Armco NITRONIC 33 Stainless Steel

HIGH STRENGTH AND NONMAGNETIC

- **High yield strength**
- **Excellent cryogenic properties**
- **Extremely low magnetic permeability**

Applications Potential

Outstanding strength, toughness, and very low magnetic permeability at sub-zero temperatures make Armco NITRONIC 33 Stainless Steel an excellent material for many cryogenic applications such as tanks, valves, cable, forgings, tubing, and piping. Riser pipe for underground electrical transmission lines is another application that uses the low magnetic permeability of the alloy even after severe forming operations. High strength, corrosion resistance, and good weldability of NITRONIC 33 Stainless Steel also make it a good choice for rotating equipment such as fans, containment rings, and fabricated structures.

ARMCO NITRONIC 33 STAINLESS STEEL

(ASTM GRADE XM-29, UNS S24000)

ARMCO

Product Data Bulletin No. S-79

Armco NITRONIC 33 Stainless Steel Product Description

Armco NITRONIC 33 Stainless Steel is an Armco developed and patented nitrogen-strengthened austenitic stainless steel that combines high yield strength with excellent toughness and ductility. Its magnetic permeability remains very low after severe cold working and also at very low temperatures, making it well-suited for cryogenic applications.

Composition

	%
Carbon	0.06 max
Manganese	11.50-14.50
Phosphorus	0.060 max
Sulfur	0.030 max
Silicon	1 00 max
Chromium	17.00-19.00
Nickel	2.25-3.75
Nitrogen	0.20-0.40

Available Forms

Armco NITRONIC 33 Stainless Steel is available in sheet, strip, bar, wire, rod, forging billets, plate, pipe, tubing and reinforcing bar.

Heat Treatment

Armco NITRONIC 33 Stainless Steel is an austenitic stainless steel and can be hardened only by cold work. Annealing is performed at 1950 F (1066 C), followed by rapid cooling.

Metric Practice

The values shown in this bulletin were established in U.S. customary units. The metric equivalents of U.S. customary units shown may be approximate. Conversion to the metric system, known as the International System of Units (SI), has been accomplished in accordance with the American Iron and Steel Institute Metric Practice Guide, 1978.

The newton (N) has been adopted by the SI as the metric standard unit of force as discussed in the Metric Practice Guide. The term for force per unit of area (stress) is the newton per square metre (N/m^2). Since this can be a large number, the prefix mega is used to indicate 1,000,000 units and the term meganewton per square metre (MN/m^2) has been designated a pascal (Pa). The relationship between the U.S. and the SI units for stress is: 1000 pounds/in^2 (psi) = 1 kip/in^2 (ksi) = 6.8948 meganewtons/m^2 (MN/m^2) = 6.8948 megapascals (MPa). Other units are discussed in the Metric Practice Guide.

Mechanical Properties

Table 1
Typical Mechanical Properties*
Sheet and Strip

Property	
UTS, ksi (MPa)	115 (793)
0.2% YS, ksi (MPa)	68 (469)
Elongation, % in 2" (50.8 mm) or 4 x D)	50
Hardness, Rockwell	B95

*Room temperature, annealed condition. Thickness—.100" (2.5 mm)

Table 2
Properties Acceptable for Material Specifications
Annealed Sheet, Strip and Plate

Product	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm) or 4 x D	Hardness, Rockwell B
Sheet, Strip	100 (689) min	60 (415) min	40 min	100 max
Plate	100 (689) min	55 (379) min	40 min	100 max

Based on the strength of Armco NITRONIC 33 Stainless Steel, ASME allowable stresses for welded tubing are 25%-35% greater than that for Type 304 stainless steel (ASME BPVC Section VIII, Division 1—Pressure Vessels).

Table 3
Typical Mechanical Properties*
Annealed Bar

UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 4 x D	Reduction of Area %	Hardness, Rockwell	Impact Charpy V-Notch ft-lbs (J)
110 (758)	60 (414)	55	70	B96	230 (307)

*Room temperature, annealed condition, 1" (25.4 mm) diameter bar.

Table 4
Properties Acceptable For Material Specifications
Annealed Bars—Up to 8" (203.2 mm) Inclusive

Condition	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm) or 4 x D	Reduction of Area %	Hardness, Rockwell
Annealed	100 (689) min	55 (379) min	30 min	50 min	B92 min

Table 5
Typical Properties of Cold-Reduced NITRONIC 33 Sheet

Property	Cold Reduction, %						
	0	10	20	30	40	50	60
UTS, ksi (MPa)	115 (793)	133 (917)	160 (1103)	184 (1269)	200 (1379)	210 (1448)	222 (1530)
0.2% YS, ksi (MPa)	68 (469)	105 (724)	140 (965)	167 (1152)	181 (1248)	191 (1317)	199 (1372)
Elongation, % in 2" (50.8 mm)	51	32	18	10	7.5	6.5	5.0
Hardness, Rockwell	B95	C30	C37	C41	C42	C44	C45

Fatigue Strength

Table 6
Rotating Beam Fatigue Strength*
Annealed Bar and Plate

Maximum Stress ksi (MPa)	Cycles to Failure	
	½" (12.9 mm) Plate	1" Diameter (25.4 mm) Bar
50.0 (345)	39,000	—
50.0 (345)	50,000	—
47.5 (328)	119,000	50,000
46.5 (320)	474,000	—
45.0 (310)	1,536,000	222,000
45.0 (310)	—	434,000
42.5 (293)	3,324,000	3,107,000
40.0 (276)	4,325,000	120,223,000**
40.0 (276)	5,885,000	—
37.5 (258)	113,059,000**	—
35.0 (241)	17,221,000	—
35.0 (241)	117,241,000**	—
32.5 (224)	102,047,000**	—

*Specimens tested in R. R. Moore Rotating Beam Machine.
**Did not fail, test discontinued

Table 7
Axial Load Fatigue Strength
Annealed Plate

Maximum Stress ksi (MPa)	Cycles to Failure	
	Stress Ratio R = +0.1 ½" (12.9 mm) Plate	Stress Ratio R = −1.0 ½" (12.9 mm) Plate
90.0 (621)	120,000	—
85.0 (586)	233,300	—
80.0 (552)	303,500	—
75.0 (517)	575,100	—
72.5 (499)	826,400	—
70.0 (483)	7,887,700	—
70.0 (483)	5,639,200	—
45.0 (310)	—	11,200
42.5 (293)	—	18,600
40.0 (276)	—	2,350,000
37.5 (258)	—	5,591,000
37.5 (258)	—	6,973,000
35.0 (241)	—	10,813,000*

*Did not fail, test discontinued.

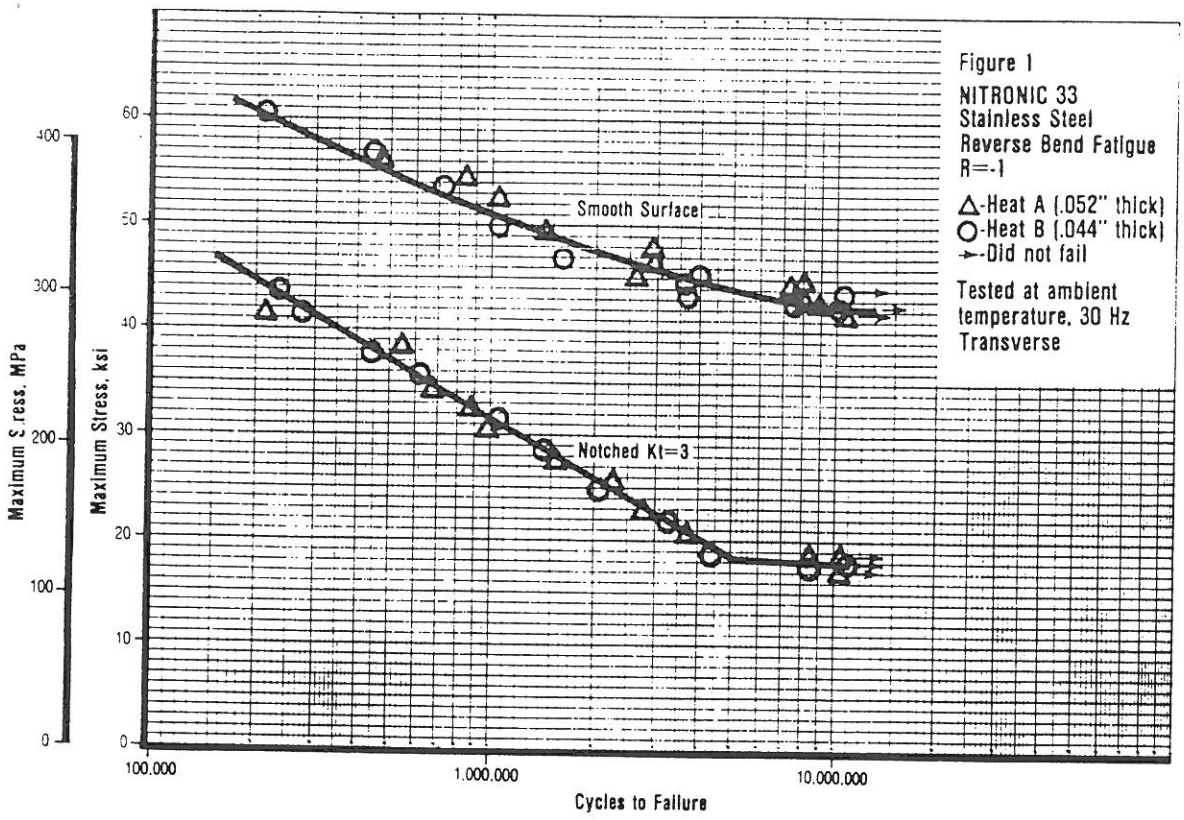


Figure 1
NITRONIC 33
Stainless Steel
Reverse Bend Fatigue
R=-1

△-Heat A (.052" thick)
○-Heat B (.044" thick)
→-Did not fail

Tested at ambient temperature, 30 Hz
Transverse

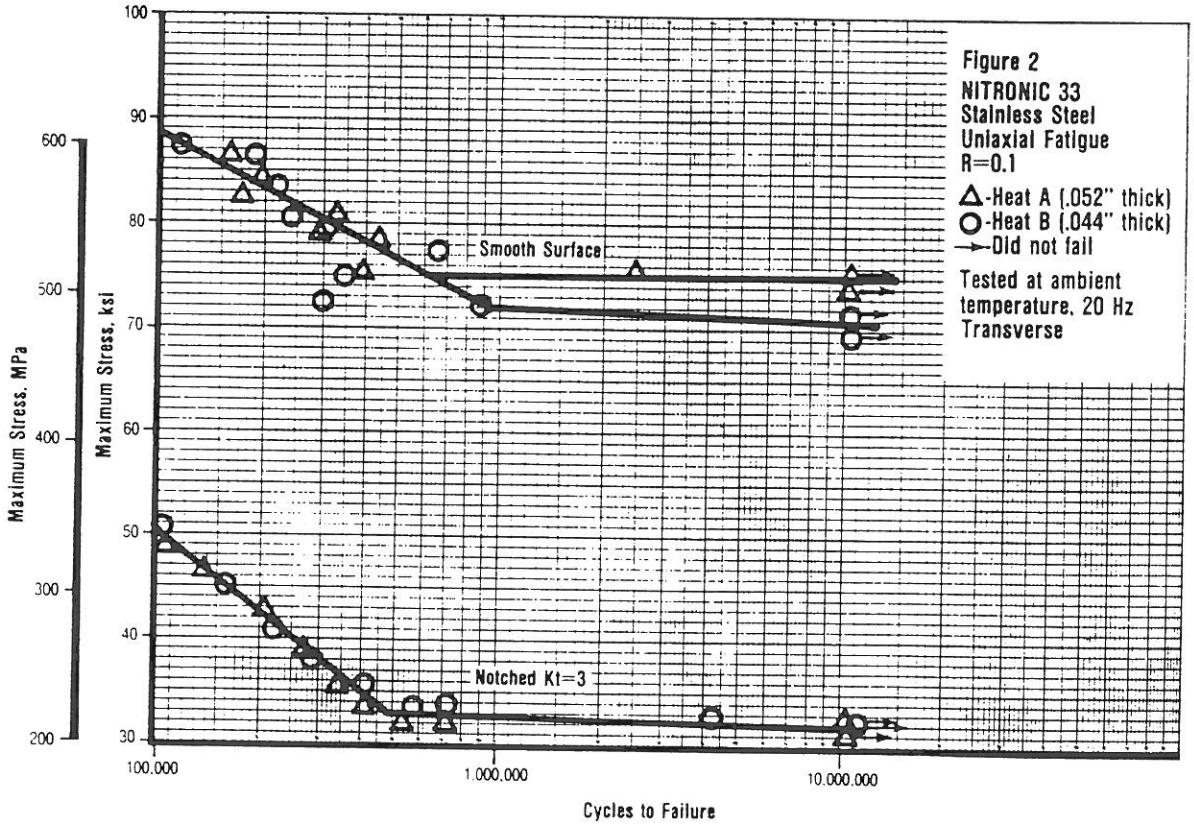


Figure 2
NITRONIC 33
Stainless Steel
Uniaxial Fatigue
R=0.1

△-Heat A (.052" thick)
○-Heat B (.044" thick)
→-Did not fail

Tested at ambient temperature, 20 Hz
Transverse

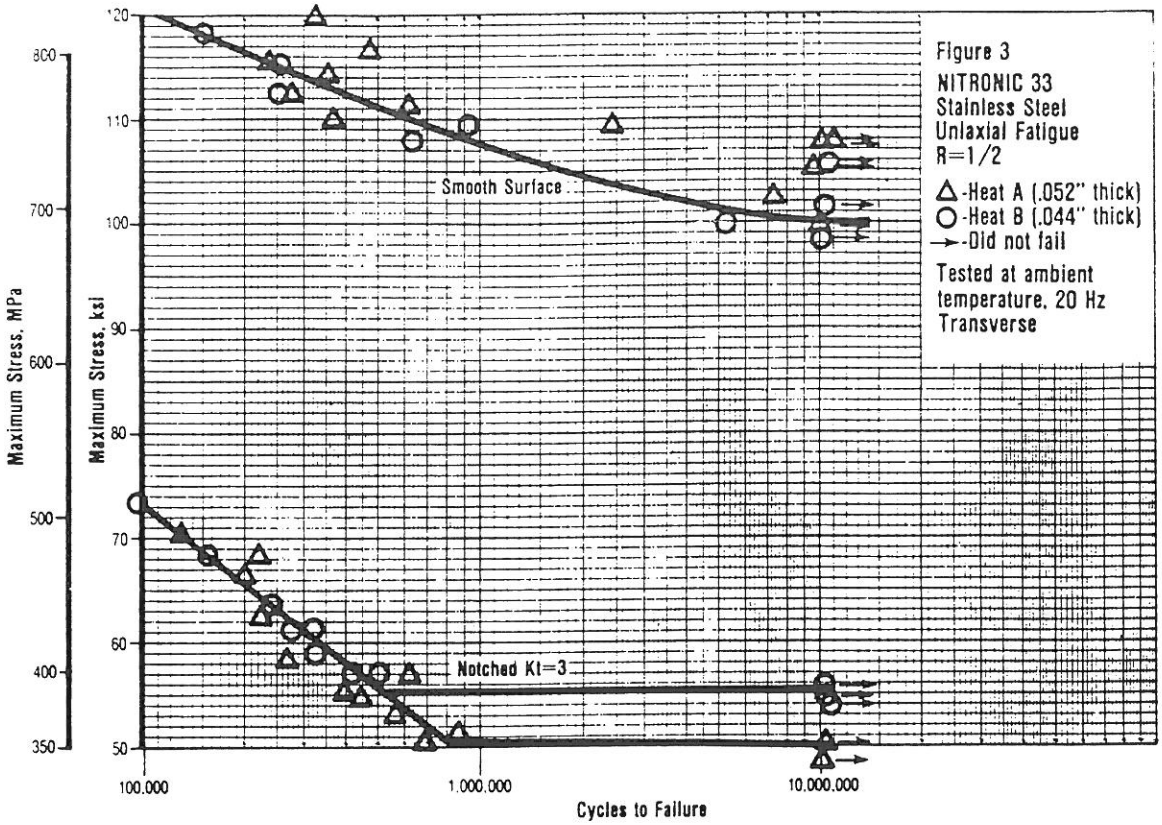


Figure 3
NITRONIC 33
Stainless Steel
Unlaxial Fatigue
R=1/2

△-Heat A (.052" thick)
○-Heat B (.044" thick)
→-Did not fail

Tested at ambient temperature, 20 Hz
Transverse

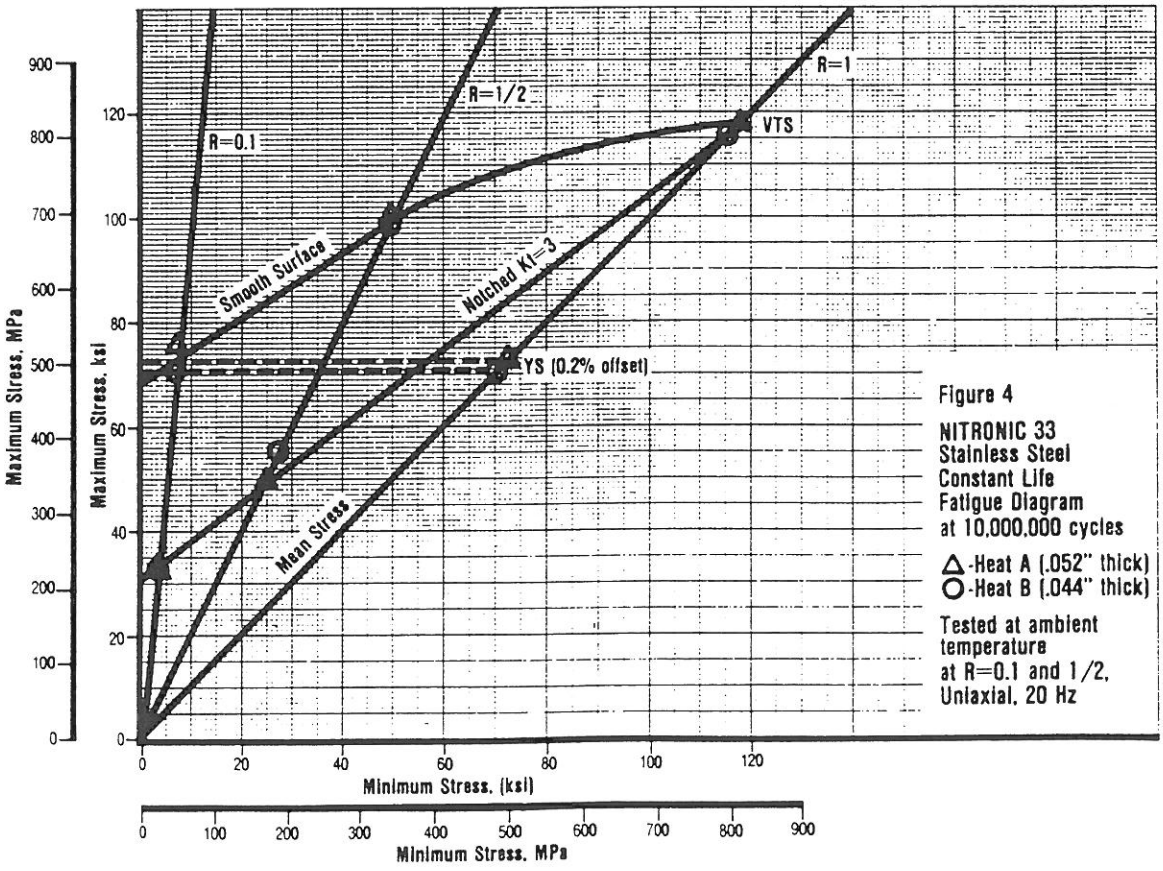


Figure 4
NITRONIC 33
Stainless Steel
Constant Life
Fatigue Diagram
at 10,000,000 cycles

△-Heat A (.052" thick)
○-Heat B (.044" thick)

Tested at ambient temperature
at R=0.1 and 1/2,
Uniaxial, 20 Hz

Excellent Cryogenic Properties

When cooled to sub-zero temperatures, Armco NITRONIC 33 Stainless Steel exhibits a large increase in tensile strength without suffering the usual loss of notch toughness. These properties, coupled with relatively high room-temperature yield strength and extremely low magnetic permeability at all temperatures, make NITRONIC 33 Stainless attractive for many cryogenic applications.

For applications at temperatures below −320 F (−196 C) where impact loading is a concern, Armco NITRONIC 40 Stainless Steel should be considered rather than Armco NITRONIC 33 Stainless Steel.

Table 8

Typical Mechanical Properties at Cryogenic Temperatures* NITRONIC 33 Stainless Steel Sheet

Test Temperature F (C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)
0 (−18)	142 (979)	85 (586)	64.5
−50 (−46)	152 (1048)	94 (648)	63
−100 (−73)	166 (1145)	104 (717)	60.5
−150 (−101)	179 (1234)	116 (800)	55
−200 (−129)	195 (1345)	132 (910)	49.5
−242 (−152)	208 (1434)	146 (1007)	42.5
−320 (−196)	229 (1579)	176.5 (1217)	20

*Data are the average of triplicate transverse tests.

Table 9

Tensile Strength and Notch Toughness* Annealed NITRONIC 33, NITRONIC 40 and Type 304 Sheet

Test Temperature F (C)	Alloy	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)	Notch Strength ksi (MPa)	Ratio NS/UTS
75 (24)	NITRONIC 33	117 (807)	71.5 (493)	44	95 (655)	0.81
	NITRONIC 40	114 (786)	71 (490)	43	92.5 (638)	0.81
	Type 304	89.5 (617)	35.5 (245)	62.5	61 (421)	0.68
−320	NITRONIC 33	229 (1579)	176.5 (1217)	20	183 (1262)	0.80
(−196)	NITRONIC 40	231 (1593)	173 (1193)	57	193 (1331)	0.83
	Type 304	225 (1551)	74 (510)	40	101 (696)	0.45

*Average of duplicate transverse tests. Notch strength determined on NASA edge notch specimens 1" (25.4 mm) wide, with 60° 0.0007" (0.0178 mm) maximum root radius.

Table 10

Comparative Tensile Properties of Sheet Cold Rolled 60%* NITRONIC 33, NITRONIC 40 and Type 304L Stainless Steel

Alloy	Test Temperature F (C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)	Hardness, Rockwell
NITRONIC 33	75 (24)	204 (1407)	183 (1262)	9	44
	0 (−18)	223 (1538)	184 (1269)	10.5	—
	−100 (−73)	242 (1669)	203 (1400)	13	—
	−150 (−101)	253 (1744)	212 (1462)	9.5	—
	−250 (−157)	287 (1979)	218 (1502)	7.5	—
	−320 (−196)	324 (2234)	254 (1751)	6.5	—
NITRONIC 40	75 (24)	203 (1400)	190 (1310)	8	44.5
	0 (−18)	216 (1489)	—	9.5	—
	−100 (−73)	239 (1648)	—	10	—
	−150 (−101)	255 (1758)	—	7.5	—
	−320 (−196)	330 (2275)	—	8.5	—
Type 304L	75 (24)	183 (1262)	158 (1089)	5	39.5
	0 (−18)	215 (1482)	158 (1089)	14	—
	−100 (−73)	231 (1593)	161 (1110)	22.5	—
	−150 (−101)	240 (1655)	165 (1138)	25	—
	−250 (−157)	256 (1765)	174 (1200)	28	—

*Data are the average of duplicate longitudinal tests.

Short-Time Elevated Temperature Properties*

Table 11
Typical Short-Time Elevated Temperature Tensile Properties* NITRONIC 33 Stainless Steel Sheet

Temperature F (C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)
75 (24)	117 (807)	72 (496)	49
200 (93)	106 (731)	59 (407)	50
400 (204)	93 (641)	45 (310)	44
600 (315)	91 (627)	39 (269)	44
800 (426)	82 (565)	36 (248)	49
1000 (538)	74 (510)	32 (221)	39

*Data points represent averages of eight tests consisting of duplicate longitudinal and transverse tests on each of two heats. Samples were taken from 0.050" (1.25 mm) thick annealed sheet.

Table 12
Typical Stress-Rupture Strength of NITRONIC 33 Stainless Steel Sheet*

Test Temperature, F (C)	Stress to Failure, ksi (MPa) in 100 Hours	1000 Hours	10,000 Hours
900 (482)	78 (538)**	63 (434)	52 (359)**
1000 (538)	58 (400)	47 (324)	37.5 (259)**
1100 (593)	49 (338)	38.5 (266)	31 (214)**
1200 (648)	36 (248)	23.5 (162)	14.5 (100)**
1350 (734)	15 (103)	7.6 (52.4)	4.0 (27.6)**
1500 (815)	6.8 (46.8)	3.3 (22.8)**	1.6 (11.0)**

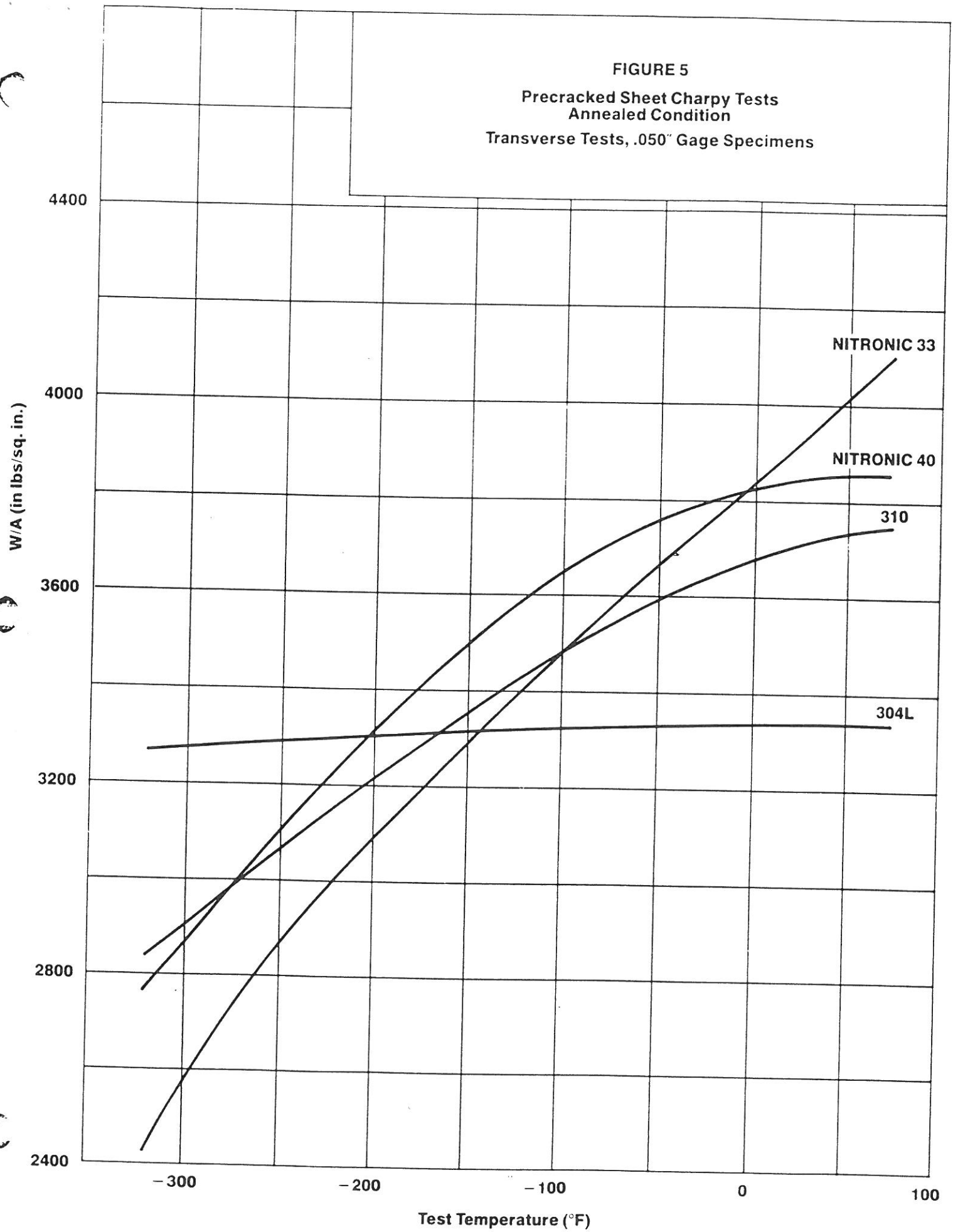
*Mill annealed .062" (1.57 mm) thick sheet. Average of duplicate tests from one heat.

**Extrapolated

FIGURE 5

Precracked Sheet Charpy Tests
Annealed Condition

Transverse Tests, .050" Gage Specimens



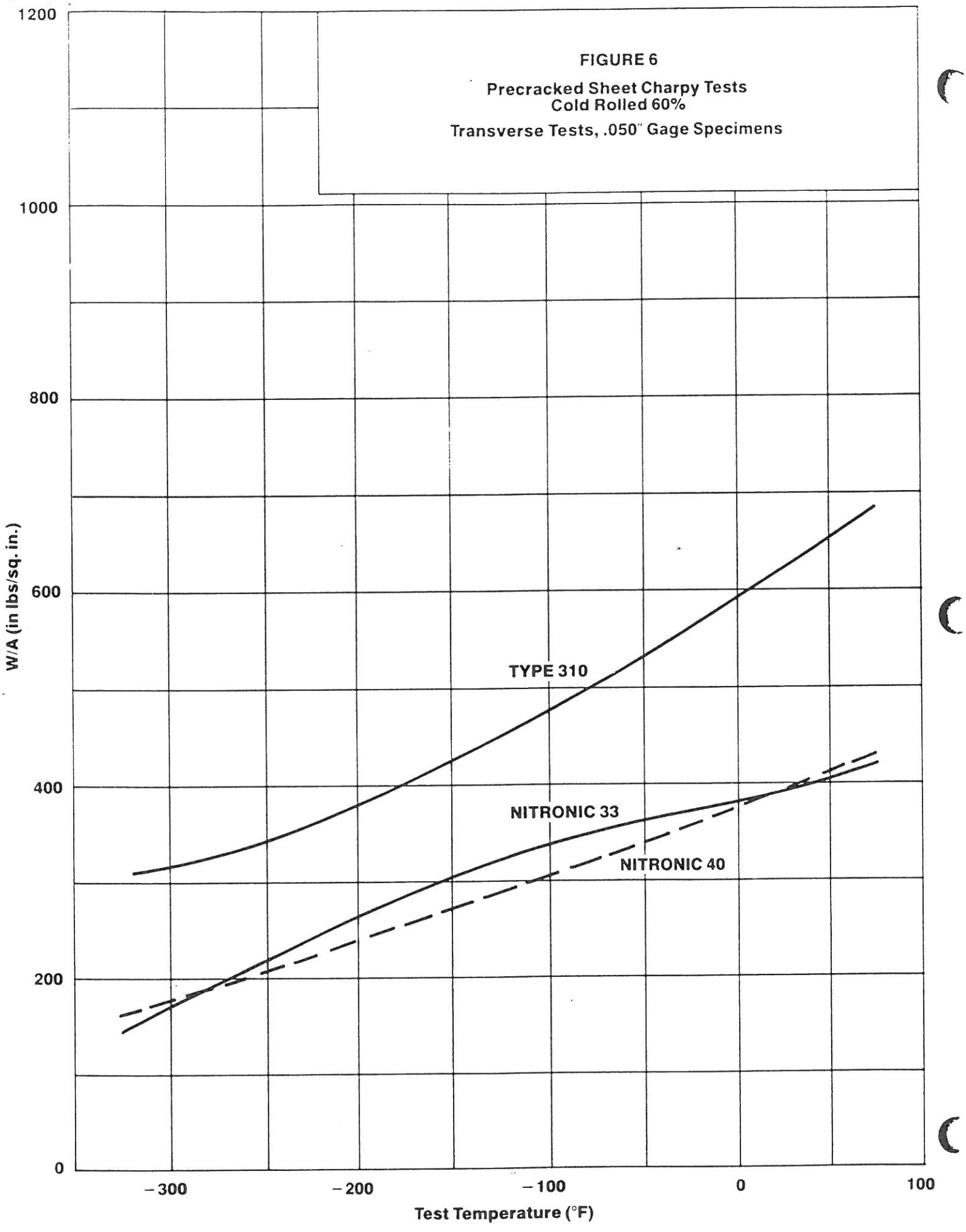


FIGURE 6
Precracked Sheet Charpy Tests
Cold Rolled 60%
Transverse Tests, .050" Gage Specimens
1200
1000
800
600
400
200
0
W/A (in lbs/sq. in.)
TYPE 310
NITRONIC 33
NITRONIC 40
−300
−200
−100
0
100
Test Temperature (°F)

Physical Properties

Density at 75 F (24 C)
7.755 g/cm³ (2% less than Type 304)
0.280 lbs/in³

Electrical Resistivity at 75 F (24 C)
70 microhm-cm

Low Magnetic Permeability

Armco NITRONIC 33 Stainless Steel provides very low magnetic permeability even after severe cold working. When cold reduced as much as 70%, the permeability remains well below 1.02. Table 13 presents data that was obtained from tests on a typical heat.

Table 13
Typical Magnetic Permeability at 75 F (24 C)
ASTM A342, Method 4

% Cold Reduction	H = 500	H = 1000
0	1.0014	1.0013
10	1.0013	1.0012
20	1.0015	1.0011
30	1.0010	1.0013
40	1.0015	1.0013
50	1.0011	1.0012
60	1.0012	1.0012
70	1.0009	1.0013

Magnetic permeability at cryogenic temperatures

The magnetic permeability of NITRONIC 33 Stainless Steel also remains very low at cryogenic temperatures. Magnetic susceptibility data shown in Table 14 were obtained on mill-annealed sheet samples using the Curie Magnetic Force Method.

Table 14
Magnetic Permeability at Cryogenic Temperatures*

Temperature F (C)	Magnetic Mass Susceptibility χ, 10^{-6} cm³ g⁻¹	Magnetic Permeability μ
77 25	17.5	1.0017
− 9 −23	18.4	1.0018
− 99 −73	20.0	1.0020
−126 −88	24.0	1.0023
−189 −123	18.0	1.0018
−279 −173	17.4	1.0017
−320 −196	16.9	1.0016

*Reference: *Advances in Cryogenic Engineering Materials*, Vol. 26 (1980), p. 33-47.

Note that the magnetic susceptibility of Armco NITRONIC 33 Stainless Steel exhibits a cusp at approximately −126 F (−88 C). This phenomenon, which also occurs for Armco NITRONIC 40 and NITRONIC 50 Stainless Steels, is dependent upon temperature but not on field strength. Unlike the AISI 300 series stainless steels, Armco NITRONIC alloys show no supermagnetism.

Thermal Expansion

Table 15
Thermal Expansion

Temperature Range F (C)	Coefficient of Linear Expansion in/in/°F (mm/mm/°C)
78- 200 (25-93)	8.93x10⁻⁶ (16.07x10⁻⁶)
78- 400 (25-204)	9.17x10⁻⁶ (16.51x10⁻⁶)
78- 600 (25-316)	9.68x10⁻⁶ (17.42x10⁻⁶)
78- 800 (25-427)	10.07x10⁻⁶ (18.13x10⁻⁶)
78-1000 (25-538)	10.43x10⁻⁶ (18.77x10⁻⁶)
78-1200 (25-649)	10.84x10⁻⁶ (19.51x10⁻⁶)
78-1400 (25-760)	11.15x10⁻⁶ (20.07x10⁻⁶)
78-1600 (25-871)	11.40x10⁻⁶ (20.52x10⁻⁶)
78-1800 (25-981)	11.69x10⁻⁶ (21.04x10⁻⁶)

Table 16

Thermal Contraction at Sub-Zero Temperatures

Temperature Range F	(C)	Coefficient of Linear Contraction △L/L per °F	△L/L per °C
68 to 0	(20 to −18)	8.33×10^{-6}	(15.00×10^{-6})
68 to −50	(20 to −46)	8.31×10^{-6}	(14.96×10^{-6})
68 to −100	(20 to −73)	8.07×10^{-6}	(14.53×10^{-6})
68 to −150	(20 to −101)	7.61×10^{-6}	(13.70×10^{-6})
68 to −200	(20 to −129)	7.05×10^{-6}	(12.69×10^{-6})
68 to −250	(20 to −157)	6.45×10^{-6}	(11.61×10^{-6})
68 to −300	(20 to −184)	5.86×10^{-6}	(10.55×10^{-6})

Table 17

Thermal Conductivity at Elevated Temperatures

Temperature F (C)	Thermal Conductivity Btu/hr/ft²/in/°F	(W/m·K)
212 (100)	110	(15.8)
392 (200)	120	(17.3)
572 (300)	131	(18.9)
752 (400)	141	(20.4)
932 (500)	152	(21.9)
1112 (600)	162	(23.4)
1292 (700)	172	(24.8)
1472 (800)	181	(26.1)

Table 18

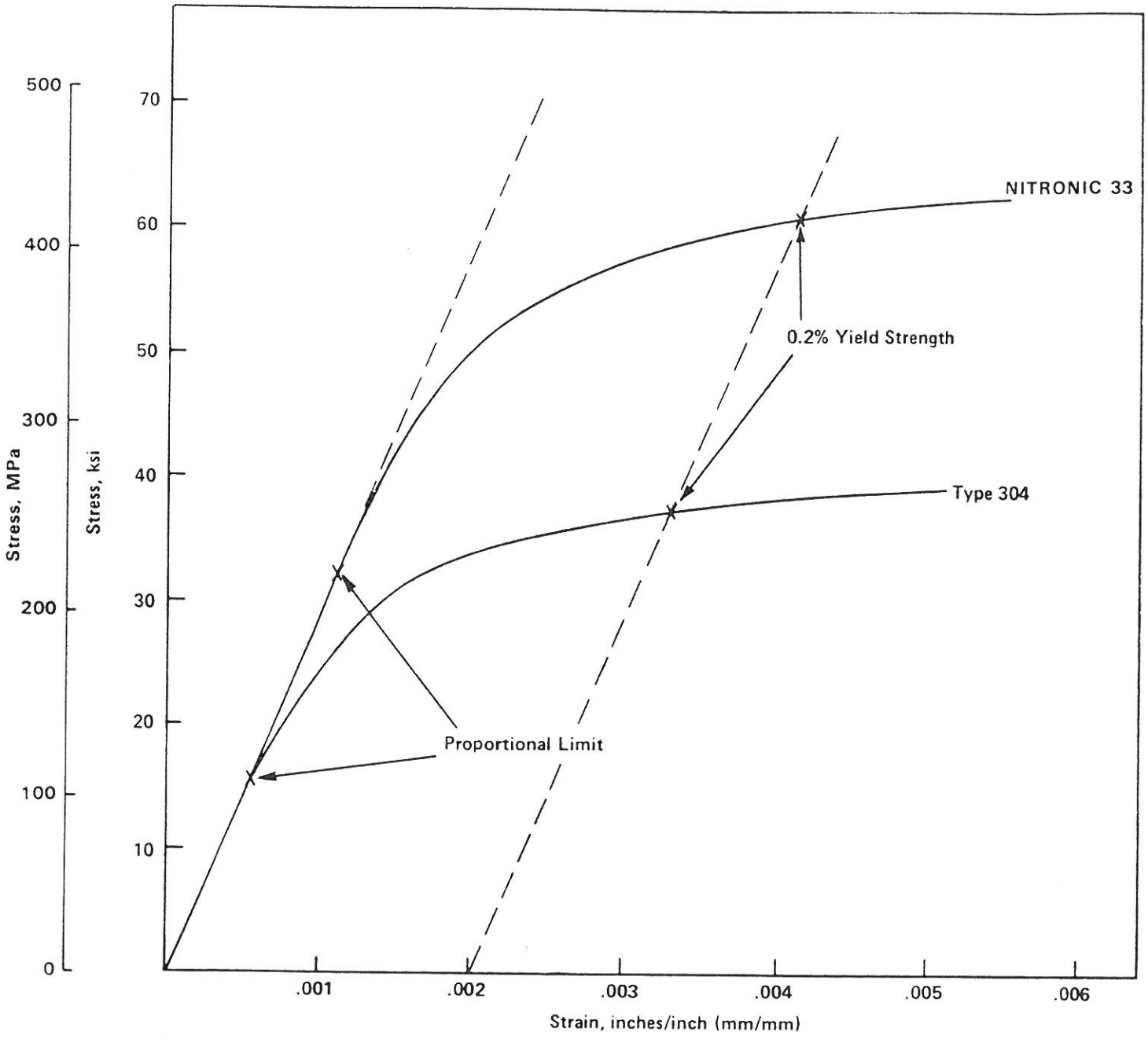
Electrical Resistivity at Elevated Temperatures

Temperature F (C)	Resistivity Microhm-cm
77 (25)	74
212 (100)	80
392 (200)	87
572 (300)	94
752 (400)	100
932 (500)	106
1112 (600)	111
1292 (700)	115
1472 (800)	119

Typical engineering stress-strain curves for Armco NITRONIC 33 and Type 304 stainless steel bar stock (tested in tension) are shown in Figure 7.

FIGURE 7

Typical Engineering Stress-Strain Curves Obtained in Tension on Bar Samples (Longitudinal Direction)



Elastic Properties at Elevated Temperatures

Table 19

Elastic Properties at Elevated Temperatures*

Temperature F (C)	Young's Modulus in Tension psi (MPa)	Poisson's Ratio
72 (22)	28.8×10^6 (199×10^3)	0.305
300 (149)	26.9×10^6 (185×10^3)	0.293
500 (260)	25.3×10^6 (174×10^3)	0.286
700 (371)	24.0×10^6 (165×10^3)	0.283

*Tests performed on sheet samples in the longitudinal direction using strain gages.

Wear Properties

Armco NITRONIC 33 Stainless Steel exhibits improved resistance to wear in sliding metal-to-metal contact compared to Type 304 stainless steel. Laboratory tests run according to ASTM G83 Crossed Cylinder Geometry gave the results shown in Table 20.

Armco NITRONIC 33 Stainless Steel exhibits improved galling resistance over Type 304 stainless and may be considered where Type 304 is marginal. Armco NITRONIC 60 Stainless Steel should be specified if galling persists.

Table 20
Metal-to-Metal Wear Properties

Alloy	Hardness (Rockwell)	Weight Loss, mg/1000 revolutions* 105 rpm	415 rpm
NITRONIC 33	B94	7.95	4.35
Type 310	B72	10.40	6.49
Type 316	B91	12.50	7.32
Type 304	B99	12.77	7.59
17-4 PH	C43	52.80	12.13
Type 410	C40	192.79	22.50

*16 pound load, 10,000 revolutions, room temperature, duplicate self-mated tests, 0.50" diameter specimens.

Corrosion Resistance

The corrosion resistance of Armco NITRONIC 33 is much better than that of Type 409, and, in general, is nearly as good as that of Type 304 stainless steel. This is illustrated by the laboratory data in Table 21.

Armco NITRONIC 33 Stainless Steel was unaffected by exposure for 500-hour periods to 100% relative humidity at 120 F (49 C) and to 5% salt fog at 95 F (35 C) following ASTM B117 test procedure. Exposure to marine atmosphere for 42 months at a location 800 feet (250 m) from the Atlantic Ocean produced light superficial rusting on both NITRONIC 33 and Type 304 stainless steels, with NITRONIC 33 Stainless the better of the two alloys.

NITRONIC 33, like most stainless steels, is prone to pitting and crevice corrosion in seawater and other aggressive environments, and should not be used under these conditions unless cathodically protected.

Intergranular Attack

Like other austenitic stainless steels, the resistance of NITRONIC 33 to intergranular attack depends upon the carbon content of the material and the length of time at temperature in the sensitizing range. Table 22 shows data for NITRONIC 33 sheet coupons containing several levels of carbon, tested according to ASTM A262, Practices A, C, and E.

Table 21
Immersion Tests in Various Media

Test Medium	Corrosion Rates in IPY Unless Otherwise Indicated [1] NITRONIC 33	Type 304	Type 409
10% $FeCl_3$ @ 25C-plain	.522 gm/in²	.424 gm/in²	.772 gm/in²
10% $FeCl_3$ @ 25C-creviced	.450 gm/in²	.358 gm/in²	.636 gm/in²
65% HNO_3 @ Boiling	.024	.010	.671
50% H_3PO_4 @ Boiling	.006	.008	.485
5% Formic @ 80C	<.001	<.001	.056[4]
33% Acetic @ Boiling	<.001	<.001	—
1% H_2SO_4 @ 80C	<.001-.089	<.001-.063	Dissolved
5% H_2SO_4 @ 80C	Dissolved	<.001-.462	Dissolved
1% HCl @ 35C	.001	<.001	.535
2% HCl @ 35C	.109	<.001-.014	—
5% Salt Fog @ 35C	OK after 500 hrs.	OK after 500 hrs	Rusting in 24 hrs.

[1] Immersion tests of 1"x2" mill annealed sheet coupons. One heat tested per alloy. Results are the average of duplicate specimens exposed for five 48-hour periods. Those specimens tested at 35°C and 80°C were intentionally activated for the third, fourth, and fifth periods. Where both active and passive conditions occurred, the averages of both are shown.

[2] Exposed for 48 hours uncreviced.

[3] Exposed for 48 hours with rubber bands to produce crevices.

[4] Average of three 48-hour periods, not activated.

Table 22
Intergranular Attack Tests

% Carbon	Condition	Practice A Oxalic Acid	Practice C Nitric Acid	Practice E Cu-CuSO$_4$
.04	Annealed	Step	.0020 IPM*	Passed
.04	1250F-20 Min.-A.C.	Step	.0037 IPM	Passed
.04	1250F-60 Min.-A.C.	Step	.0040 IPM	Passed
.05	Annealed	Step	.0020 IPM	Passed
.05	1250F-20 Min.-A.C.	Step	.0037 IPM	Passed
.05	1250F-60 Min.-A.C.	Dual	.0095 IPM	Failed
.06	Annealed	Step	.0020 IPM	Passed
.06	1250F-20 Min.-A.C.	Dual	.0029 IPM	Failed
.06	1250F-60 Min.-A.C.	Dual	.0125 IPM	Failed

*Inches per month penetration

When reheated to temperatures in the sensitizing range of 1000 F to 1500 F (538 C to 815 C) and held for 20 minutes, NITRONIC 33 Stainless has good resistance to intergranular attack for carbon contents up to .05%. This time period represents the maximum exposure to these temperatures that would be caused by welding all but extremely heavy plate.

When held for 60 minutes at temperatures in this range, the carbon content of NITRONIC 33 Stainless should be restricted to a maximum of .04% for good resistance to intergranular attack. One-hour sensitizing heat treatments are commonly used to evaluate stainless steels for use in welded construction, but are not realistic in that they almost always are longer than the actual time experienced in fabrication and, as a result, are too severe.

Stress Corrosion Cracking

Like most stainless steels, Armco NITRONIC 33 may suffer stress corrosion cracking in hot chloride environments under certain conditions. The threshold stress for cracking of NITRONIC 33 in boiling 42% $MgCl_2$ solution (a very severe test) is about 25 ksi (172 MPa), compared with about 10 ksi (69 MPa) for Types 304 and 304L. This means NITRONIC 33 is markedly more resistant than these alloys to cracking in hot chloride containing solutions at lower stress levels. At higher stress levels (about 25 ksi and above), the chloride stress corrosion cracking resistance of NITRONIC 33 Stainless Steel is about that of Types 304 and 304L. This is illustrated by the data derived by the dead-weight-loaded tensile method described in ASTM STP 425 and shown in Table 23.

U-bend stress corrosion test specimens of Armco NITRONIC 33 Stainless Steel (.046% C material) in the mill-annealed condition pitted but did not crack when boldly exposed to a severe marine atmosphere 80 feet (25 m) from the ocean at Kure Beach, North Carolina for 15 years. Additional test specimens that were furnace sensitized at 1250 F (677 C) for one hour before exposure suffered intergranular stress corrosion cracking after 811 days in test. This corroborates the data presented previously, in that exaggerated heat treatments in the sensitizing temperature range may render NITRONIC 33 Stainless Steel susceptible to intergranular attack by aggressive media when the carbon content is greater than .04%.

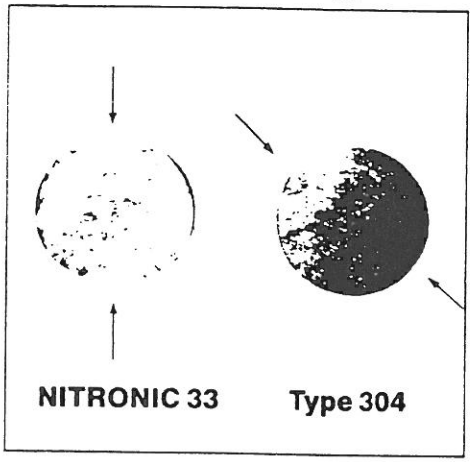
Table 23

Alloy	Condition	Time to Failure, Hr, Under Stress of: 75 ksi (517 MPa)	50 ksi (345 MPa)	25 ksi (172 MPa)
NITRONIC 33	Annealed	0.3	1.0	>1000
Types 304, 304L	Annealed	0.2	0.7	2.5

Test weldments of NITRONIC 33 in the as-welded condition did not crack in exposure to boiling 42% $MgCl_2$ solution for 264 hours. In contrast, Type 304 tested under identical conditions cracked in less than 24 hours.

The specimens used in this test were equal-size bars of Armco NITRONIC 33 and Type 304 stainless steels in the annealed condition. Fusion welds, about 3/32" (4 mm) deep, were made on diametrically opposite sides of the bars to induce a high level of residual stress within the bars. Sections of the bars were then subjected to boiling magnesium chloride. Arrows indicate location of welds.

FIGURE 8
Stress Corrosion Cracking Tests of NITRONIC 33 and Type 304



Sulfide Stress Cracking

Laboratory tests show that although Armco NITRONIC 33 Stainless Steel is subject to sulfide stress cracking, it is more resistant than Armco 17-4 PH Stainless Steel in Condition H 1150 + 1150. Armco 17-4 PH Stainless Steel is widely used in oil and gas production, and is included in NACE Standard MR-01-75, "Sulfide Stress Cracking Resistant Metallic Materials for Oil Field Equipment".

When exposed for 720 hours at room temperature to the solution described in NACE TM-01-77 (5% NaCl + ½% acetic acid, saturated with H_2S), the threshold stress for cracking of annealed NITRONIC 33 bar was about 30 ksi (207 MPa), or approximately 50% of its yield strength. Tested under identical conditions, Armco 17-4 PH bar in Condition H 1150 + 1150 had a threshold stress of only about 15 ksi (103 MPa), or about 15% of its yield strength.

Polythionic Acid Resistance

Armco NITRONIC 33 Stainless Steel exhibits excellent resistance to cracking in polythionic acids. Polythionic acids are of the general formula $H_2S_xO_6$ where x is usually 3, 4, or 5. These acids can form readily in petroleum refinery units (particularly in desulfurizers) during shutdown.

Stressed U-bend specimens of NITRONIC 33 Stainless (.046% C material), in both the annealed condition and after sensitizing at 1250 F (577 C) for one hour, showed no trace of cracking after exposure to polythionic acids for 500 hours at room temperature.

Fabrication

Although Armco NITRONIC 33 Stainless Steel is considerably stronger than the conventional 300 series stainless steels, the same fabricating equipment and techniques can generally be used. There may be occasions where more power is required in forming. In-process annealing should be accomplished between 1900 F and 2000 F (1038 C and 1093 C). Cooling practices are the same as those required for the 300 stainless series—rapid air cooling for sheet stock.

Weldability

Armco NITRONIC 33 Stainless Steel can be readily welded by all conventional welding techniques. However, caution should be used when Electron Beam Welding any of the high-nitrogen austenitic stainless steels as field reports indicate the possibility of severe outgassing when using a vacuum atmosphere. Also, the rapid solidification rates developed during laser and Electron Beam Welding inhibit ferrite formation in austenitic stainless steel welds and may render such weldments more sensitive to solidification cracking than observed with conventional arc welding processes. Good weld practices should be used, as with welding all stainless steels, to assure the excellent weld metal properties of the alloy.

Arc Welding

Armco NITRONIC 33 Stainless Steel is readily Arc Welded by the SMA, GTA, and GMA processes. Autogenous welds are crack resistant since the alloy is designed to form a small amount of ferrite in the weld metal during solidification. The choice of a suitable weld filler is discussed later in "Conventional Weld Filler Metal in Arc Welding NITRONIC 33".

Shielded Metal-Arc Welding (SMAW)

Armco NITRONIC 33 Stainless Steel, when welded by the shielded metal-arc process with the matching filler Armco NITRONIC 35W, exhibits properties shown in Table 24.

Table 24
Typical Mechanical Properties of Armco NITRONIC 33 Stainless Steel in Shielded Metal-Arc Weld Joints

Test Sample	Test Thickness	Condition	Weld Filler	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)	Fracture Location
Unwelded Base Metal	.140" (3.56 mm)	1950 F (1066 C) Anneal	—	117 (807)	67 (461)	38	—
Welded Joint	.140" (3.56 mm)	As Welded	NITRONIC 35W	106 (731)	65 (448)	36	Weld Metal
Unwelded Base Metal	.250" (6.35 mm)	1950 F (1066 C) Anneal	—	104 (717)	56 (386)	55	—
Welded Joint	.250" (6.35 mm)	As Welded	NITRONIC 35W	104 (717)	63 (434)	24	Weld Metal

All welds made with 5/32" Ø (3.97 mm) coated electrodes

Gas Metal-Arc Welding (GMAW)

Table 25 contains mechanical properties of GMA welded joints in Armco NITRONIC 33 Stainless Steel using Armco 35W, 0.062" (1.57 mm) diameter filler wire. The GMA welding mode used was short arc in the 0.062" (1.57 mm) thickness joints and spray arc in the 0.140" (3.56 mm) thickness joints.

Table 25
Typical Mechanical Properties of Armco NITRONIC 33 Stainless Steel in Gas Metal-Arc Weld Joints

Test Sample	Test Thickness	Condition	Weld Filler	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)	Fracture Location
Unwelded Base Metal	.062" (1.57 mm)	1950 F (1066 C) Anneal	—	111 (765)	65 (448)	53	—
Welded Joint	.062" (1.57 mm)	As Welded	NITRONIC 35W	102 (703)	67 (462)	20	Weld Metal
Unwelded Base Metal	.140" (3.56 mm)	1950 F (1066 C) Anneal	—	117 (807)	67 (462)	38	—
Welded Joint	.140" (3.56 mm)	As Welded	NITRONIC 35W	107 (737)	71 (489)	36	Weld Metal

Gas Tungsten-Arc Welding (GTAW)

Armco NITRONIC 33 Stainless Steel may be welded autogenously using the GTAW process which yields sound welds with good mechanical properties. Table 26 shows these properties as well as properties developed using NITRONIC 35W filler wire. Filler wire was 0.062" (1.57 mm) diameter, added at a rate of 1"/1" (1 mm/1 mm). Helium gas shielding is suggested for best penetration and maximum weld travel speed.

Table 26
Typical Mechanical Properties of Armco NITRONIC 33 in Gas Tungsten-Arc Welding

Test Sample	Test Thickness	Condition	Weld Filler	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)	Fracture Location
Unwelded Base Metal	.062" (1.57 mm)	1950 F (1066 C) Anneal	—	111 (765)	65 (448)	53	—
Welded* Joint	.062" (1.57 mm)	As Welded	None	114 (786)	68 (469)	40	WM-BM Interface
Welded Joint	.062" (1.57 mm)	As Welded	NITRONIC 35W	112 (772)	73 (503)	27	Weld Metal
Unwelded Base Metal	.120" (3.05 mm)	1950 F (1066 C) Anneal	—	117 (807)	67 (462)	38	—
Welded* Joint	.120" (3.05 mm)	As Welded	None	112 (772)	67 (462)	39	Weld Metal
Welded Joint	.120" (3.05 mm)	As Welded	NITRONIC 35W	113 (779)	67 (462)	50	Base Metal

*Welds made with automatic GTAW: travel speeds 12 ipm (304.8 mm/minute); other welds made with manual GTAW: helium gas shielding used for all welds.

When welding Armco NITRONIC 33 Stainless Steel using inert gas shielded processes (primarily GTA), the metal should be handled carefully to avoid contamination from other materials such as copper, brass, or bronze. Defects resulting from such contamination usually occur as shallow surface cracks in the base metal immediately adjacent to the weld deposit.

Copper back-up and hold-down fixtures commonly used in welding stainless steels are the principal source of this contamination. In addition to careful handling, the use of chromium-plated fixtures is suggested. However, chromium stainless steel, steel, or aluminum fixtures are satisfactory.

Submerged Arc Welding

The use of submerged arc welding with Armco NITRONIC 33 Stainless Steel yields sound weld joints with good mechanical properties. Table 27 contains typical mechanical properties of Armco NITRONIC 33 Stainless submerged arc welds using Armco NITRONIC 35W, 3/32" (2.38 mm) weld wire and Linde 709-5 welding flux.

Table 27
Typical Mechanical Properties of Armco NITRONIC 33 in Submerged Arc Weld Joints

Test Sample	Test Thickness	Condition	Weld Filler	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)	Fracture Location	Bend Test Over ¼" (6.35 mm) Mandrel	
								Bend Location	Degree of Bend
Unwelded Base Metal	120" (3.05 mm)	—	—	112 (772)	67 (462)*	50	—	—	—
Welded Joints	120" (3.05 mm)	As Welded	NITRONIC 35W	107 (737)	64 (441)	24	Weld Metal	Face Bend WM	180°
								Face Bend HAZ	180°

*Typical yield strength value.

Conventional Weld Filler Metal in Arc Welding NITRONIC 33

Armco NITRONIC 33 Stainless Steel may be welded with more conventional weld filler metals in cases where Armco NITRONIC 35W (AWS E240 and ER240) filler metal might not be readily available. Type 308L filler produces matching yield strengths and toughness over a wide range of temperatures. Type 312 weld filler produces matching ultimate and yield strengths as well as corrosion resistance for applications at ambient temperatures. All of these conventional fillers produce sound welds in Armco NITRONIC 33 Stainless Steel. Table 28 contains the nominal composition and typical mechanical properties for all-weld deposits with Types 308L and 312. Armco NITRONIC 35W filler is also shown for comparison. For applications requiring very low as-deposited magnetic permeability, Ni-base fillers are suggested.

Table 28
Nominal Composition and Typical Mechanical Properties of Several Austenitic All-Weld Metal Deposits

Alloy Type	Composition Wt, %					Typical Mechanical Properties		
	C	Mn	Cr	Ni	N	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)
NITRONIC 35W	.04	12.00	18.00	5.00	.15	106 (731)	85 (586)	24
308L	.025 max	2.10	20.40	9.90	—	85 (586)	55 (379)	45
312	.10	1.50	30.00	9.00	—	110 (758)	80 (550)	30

Weld Corrosion Resistance

The corrosion resistance of an all-weld metal deposit (GMAW) of Armco NITRONIC 35W in the standard boiling 65% nitric acid test (ASTM A 262, Practice C) is 0.0015 inches per year after five periods. The heat-affected zones of the weld metal (multipass weld) were free of accelerated attack. Armco NITRONIC 33 Stainless, autogenously welded (GTAW) and tested in the as-welded condition in the boiling 65% nitric acid test, revealed no selective attack occurring in the weld heat-affected zone. Extensive work reveals that the weld heat-affected zones of weldments in Armco NITRONIC 33 Stainless are free of carbide precipitation.

Resistance Welding

Although no direct resistance welding experience has been obtained with Armco NITRONIC 33 Stainless, the similarity of the alloy to Armco NITRONIC 40 Stainless Steel suggests a good response to resistance spot welding and cross-wire welding techniques. Higher electrode tip pressure will be required as compared with pressures suggested for austenitic stainless steels. Average shear strength data for spot-welded joints in Armco NITRONIC 40 Stainless appear in the Armco NITRONIC 40 Stainless Steel Product Data Bulletin and is reproduced in Table 29. We expect Armco NITRONIC 33 Stainless to perform in a similar manner, but trial welds should be made before manufacturing design is established.

Table 29
Properties of Spot Welded Joints

Alloy	Condition	Thickness, in. (mm)	Average Shear* Strength—lbs (N)
NITRONIC 40	Annealed	.040 (1.02)	1450 (6,950)
		.050 (1.27)	2430 (10,809)
		.060 (1.52)	2795 (12,432)
NITRONIC 40	CR 15%	.030 (0.76)	943 (4,194)
		.040 (1.02)	2060 (9,163)
		.050 (1.27)	2450 (10,898)
NITRONIC 40	CR 30%	.025 (0.64)	854 (3,799)
		.035 (0.89)	1490 (6,628)
		.040 (1.02)	2315 (10,297)
Type 347	Annealed	.065 (1.65)	2360 (10,497)
	CR 15%	.055 (1.40)	1759 (7,824)
	CR 30%	.045 (1.14)	1694 (7,535)
19-9 DL	Annealed	.050 (1.27)	1867 (8,304)
	CR 15%	.045 (1.14)	1302 (7,913)
	CR 30%	.035 (0.89)	1055 (4,693)

*All samples failed in shear at sheet interfaces

Specifications

The following specifications are listed without year of revision indications. Contact ASTM Headquarters for latest ASTM revisions.

Listed as Grade XM-29 (UNS S24000) in

ASTM A 240	Plate, Sheet and Strip for Fusion Welded Unfired Pressure Vessels
ASTM A 276	Bars and Shapes
ASTM A 412	Plate, Sheet and Strip
ASTM A 580	Wire
ASTM A 313	Spring Wire
ASTM A 479	Bars and Shapes
ASTM A 314	Billets and Bars for Forging

Listed as Grade TP XM-29 in

ASTM A 269	Seamless and Welded Tubing for General Service
ASTM A 312	Seamless and Welded Pipe
ASTM A 688	Welded Feedwater Tubes
ASTM A 249	Welded Superheater, Heat Exchanger and Condenser Tubes
ASTM A 358	Electric Fusion Welded Pipe

Listed as Grade XM-29 in ASME Section VIII Division I (Pressure Vessels)

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