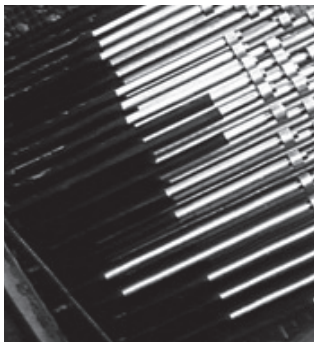
AK Steel International

ARMCO® NITRONIC® 60

STAINLESS STEEL

Product Data Bulletin



- **Bridge Pins**
- **Couplings**
- **Thread Inserts**
- **Turbocharger Components**

Outstanding galling resistance at both ambient and elevated temperatures makes AK Steel's ARMCO® NITRONIC® 60 Stainless Steel a valuable material for valve stems, seats and trim; fastening systems, including nuts and bolts; screening; chain-drive systems; pins; bushings and roller bearings; and pump components such as wear rings and lobes.

ARMCO *Representing ARMCO® products since 1924*

AK Steel International

ARMCO® NITRONIC® 60 STAINLESS STEEL

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AK Steel International

ARMCO® NITRONIC® 60 STAINLESS STEEL

Product Description

AK Steel's ARMCO NITRONIC 60 Stainless Steel provides a significantly lower cost way to fight wear and galling compared with cobalt-bearing and high nickel alloys. Its uniform corrosion resistance is better than Type 304 in most media. Chloride pitting resistance is superior to Type 316. Room temperature yield strength is nearly twice that of Types 304 and 316. In addition, ARMCO NITRONIC 60 Stainless Steel provides excellent high-temperature oxidation resistance and low temperature impact resistance. The latter makes this stainless steel an idea choice for cryogenic application involving unlubricated metal-on-metal wear.

Composition		(wt %)
Carbon	(C)	0.10 max.
Manganese	(Mn)	7.00 – 9.00
Silicon	(Si)	3.50 – 4.50
Phosphorus	(P)	0.040 max.
Sulfur	(S)	0.030 max.
Chromium	(Cr)	16.00 – 18.00
Nickel	(Ni)	8.00 – 9.00
Nitrogen	(N)	0.08 – 0.18

AVAILABLE FORMS

AK Steel's ARMCO NITRONIC 60 Stainless Steel is available in bar, wire, remelt stock, weld wire, and forging billets. A special hot worked un-annealed High Strength (HS) version is available upon request.

A critical part of the coolant circulation pump of NASA's Extravehicular Mobilty Unit (EMU) Primary Life Support Sub-system (PLSS) has been made from NITRONIC 60.

Specifications

HEAT TREATMENT

AK Steel's ARMCO NITRONIC 60 Stainless Steel is not hardenable by heat treatment. Annealing at 1066 °C (1950 °F) followed by water quenching is recommended.

SPECIFICATIONS

AK Steel's ARMCO NITRONIC 60 Stainless Steel is listed as Grade UNS S21800 in:

ASTM A276 Bars and Shapes
ASTM A314 Stainless and Heat-Resisting Steel Billets and Bars for Forging
ASTM A479 Bars and Shapes for Use in Boilers and Other Pressure Vessels
ASTM A580 Wire
ASTM A193 Bolting (Grade B8S)
ASTM A194 Nuts (Grade 8S)
ASTM A351 Austenitic Steel Castings for High Temperature Service (Grade CF 10S MnN)
ASTM A743 Corrosion-Resistant Iron-Chromium, Iron-Chromium-Nickel, and Nickel-Base Alloy Castings for General Application (Grade CF 10S MnN)
AMS 5848 Bars, Forgings, Extrusions, Tubing and Rings
ASME Design Allowables – ASME Boiler and Pressure Vessel Code (BPVC) Design Allowables
ASME Design Values – ASME Boiler and Pressure Vessel Code (BPVC) Design Values

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.

Mechanical Properties

TABLE 1 – TYPICAL ROOM TEMPERATURE TENSILE PROPERTIES

(see Table 7 for acceptable specification values)

Condition	ø Size, mm (in.)	Hardness	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area %
Annealed	25.4 (1)	95 HRB	710 (103)	414 (60)	64	74
Annealed	44.4 (1.75)	100 HRB	696 (101)	386 (56)	62	73
Annealed	57.2 (2.25)	100 HRB	696 (101)	414 (60)	60	76
Annealed	76.2 (3)	97 HRB	779 (113)	448 (65)	55	67
Annealed	104.8 (4.125)	95 HRB	731 (106)	386 (56)	57	67
10% Cold Drawn	11.2 (0.442) ø Start Size	24 HRC	827 (120)	627 (91)	51	68
20% Cold Drawn		31 HRC	965 (140)	772 (112)	35	65
30% Cold Drawn		34 HRC	1110 (161)	910 (132)	26	62
40% Cold Drawn		38 HRC	1344 (195)	1055 (153)	20	57
50% Cold Drawn		41 HRC	1496 (217)	1200 (174)	15	53
60% Cold Drawn		43 HRC	1655 (240)	1344 (195)	12	48
70% Cold Drawn		46 HRC	1813 (263)	1496 (217)	10	40

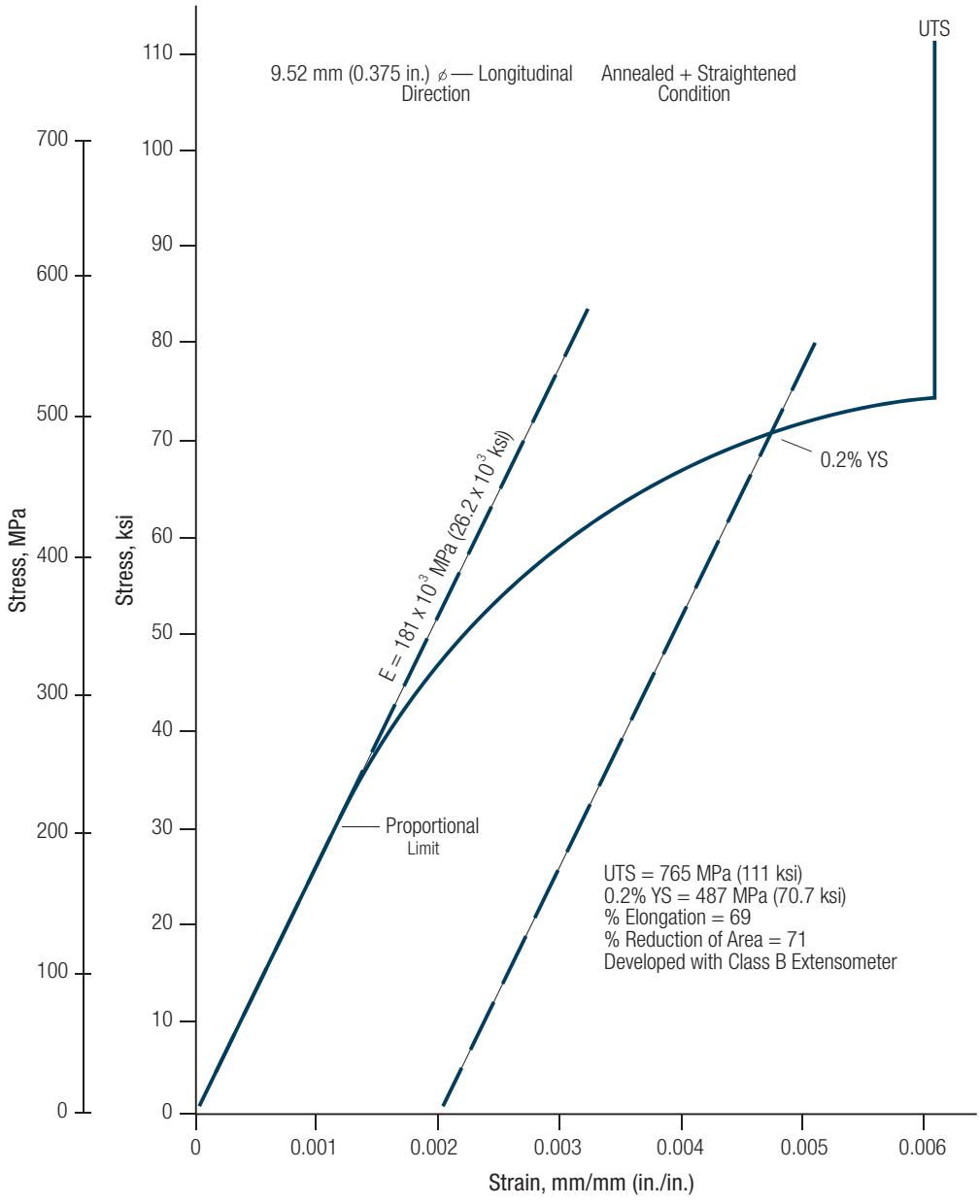
Data based on duplicate tests.

TABLE 2 – TYPICAL BEARING PROPERTIES ASTM E238

Condition	Bearing Strength, MPa (ksi)	Bearing yield Strength, MPa (ksi)	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Hardness, (R)
Annealed	1313 (190.5)	548 (79.5)	723 (104.9)	360 (52.2)	49	B90
10% Cold Rolled	1462 (212)	916 (132.8)	849 (123.1)	625 (90.6)	40	C26

Mechanical Properties

FIGURE 1 – TYPICAL ENGINEERING STRESS-STRAIN CURVE OF ARMCO NITRONIC 60 IN TENSION



Mechanical Properties

TABLE 3 – TYPICAL ROOM TEMPERATURE TORSION AND SHEAR PROPERTIES

Condition	Diameter, mm (in.)	Hardness HRB	Torsional Modulus G, GPa (Mpsi)	0.2% Torsional YS, MPa (ksi)		Modulus of Rupture, MPa (ksi)	Double Shear Strength, MPa (ksi)
				ɣ	ε		
Annealed	25.4 (1)	95	61 (8.83)	337 (48.9)	350 (50.7)	855 (124)	–
Annealed	9.5 (0.375)	95	–	–	–	–	593 (86)

Data based on duplicate tests.

TABLE 4 – DOUBLE SHEAR STRENGTH (COLD DRAWN – 11.23 mm (0.442 in.) START SIZE)

% Cold Drawn	Shear Strength, MPa (ksi)
10	614 (89)
20	676 (98)
30	731 (106)
40	779 (113)
50	841 (122)
60	896 (130)

Data based on duplicate tests.

TABLE 5 – FATIGUE STRENGTH (R.R MOORE MACHINE)

Condition	Diameter, mm (in.)	Hardness	Fatigue Limit, MPa (ksi) 10^8 Cycles
Annealed	25.4 (1)	95 HRB	258 (37.5)
Cold Worked 54.6%	17.8 (0.70)	44 HRC	500 (72.5)

TABLE 6 – ROOM TEMPERATURE COMPRESSION STRENGTH

Condition	Diameter, mm (in.)	0.2% YS, MPa (ksi)
Annealed	12.7 (0.500)	466 (67.6)
Cold Drawn 39%	11.2 (0.440)	834 (121.0)

TABLE 7 – PROPERTIES ACCEPTABLE FOR MATERIAL SPECIFICATION (BAR AND WIRE)

Condition	Diameter, mm (in.)	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area %	Hardness HRB
Annealed	≤ 12.7 (0.5)	724 (105 min)	379 (55 min)	35 min	55 min	85 min
Annealed	> 12.7 (0.5)	655 (95 min)	345 (50 min)	35 min	55 min	85 min

Mechanical Properties

TABLE 8 – TYPICAL ELEVATED TEMPERATURE MECHANICAL PROPERTIES (ANNEALED 19.05 and 25.4 mm (0.75 and 1 in.) DIAMETER BAR STOCK)

Test Temperature, °C (°F)	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area %	Brinell Hardness
Room Temperature	734 (106.5)	389 (56.5)	62	72	200
93 (200)	677 (98.2)	306 (44.4)	63	72	187
149 (300)	620 (89.9)	260 (37.8)	64	74	–
204 (400)	580 (84.4)	227 (32.8)	64	74	168
260 (500)	566 (82.1)	222 (32.1)	62	73	–
316 (600)	555 (80.5)	205 (29.7)	60	73	155
371 (700)	548 (79.5)	201 (29.2)	59	73	–
427 (800)	540 (78.3)	200 (29.0)	57	72	148
482 (900)	532 (77.1)	195 (28.3)	54	72	–
538 (1000)	520 (75.4)	193 (28.0)	52	70	145
593 (1100)	494 (71.6)	198 (28.7)	49	70	–
649 (1200)	459 (66.6)	194 (28.1)	48	70	144
704 (1300)	407 (59.0)	189 (27.5)	41	50	–
760 (1400)	344 (49.8)*	174 (25.3)	47	54	143
816 (1500)	255 (37.0)*	164 (23.8)	73	75	–
871 (1600)	208 (30.2)*	113 (16.4)	73	–	110

Triplicate tests of 2 heats and single tests of 1 heat.
**Single tests of 1 heat.*

TABLE 9 – ELEVATED TEMPERATURE TENSILE PROPERTIES (COLD SWAGED 54% TO 17.8 mm (0.700 in.) DIAMETER)

Test Temperature, °C (°F)	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area %
Room Temperature	1586 (230)	1489 (216)	12	55
93 (200)	1482 (215)	1413 (205)	12	54
149 (300)	1420 (206)	1372 (199)	11	52
204 (400)	1379 (200)	1338 (194)	11	51
260 (500)	1344 (195)	1317 (191)	11	48
316 (600)	1331 (193)	1296 (188)	11	47
371 (700)	1317 (191)	1213 (176)	10	47
427 (800)	1310 (190)	1269 (184)	9	46
482 (900)	1289 (187)	1220 (177)	11	44
538 (1000)	1234 (179)	1145 (166)	11	47
593 (1100)	1117 (162)	993 (144)	13	52
649 (1200)	772 (112)	496 (72)	11	25

Mechanical Properties

TABLE 10 – ELEVATED TEMPERATURE STRESS RUPTURE STRENGTH (ANNEALED BARS 16.0 TO 25.4 mm (0.625 TO 1 in.) DIAMETER)

Temperature, °C (°F)	Number of Heats	Stress Rupture Strength, MPa (ksi)		
		100 hr life	1000 hr life	10000 hr life
538 (1000)	3	496 (72)	359 (52)	241 (35)
593 (1100)	3	338 (49)	214 (31)	138 (20)
649 (1200)	4	200 (29)	117 (17)	69 (10)*
732 (1350)	1	97 (14)	55 (8)	–
816 (1500)	1	46 (6.7)	28 (4)	–

**Extrapolated.*

TABLE 11 – CRYOGENIC TENSILE PROPERTIES

Condition	Diameter, mm (in.)	Temperature, °C (°F)	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area %
Annealed	9.5 (0.375)	-73 (-100)	1069 (155)	524 (76)	57	69
	9.5 (0.375)	-129 (-200)	1172 (170)	600 (87)	56	71
	25.4 (1)	-196 (-320)	1469 (213)	752 (109)	60	67
Cold Swaged 54%	17.8 (700)	-196 (-320)	2220 (322)	1875 (272)	10	53
	17.8 (700)	-129 (-200)	1979 (287)	1724 (250)	13	62

Duplicate test.

TABLE 12 – LOW TEMPERATURE MECHANICAL PROPERTIES OF ARMCO NITRONIC 60 STAINLESS STEEL LONGITUDINAL TENSILE SPECIMENS

Test Temperature, °C (°F)	UTS, MPa (ksi)	0.2% Offset YS, MPa (ksi)	Elongation % in 25,4 mm (1 in.) or $4D_0$	Reduction of Area %	Fracture Strength, MPa (ksi)	Modulus of Elasticity, GPa (Mpsi)	N/U tensile* Ratio	Charpy V-Notch Impact J (ft•lbs)
24 (75)	754 (109.3)	400 (58.1)	66	79	2317 (336.1)	165 (24.0)	1.44	310 (231)
-18 (0)	883 (128.1)	464 (67.3)	71	80	2988 (433.4)	163 (23.7)	1.37	292 (216)
-73 (-100)	1023 (148.4)	537 (77.9)	71	81	3083 (447.1)	167 (24.2)	1.45	267 (197)
-129 (-200)	1155 (167.6)	603 (87.4)	62	78	3151 (457.0)	167 (24.2)	1.46	231 (170)
-196 (-320)	1502 (217.9)	699 (101.4)	60	66	4095 (594.0)	171 (24.8)	1.26	188 (138)
-253 (-423)	1405 (203.8)	864 (125.3)	24	27	1914 (277.6)	171 (24.8)	1.33	–

**6.35 mm (0.250 in.) diameter, machined from a 25.4 mm (1 in.) diameter annealed and straightened bar. Four specimen average.*
Average Stress Concentration Factor K_t=7.0 .
Data taken with permission from NASA TM X-73359, Jan. 1977.

Mechanical Properties

TABLE 13 – IMPACT PROPERTIES*

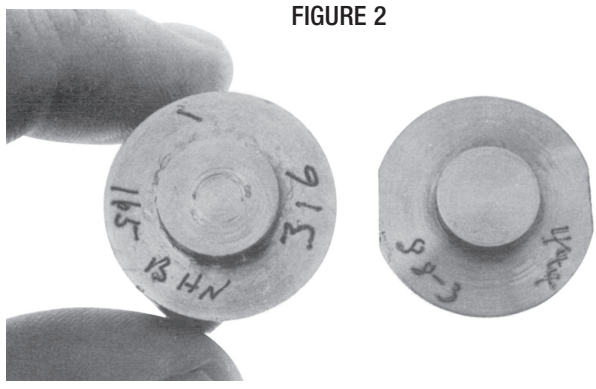
Condition	Diameter, mm (in.)	Test Temperature, °C (°F)	Charpy V Notch Impact J (ft•lbs)
Annealed	25.4 (1)	Room Temperature	325 (240)#
		-73 (-100)	310 (229)
		-196 (-320)	195 (144)
Annealed	54.2 (2.25)	Room Temperature	325 (240)#
		-73 (-100)	325 (240)#
		-196 (-320)	217 (160)
Cold Swaged 18% Hardness RC29	23.7 (0.932)	-196 (-320)	91 (67)
Cold Swaged 40% Hardness RC37	20.2 (0.795)	-196 (-320)	54 (40)
Cold Swaged 54% Hardness RC42	17.8 (0.700)	-196 (-320)	35 (26)
Cold Swaged 18% Hardness RC29	23.7 (0.932)	-129 (-200)	122 (90)
Cold Swaged 40% Hardness RC37	20.2 (0.795)	-129 (-200)	60 (44)
Cold Swaged 54% Hardness RC42	17.8 (0.700)	-129 (-200)	41 (30)

**Data based on duplicate tests.*
#Did not fracture completely.

Galling Resistance

Galling is the tearing of metal surfaces which suddenly renders a component unserviceable. Galling is a major concern in two application areas in particular – threaded assemblies and valve trim. AK Steel uses a button and block galling test to rank alloys for their galling tendencies. In the test procedure, a dead-load weight is applied in a floor model Brinell Hardness Tester on two flat, polished surfaces 0.25 – 0.50 µm. (10 – 20 µin.). The 12.7 mm (0.5 in.) diameter button is slowly rotated by hand 360° under the load and then examined for galling at a 7X magnification. If galling has not occurred, new specimens are tested at higher stresses until galling is observed. The threshold galling stress is selected as the stress midway between the highest nongalled stress and the stress where galling was first observed. Results are reproducible within ±18 MPa (2.5 ksi). However, this test should not be used for design purposes because of the many unknown variables in a particular application. The test has proven highly successful as a method of screening alloys for prototype service evaluation.

FIGURE 2



Button at left is Type 316 stainless steel tested against Type 304 at only 21 MPa (3 ksi). The scoring shown on the Type 316 is the result of metal pickup initiated by galling. Button at right is ARMCO NITRONIC 60 stainless tested at 303 MPa (44 ksi) against Type 303.

TABLE 14 – UNLUBRICATED GALLING RESISTANCE OF STAINLESS STEELS THRESHOLD GALLING STRESS IN MPa (ksi) (STRESS AT WHICH GALLING BEGAN)

Conditions & Nominal Hardness (Brinell)	Type 410	Type 416	Type 430	Type 440C	Type 303	Type 304	Type 316	17-4 PH®	NITRONIC 32	NITRONIC 60
Hardened & Stress Relieved (352) Type 410	21 (3)	28 (4)	21 (3)	21 (3)	28 (4)	14 (2)	14 (2)	21 (3)	317 (46)	345 (50+)
Hardened & Stress Relieved (342) Type 416	28 (4)	90 (13)	21 (3)	145 (21)	62 (9)	165 (24)	290 (42)	14 (2)	310 (45)	345 (50+)
Annealed (159) Type 430	21 (3)	21 (3)	14 (2)	14 (2)	14 (2)	14 (2)	14 (2)	21 (3)	55 (8)	248 (36)
Hardened & Stress Relieved (560) Type 440C	21 (3)	145 (21)	14 (2)	76 (11)	34 (5)	21 (3)	255 (37)	21 (3)	345 (50+)	345 (50+)
Annealed (153) Type 303	28 (4)	62 (9)	14 (2)	34 (5)	14 (2)	14 (2)	21 (3)	21 (3)	345 (50+)	345 (50+)
Annealed (140) Type 304	14 (2)	165 (24)	14 (2)	21 (3)	14 (2)	14 (2)	14 (2)	14 (2)	207 (30)	345 (50+)
Annealed (150) Type 316	14 (2)	290 (42)	14 (2)	255 (37)	21 (3)	14 (2)	14 (2)	14 (2)	21 (3)	262 (38)
H950 (415) 17-4 PH	21 (3)	14 (2)	21 (3)	21 (3)	14 (2)	14 (2)	14 (2)	14 (2)	345 (50+)	345 (50+)
Annealed (235) NITRONIC 32	317 (46)	310 (45)	55 (8)	345 (50+)	345 (50+)	207 (30)	21 (3)	345 (50+)	207 (30)	345 (50+)
Annealed (205) NITRONIC 60	345 (50+)	345 (50+)	248 (36)	345 (50+)	345 (50+)	345 (50+)	262 (38)	345 (50+)	345 (50+)	345 (50)

+Did not gall.
Note: Condition and hardness apply to both horizontal and vertical axis.

Galling Resistance

TABLE 15 – UNLUBRICATED GALLING RESISTANCE OF SEVERAL METAL COMBINATIONS

Couple - (Brinell Hardness)	Threshold Galling Stress MPa. (ksi) (Stress at which galling began)	Couple - (Brinell Hardness)	Threshold Galling Stress MPa (ksi) (Stress at which galling began)
Waukesha 88 (141) vs. Type 303 (180)	345 (50+)	Type 201 (202) vs. Type 304 (140)	14 (2)
Waukesha 88 (141) vs. Type 201 (202)	345 (50+)	Type 201 (202) vs. 17-4 PH (382)	14 (2)
Waukesha 88 (141) vs. Type 316 (200)	345 (50+)	Type 410 (322) vs. Type 420 (4720)	14 (2)
Waukesha 88 (141) vs.17-4PH (405)	345 (50+)	Type 304 (140) vs. AISI 1034 (205)	14 (2)
Waukesha 88 (141) vs. 20 Cr-80 Ni (180)	345 (50+)	Type 304 (337) vs. Type 304 (337)	14 (2)
Waukesha 88 (141) vs. Type 304 (207)	345 (50+)	Type 304 (207) vs. Type 304 (337)	14 (2)
Silicon Bronze (200) vs. Silicon Bronze (200)	28 (4)	Duplex 2205 (235) vs. Type 303 (153)	14 (2)
A-286 (270) vs. A-286 (270)	21 (3)	Duplex 2205 (235) vs. Type 304 (270)	14 (2)
NITRONIC 60 (205) vs. A-286 (270)	338 (49+)	Duplex 2205 (235) vs. Type 316 (150)	14 (2)
NITRONIC 60 (205) vs. 20Cr-80Ni (180)	248 (36)	Duplex 2205 (235) vs. Type 416 (342)	14 (2)
NITRONIC 60 (205) vs. Ti-6Al-4V (332)	345 (50+)	Duplex 2205 (235) vs. 17-4 PH (415)	14 (2)
AISI4337 (484) vs. AISI 4337 (415)	14 (2)	Duplex 2205 (235) vs. NITRONIC 60 (210)	207 (30)
AISI 1034 (415) vs. AISI 1034 (415)	14 (2)	IN 625 (215) vs. Type 303 (153)	14 (2)
NITRONIC 60 (205) vs. AISI 4337 (448)	345 (50+)	IN 625 (215) vs. Type 304 (270)	14 (2)
NITRONIC 60 (205) vs. Stellite 6B (415)	345 (50+)	IN 625 (215) vs. Type 316 (161)	14 (2)
NITRONIC 32 (234) vs. AISI 1034 (205)	14 (2)	IN 625 (215) vs. 17-4 PH (415)	14 (2)
NITRONIC 32 (231) vs. Type 201 (202)	345 (50+)	IN 625 (215) vs. NITRONIC 60 (210)	227 (33)
NITRONIC 60 (205) vs. 17-4 PH (322)	345 (50+)	Stellite 21 (270) vs. Type 316 (161)	14 (2)
NITRONIC 60 (205) vs. NITRONIC 50 (205)	345 (50+)	Stellite 21 (270) vs. NITRONIC 50 (210)	14 (2)
NITRONIC 60 (205) vs. PH 13-8 Mo (297)	345 (50+)	Stellite 21 (270) vs. NITRONIC 60 (210)	297 (43+)
NITRONIC 60 (205) vs. PH 13-8 Mo (437)	345 (50+)	K-500 Monel (321) vs. Type 304 (270)	14 (2)
NITRONIC 60 (205) vs. 15-5 PH (393)	345 (50+)	K-500 Monel (321) vs. Type 316 (161)	14 (2)
NITRONIC 60 (205) vs. 15-5 PH (283)	345 (50+)	K-500 Monel (321) vs. 17-4 PH (415)	14 (2)
NITRONIC 60 (205) vs. 17-7 PH (404)	345 (50+)	K-500 Monel (321) vs. NITRONIC 50 (245)	14 (2)
NITRONIC 60 (205) vs. NITRONIC 40 (185)	345 (50+)	K-500 Monel (321) vs. NITRONIC 60 (210)	117 (17)
NITRONIC 60 (205) vs. Type 410 (240)	248 (36)	NITRONIC 60 (210) vs. Tribaloy 700 (437)	310 (45+)
NITRONIC 60 (205) vs. Type 420 (472)	345 (50+)	Stellite 6B (450) vs. Type 316 (61)	55 (8)
NITRONIC 60 (210) vs. Type 201 (202)	317 (46+)	Stellite 6B (450) vs. Type 304 (150)	324 (47+)
NITRONIC 60 (210) vs. AISI 4130 (234)	234 (34)	Stellite 6B (450) vs. NITRONIC 60 (210	345 (50+)
NITRONIC 60 (205) vs. Type 301 (169)	345 (50+)	Type 410 (210) vs. Type 410 (210)	14 (2)
Type 440C (600) vs. Type 420 (472)	21 (3)	Type 410 (363) vs. Type 410 (363)	14 (2)
Type 201 (202) vs. Type 201 (202)	137 (20)	Type 410 (210) vs. Type 410 (363)	14 (2)
NITRONIC 60 (205) vs. Cr plated Type 304	345 (50+)	17-4 PH (H 1150D) (313) vs. 17-4 PH (H 1150D) (313)	14 (2)
NITRONIC 60 (205) vs. Cr plated 15-5PH (H 1150D)	345 (50+)		
NITRONIC 60 (205) vs. Inconel 718 (306)	345 (50+)	Type 410 (210) vs. 17-4 PH (H 1150D) (313)	14 (2)
NITRONIC 60 (205) vs. CP Titanium (185)	324 (47+)		
NITRONIC 60 (205) vs. Ni Resist Type 2 (145)	345 (50+)	NITRONIC 60 (210) vs. 17-4 PH (H 1150D) (313)	145 (21)
NITRONIC 60 (205) vs. Stellite 21 (295)	296 (43+)		
		NITRONIC 60 (210) vs. Type 410 (210)	165 (24)

+ Did not gall.

Galling Resistance

TABLE 16 – CRYOGENIC GALLING RESISTANCE*

Couple - (Brinell Hardness)	Threshold Galling Stress MPa (ksi) (Stress at which galling began)
NITRONIC 60 (189) vs. NITRONIC 60 (189)	345 (50+)
NITRONIC 60 (189) vs. Type 410 (400)	345 (50+)
NITRONIC 60 (189) vs. 17-4 PH (415)	345 (50+)
NITRONIC 60 (189) vs. Type 304 (178)	345 (50+)
17-4 PH (404) vs. Type 410 (400)	48 (7)
Type 304 (178) vs. Type 410 (400)	152 (22)

+Did not gall.
**Tested in liquid nitrogen. -196 °C (-320 °F)*

ELEVATED TEMPERATURE GALLING APPLICATIONS

ARMCO NITRONIC 60 Stainless Steel has performed successfully in elevated temperature service for valve trim. Several austenitic stainless steels were evaluated as stems and bushings in an automotive emissions control butterfly valve. However, only ARMCO NITRONIC 60 operated smoothly over the entire temperature range. The other alloys galled in the 427 – 816 °C (800 – 1500 °F) temperature range.

Another application involved a 508 mm (20 in.) gate valve which opened and closed every 170 seconds at 399 °C (750 °F). ARMCO NITRONIC 60 weld overlay on the seat and disk lasted 140 days without galling which would have quickly contaminated the process. A similar valve with Stellite 6B hard faced trim lasted only 90 days.

FIGURE 3

Throttle Valve

FIGURE 4

20 inch valve with NITRONIC 60 weld overlay on the seat and disk, operating in 400 °C (750 °F) conditions, lasting 140 days without galling.

Wear Resistance

Data shown in Tables 17 through 29 were developed under the following test conditions: Taber Met-Abrader machine, 12.7 mm (0.5 in.) crossed 90° cylinders, no lubricant, 71 N (16 lbs) load, 105 RPM (and 415 RPM where noted), room temperature, 120 grit surface finish, 10,000 cycles, degreased in acetone, duplicate tests, weight loss corrected for density differences.

TABLE 17 – WEAR COMPATIBILITY OF SELF-MATED AUSTENITIC STAINLESS STEELS

Alloy	Rockwell Hardness	Weight Loss, mg/1000 cycles	
		@ 105 RPM	@ 415 RPM
NITRONIC 60	B95	2.79	1.58
Type 201	B90	4.95	4.68
Type 301	B90	5.47	5.70
Type 302B	B90	5.47	4.62
NITRONIC 32	B95	7.39	3.08
NITRONIC 33	B94	7.95	4.35
NITRONIC 40	B93	8.94	5.35
NITRONIC 50	B99	9.95	4.60
Type 310	B72	10.40	6.49
Type 316	B91	12.50	7.32
Type 304	B99	12.77	7.59
Duplex 2205	B99	17.40	4.02
21-4N	C33	21.38	10.02
Type 303	B98	386.10	50.47

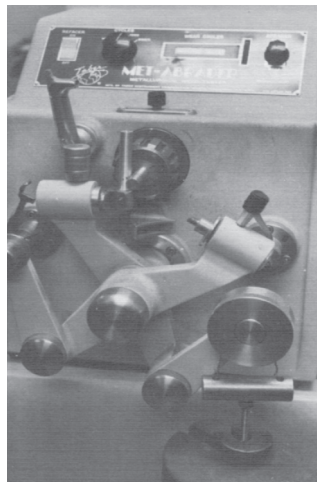
TABLE 18 – WEAR COMPATIBILITY OF SELF-MATED MARTENSITIC AND FERRITIC STAINLESS STEEL

Alloy	Rockwell Hardness	Weight Loss, mg/1000 cycles	
		@ 105 RPM	@ 415 RPM
Type 440C	C57	3.81	0.54
PH 13-8 Mo	C47	38.11	5.41
17-4 PH	C43	52.80	12.13
Type 416	C39	58.14	99.78
PH 13-8 Mo	C32.5	60.15	10.95
Type 430 (5000 cycles)	B94	120.00	69.93
Type 440C	C35	153.01	163.35
Type 420 (5000 cycles)	C46	169.74	12.73
Type 431 (5000 cycles)	C42	181.48	10.35
Type 410	C40	192.79	22.50

TABLE 19 – WEAR COMPATIBILITY OF SELF-MATED CAST ALLOYS AND COATINGS

Alloy	Rockwell Hardness	Weight Loss, mg/1000 cycles	
		@ 105 RPM	@ 415 RPM
Ni-Hard	C44.5	0.13	0.39
Tufftrided PH	C70	0.33	–
White Cast Iron	C60	0.38	0.20
Tribaloy 800	C54.5	0.65	0.37
Tribaloy 700	C45	0.93	0.50
Borided AISI 1040	C70	1.01	2.08
Colmonoy 6	C56	1.06	0.58
Stellite 31	C24	1.65	6.04
Chrome Plate	–	1.66	1.28
Nitrided PH	–	–	1.11
Ni-Resist Type 1	B80	4.45	508.52
Ni-Resist Type 2	B80	8.80	522.32
Waukesha 88	B81	7.09	6.10
Inconel	C25	19.67	2.67
HN	B78	21.75	2.94
CA6-NM	C26	130.41	55.60

FIGURE 5



Taber Met-Abrader crossed cylinder wear test.

Wear Resistance

TABLE 20 – WEAR COMPATIBILITY OF SELF-MATED VARIOUS WROUGHT ALLOYS

Alloy	Rockwell Hardness	Weight Loss, mg/1000 cycles	
		@ 105 RPM	@ 415 RPM
D2 Tool Steel	C61	0.46	0.34
AISI 4337	C52	0.73	0.48
Stellite 6B	C48	1.00	1.27
Hadfield Mn Steel	B95	1.25	0.41
Haynes 25	C28	1.75	23.52
Aluminum Bronze (10.5Al)	B87	2.21	1.52
Be-Cu	C40	2.97	2.56
Silicon Bronze	B93	5.57	4.18
Ti-6Al-4V	C36	7.64	4.49
Inconel 718	C38	9.44	2.85
AISI 4130	C47	9.44	6.80
Waspaloy	C36	11.25	3.28
Inconel 625	B96	11.34	3.49
Hastelloy C	B95.5	13.88	4.50
20 Cb-3	B99	16.47	7.22
6061-T6 Aluminum	B59	17.06	21.15
A-226	C33	17.07	7.62
Inconel X750	C36	18.70	5.56
H13 Tool Steel	C45	20.74	10.15
k-500 Monel	C34	30.65	23.87
20 Cr-80 Ni	B87	44.01	13.92
Copper	B49	57.01	29.25
Leaded Brass	B72	127.91	67.12
AISI 1034	B95	134.05*	106.33
Nickel	B40	209.72	110.25
Astralloy V	C46	213.58	8.22
AISI 4130	C32	257.59	262.64

**5000 cycles.*

Wear Resistance

TABLE 21 – WEAR COMPATIBILITY OF STAINLESS STEEL COUPLES

Alloy	vs.	Weight Loss mg/1000 Cycles						
		Type 304	Type 316	17-4 PH	NITRONIC 32	NITRONIC 50	NITRONIC 60	Type 440C
Rockwell Hardness		B99	B91	C43	B95	B99	B95	C57
Type 304		12.8	–	–	–	–	–	–
Type 316		10.5	12.5	–	–	–	–	–
17-4 PH		24.7	18.5	52.8	–	–	–	–
NITRONIC 32		8.4	9.4	17.2	7.4	–	–	–
NITRONIC 50		9.0	9.5	15.7	8.3	10.0	–	–
NITRONIC 60		6.0	4.3	5.4	3.2	3.5	2.8	–
TYPE 440C		4.1	3.9	11.7	3.1	4.3	2.4	3.8

TABLE 22 – WEAR COMPATIBILITY OF CORROSION-RESISTANT COUPLES

Alloy	vs.	Weight Loss mg/1000 cycles		
		Silicon Bronze	Chrome Plate	Stellite 6B
Rockwell Hardness		B93	(-)	C48
Type 304 (B99)		2.1	2.3	3.1
17-4 PH (C43)		2.0	3.3	3.8
NITRONIC 32 (B95)		2.3	2.5	2.0
NITRONIC 60 (B95)		2.2	2.1	1.9
Silicon Bronze		5.6	1.3	1.9
Chrome Plate		–	1.7	0.33
Stellite 6B		–	–	1.00

TABLE 23 – WEAR COMPATIBILITY OF ARMCO NITRONIC 60, ARMCO 17-4 PH AND STELLITE 6B AGAINST VARIOUS ALLOYS

Alloy	Rockwell Hardness	Weight Loss mg/1000 cycles		
		17-4 PH (C43)	NITRONIC 60 (B95)	Stellite 6B (C48)
Type 304	B99	24.7	6.0	3.1
Type 316	B91	18.5	4.3	5.5
17-4 PH	C31.5	66.1	4.9	2.7
17-4 PH	C43	52.8	5.4	3.8
NITRONIC 32	B95	17.2	3.2	2.0
NITRONIC 50	B99	15.7	3.5	2.9
NITRONIC 60	B95	5.4	2.8	1.9
Stellite 6B	C48	3.8	1.9	1.0
Chrome Plate	–	3.3	2.1	0.3
Silicon Bronze	B93	2.0	2.2	1.9
K 500 Monel	C34	34.1	22.9	18.8
Type 416	C24	–	5.5	43.0
Type 431	C32	–	3.0	1.0
Waspaloy	C36	–	3.1	2.4
Inconel 718	C38	–	3.1	2.7
Inconel X-750	C36	–	5.5	8.0

Wear Resistance

TABLE 24 – COMPARATIVE SLIDING COMPATIBILITY OF ARMCO NITRONIC 60 STAINLESS STEEL AND WAUKESHA 88 IN CONTACT WITH STAINLESS STEELS

Alloy	vs.	Weight Loss mg/1000 cycles	
		NITRONIC 60	Waukesha 88
Rockwell Hardness		B95	B81
NITRONIC 60 (B95)		2.79	8.44
Waukesha 88 (B81)		8.44	7.09
Type 304 (B99)		6.00	8.14
Type 316 (B91)		4.29	9.55
Type 440C (C57)		2.36	6.90
17-4 PH (C43)		5.46	9.12
NITRONIC 32 (B95)		3.18	7.57

TABLE 25 – WEAR TYPE 410 AND 17-4 PH IN NACE – APPROVED CONDITIONS FOR SOUR WELL SERVICE

Alloy Couple, (Rockwell Hardness)	Weight Loss mg/1000 cycles	
	@ 105 RPM	@ 415 RPM
Type 410 (B95) – Self	261.07	115.69
17-4 PH (C34, Condition H 1150D) – Self	75.42	26.80
17-4 PH (C34, Condition H 1150D) – Type 410 (B95)	104.80	58.94
17-4 PH (C34, Condition H 1150D) – NITRONIC 60 (B95)	4.14	4.34
Type 410 (B95) – NITRONIC 60 (B95)	3.81	5.19

Wear Resistance

TABLE 26 – WEAR COMPABITILITY OF MISCELLANEOUS DISSIMILAR COUPLES

Couple, (Rockwell Hardness)	Couple Weight Loss, (mg/1000 cycles)
NITRONIC 60 (B95) vs. Type 431 (C32)	3.01
NITRONIC 60 (B95) vs. Type 431 (C42)	3.01
NITRONIC 60 (B95) vs. Type 416 (C39)	16.50
NITRONIC 60 (B95) vs. 17-4 PH (C31.5)	4.91
NITRONIC 60 (B95) vs. Type 301 (B90)	2.74
NITRONIC 60 (B95) vs. Type 303 (B98)	144.30
NITRONIC 60 (B95) vs. K-500 (C34)	22.90
NITRONIC 60 (B95) vs. A-286 (C33)	5.86
NITRONIC 60 (B95) vs. AISI 4337 (C52)	2.50
NITRONIC 60 (B95) vs. D2 Tool Steel (C61)	1.94
NITRONIC 60 (B95) vs. Ni-Hard (C44.5)	2.19
NITRONIC 60 (B95) vs. Tufftrided PH	2.72
NITRONIC 60 (B95) vs. Borided AISI 1040	2.53
NITRONIC 60 (B95) vs. Tribaloy 700 (C45)	2.08
NITRONIC 60 (B95) vs. Tribaloy 800 (C54.5)	1.34
NITRONIC 60 (B95) vs. Haynes 25 (C28)	2.10
NITRONIC 60 (B95) vs. PH 13-8 Mo (C44)	3.74
NITRONIC 60 (B95) vs. AISI 1040 (B95)	4.09
NITRONIC 60 (B95) vs. Inconel 625 (B99)	3.20
17-4 PH (C43) vs. Type 440C (C34)	113.60
17-4 PH (C43) vs. A-286 (C33)	15.50
17-4 PH (C43) vs. K-500 (C34)	34.10
17-4 PH (C43) vs. D2 Tool Steel (C61)	5.69
17-4 PH (C43) vs. Ni-Hard (C44.5)	4.58
17-4 PH (C43) vs. Haynes 25 (C28)	1.46
17-4 PH (C43) vs. Ti-6Al-4V (C36)	11.70
17-4 PH (C43) vs. Borided AISI 1040	11.70
17-4 PH (C43) vs. Inconel 625 (B99)	8.84
X 750 (C36) vs. A-286 (C33)	16.70
X 750 (C36) vs. Haynes 25 (C28)	2.10
X 750 (C36) vs. Ti-6Al-4V (C36)	7.85
Type 304 (B99) vs. D2 Tool Steel (C61)	3.33
Type 316 (B91) vs. K-500 (C34)	33.80
NITRONIC 32 (B95) vs. Type 416 (C39)	34.80
NITRONIC 32 (B95) vs. Type 431 (C42)	4.86
NITRONIC 50 (B99) vs. Tufftrided PH	7.01
Type 416 (C39) vs. Be-Cu (C40)	4.12
Type 431 (C32) vs. Stellite 6B (C48)	2.08
Type 431 (C42) vs. Stellite 6B (C48)	0.66

Wear Resistance

TABLE 27 – EFFECT OF HARDNESS ON THE WEAR RESISTANCE OF AUSTENITIC STAINLESS STEELS

Self-Mated Series Weight Loss of Test Couple (mg/1000 cycles)					
Type 316L		NITRONIC 60		NITRONIC 50	
HRB 72 vs. HRB 72	11.58	HRB 92 vs. HRB 92	3.09	HRB 99 vs. HRB 99	9.95
HRB 76 vs. HRB 76	11.86	HRC 29 vs. HRC 29	3.12	HRC 28 vs. HRC 28	9.37
HRC 24 vs. HRC 24	12.54	HRB 92 vs. HRC 29	3.40	HRC 38 vs. HRC 38	9.26
HRC 29 vs. HRC 29	12.51	–	–	HRB 99 vs. HRC 38	9.31
HRC 30.5 vs. HRC 30.5	12.52	–	–	–	–
HRB 72 vs. HRC 30.5	12.06	–	–	–	–
HRB 76 vs. HRC 29	12.34	–	–	–	–

TABLE 28 – EFFECT OF HARDNESS ON THE WEAR RESISTANCE OF AUSTENITIC STAINLESS STEELS

Dissimilar Couple Series Weight Loss of Test Couple (mg/1000 cycles)					
Type 316L		NITRONIC 50		NITRONIC 60	
HRB 76 vs. Type 304L	11.75	HRB 99 vs. Type 304L	9.00	HRB 92 vs. Type 304L	5.04
HRC 24 vs. Type 304L	11.18	HRC 28 vs. Type 304L	9.24	HRC 29 vs. Type 304L	5.81
HRC 29 vs. Type 304L	10.61	HRC 38 vs. Type 304L	10.08		
HRB 76 vs. 17-4 PH	17.95	HRB 99 vs.17-4 PH	15.69	HRB 92 vs. 17-4 PH	4.11
HRC 24 vs. 17-4 PH	16.22	HRC 28 vs. 17-4 PH	12.56	HRC 29 vs. 17-4 PH	4.29
HRC 29 vs. 17-4 PH	17.46	HRC 38 vs. 17-4 PH	13.25		
HRB 72 vs. Stellite 6B	5.77	HRB 99 vs. Stellite 6B	2.25	HRB 92 vs. Stellite 6B	1.87
HRB 76 vs. Stellite 6B	5.55	HRC 28 vs. Stellite 6B	2.94	HRC 29 vs. Stellite 6B	1.98
HRC 24 vs. Stellite 6B	5.53	HRC 38 vs. Stellite 6B	2.33		
HRC 29 vs. Stellite 6B	5.74				

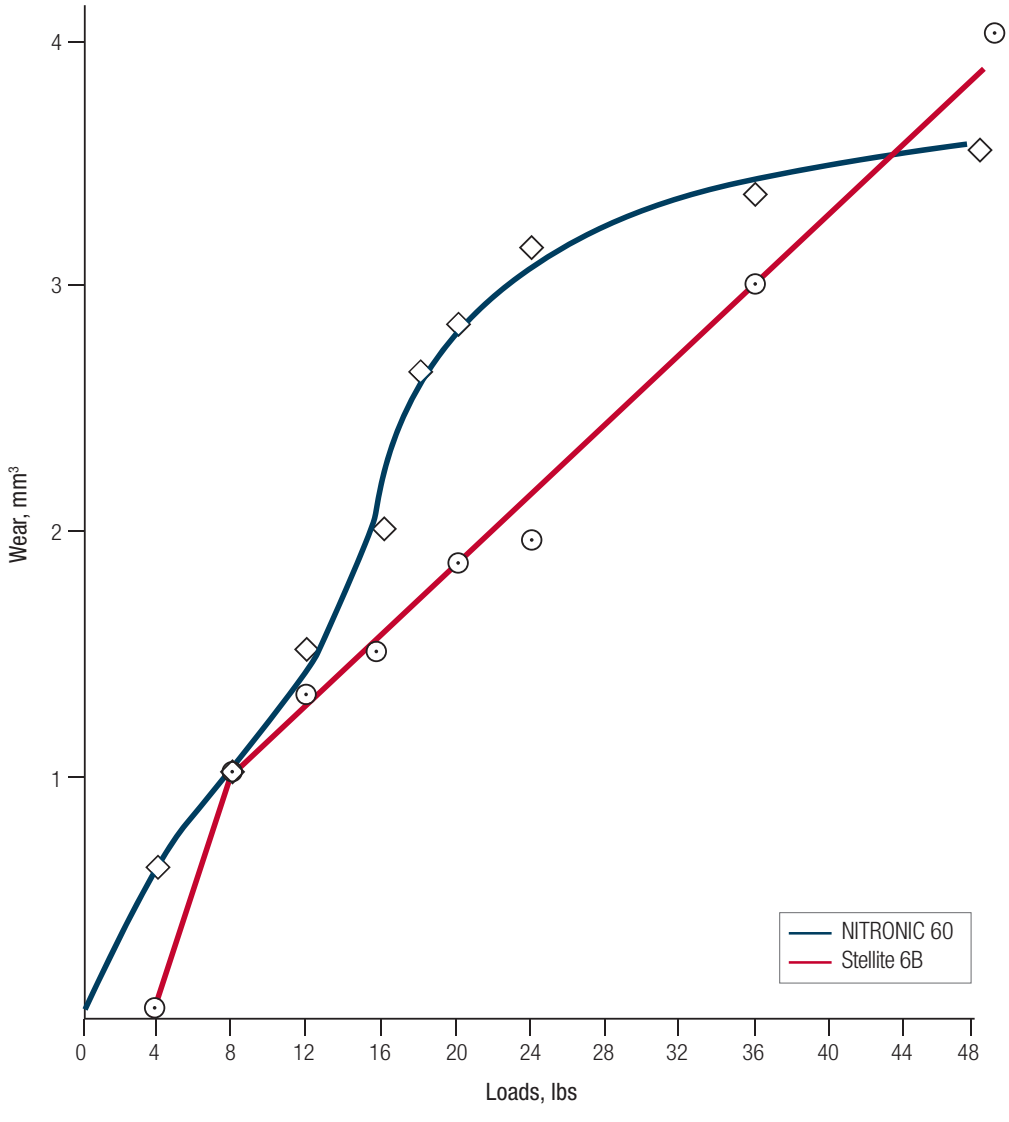
TABLE 29 – EFFECT OF SURFACE FINISH ON THE WEAR RESISTANCE OF STAINLESS STEELS

Self-Mated Test Weight Loss of Couple (mg/1000 cycles)				
Emery Grit	Surface Finish µin (AA)	NITRONIC 60	17-4 PH	Type 430 F*
60	70	2.9	82.0	380
120	21	3.2	81.4	411
240	13	2.7	86.7	403
0	5/6	3.1	84.2	412
3/0	4/5	3.1	83.2	390
electropolished	–	2.9	86.0	416

**4000 cycles and triplicate tests.*

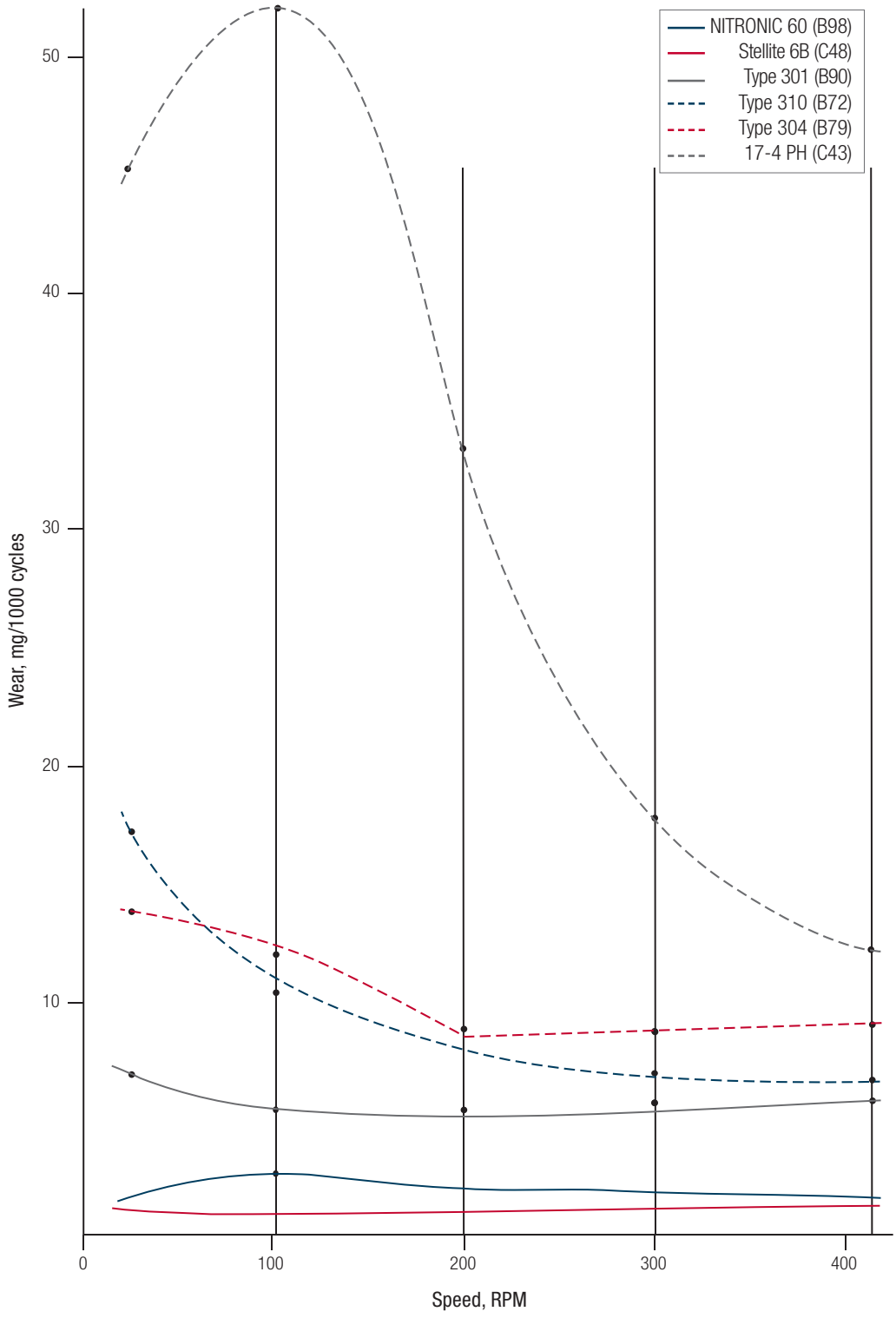
Wear Resistance

FIGURE 6 – EFFECT OF LOAD ON THE WEAR OF ARMCO NITRONIC 60 AND STELLITE 6B TABER MET-ABRADER 12.7 mm (0.5 in.) DIAMETER CROSSED CYLINDERS, SELF-MATED, 27.6 cm/sec. (415 RPM), 10 000 CYCLES, DRY, IN AIR



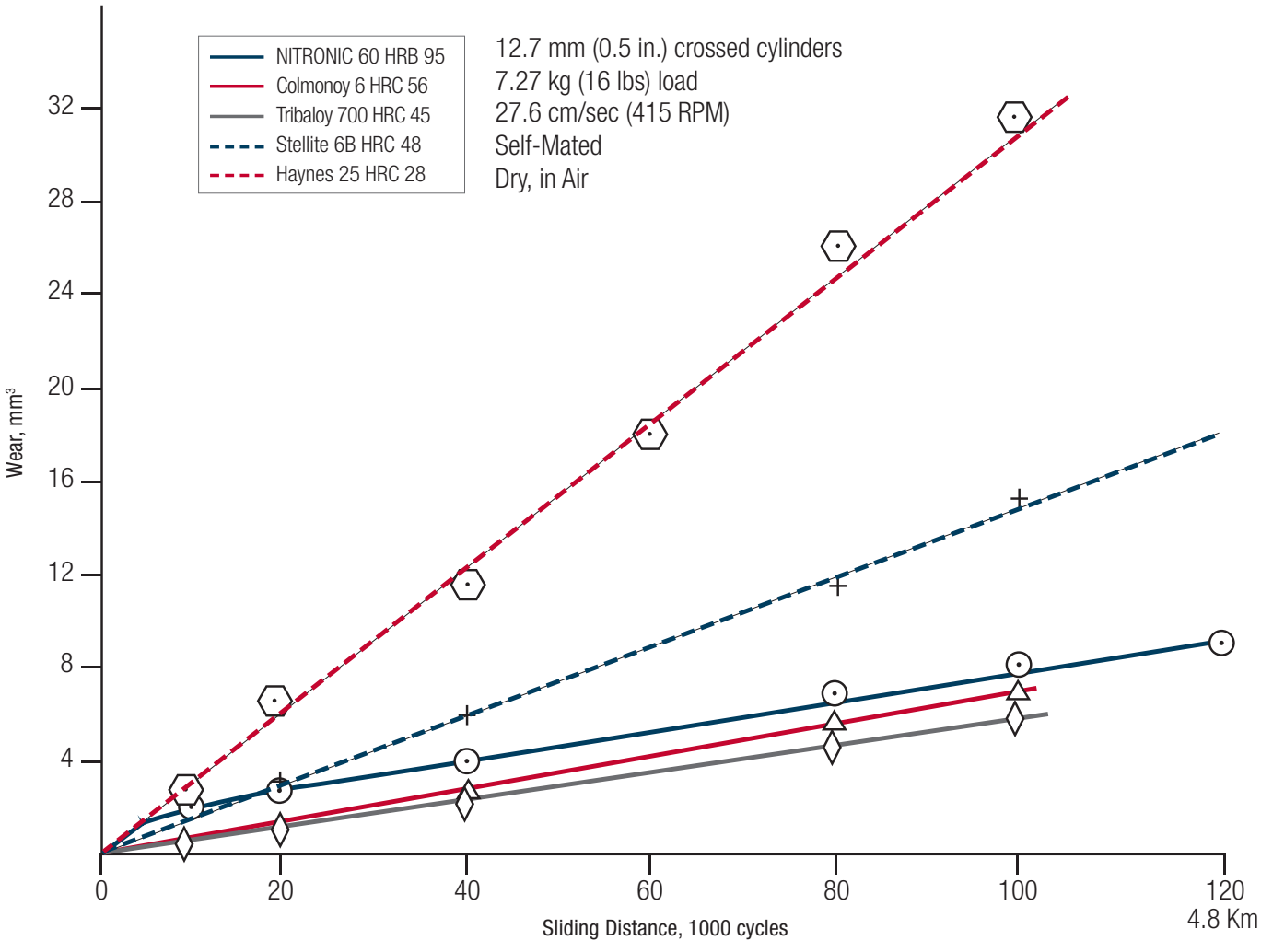
Wear Resistance

FIGURE 7 – EFFECT OF SPEED ON WEAR, 71 N (16 lbs), 10 000 CYCLES, SELF-MATED 12.7 mm (0.5 in.) CROSSED CYLINDERS CORRECTED FOR DENSITY DIFFERENCES



Wear Resistance

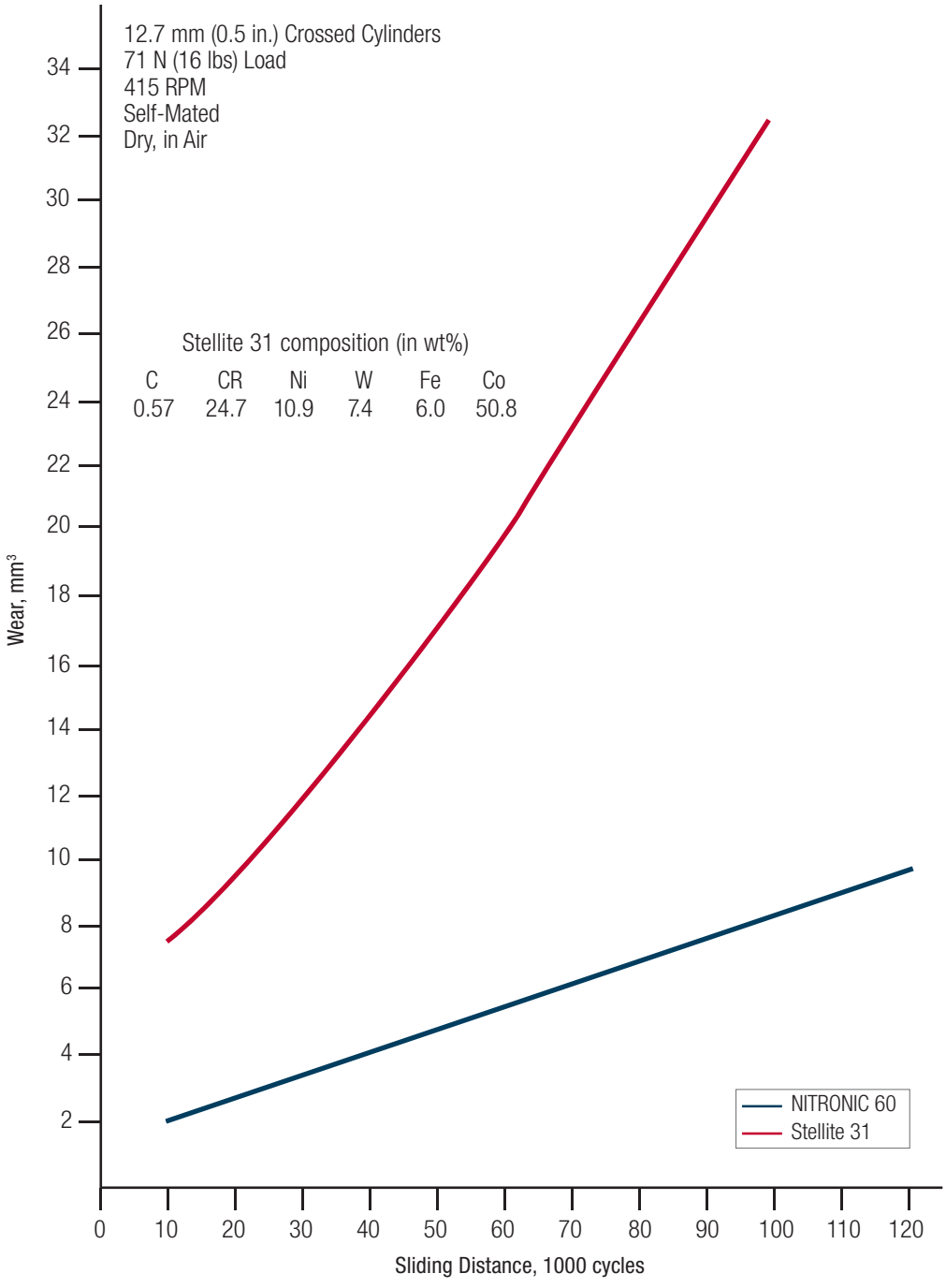
FIGURE 8 – EFFECT OF DISTANCE ON WEAR RESISTANCE OF ARMCO NITRONIC 60 COMPARED TO NICKEL AND COBALT ALLOYS



This plot of wear versus sliding distance at 415 rpm compares ARMCO NITRONIC 60 stainless to nickel and cobalt alloys. ARMCO NITRONIC 60 was significantly better than the two cobalt alloys. Haynes 25 and Stellite 6B, and only slightly inferior to the nickel-base alloys Colmonoy 6 and Tribaloy 700.

Wear Resistance

FIGURE 9 – WEAR OF ARMCO NITRONIC 60 AND STELLITE 31



Wear Resistance

ELEVATED TEMPERATURE WEAR

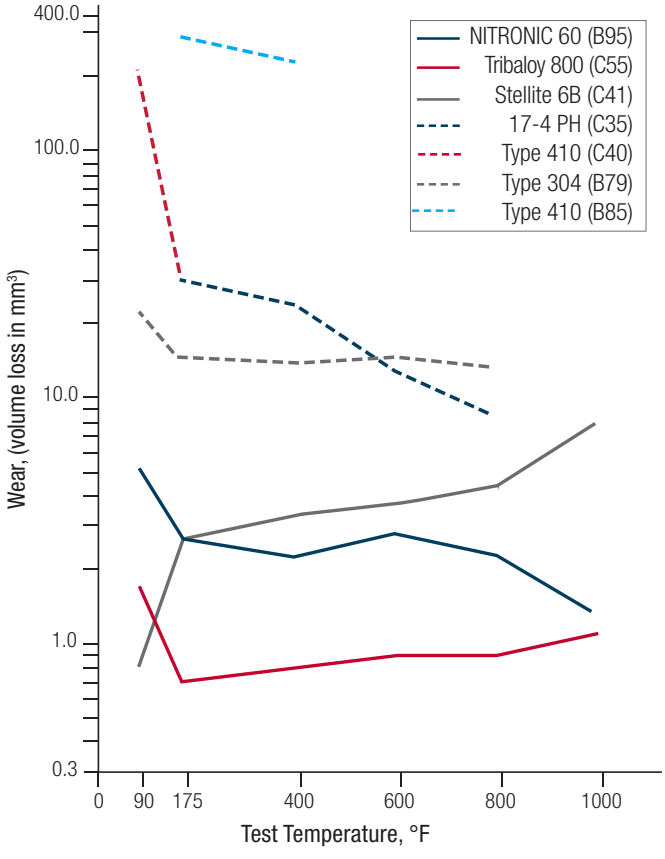
The elevated temperature wear resistance of ARMCO NITRONIC 60 is excellent despite the alloy's relatively low hardness when compared with cobalt and nickel-base wear alloys. ARMCO NITRONIC 60 relies on a thin, adherent oxide film and a high strain hardening capacity to support this film to minimize wear. ARMCO NITRONIC 60 also performs well in metal-to-metal wear in nominally inert atmospheres.

TABLE 30 – HIGH TEMPERATURE WEAR RESISTANCE OF ARMCO NITRONIC 60*

Alloy	Atmosphere	Volume Loss, mm^3	Wear index
NITRONIC 60	Helium	6.94	38.3
NITRONIC 60	Air + Steam#	8.74	30.4
NITRONIC 60	Air + Steam	10.57	25.2
Stellite 6B	Air + Steam	28.00	9.5
Type 304	Air + Steam	106.00	2.5
Mild Steel	Air + Steam	266.00	1.0 (base)

**Test Conditions: Self-mated thrust washers, 260 °C (500 °F), 500 rpm, 489 N (110 lbs.), 4000 cycles. Tested at the U.S. Bureau of Mines.*
#Preoxidized – 538 °C (1000 °F), 3 hours in air.

FIGURE 10 – EFFECT OF TEMPERATURE ON WEAR



**Test conditions – 71 N (16 lbs.) load, 20 000 rev., 415 RPM, self-mated, stationary specimen only heated to test temperature.*

Wear Resistance

FRETTING WEAR

Fretting wear is caused by high loads at very small slip amplitudes (40 µm) such as found in vibrating components. ARMCO NITRONIC 60 exhibits fretting wear at 600 °C (1112 °F) similar to Inconel 718 which has been found to be one of the most fretting-resistant alloys at this temperature.

CAVITATION EROSION

Cavitation erosion resistance of ARMCO NITRONIC 60 is superior to the austenitic stainless steels as well as high-strength duplex (ferric) stainless steels. It approaches the cobalt-base alloys which are considered among the most cavitation resistant alloys available. ARMCO NITRONIC 60 Stainless Steel has proven highly successful for wear rings in vertical centrifugal pumps. The combination of ARMCO NITRONIC 60 and ARMCO NITRONIC 50 Stainless Steels has replaced cobalt wear alloys in some cases, and offers outstanding wear and corrosion protection. ARMCO NITRONIC 60 Stainless Steel also has been cast up to 8550 lbs. for water pump impellers where CA-6NM has proven inadequate. It is anticipated that the excellent galling resistance, cavitation erosion resistance and good castability of ARMCO NITRONIC 60 Stainless will make it an ideal choice for turbine runners, especially with integrally cast wear rings.

FIGURE 11

Wear Rings

TABLE 31 – RELATIVE CAVITATION EROSION RATE

Series 1*	NITRONIC 60 1.00	Type 308L 1.89	Al Bronze 3.00	Type 304 3.67	CA-6NM 6.80	AISI 1020 15.44
Series 2*	Stellite 6B 0.67	NITRONIC 60 1.00	Duplex 225 3.33	Duplex 2205 4.33	–	Type 316L, Type 317L 5.67
Series 3#	NITRONIC 60 1.00	Type 410 1.70	17-4 PH 1.90	Type 316 3.70	CA – 6NM 6.60	–
Series 4 Weld Overlays#	Stellite 6B 0.76	NITRONIC 60 1.00	Type 308L 3.38	Type 316 4.62	Al Bronze 12.4	–

**Laboratory Ultrasonic Cibration Test Method 20 kHz, 27 °C (80 °F) H_2O, 0.05 mm (0.002 in.) amplitude.*

#High-pressure jet impingement apparatus. All reported tests were conducted by either pump manufacturers or hydroelectric equipment end users.

Wear Resistance

TABLE 32 – ABRASION RESISTANCE OF CORROSION-RESISTANT ALLOYS MATED WITH AL_2O_3#

Alloy	Rockwell Hardness	Alloy Wear, mm^3	Al_2O_3 Wear, mm^3	Total, mm^3
			Speed 105 rpm	
Tribaloy 700	C45	0.92	NIL	0.92
Colmonoy 6	C56	1.10	0.05	1.15
Stellite 6B	C48	1.63	0.18	1.81
Type 440C	C56	2.10	0.30	2.40
NITRONIC 60	B95	3.54	0.58	4.12
Type 301	B90	4.66	0.83	5.49
NITRONIC 50	C33	4.49	1.53	6.02
NITRONIC 32	B94	5.76	1.40	7.16
Type 304	B79	6.76	1.68	8.44
Type 310	B72	8.84	2.85	11.69
17-4 PH	C43	24.13	3.63	27.76
			Speed 415 rpm	
Type 440C	C56	0.73	0.15	0.88
Colmonoy 6	C56	0.84	0.10	0.94
NITRONIC 60	B95	0.98	0.28	1.26
17-4 PH	C43	1.60	0.33	2.13
Stellite 6B	C48	2.10	0.03	2.13
NITRONIC 60*	B95	2.68	0.04	2.72
Type 304	B79	5.06	1.68	6.74
Stellite 6B*	C48	8.46	NIL	8.46

**40,000 cycles.*

#Test Conditions: Taber Met-Abrader machine, 12.7 mm (0.5 in.) diameter specimen mated with 6.4 mm (0.25 in.) flat Al_2O_3 in fixed position, 71 N (16 lbs), room temperature, 10 000 cycles, dry, in air.

Wear Resistance

TABLE 33 – ABRASION RESISTANCE OF CORROSION RESISTANT ALLOYS MATED WITH TUNGSTEN CARBIDE

Alloy	Rockwell Hardness	Alloy Wear mm^3 *	
		10 000 cycles @ 105 RPM	40 000 cycles @ 415 RPM
D2 Tool Steel	C61	0.09	0.35
Ni-Hard	C45	0.19	0.32
Hadfield Mn	B95	0.67	0.96
Colmonoy 6	C56	1.08	3.12
Boride	C75	1.16	2.88
Stellite 6B	C48	1.35	4.94
Tribaloy 700	C45	1.43	3.90
Type 440C	C56	1.50	1.51
Si Bronze	B93	1.65	5.89
Haynes 25	C28	2.00	15.39
NITRONIC 60	B95	2.82	9.04
Al Bronze	B97	3.17	8.39
Type 301	B90	3.80	16.03
NITRONIC 32	B94	4.20	17.39
Type 304	B79	6.18	52.80
Type316	B74	7.70	34.06
NITRONIC 50	B99	8.72	30.18
Type 431	C42	9.84	6.16
17-4 PH	C43	9.92	22.37
A-286	C33	13.92	36.68
Type 310	B72	15.26	39.09
Type 416	C39	59.63	285.61
X750	C36	–	51.60

Test Conditions Taber Met-Abrader machine. 12.7 mm (0.5 in.) diameter crossed cylinders. 71 N (16 lbs) room temperature duplicates. Tungsten Carbide (WC) In fixed position, dry, in air.
**Wear to WC was almost nil in all cases and was not monitored.*

TABLE 34 – ABRASION RESISTANCE OF CORROSION RESISTANT ALLOYS MATED TO SILICON CARBIDE

Alloy	Rockwell Hardness	Alloy Wear mm^3 10 000 cycles	
		@ 105 RPM	@ 415 RPM
Type 440C	C56	1.21	0.32
Colmonoy 6	C56	2.91	2.17
Stellite 6B	C41	3.46	3.45
Al Bronze	B87	7.00	5.19
NITRONIC 32	B94	7.08	6.75
NITRONIC 60	B95	7.26	5.42
DUPLEX 2205	–	19.02	6.13
NITRONIC 50	B99	21.15	9.03
Type 316	B76	22.41	15.59
Type 304	B79	25.33	13.48
Hastelloy C	B96	33.52	15.01
Type 310	B72	37.24	18.12
20 Cb-3	B99	44.82	17.51
INCONEL 600	B90	55.60	29.93
CA 6-NM	C26	66.04	118.72
17-4 PH	C43	104.22	37.94

Only wear to the rotating alloy was measured.

Corrosion Resistance

The general corrosion resistance of ARMCO NITRONIC 60 Stainless Steel falls between that of Types 304 and 316. However, experience shows that in a wear system a galling or seizure failure occurs first, followed by dimensional loss due to wear, and finally corrosion. Galling and wear must be the first concerns of the design engineer. Although the general corrosion resistance of ARMCO NITRONIC 60 is not quite as good as Type 316, it does offer better chloride pitting resistance, stress corrosion cracking resistance and crevice corrosion resistance than Type 316 in laboratory conditions. Corrosion tests are not normally performed on ARMCO NITRONIC 60 HS.

TABLE 35 – CORROSION PROPERTIES

Media	Annealed ARMCO NITRONIC 60, mm/y (in./y)	Annealed Type 304, mm/y (in./y)	Annealed Type 316, mm/y (in./y)	ARMCO 17-4 PH (H 925), mm/y (in./y)
65% Boiling HNO_3	1.52 (0.060)	0.30 (0.012)	0.30 (0.012)	3.35 (0.132)
1% HCL @ 35 °C	0.25 (0.010)	1.35 (0.053)	–	0.61 (0.024)
2% H_2SO_4 @ 80 °C	1.14 (0.045)	6.17 (0.243)	0.28 (0.011)	0.53 (0.021)
5% H_2SO_4 @ 80 °C	13.23 (0.521)	33.02 (1.300)	1.52 (0.060)	–
5% Formic Acid @ 80 °C	<0.03 (<0.001)	2.06 (0.081)	<0.03 (<0.001)	0.03 (0.001)
33% Boiling Acetic Acid	0.28 (0.011)	3.84 (0.151)	<0.03 (<0.001)	0.15 (0.006)
70% Hydrazine 76 °C (168 °F) 72 Hours	No Reaction – PASSED	–	–	–
5% Salt Spray @ 35 °C (95 °F) (120 Hours)	NITRONIC 60 exhibited resistance to general rusting comparable to Type 304			

Data based on duplicate tests. Corrosion rates are mm per year (inch per year).

TABLE 36 – CHLORIDE PITTING RESISTANCE

Media	Annealed ARMCO NITRONIC 60, g/cm² (g/in²)	Annealed Type 304, g/cm² (g/in²)	Annealed Type 316, g/cm² (g/in²)	ARMCO 17-4 PH (H 925), g/cm² (g/in²)
10% $FeCl_3$ @ RT (pitting test) 50 hours	0.001 (0.004) No Pits	0.010 (0.065) Pitted	0.002 (0.011) Pitted	0.024 (0.154) Pitted
10% $FeCl_3$ @ RT with (artificial crevices) 50 hours	0.004 (0.024) Slight	0.043 (0.278) Heavy	0.029 (0.186) Heavy	–

Data based on duplicate tests of three different heats tested in acidified 10% $FeCl_3$ solution.

TABLE 37 – STRESS CORROSION CRACKING RESISTANCE (BOILING 42% $MgCl_2$ – 4 NOTCH TENSION SPECIMENS)

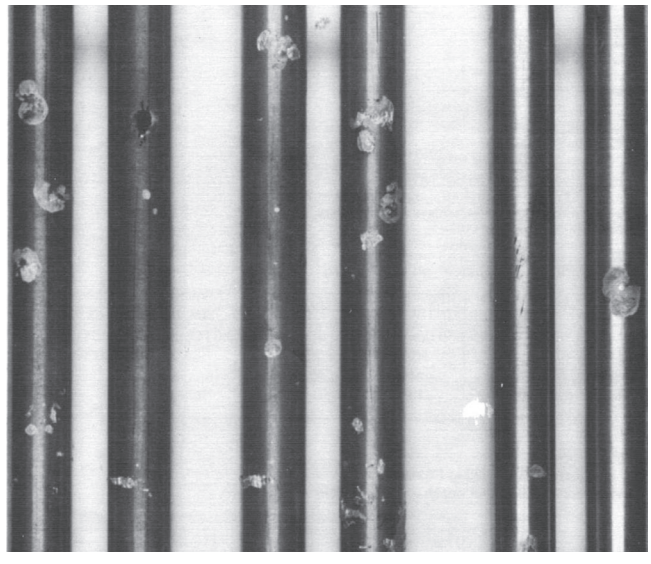
Alloy	Hours to Failure at Various Stress Levels				
	138 MPa (20 ksi)	172 MPa (25 ksi)	207 MPa (30 ksi)	241 MPa (35 ksi)	276 MPa (40 ksi)
NITRONIC 60 (Number of Tests)	192 (8)	32.6 (8)	47 (2)	2.8 (1)	1.8 (6)
Type 304 (Multiple Tests)	2.3	1.9	1.5	1.2	1.0
Type 316	8	7	6	4.5	4

Corrosion Resistance

SEAWATER CORROSION RESISTANCE

When exposed for 6 months in quiet seawater at ambient temperature, ARMCO NITRONIC 60 stainless exhibited far better crevice corrosion resistance than Type 304 and slightly better resistance than Type 316 stainless steels. These tests were run on duplicate specimens, and all grades were exposed simultaneously.

FIGURE 12 – CREVICE CORROSION IN STAINLESS STEEL AFTER 6 MONTHS IN QUIET SEAWATER AT AMBIENT TEMPERATURE



Type 304 Type 316 NITRONIC 60

TABLE 38 – SULFIDE STRESS CRACKING RESISTANCE

17-4 PH (H 1150-M)			NITRONIC 60 (Annealed)		
0.2%YS, MPa (ksi)	Stress Applied Expressed as a % YS	Time to Failure Hours	0.2 % YS, MPa (ksi)	Stress Applied Expressed as a % YS	Time to Failure Hours
749 (108.7)	90.6	8.9	381 (55.3)	110	720 (NF)
749 (108.7)	85.0	19.5	405 (58.7)	110	720 (NF)
749 (108.7)	81.6	21.9	365 (52.8)	100	720 (NF)
749 (108.7)	72.8	26.7	374 (54.3)	100	720 (NF)
749 (108.7)	60.7	50.1	385 (55.3)	100	720 (NF)
749 (108.7)	44.9	104.5	405 (58.7)	100	720 (NF)
762 (110.5)	34.6	214.6	405 (58.7)	85	720 (NF)
762 (110.5)	28.0	572.1	Passed NACE requirements of 720 hours stressed at 100% of 0.2% YS without failure		
762 (110.5)	22.0	720 (NF)			

Tested according to NACE TM0177 using Cortest Proof Rings.
NF = No Failure

TABLE 39 – SULFIDATION RESISTANCE

Test Temperature, °C (°F)	Weight Loss, mg/cm² (mg/in²)	
	NITRONIC 60	Type 309
870 (1600)	0.217 (1.40)	0.209 (1.35)
930 (1700)	0.332 (2.14)	580.1 (3745)
980 (1800)	471.201 (3040)	Dissolved

Conditions: Duplicate wire specimens placed in mixture of 90% Na_2SO_4 10% KCl for 1 hr at each temperature.

Carburization Resistance

ARMCO NITRONIC 60 stainless retained the best combination of strength and ductility after exposure compared to Types 316L and 309 as shown in Table 40.

TABLE 40 – CARBURIZATION RESISTANCE

Alloy		UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area	Bend 1.5T
NITRONIC 60	Unexposed	800 (116.0)	341 (49.5)	74	66	180°
	Exposed	630 (91.5)	400 (58.0)	19	22	100°
Type 316L	Unexposed	524 (76.0)	207 (30.0)	68	74	180°
	Exposed	448 (65.0)	248 (36.0)	24	21	110°
Type 309	Unexposed	683 (99.0)	283 (41.0)	54	65	180°
	Exposed	589 (85.5)	313 (45.5)	14	12	75°

Conditions: Duplicate tests exposed at 982 °C (1800 °F) for 2 hrs in packed 90% graphite – 10% sodium carbonate.

Oxidation Resistance

ARMCO NITRONIC 60 offers far superior oxidation resistance compared to AISI Types 304 and 316 and about the same oxidation resistance as AISI Type 309.

TABLE 41 – STATIC OXIDATION RESISTANCE

Test Temperature, °C (°F)		Weight Loss, mg/cm²			
		RA 333	Type 310	NITRONIC 60	Type 304
1149 (2100)	Before Descaling	3.1	4.6	16.5	1220
	After Descaling	12.2	15.7	23.2	1284
1204 (2200)	Before Descaling	10.1	10.1	26.1	2260
	After Descaling	16.7	20.6	35.4	2265

240 hours at temperature, duplicate tests.

TABLE 42 – CYCLIC OXIDATION RESISTANCE

Cycle	Alloy	Weight Change mg/cm² at number of cycles indicated					
		134 cycles	275 cycles	467 cycles	200 cycles	304 cycles	400 cycles
871 – 927 °C (1600 – 1700 °F) 25 minutes heat 5 minutes cool duplicate tests	RA 330	0.53	0.76	0.99	–	–	–
	Type 310	0.62	1.04	-3.52	–	–	–
	Type 309	0.47	-6.45	-15.6	–	–	–
	NITRONIC 60	0.23	-10.7	-26.0	–	–	–
	Type 316	-73.3	-150	-200	–	–	–
		Weight Loss, mg/cm²					
1038 °C (1900 °F) 30 minutes heat 30 minutes cool	Type 446	–	–	–	1.47	1.72	1.97
	Type 310	–	–	–	2.70	15.9	17.2
	Type 309	–	–	–	22.5	26.3	33.7
	NITRONIC 60	–	–	–	43.0	60.4	74.8
	Type 316	–	–	–	93.0	135.3	178.3

High Strength (HS) Bar Properties

ARMCO NITRONIC 60 Stainless Steel Bars are also available in a high-strength condition attained by special processing techniques. Because high strength is produced by mill processing, hot forging or welding operations cannot be performed on this material without loss of strength. Aqueous corrosion resistance may also be lessened to varying degrees, depending upon the environment.

TABLE 43 – MINIMUM ROOM TEMPERATURE PROPERTIES ARMCO NITRONIC 60 HS BARS (ROTARY FORGE ONLY; SPECIAL PRACTICE)

Diameter, mm (in.)	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area %	Rockwell Hardness
63.5 – 127 incl. (2.5 – 5.0)	758 (110)	621 (90)	20	45	C20
Over 127 – 152 incl. (5 – 6)	758 (110)	483 (70)	20	45	C20
Over 152 (6)	Not Available				

TABLE 44 – TYPICAL MECHANICAL PROPERTIES ARMCO NITRONIC 60 HS BARS

Diameter, mm (in.)	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area %
88.9 (3.5)	827 (120)	641 (93)	21	27

Room temperature, transverse direction. Pertains to all properties listed for HS material in this section. Values taken from tests on one heat.

TABLE 45 – EFFECT OF TEMPERATURE ON TENSILE PROPERTIES

Test Temperature, °C (°F)	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area %
-196 (-320)	1455 (211)	910 (132)	28	16
-73 (-100)	1138 (165)	745 (108)	50	58
Room Temperature	876 (127)	662 (96)	37	60
93 (200)	814 (118)	600 (87)	44	59
149 (300)	745 (108)	531 (77)	43	61
204 (400)	710 (103)	510 (74)	39	61
316 (600)	683 (99)	490 (71)	41	57
427 (800)	662 (96)	476 (69)	37	63
538 (1000)	627 (91)	469 (68)	31	62
649 (1200)	510 (74)	386 (56)	42	64
760 (1400)	303 (44)	214 (31)	63	83

**Typical values, longitudinal direction, duplicate tests.*

High Strength (HS) Bar Properties

TABLE 46 – TYPICAL SUB-ZERO IMPACT STRENGTH ARMCO NITRONIC 60 HS BARS (88.9 mm (3.5 in.) DIAMETER)

Test Temperature, °C (°F)	Charpy V-Notch Impact J (ft•lbs)	
	Longitudinal	Transverse
RT	116 (85)	54 (40)
-46 (-50)	–	29 (21)
-73 (-100)	58 (43)	24 (18)
-129 (-200)	46 (34)	–
-196 (-320)	22 (16)	8 (6)

TABLE 47 – WEAR AND GALLING PROPERTIES ARMCO NITRONIC 60 HS BARS

Couple (Rockwell Hardness)	Weight Loss, mg/1000 Cycles	
	105 RPM	415 RPM
NITRONIC 60 HS (C29) – Self (C29)	2.94	1.70
NITRONIC 60 HS (C29) – 17-4 PH (C43)	3.69	–
	Threshold Galling Stress, MPa (ksi)	
NITRONIC 60 HS (C29) – NITRONIC 60 (B95)	283 (41)	
NITRONIC 60 HS – 17-4 PH (C43)	324 (47+)	
NITRONIC 60 HS – NITRONIC 50 (C23)	338 (49+)	
NITRONIC 60 HS – Type 316 (B85)	248 (36)	
NITRONIC 60 HS – 17-4 PH (C34) (H 1150D)	255 (37)	

Metal-to-metal wear-crossed cylinders.

TABLE 48 – SULFIDE STRESS CRACKING OF ARMCO NITRONIC 60 HS BARS*

Applied Stress MPa (ksi)	% Yield Strength	Location	Time to Failure Hours
669 (97)	100	Surface Intermediate Central	235 160 132
503 (73)	75	Surface Intermediate Central	302 208 227
400 (58)	60	Surface Intermediate Central	720 NF# 720 NF 720 NF
338 (49)	50	Surface Intermediate Central	720 NF 720 NF 720 NF

**NACE TM0177, Cortest Proof Rings, Yield Strength = 669 MPa (97 ksi).*
#NF = No Failure

TABLE 49 – CHLORIDE STRESS CORROSION CRACKING RESISTANCE NITRONIC 60 HS

Condition	Hardness (HR)	Result
Hot Rolled 2.54 mm (0.1 in.) thick strip	C36	No Failure
1066 °C (1950 °F) + 704 °C (1300 °F) –10 min - AC*	B92	No Failure
1066 °C (1950 °F) + 788 °C (1450 °F) – 10 min - AC* 1.5 mm (0.06 in.) thick strip	B92	No Failure

U-Bends, 6.96 mm (1.25 in.) Diameter Mandrel – 5% NaCl + 0.5% acetic acid, boiling for 30 days + 10% NaCl +0.5% acetic acid, boiling for 30 days.
**Simulates partially sensitized condition often found in materials used in oil exploration equipment.*

Physical Properties

TABLE 50 – PHYSICAL PROPERTIES

Density at 24 °C (75 °F)	7.622 (g/cm^3)
Electrical Resistivity	98.2 μΩ•cm
Modulus of Elasticity	180 GPa (26.26 Mpsi)
Poisson's Ratio	0.298

TABLE 51 – MEAN COEFFICIENT OF THERMAL EXPANSION

Temperature °C (°F)	μm/m/°C (in./in./°F)
24 – 93 (75 – 200)	15.8 (8.8 x 10^{-6})
24 – 204 (75 – 400)	16.6 (9.2 x 10^{-6})
24 – 316 (75 – 600)	17.3 (9.6 x 10^{-6})
24 – 427 (75 – 800)	17.6 (9.8 x 10^{-6})
24 – 538 (75 – 1000)	18.0 (10.0 x 10^{-6})
24 – 649 (75 – 1200)	18.5 (10.3 x 10^{-6})
24 – 760 (75 – 1400)	18.9 (10.5 x 10^{-6})
24 – 871 (75 – 1600)	19.3 (10.7 x 10^{-6})
24 – 982 (75 – 1800)	19.8 (11.0 x 10^{-6})

TABLE 52 – MAGNETIC PERMEABILITY

Condition	Magnetic Permeability (μ)
Annealed	1.003
25% Cold Drawn	1.004
50% Cold Drawn	1.007
75% Cold Drawn	1.010

TABLE 53 – MAGNETIC PERMEABILITY OF HS BAR

Bar Location	Field Strength Ampere/Metres (Oersteds)			
	7958 (100)	15 916 (200)	39 790 (500)	79 580 (1,000)
Surface	1.0009	1.0040	1.0029	1.0029
Intermediate	1.0003	1.0022	1.0039	1.0029
Central	1.0013	1.0024	1.0033	1.0031

ASTM A342, method 4.

TABLE 54 – DYNAMIC COEFFICIENT OF FRICTION

Alloy	Dynamic Coefficient of Friction					
	Test Stress Level, N/mm^2					
	0.8	5.6	14.0	28.0	56.0	112.0
NITRONIC 60	0.50	0.35	0.38	0.44	0.44	0.44
Stellite 6B	0.30	0.60	0.63	–	–	–
NITRONIC 32	–	–	0.43	0.53	0.65	0.58

Tested in water at 20 °C, self-mated.

TABLE 55 – DYNAMIC COEFFICIENT OF FRICTION RING ON BLOCK 57 – 200 N (15 – 45 lbs)

Ring	Block	Coefficient of Friction
Type 440C	NITRONIC 60	0.4 in Argon 0.4 in Air
Type 440C	Type 304	0.4 in Air
Type 440C	Type 316	0.5 in Air

Taken from: "Friction, Wear, and Microstructure of Unlubricated Austenitic Stainless Steel," by K.L. Hsu, T. M. Ahn, and D. A. Rigney, Ohio State University, ASME Wear of Materials-1979.

Machinability

TABLE 56 – MACHINABILITY

AISI B1112	Type 304	AK Steel's ARMCO NITRONIC 60
100%	45%	23%

25.4 mm (1 in.) – annealed-R_B 95.
Five-hour form tool life using high-speed tools.
Data based on duplicate tests.

SUGGESTED MACHINING RATES

Because of desirable metallurgical characteristics of ARMCO NITRONIC 60, machinability is not easy. However, with sufficient power and rigidity, ARMCO NITRONIC 60 Stainless Steel can be machined. It is suggested that coated carbides be considered for machining. ARMCO NITRONIC 60 machines at about 50% of the rates used for Type 304; however, when using coated carbides, higher rates may be realized. Suggestions for starting rates are:

TABLE 57 – RECOMMENDED MACHINING RATES FOR ARMCO NITRONIC 60

Machining Operation	Cutting Rates, Depth/Rev Feed	Cutting Rates, SFM
Single Point Turning Carbide Tools		
Roughing	0.150 – 0.015	197 – 328
Finishing	0.025 – 0.007	203 – 394
Drilling		
0.25 in. diameter hole	0.004	60
0.50 in. diameter hole	0.007	60
0.75 in. diameter hole	0.010	60
Reaming*		
0.25 in. diameter hole	0.004	100
0.50 in. diameter hole	0.007	100
0.75 in. diameter hole	0.010	100
Side and Slot Milling		
Roughing	0.250 – 0.007	125
Finishing	0.050 – 0.009	140

SFM = Surface Foot per Minute
**These rates are suggested for carbide tools, Type C-2 for roughing, drilling, and reaming, Type C-3 for finishing.*

Welding

ARMCO NITRONIC 60 Stainless Steel is readily welded using conventional joining processes. Autogenous welds made using the Gas Tungsten-Arc process are sound, with wear characteristics approximating those of the unwelded base metal. Heavy weld deposits made using the Gas Metal-Arc process and the matching weld filler are also sound, with tensile strengths slightly above those of the unwelded base metal. Wear properties are near, but slightly below those of the base metal. Weld properties compared to unwelded base metal are shown in Table 57. The use of ARMCO NITRONIC 60 Stainless Steel for weld overlay on most other stainless steels and certain carbon steels develops sound deposits having properties about equal to that of an all weld deposit. For detailed information, contact AK Steel. The American Welding Society has included ARMCO NITRONIC 60W bare wire in AWS A5.9 as ER 218 alloy.

TABLE 58 – COMPARATIVE PROPERTIES OF BASE METAL VS WELD METAL

	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Red. of Area %	Rockwell Hardness	Impact Chary V-Notch J (ft•lbs)		Galling Stress NITRONIC 60 vs NITRONIC 60 MPa (ksi)
As-Welded Weld Metal (by Gas Metal-Arc welding)	848 (123)	586 (85)	19	22	C25	Room Temperature	73 (54)	276 (40)
						-196 °C (-320 °F)	15 (11)	
Annealed Base Metal	710 (103)	414 (60)	64	74	B95	Room Temperature	325 (240+)	345 (50+)
						-196 °C (-320 °F)	195 (144)	

+ Did not gall.

TABLE 59 – INTERGRANULAR CORROSION RESISTANCE OF ARMCO NITRONIC 60 WELD OVERLAY ON TYPE 304

Condition	Corrosion Rate, mm/year (in./month)
As-deposited	0.49 (0.0016)
927 °C (1700 °F) – 1 hr – Water Quenched (stress relief)	0.61 (0.0020)
927 °C (1700 °F) – 1hr – Air Cooled (stress relief)	1.92 (0.0063)

2 layers of ARMCO NITRONIC 60 Stainless, gas metal-arc process. ASTM A262 Practice B (Ferric Sulfate). Intergranular corrosion per ASTM A262 – applicable to annealed material.

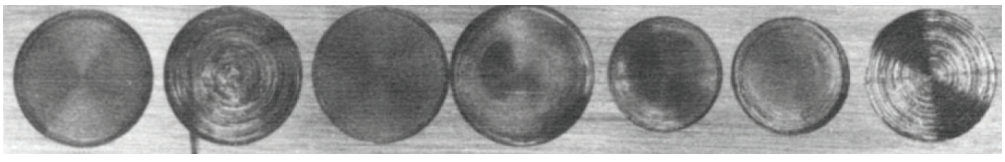
Welding

FOLLOWING ARE EXAMPLES OF EXCELLENT GALLING RESISTANCE OF ARMCO NITRONIC 60 IN THE AS-DEPOSITED, WELD OVERLAY CONDITION

NITRONIC 60 Galling Block

2 Layers of NITRONIC 60 on Type 304

GMAW Process

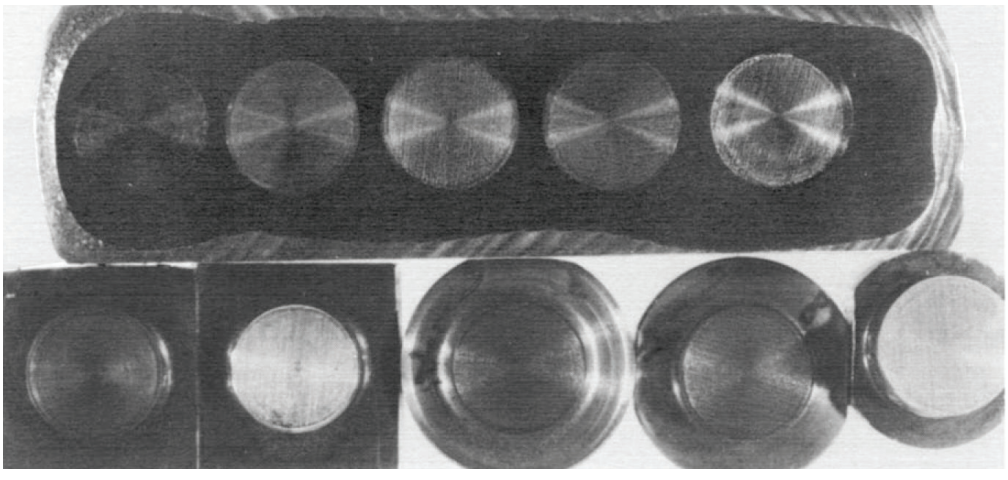


Mating Alloy	17-4 PH	Type 316	PH 13-8 Mo	Type 304	Type 440C	Type 410	Type 316
Contact Stress MPa (ksi)	282 (40.8) OK	276 (40.0) Galled	282 (40.8) OK	260 (37.7) OK	392 (56.9) OK	402 (58.3) OK	236 (34.3) Scored

NITRONIC 60 Galling Block

2 Layers of NITRONIC 60 on Carbon steel

Plasma Transferred Arc Process



Mating Alloy	17-4 PH	17-4 PH	Type 416	Type 416	Stellite 6B
Contact Stress MPa (ksi)	247 (35.8) OK	365 (52.7) OK	247 (35.8) OK	319 (46.3) OK	329 (47.8) OK

Forging

The following practice should be followed when forging ARMCO NITRONIC 60 stainless sections 330 mm (13 in.) or smaller:

1) Charge in furnace below 816 °C (1500 °F).

2) Raise to 1093 °C (2000 °F), equalize.

3) Raise to 1177 °C (2150 °F), equalize and forge.

4) Reheat as necessary.

Casting

ARMCO NITRONIC 60 Stainless Steel may be cast by all conventional casting techniques. Since ARMCO NITRONIC 60 is patented, non-licensees must use AK Steel-produced remelt stock. Contact your AK Steel sales office if castings are of interest.

Casting Parameters Liquidus 1391 °C (2536 °F) Solidus 1352 °C (2465 °F) Estimated Shrinkage – 7.9375 mm/m (0.3125 in./ft) Finish Allowance – 3.175 mm (0.125 in.).

ARMCO NITRONIC 60 Stainless Steel Castings may be partially stress relieved at 566 ± 14 °C (1050 ± 25 °F) for 2 hours followed by air cooling and still pass ASTM A262-E for intergranular corrosion resistance. This heat treatment has been used to minimize distortion during the fabrication of wear rings.

TABLE 60 – TYPICAL ELEVATED TEMPERATURE PROPERTIES* CAST ARMCO NITRONIC 60 (CF10S MnN) ANNEALED

Test Temperature, °C (°F)	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area %
24 (75)	662 (96)	324 (47)	54	55
93 (200)	586 (85)	255 (37)	61	61
204 (400)	496 (72)	193 (28)	62	64
316 (600)	462 (67)	165 (24)	60	60
427 (800)	434 (63)	159 (23)	58	64
538 (1000)	421 (61)	159 (23)	57	64
649 (1200)	379 (55)	159 (23)	50	57

**Average of 4 tests.*

TABLE 61 – STRESS RUPTURE STRENGTH* CAST ARMCO NITRONIC 60 (ANNEALED)

Test Temperature, °C (°F)	Stress, MPa (ksi)	Time to Failure Hours	Elongation % in $4D_0$	Reduction of Area %
649 (1200)	172 (25)	348	32	53
649 (1200)	207 (30)	108	29	48
649 (1200)	241 (35)	34	23	31

**Average of tests of 11 heats.*
Data supplied by Wisconsin Centrifugal Inc.

Casting

TABLE 62 – TYPICAL ROOM TEMPERATURE MECHANICAL PROPERTIES 152 MM (6 in.) SQUARE CAST ARMCO NITRONIC 60 STAINLESS STEEL

Condition	Location	UTS, MPa (ksi)	0.2% YS, MPa (ksi)	Elongation % in $4D_0$	Reduction of Area %	Rockwell Hardness, B	CVN Impact J (ft•lbs)
As-Cast	Surface	676 (98)	338 (49)	43	34	91	50 (37)
As-Cast	Intermediate	503 (73)	338 (49)	12	15	89	37 (27)
Annealed (Surface)	1093 °C (2000 °F)	696 (101)	331 (48)	62	67	91	220 (162)
Annealed (Intermediate)	1093 °C (2000 °F)	662 (96)	317 (46)	54	56	89	–

**Average of tests of 11 heats.*
Data supplied by Wisconsin Centrifugal Inc.

TABLE 63 – TYPICAL IMPACT STRENGTH SIMULATED SLOW COOL IN MOLD STUDY

Temperature, °C (°F)	Charpy V-Notch Impact J, (ft•lbs)
22.8 (73)	29.2 (21.5)
15.6 (60)	50.8 (37.5)

Cast 225 mm (9 in.) square x 100 mm (4 in.) thick section, center cooled from 1121 – 191 °C (2050 – 357 °F) in 2 hrs in still air.

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AK Steel International

AK Steel International B.V.
Rat Verleghstraat 2A
4815 NZ Breda
The Netherlands
+31.(0)76.523.73.00

AK Steel International B.V.
Germany Branch
Holzmarkt 1
50676 Cologne
Germany
+49.(0)221.97352.0

AK Steel Merchandising S.A.
Muntaner, 374 – 376
08006 Barcelona
Spain
+34.93.209.41.77

AK Steel SARL
2-6 rue des Bourets
92150 Suresnes
France
+33.(0)1.80.46.37.46

AK Steel s.r.l.
Piazza della Vittoria 15/31
16121 Genoa
Italy
+39.010.582746

AK Steel Ltd
The Business & Technology Centre
Room S04
Bessemer Drive
Stevenage
Hertfordshire
SG1 2DX
United Kingdom
+44.(0)1438.842910

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AK Steel is a leading producer of flat-rolled carbon, stainless and electrical steel products, primarily for the automotive, infrastructure and manufacturing, including electrical power, and distributors and converters markets. Through its subsidiaries, the company also provides customer solutions with carbon and stainless steel tubing products, die design and tooling, and hot- and cold-stamped components. Headquartered in West Chester, Ohio (Greater Cincinnati), the company has approximately 9,200 employees at manufacturing operations in the United States, Canada and Mexico, and facilities in Western Europe. Additional information about AK Steel is available at www.aksteel.com.

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