room Temperature Tensile Properties of Tube (Cold-worked in the Range 52-53%)

Condition	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation
	ksi	MPa	ksi	MPa	%
Cold-worked Tube	187.3	1291	195	1345	15.1

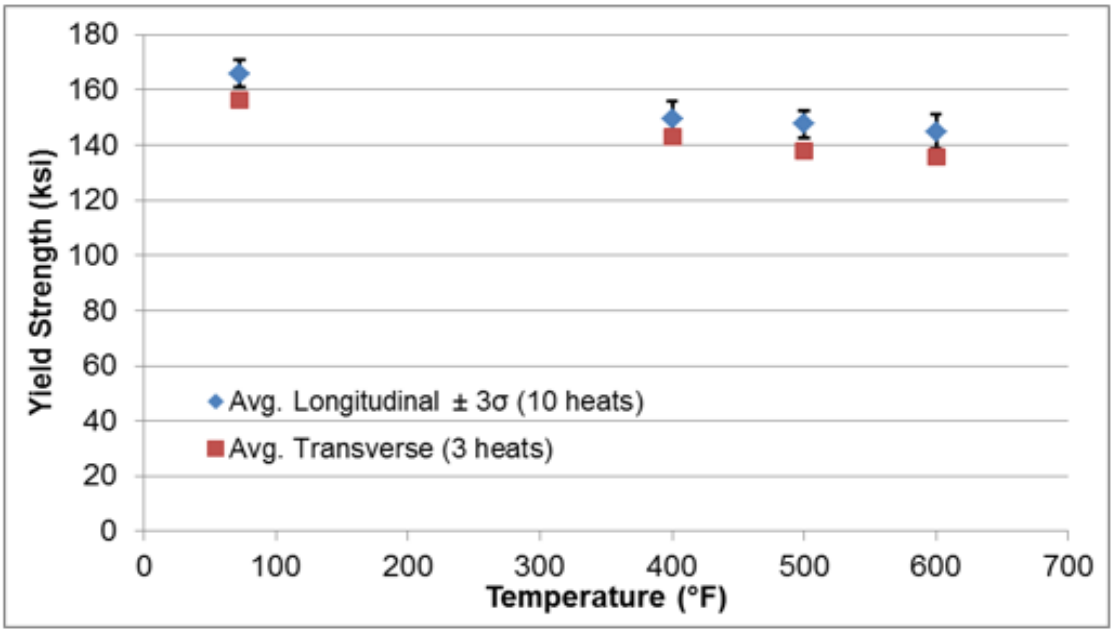
Room and Elevated Temperature Tensile Properties of Cold-worked Tube (3.5 in Diameter by 0.43 in Wall Thickness) (52-53%) as a Function of Orientation (Longitudinal and Transverse)

Test Temperature		Orientation	0.2% Offset Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
°F	°C	-	ksi	MPa	ksi	MPa	%	%
RT	RT	Longitudinal	166	1145	180.4	1244	18.8	69.5
		Transverse	156.3	1078	175.8	1212	29.2	63.6
400	204	Longitudinal	149.3	1029	157.6	1087	16.8	68.7
		Transverse	143.2	987	155.1	1069	25.8	64.8
500	260	Longitudinal	147.6	1018	154.2	1063	16.5	67.1
		Transverse	138	951	151.4	1044	24.8	60.9
600	316	Longitudinal	144.9	999	151.5	1045	16.9	66.4
		Transverse	135.7	936	147.5	1017	25.5	62.3

Values are averages from 10 tests
RT= Room Temperature

Tensile Properties of Cold-worked Material Continued

Statistical Temperature De-rating C-22HS® Cold-worked Tubing



Impact Strength

Room and Cryogenic Temperature Charpy (V-Notch) Impact Strength of 1 in Diameter Cold Worked (44%) Bar

Test Temperature	Impact Strength	
	ft.lbf	J
RT	146	198
-75°F (-59°C)	153	207
-320°F (-196°C)	113	153

Values are averages from 2 tests; all samples were longitudinal

Room and Cryogenic Temperature Charpy (V-Notch) Impact Strength of 2.375 in Diameter Cold-worked (54%) Bar as a Function of Orientation (Longitudinal and Transverse)

Test Temperature	Sample Orientation	Impact Strength	
		ft.lbf	J
RT	Longitudinal	148	201
	Transverse (Notch: Longitudinal)	60	81
	Transverse (Notch: Transverse)	54	73
-75°F (-59°C)	Longitudinal	141	191
	Transverse (Notch: Longitudinal)	63	85
	Transverse (Notch: Transverse)	52	71

Values are averages from 2 tests

Fracture Toughness

Room Temperature ASTM E1820 Tests

Material Condition	Specimen	Jc (lbs/in)	KJC (ksi.in$^{1/2}$)
Cold-worked (52-53%)	1	921	174
	2	1151	195
	3	897	172

4.25 in (108 mm) OD x 2.25 in (57 mm) ID Tube Pre-Cracked Half-T Compact Tension [C(T)] Specimens Located at 120° Increments

Hardness

Material Condition	Hardness, HRC*
Cold-worked (43-47%) Bar	42
Cold-worked (43-47%) Tube	42

*Average values
HRC= Hardeness Rockwell "C"

Compressive Strength

Room Temperature Compressive Strength of 0.75 in Diameter Cold-worked (44%) Bar and Corresponding Tensile Data

Material Condition	Compressive Yield Strength*		Compressive Strength*		Tensile Yield Strength*		Tensile Strength*	
	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
Cold-worked (44%) Bar	163	1124	219	1510	205	1413	210	1448

*Average from two tests

Resistance to Sour Gas Environments

Sour Gas Testing – NACE TM0177 Test Levels II and III, Method A, Solution A, Applied Stress = 100% YS

Material Condition	Heat	Coupling	Result*
Cold-worked	Heat 1	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
	Heat 2	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
	Heat 3	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass

*Triplicate tests

Sour Gas Testing – NACE TM0198 Slow Strain Rate Tensile, Level VII, Without (w/o) Elemental Sulfur

Material Condition	Environment*	Time to Failure (h)	Elong. (%)	R.A. (%)	Time to Failure Ratio	Elong. Ratio	R.A. Ratio	Secondary Cracking
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

*Air – single test; Level VII w/o S – triplicate tests

Sour Gas Testing – NACE TM0198 Slow Strain Rate Tensile, Level VII, With Elemental Sulfur

Material Condition	Environment*	Time to Failure (h)	Elong. (%)	R.A. (%)	Time to Failure Ratio	Elong. Ratio	R.A. Ratio	Secondary Cracking
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

*Air – single test; Level VII w/S – triplicate tests

Sour Gas Testing - NACE TM0198 Slow Strain Rate Tensile, Level VII, Test Environment: 25% NaCl, 1000 psi (6.9 MPa) H_2S + 1000 psi (6.9 MPa) CO_2, Material Condition: Cold-worked

Test Temperature		Environment*	Time to Failure (h)	Elong. (%)	R.A. (%)	Time to Failure Ratio	Elong. Ratio	R.A. Ratio	Secondary Cracking
500°F	260°C	Air	5.4	7.8	50.2	-	-	-	-
		Test Environment	5.2	7.6	50.3	0.96	0.97	1	No
550°F	288°C	Air	5.3	7.6	51.2	-	-	-	-
		Test Environment	5.4	7.8	49.6	1.02	1.02	0.97	No

*Air – single test; Test Environment – triplicate tests

Resistance to Sour Gas Environments Continued

Sour Gas Testing – NACE Standard 90 day C-Ring Test, 25% NaCl, 500 psi (3.5 MPa) H_2S + 500 psi (3.5 MPa) CO_2, 401°F (205°C), Test Level VII, Elemental Sulfur = 1 g/l and 5 g/l, Applied Stress = 100% YS**

Material Condition	Heat	Yield Strength (ksi)	Result*
Cold-worked	Heat 1	205.2	1 g/l S: Pass 5 g/l S: Pass
	Heat 2	186.6	1 g/l S: Pass 5 g/l S: Pass
	Heat 3	187.9	1 g/l S: Pass 5 g/l S: Pass

*Triplicate tests
**With stirring

Sour Gas Testing – NACE Standard 90 day C-Ring Test, 25% NaCl, 1000 psi (6.9 MPa) H_2S + 1000 psi (6.9 MPa) CO_2, 550°F (288°C), Test Level VII, Applied Stress = 100% YS

Material Condition	Heat	Yield Strength (ksi)	Result*
Cold-worked	Heat 1	205.2	Pass
	Heat 2	186.6	Pass
	Heat 3	187.9	Pass

*Triplicate tests

Resistance to Hydrpgen Embrittlement

Slow Strain Rate Tensile Test – Cold-worked Material

Environment	Max. Load		Normalized Factor	Time to Failure
	lb	kg	-	h
Air	3997	1813	-	11.6
Air	4008	1818	-	14.1
3.5% NaCl	4020	1823	1	12.9
3.5% NaCl	3937	1786	0.98	11.1
3.5% NaCl @ -850 mV	3925	1780	0.98	10.9
3.5% NaCl @ -850 mV	4003	1816	1	13.6
3.5% NaCl @ -1000 mV	3956	1794	0.99	13.8
3.5% NaCl @ -1000 mV	3908	1773	0.98	10.9

Resistance to Acids

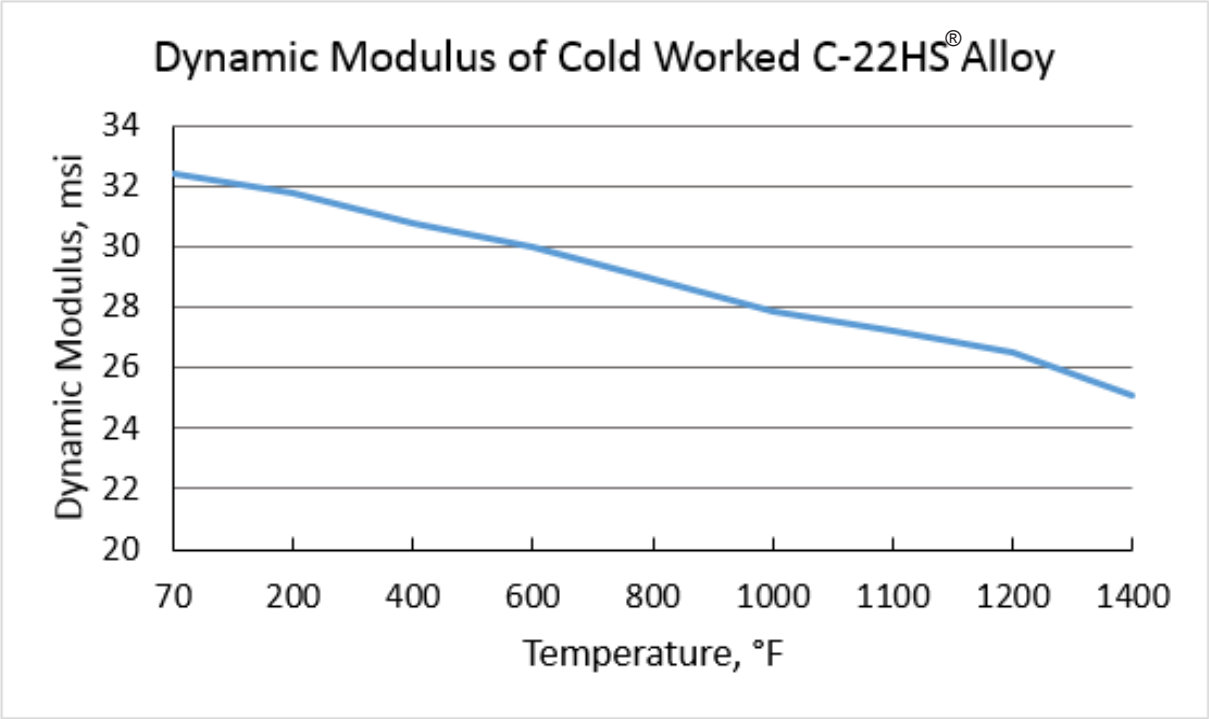
Corrosion Rates of Cold Worked (40%) Sheet in Aqueous Solutions of Common Acids

Acid	Concentration	Temperature		Corrosion Rate	
	wt%	°F	°C	mpy	mm/y
Hydrochloric	1	Boiling		0.4	0.01
	5	175	79	30	0.76
	10	100	38	<0.1	<0.01
	20	100	38	7.2	0.18
Hydrobromic Nitric	5	200	93	1.7	0.04
	20	Boiling		1.7	0.04
	40	175	79	2.1	0.05
	60	175	79	4.7	0.12
Hydrofluoric	5	125	52	0.48	0.48
Phosphoric	60	Boiling		4.7	0.12
Chromic	10	150	66	5.1	0.13
Sulfuric	10	200	93	3.8	0.1
	20	200	93	2.8	0.07
	30	200	93	6.8	0.17
	40	175	79	1.1	1.1
	50	175	79	13.1	0.03
	60	150	66	0.3	0.33
	70	150	66	3.1	0.01
	80	150	66	4.8	0.12
	90	150	66	1.3	0.03
ASTM G-28A*	-	Boiling		42.4	1.08
ASTM G-28B**	-	Boiling		9.8	0.25

*ASTM G-28A = 50% H_2SO_4 + 42 g/l $Fe_2(SO_4)_3$

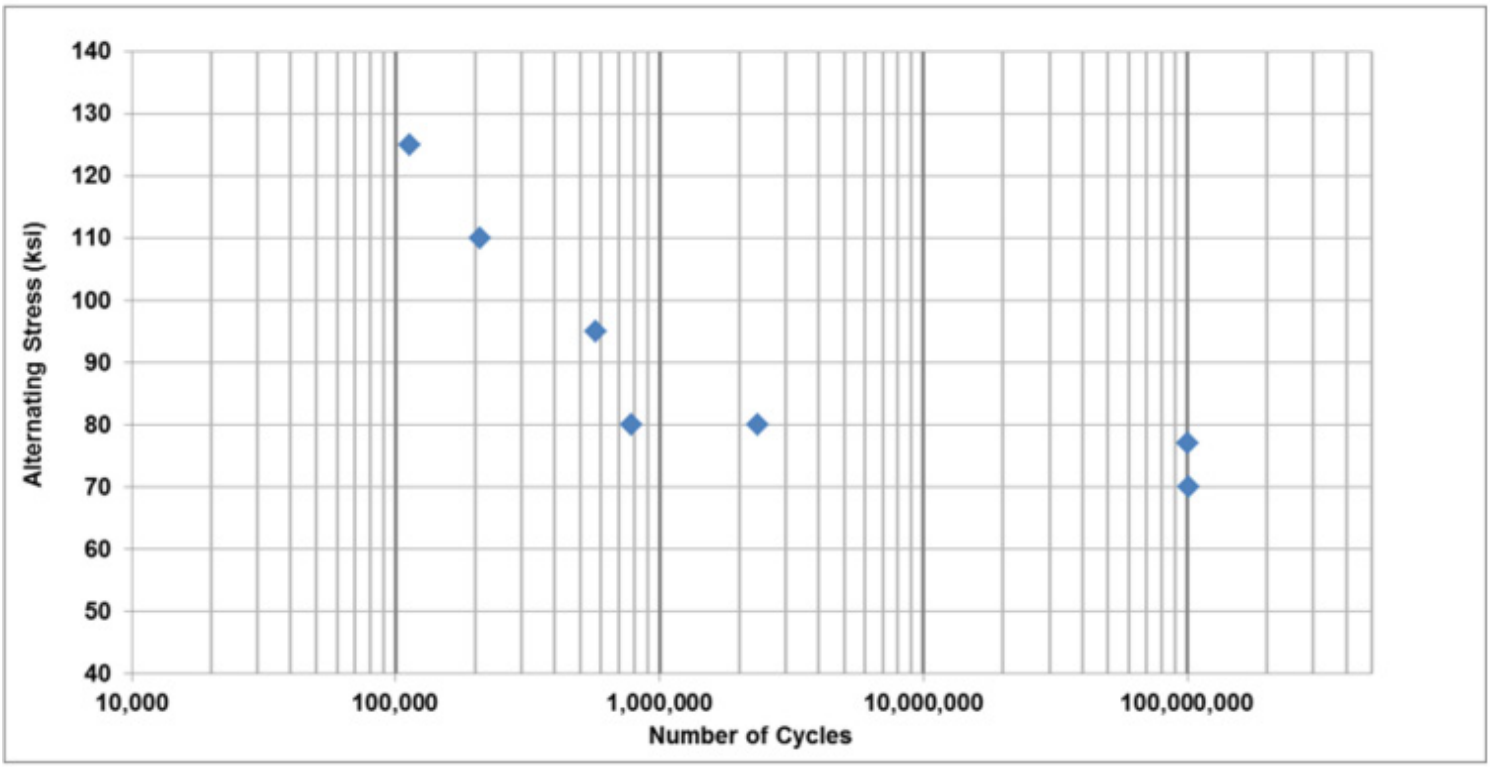
**ASTM G-28B = 23% H_2SO_4 + 1.2% HCl + 1% Fe_3Cl + 1% $CuCl_2$

Dynamic Modulus

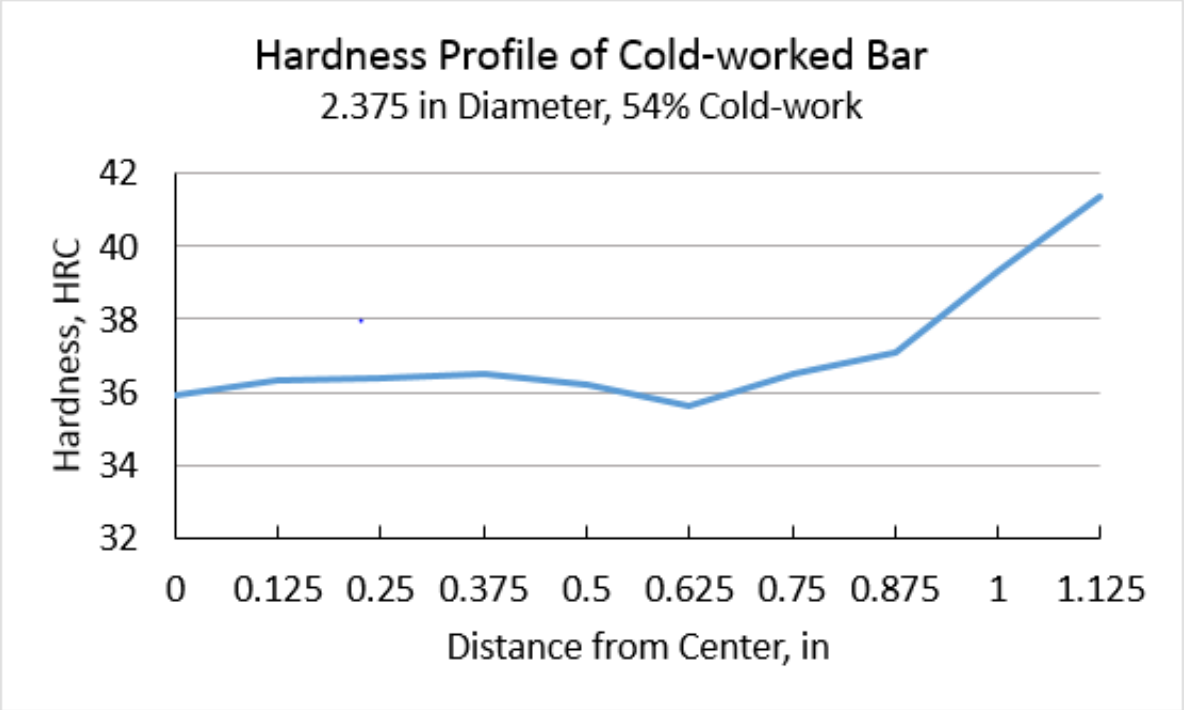


High-Cycle Fatigue

Material: 0.5 in Diameter 43% Cold Worked Bar
(0.2%YS – 191 ksi, UTS – 196 ksi, %EL – 18, %RA – 66)
Rotating Bend Fatigue Testing, RR Moore Rotating 4-Point Bend
R = -1.0 Stress Ratio, 167 Hz, Room Temperature



Hardness Profile



HRC = Hardness, Rockwell C Scale

Diameter	% Cold-Worked	Yield Strength (ksi)		Hardness (HRC)	
		1" Below Surface	Mid-Radius	1" Below Surface	Mid-Radius
7.5	50	185.5	180.3	-	-
8	50	175.4	-	-	-
8.25	40	168.1	166.2	38.6	36.1
10	30	162.3	149.8	40	35

HRC= Hardness Rockwell "C"

Thermal Stability

Effects of Thermal Exposure on Tensile Properties of 0.5 in Diameter, Cold-worked (43%) Bar

Initial Material Condition	Thermal Exposure	Test Temperature		0.2% Offset Yield Strength		Ultimate Tensile Strength		Elong.	R.A.
		°F	°C	ksi	MPa	ksi	MPa	%	%
43% Cold-worked Bar	-	RT	RT	195.1	1345	200.4	1382	18	65.2
		500	260	181	1248	181.1	1249	14.1	60.8
43% Cold-worked Bar	500°F/4000h/AC	RT	RT	205.8	1419	212.6	1466	16	62.6
		500	260	176	1214	178.5	1231	15	61.1
43% Cold-worked Bar	500°F/8000h/AC	RT	RT	209.9	1447	209.9	1447	16	60.7
		200	93	192.8	1329	192.8	1329	17	63.8
		500	260	186.6	1287	186.6	1287	13.4	60.7

AC=Air Cool
RT= Room Temperature
R.A.= Reduction of Area

Effects of Thermal Exposure on Impact Strength of 1 in Diameter, Cold-worked (44%) Bar

Initial Material Condition	Thermal Exposure	Charpy Impact Energy	
		ft.ibf	J
		RT	-75°F (-59°C)
44% Cold-worked	-	146 (198)	153 (207)
44% Cold-worked	500°F/4000h/AC	136 (184)	135 (183)

AC= Air Cooled
RT= Room Temperature

Resistance of Welds to Sour Gas Environments

Sour Gas Testing – NACE TM0177 Test Levels II and III, Method A, Solution A, Applied Stress = 100% YS, Material Condition: All Weld Metal, As Welded

Heat	Yield Strength (ksi)	Coupling	Result*
1	62	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
2	65	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass
3	63	Coupled to Carbon Steel	Pass
		NOT Coupled to Carbon Steel	Pass

*Triplicate tests

Sour Gas Testing – NACE TM0198 Slow Strain Rate Tensile, Level VII, Test Environment: 25% NaCl, 500 psi (3.5 MPa) H_2S + 500 psi (3.5 MPa) CO_2, 401°F (205°C), Material Condition: All Weld Metal, As Welded

Heat	Environment*	Time to Failure (h)	Elong. (%)	R.A. (%)	Time to Failure Ratio	Elongation Ratio	R.A. Ratio	Secondary Cracking
1	Air	33.3	47.9	63.5	-	-	-	-
	Level VII w/o S	32.1	46.2	61.2	0.96	0.96	0.96	No
2	Air	28.4	40.9	58.4	-	-	-	-
	Level VII w/o S	26.5	38.2	55.7	0.93	0.93	0.95	No
3	Air	28.9	41.6	59.7	-	-	-	-
	Level VII w/o S	28.5	41.2	61	0.99	0.99	1.02	No

*Air – duplicate tests, Level VII w/o sulfur – triplicate tests
R.A.= Reduction of Area

Sour Gas Testing – NACE TM0198 Slow Strain Rate Tensile, Level VII, Test Environment: 25% NaCl, 500 psi (3.5 MPa) H_2S + 500 psi (3.5 MPa) CO_2, Material Condition: All Weld Metal, As Welded, Heat 1

Test Temperature	Environment*	Time to Failure (h)	Elong. (%)	R.A. (%)	Time to Failure Ratio	Elongation Ratio	R.A. Ratio	Secondary Cracking
350°F (177°C)**	Air	35.2	50.7	64.1	-	-	-	-
	Test Environ. + Sulfur	34.2	49.3	63.6	0.97	0.97	0.99	No
400°F (204°C)***	Air	35.8	51.5	63.1	-	-	-	-
	Test Environ. + Sulfur	34.5	49.6	56.1	0.96	0.96	0.89	No
500°F (260°C)***	Air	33.7	48.5	64.3	-	-	-	-
	Test Environment	33.7	48.6	61	1	1	0.95	No
550°F (288°C)**	Air	34.1	49.1	65.7	-	-	-	-
	Test Environment	32.2	46.3	61.7	0.94	0.94	0.94	No

*Air – single test; Test Environment - **duplicate tests, ***triplicate tests

Specifications

Specifications

HASTELLOY® C-22HS® alloy (N07022)	
Sheet, Plate & Strip	-
Billet, Rod & Bar	B 637
Coated Electrodes	-
Bare Welding Rods & Wire	-
Seamless Pipe & Tube	B 983
Welded Pipe & Tube	-
Fittings	-
Forgings	B 637
DIN	-
TÜV	-
Others	NACE MR0175