Armco NITRONIC 60 Stainless Steel

NOW AVAILABLE IN BAR, WIRE, SHEET, PLATE, WELD WIRE, HIGH STRENGTH SHAFTING, AND MADE TO ORDER ITEMS.

- **FIGHTS GALLING AND WEAR**
- **STRONGER THAN 304 / 316 SS**

Applications Potential

Outstanding galling resistance at both ambient and elevated temperatures makes NITRONIC 60 Stainless Steel a valuable material for valve stems, seats and trim; fastening systems, including nuts and bolts; screening; chaindrive systems; pins, bushings, wear rails and roller bearings; and pump components such as wear rings and lobes. NITRONIC 60 is the most effective wear and galling resistant alloy for bridge pins and other critical construction applications.

HPA ALLOYS Since 1984

ARMCO NITRONIC 60 STAINLESS STEEL BAR AND WIRE

(UNS-S21800)

Product Data Bulletin

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Armco NITRONIC 60 Stainless Steel Product Description

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.

Composition

	%
Carbon	.10 max.
Manganese	7.00-9.00
Silicon	3.50-4.50
Chromium	16.00-18.00
Nickel	8.00-9.00
Nitrogen	.08-.18

Available Forms

Armco NITRONIC 60 Stainless Steel is available in bar, wire, remelt stock, weld wire, and forging billets. Forms available from other manufacturers include castings, extrusions, seamless tubing, and plate.

Armco NITRONIC 60 is covered by U.S. Patent 3,912,503.

Specifications

Armco NITRONIC 60 Stainless Steel is listed as Grade UNS S21800 in:

ASTM A 276 Bars and Shapes

ASTM A 479 Bars and Shapes for Use in Boilers and Other Pressure Vessels

ASTM A 580 Wire

ASTM A 193 Bolting (Grade B8S)

ASTM A 194 Nuts (Grade 8S)

ASTM A 351 Austenitic Steel Castings for High-Temperature Service (Grade CF10SMnN)

ASTM A 743-82b Corrosion-Resistant Iron-Chromium, Iron-Chromium-Nickel, and Nickel-Base Alloy Castings for General Application (Grade CF10SMnN)

ASME Code Case 1817 Bolting including Studs and Nuts to Requirements of Section VIII, Division 1.

Heat Treatment

Armco NITRONIC 60 Stainless Steel is not hardenable by heat treatment. Annealing at 1950 F (1066 C) followed by water quenching is recommended.

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 AISI 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) is used. The unit (N/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.

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.

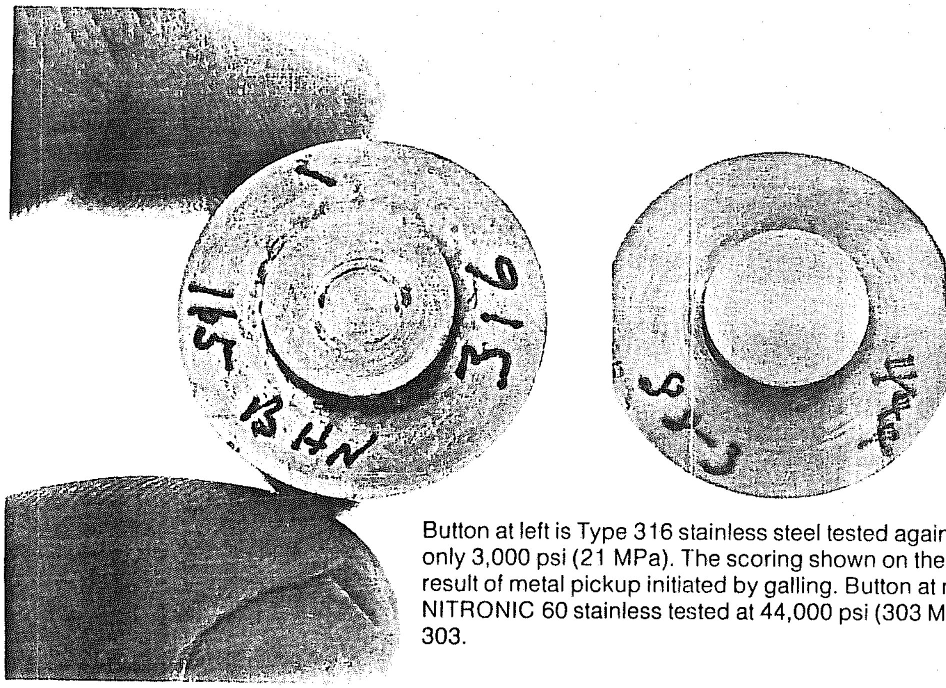
Armco uses a button and block galling test to rank alloys for their galling tendencies. In the test procedure, a dead-load weight is applied in a floor model Brinell Hardness Tester on two flat, polished surfaces (10-20 micro-inches). The 0.5-inch (12.7 mm) diameter button is slowly rotated by hand 360° 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 ± 2.5 ksi (18 MPa). 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. For further details of the test procedure, see April 1973 Materials Engineering, page 60.

Table 1
Unlubricated Galling Resistance of Stainless Steels
Threshold Galling Stress in ksi (MPa)
(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	3 (21)	4 (28)	3 (21)	3 (21)	4 (28)	2 (14)	2 (14)	3 (21)	46 (317)	50+(345)
Hardened & Stress Relieved (342) Type 416	4 (28)	13 (90)	3 (21)	21 (145)	9 (62)	24 (165)	42 (290)	2 (14)	45 (310)	50+(345)
Annealed (159) Type 430	3 (21)	3 (21)	2 (14)	2 (14)	2 (14)	2 (14)	2 (14)	3 (21)	8 (55)	36 (248)
Hardened & Stress Relieved (560) Type 440C	3 (21)	21 (145)	2 (14)	11 (76)	5 (34)	3 (21)	37 (255)	3 (21)	50+(345)	50+(345)
Annealed (153) Type 303	4 (28)	9 (62)	2 (14)	5 (34)	2 (14)	2 (14)	3 (21)	3 (21)	50+(345)	50+(345)
Annealed (140) Type 304	2 (14)	24 (165)	2 (14)	3 (21)	2 (14)	2 (14)	2 (14)	2 (14)	30 (207)	50+(345)
Annealed (150) Type 316	2 (14)	42 (290)	2 (14)	37 (255)	3 (21)	2 (14)	2 (14)	2 (14)	3 (21)	38 (262)
H 950 (415) 17-4 PH	3 (21)	2 (14)	3 (21)	3 (21)	2 (14)	2 (14)	2 (14)	2 (14)	50+(345)	50+(345)
Annealed (235) NITRONIC 32	46 (317)	45 (310)	8 (55)	50+(345)	50+(345)	30 (207)	3 (21)	50+(345)	30 (207)	50+(345)
Annealed (205) NITRONIC 60	50+(345)	50+(345)	36 (248)	50+(345)	50+(345)	50+(345)	38 (262)	50+(345)	50+(345)	50 (345)

+ Did Not Gall
(Note: Condition and Hardness apply to both horizontal and vertical axes.)



Button at left is Type 316 stainless steel tested against Type 304 at only 3,000 psi (21 MPa). The scoring shown on the Type 316 is the result of metal pickup initiated by galling. Button at right is NITRONIC 60 stainless tested at 44,000 psi (303 MPa) against Type 303.

Table 2
Unlubricated Galling Resistance of Several Metal Combinations

Couple — (Brinell Hardness)			Threshold Galling Stress ksi (MPa) (Stress at which galling began)
Waukesha 88 (141)	vs.	Type 303 (180)	50+ (345)
Waukesha 88 (141)	vs.	Type 201 (202)	50+ (345)
Waukesha 88 (141)	vs.	Type 316 (200)	50+ (345)
Waukesha 88 (141)	vs.	17-4 PH (405)	50+ (345)
Waukesha 88 (141)	vs.	20 Cr-80 Ni (180)	50+ (345)
Waukesha 88 (141)	vs.	Type 304 (207)	50+ (345)
Silicon Bronze (200)	vs.	Silicon Bronze (200)	4 (28)
A-286 (270)	vs.	A-286 (270)	3 (21)
NITRONIC 60 (205)	vs.	A-286 (270)	49+ (338)
NITRONIC 60 (205)	vs.	20 Cr-80 Ni (180)	36 (248)
NITRONIC 60 (205)	vs.	Ti-6Al-4V (332)	50+ (345)
AISI 4337 (484)	vs.	AISI 4337 (415)	2 (14)
AISI 1034 (415)	vs.	AISI 1034 (415)	2 (14)
NITRONIC 60 (205)	vs.	AISI 4337 (448)	50+ (345)
NITRONIC 60 (205)	vs.	Stellite 6B (415)	50+ (345)
NITRONIC 32 (234)	vs.	AISI 1034 (205)	2 (14)
NITRONIC 32 (231)	vs.	Type 201 (202)	50+ (345)
NITRONIC 60 (205)	vs.	17-4 PH (322)	50+ (345)
NITRONIC 60 (205)	vs.	NITRONIC 50 (205)	50+ (345)
NITRONIC 60 (205)	vs.	PH 13-8 Mo (297)	50+ (345)
NITRONIC 60 (205)	vs.	PH 13-8 Mo (437)	50+ (345)
NITRONIC 60 (205)	vs.	15-5 PH (393)	50+ (345)
NITRONIC 60 (205)	vs.	15-5 PH (283)	50+ (345)
NITRONIC 60 (205)	vs.	17-7 PH (404)	50+ (345)
NITRONIC 60 (205)	vs.	NITRONIC 40 (185)	50+ (345)
NITRONIC 60 (205)	vs.	Type 410 (240)	36 (248)
NITRONIC 60 (205)	vs.	Type 420 (472)	50+ (345)
NITRONIC 60 (210)	vs.	Type 201 (202)	46+ (317)
NITRONIC 60 (210)	vs.	AISI 4130 (234)	34 (234)
NITRONIC 60 (205)	vs.	Type 301 (169)	50+ (345)
Type 440C (600)	vs.	Type 420 (472)	3 (21)
Type 201 (202)	vs.	Type 201 (202)	20 (137)
NITRONIC 60 (205)	vs.	Cr plated Type 304	50+ (345)
NITRONIC 60 (205)	vs.	Cr plated 15-5PH (H 1150)	50+ (345)
NITRONIC 60 (205)	vs.	Inconel 718 (306)	50+ (345)

Couple — (Brinell Hardness)			Threshold Galling Stress ksi (MPa) (Stress at which galling began)
Type 201 (202)	vs.	Type 304 (140)	2 (14)
Type 201 (202)	vs.	17-4 PH (382)	2 (14)
Type 410 (322)	vs.	Type 420 (472)	3 (21)
Type 304 (140)	vs.	AISI 1034 (205)	2 (14)
Type 304 (337)	vs.	Type 304 (337)	2 (14)
Type 304 (207)	vs.	Type 304 (337)	2 (14)
Duplex 2205 (235)	vs.	Type 303 (153)	2 (14)
Duplex 2205 (235)	vs.	Type 304 (270)	2 (14)
Duplex 2250 (235)	vs.	Type 316 (150)	2 (14)
Duplex 2205 (235)	vs.	Type 416 (342)	2 (14)
Duplex 2205 (235)	vs.	17-4 PH (415)	2 (14)
Duplex 2205 (235)	vs.	NITRONIC 60 (210)	30 (207)
IN 625 (215)	vs.	Type 303 (153)	2 (14)
IN 625 (215)	vs.	Type 304 (270)	2 (14)
IN 625 (215)	vs.	Type 316 (161)	2 (14)
IN 625 (215)	vs.	17-4 PH (415)	2 (14)
IN 625 (215)	vs.	NITRONIC 60 (210)	33 (227)
Stellite 21 (270)	vs.	Type 316 (161)	2 (14)
Stellite 21 (270)	vs.	NITRONIC 50 (210)	2 (14)
Stellite 21 (270)	vs.	NITRONIC 60 (210)	43+ (297)
K-500 Monel (321)	vs.	Type 304 (270)	2 (14)
K-500 Monel (321)	vs.	Type 316 (161)	2 (14)
K-500 Monel (321)	vs.	17-4 PH (415)	2 (14)
K-500 Monel (321)	vs.	NITRONIC 50 (245)	2 (14)
K-500 Monel (321)	vs.	NITRONIC 60 (210)	17 (117)
NITRONIC 60 (210)	vs.	Tribaloy 700 (437)	45+ (310)
Stellite 6B (450)	vs.	Type 316 (61)	8 (55)
Stellite 6B (450)	vs.	Type 304 (150)	47+ (324)
Stellite 6B (450)	vs.	NITRONIC 60 (210)	50+ (345)
Type 410 (210)	vs.	Type 410 (210)	2 (14)
Type 410 (363)	vs.	Type 410 (363)	2 (14)
Type 410 (210)	vs.	Type 410 (363)	2 (14)
17-4 PH (H 1150 + H 1150) (313)	vs.	17-4 PH (H 1150 + H 1150) (313)	2 (14)
Type 410 (210)	vs.	17-4 PH (H 1150 + H 1150) (313)	2 (14)
NITRONIC 60 (210)	vs.	17-4 PH (H 1150 + H 1150) (313)	21 (145)
NITRONIC 60 (210)	vs.	Type 410 (210)	24 (165)

+ Did not gall

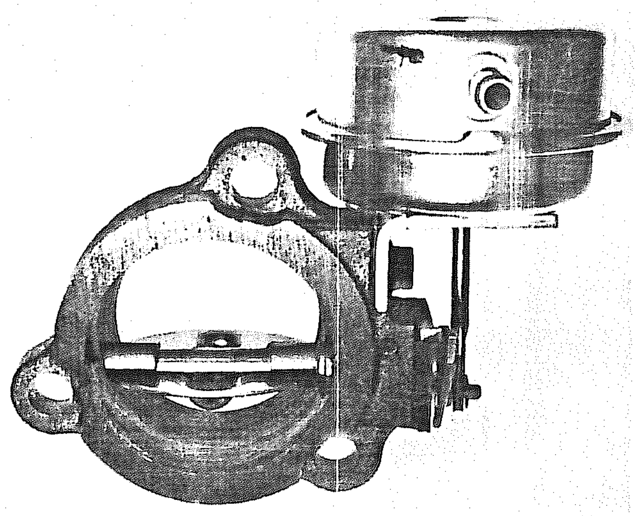
Table 3
Cryogenic Galling Resistance*

Couple — (Brinell Hardness)			Threshold Galling Stress, ksi (MPa) (Stress at which galling began)
NITRONIC 60 (189)	vs.	NITRONIC 60 (189)	50+ (345)
NITRONIC 60 (189)	vs.	Type 410 (400)	50+ (345)
NITRONIC 60 (189)	vs.	17-4 PH (415)	50+ (345)
NITRONIC 60 (189)	vs.	Type 304 (178)	50+ (345)
17-4 PH (404)	vs.	Type 410 (400)	7 (49)
Type 304 (178)	vs.	Type 410 (400)	22 (152)

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

Elevated Temperature Galling Applications

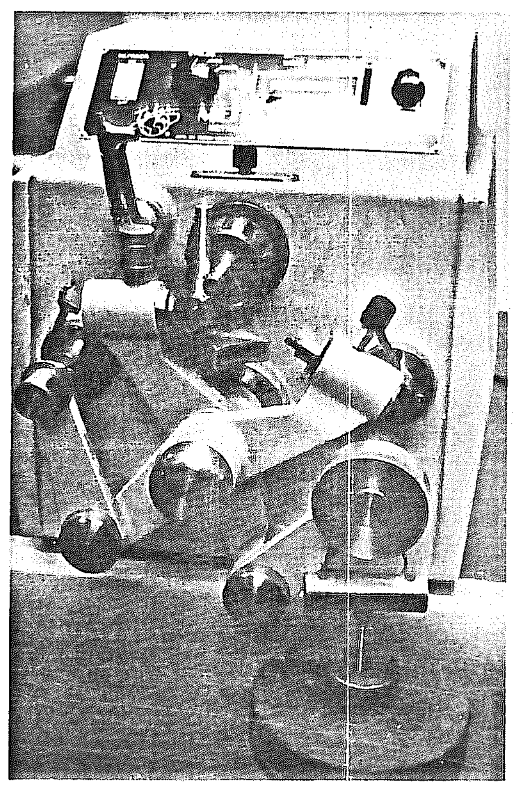
Armco NITRONIC 60 Stainless Steel has performed successfully in elevated temperature service for valve trim. Several austenitic stainless steels were evaluated as stems and bushings in an automotive emissions control butterfly valve. However, only NITRONIC 60 operated smoothly over the entire temperature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



Another application involved a 20-inch (508 mm) gate valve which opened and closed every 170 seconds at 750 F (399 C). 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 hardfaced trim lasted only 90 days.

Wear Resistance

Data shown in Tables 4 through 10, 14 and 15 and Figure 1, were developed under the following test conditions: Taber Met-Abrader machine, 0.500-inch (12.7 mm) crossed 90° cylinders, no lubricant, 16-pound (71 N) load, 105 RPM, room temperature, 120 grit surface finish, 10,000 cycles, degreased in acetone, duplicate tests, weight loss corrected for density differences.



Taber Met-Abrader crossed cylinder wear test.

Table 4
Wear Compatibility of Self-Mated Austenitic Stainless Steels

Alloy	Hardness Rockwell	Weight Loss, mg/1000 cycles @ 105 RPM	Weight Loss, mg/1000 cycles @ 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 5
Wear Compatibility of Self-Mated Martensitic and Ferritic Stainless Steels

Alloy	Hardness Rockwell	Weight Loss, mg/1000 cycles @ 105 RPM	Weight Loss, mg/1000 cycles @ 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 6
Wear Compatibility of Self-Mated Cast Alloys and Coatings

Alloy or Coating	Hardness Rockwell	Weight Loss, mg/1000 cycles @ 105 RPM	Weight Loss, mg/1000 cycles @ 415 RPM
Ni-Hard	C44.5	0.13	0.39
Tufftrided PH	C75	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	C75	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

Table 7
Wear Compatibility of Self-Mated Various Wrought Alloys

Alloy	Hardness Rockwell	Weight Loss, mg/1000 cycles @ 105 RPM	Weight Loss, mg/1000 cycles @ 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 (10.5 Al)	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-286	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	44.91	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

Table 8
Wear Compatibility of Stainless Steel Couples

Alloy vs.	Type 304	Type 316	17-4 PH	NITRONIC 32	NITRONIC 50	NITRONIC 60	Type 440C
	Weight Loss, mg/1000 cycles						
Hardness Rockwell	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 9
Wear Compatibility of Corrosion-Resistant Couples

Alloy		Weight Loss, mg/1000 cycles		
	vs.	Silicon Bronze	Chrome Plate	Stellite 6B
Hardness Rockwell		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 10
Wear Compatibility of Armco NITRONIC 60 Compared with 17-4 PH and Stellite 6B Against Various Alloys

Alloy	Hardness Rockwell	Weight Loss of Couple (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

Table 11
Comparative Sliding Compatibility of Armco NITRONIC 60 Stainless Steel and Waukesha 88 in Contact with Stainless Steels

Alloy		Weight Loss, mg/1000 cycles	
	vs.	NITRONIC 60	Waukesha 88
Hardness Rockwell		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 12
Wear of 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 1150 + H 1150) — Self	75.42	26.80
17-4 PH (C34, Condition H 1150 + H 1150) — Type 410 (B95)	104.80	58.94
17-4 PH (C34, Condition H 1150 + H 1150) — NITRONIC 60 (B95)	4.14	4.34
Type 410 (B95) — NITRONIC 60 (B95)	3.81	5.19

Table 13
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)	16.5
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)	144.3
NITRONIC 60 (B95)	vs.	K-500 (C34)	22.9
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)	113.6
17-4 PH (C43)	vs.	A-286 (C33)	15.5
17-4 PH (C43)	vs.	K-500 (C34)	34.1
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)	11.7
17-4 PH (C43)	vs.	Borided AISI 1040	11.7
17-4 PH (C43)	vs.	Inconel 625 (B99)	8.84
X 750 (C36)	vs.	A-286 (C33)	16.7
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)	33.8
NITRONIC 32 (B95)	vs.	Type 416 (C39)	34.8
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

Table 14
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 15
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 16
Effect of Surface Finish on the Wear Resistance of Stainless Steels

Self-Mated Tests
Weight Loss of Couple (mg/1000 cycles)

Emery Grit	Surface Finish micro inches (AA)	NITRONIC 60	17-4 PH	Type 430F*
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

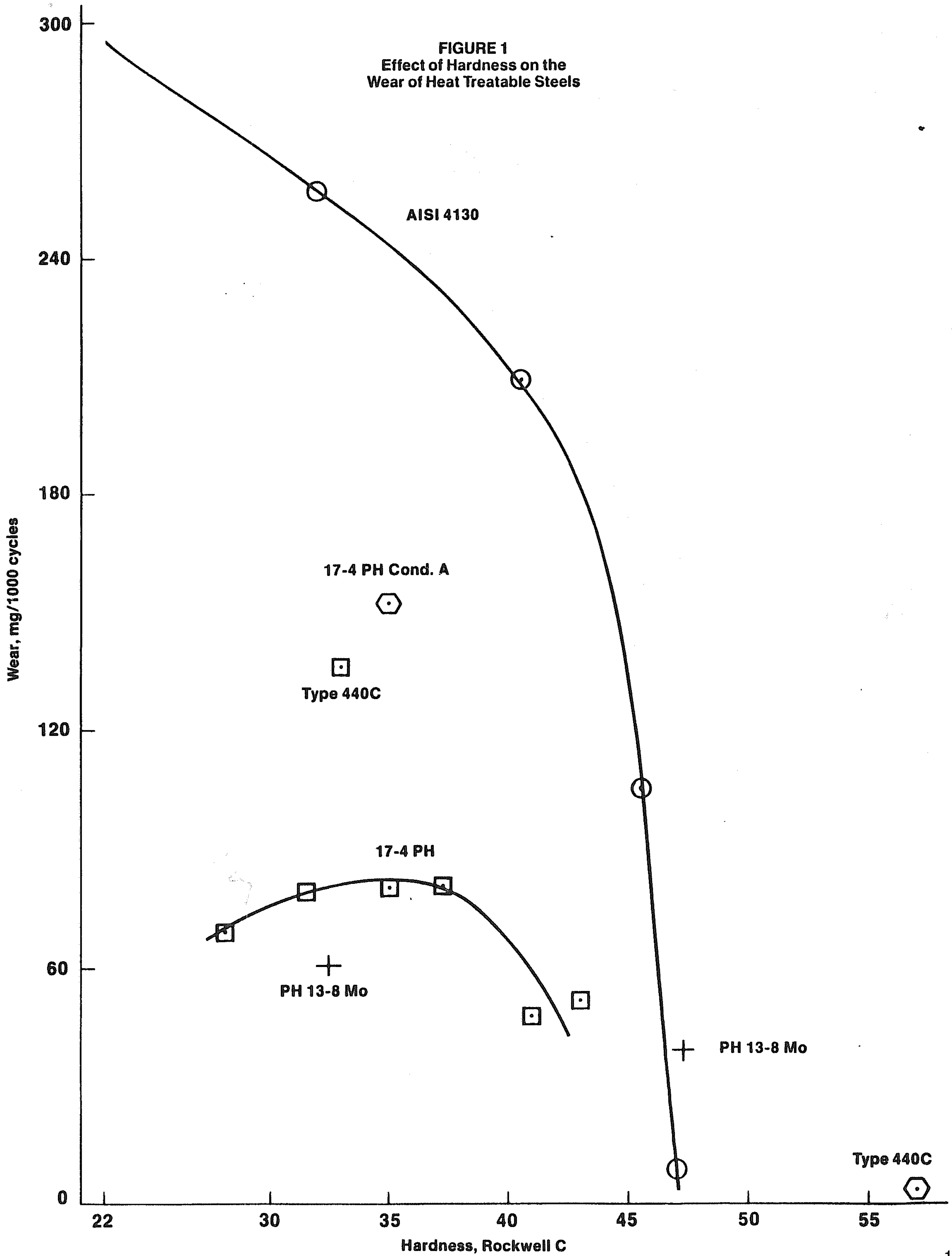
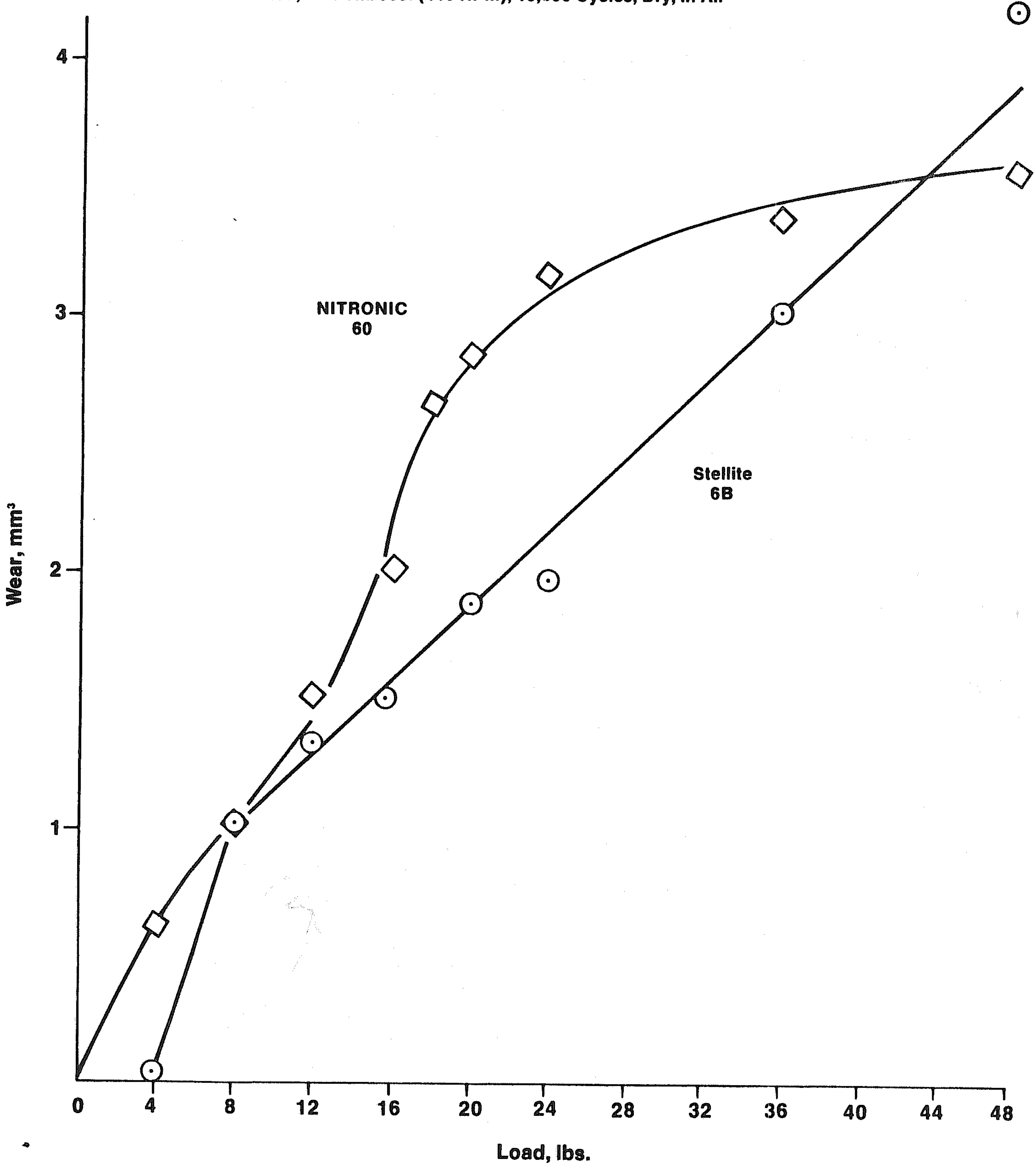


FIGURE 1
Effect of Hardness on the
Wear of Heat Treatable Steels
AISI 4130
17-4 PH Cond. A
Type 440C
17-4 PH
PH 13-8 Mo
PH 13-8 Mo
Type 440C
Wear, mg/1000 cycles
300
240
180
120
60
0
22
30
35
40
45
50
55
Hardness, Rockwell C

FIGURE 2
Effect of Load on the Wear of NITRONIC 60 and Stellite 6B-Taber Met-Abrader, 0.5" (12.7 mm) ø Crossed Cylinders, Self-Mated, 27.6 cm/sec. (415 RPM), 10,000 Cycles, Dry, in Air



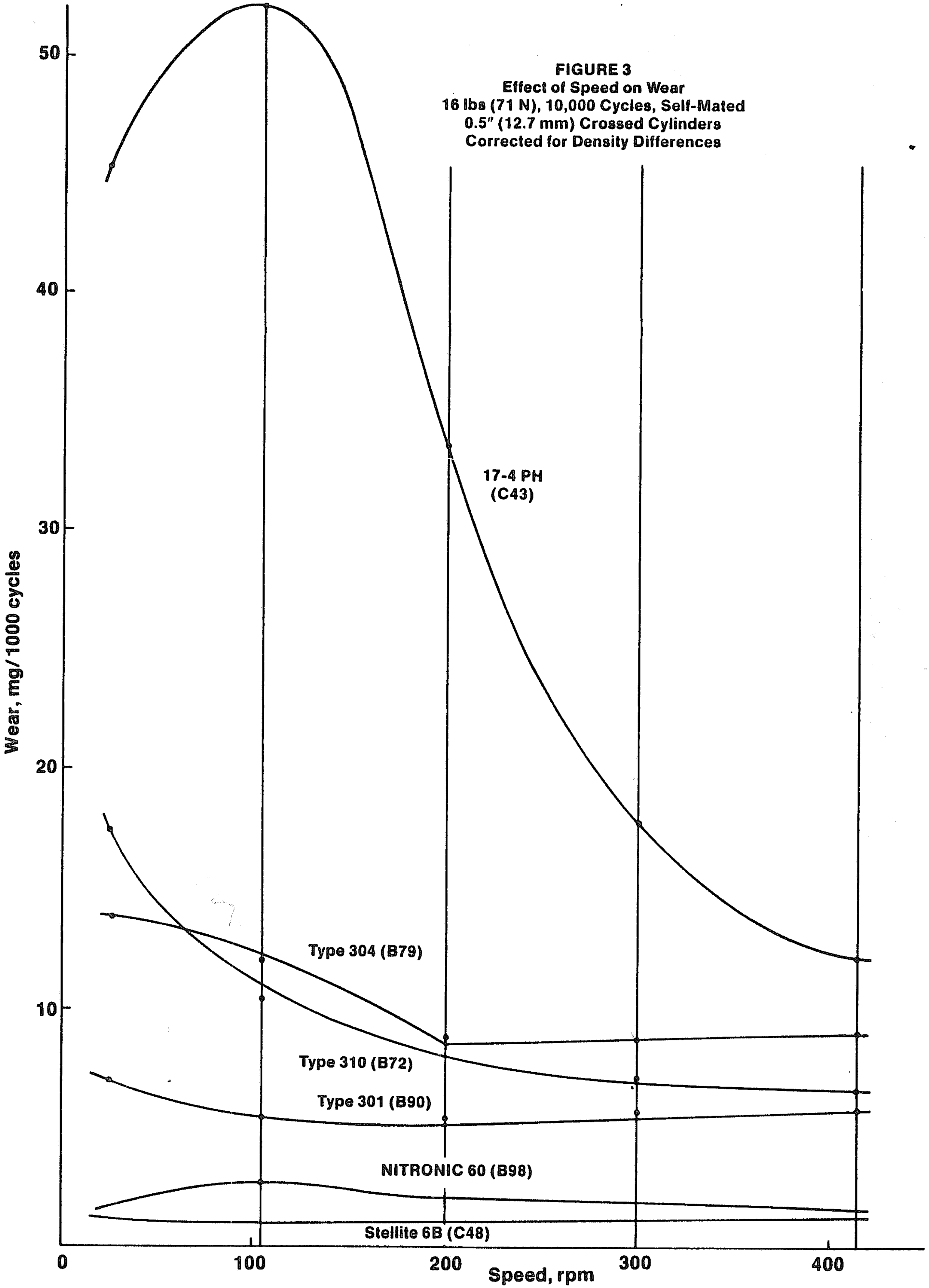
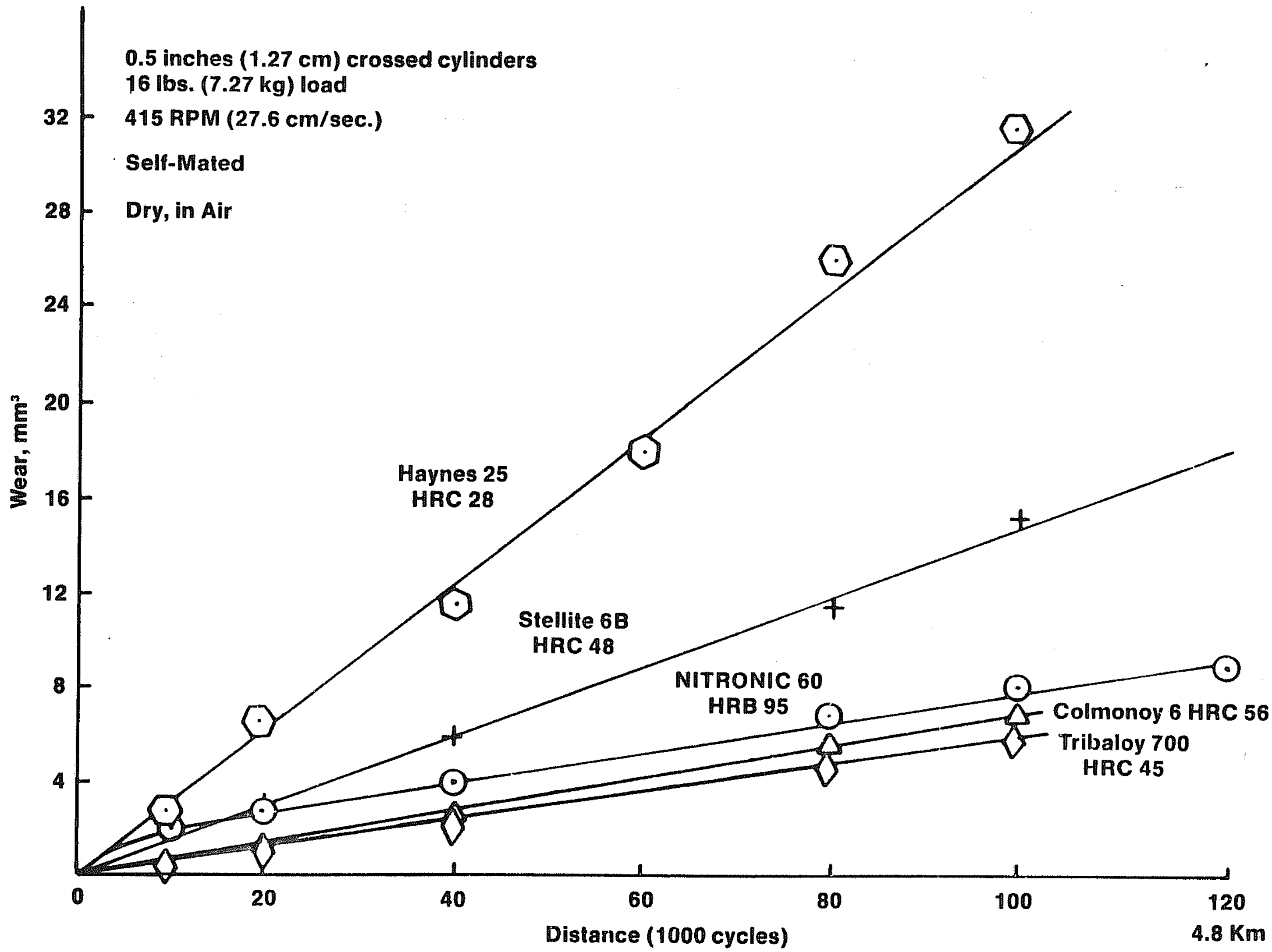


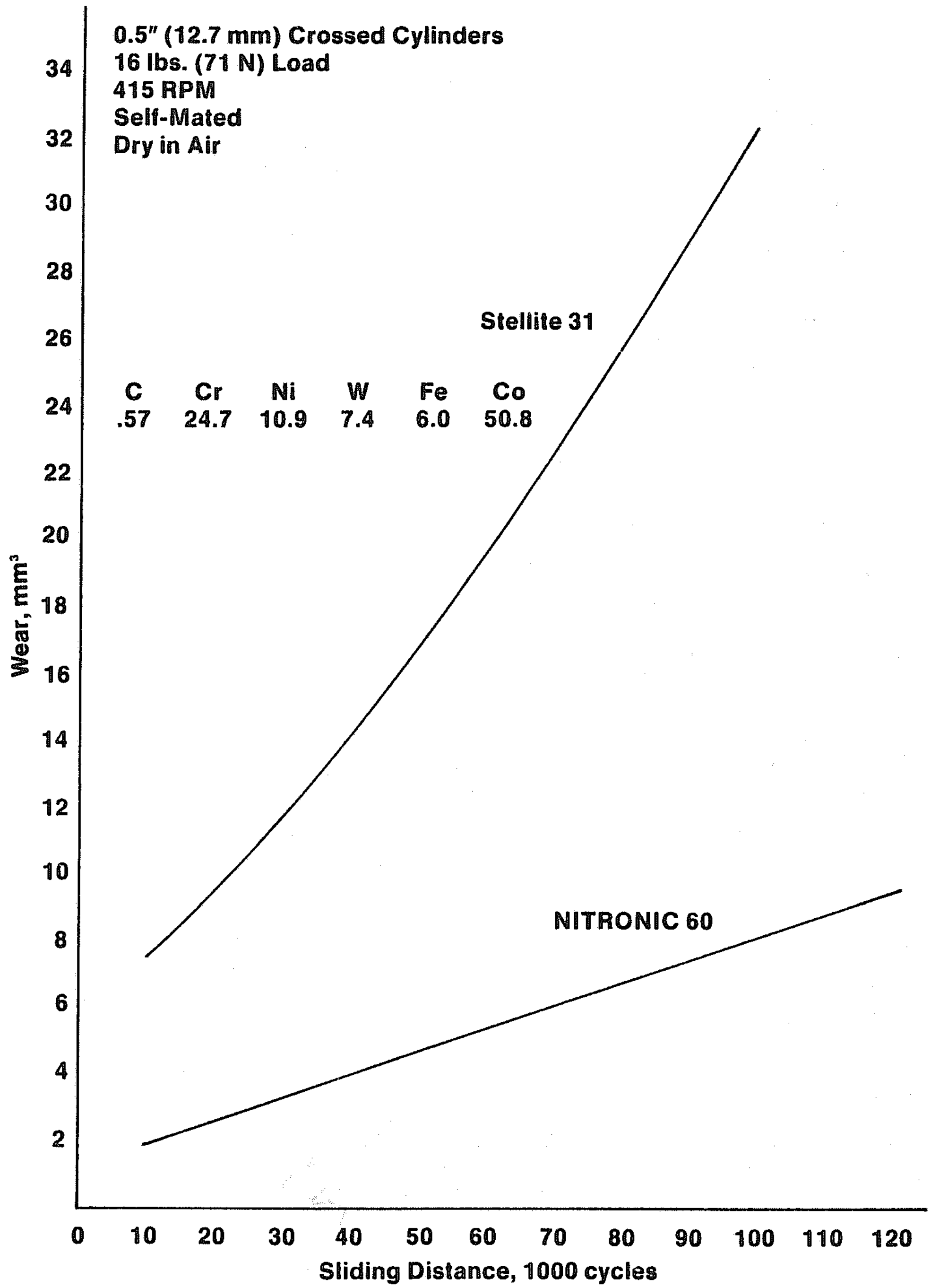
FIGURE 3
Effect of Speed on Wear
16 lbs (71 N), 10,000 Cycles, Self-Mated
0.5" (12.7 mm) Crossed Cylinders
Corrected for Density Differences
Wear, mg/1000 cycles
Speed, rpm
0
100
200
300
400
10
20
30
40
50
17-4 PH
(C43)
Type 304 (B79)
Type 310 (B72)
Type 301 (B90)
NITRONIC 60 (B98)
Stellite 6B (C48)

FIGURE 4
Effect of Distance on Wear Resistance of NITRONIC 60 Compared to Nickel and Cobalt Alloys



This plot of wear versus sliding distance at 415 rpm compares NITRONIC 60 stainless to nickel and cobalt alloys. 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.

FIGURE 5
Wear of NITRONIC 60 and Stellite 31



Elevated Temperature Wear

The elevated temperature wear resistance of 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. NITRONIC 60 also performs well in metal-to-metal wear in nominally inert atmospheres.

Table 17

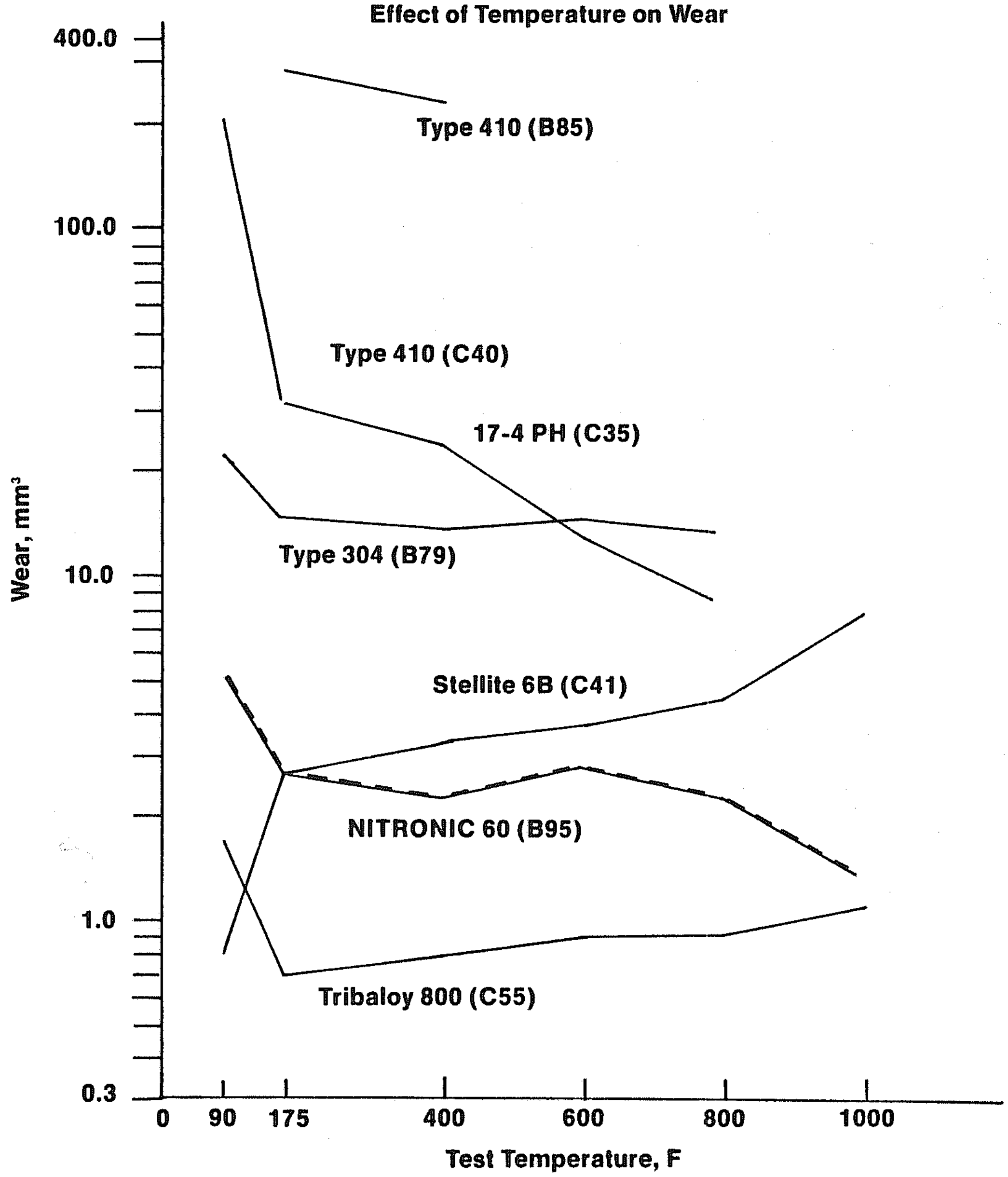
High Temperature Wear Resistance of NITRONIC 60*

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	106.0	2.5
Mild Steel	Air + Steam	266.0	1.0 (Base)

*Test Conditions: Self-mated thrust washers, 500 F (260 C), 500 rpm, 110 lbs (489 N), 4000 cycles. Tested at the U.S. Bureau of Mines.

**Preoxidized—1000 F (538 C), 3 hours in air.

FIGURE 6
Effect of Temperature on Wear



Fretting Wear

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

Cavitation Erosion

Cavitation erosion resistance of NITRONIC 60 is superior to the austenitic stainless steels as well as high strength duplex (ferritic-austenitic) stainless steels. It approaches the cobalt-base alloys which are considered among the most cavitation-resistant alloys available.

Table 18

Relative Depth of Cavitation Damage*

Series 1	NITRONIC 60 1.00	Type 308L 1.89	Al Bronze 3.00	Type 304 3.67	AISI 1020 15.44
Series 2	Stellite 6B 0.67	NITRONIC 60 1.00	Duplex 255 3.33	Duplex 2205 4.33	Type 316L, Type 317L 5.67

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

Table 19

Abrasion Resistance of Corrosion-Resistant Alloys Mated With Al_2O_3**

Alloy	Hardness Rockwell	Alloy Wear, mm³	Al_2O_3 Wear, mm³	Total, mm³
			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	1.80	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, 0.5" (12.7 mm) diameter specimen mated with 0.25" (6.4 mm) flat Al_2O_3 in fixed position, 16 lbs (71 N), room temperature, 10,000 cycles, dry, in air.

Table 20
Abrasion Resistance of Corrosion-Resistant Alloys Mated With Tungsten Carbide*

Alloy	Hardness Rockwell	Alloy Wear, mm³** 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
Type 316	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, 0.5" (12.7 mm) diameter crossed cylinders, 16 lbs (71 N), room temperature, duplicates, WC in fixed position, dry, in air.
**Wear to WC was almost nil in all cases and was not monitored.

Table 21
Abrasion Resistance of Corrosion-Resistant Alloys Mated to Silicon Carbide*

Alloy	Hardness Rockwell	Alloy Wear, mm³—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	21.45	9.03
Type 316	B76	22.41	15.59
Type 304	B79	25.23	13.48
Type 310	B72	37.24	18.12
20 Cb-3	B99	44.82	17.51
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 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.

Table 22
Corrosion Properties*

Media	Annealed Armco NITRONIC 60	Annealed Type 304	Annealed Type 316	Armco 17-4 PH (H 925)
65% Boiling HNO_3	0.060	0.012	0.012	0.132
1% HCl @ 35 C	0.010	0.053	—	0.024
2% H_2SO_4 @ 80 C	0.045	0.243	0.011	0.021
5% H_2SO_4 @ 80 C	0.521	1.300	0.060	—
5% Formic Acid @ 80 C	<.001	.081	<.001	0.001
33% Boiling Acetic Acid	0.011	0.151	<.001	0.006
70% Hydrazine 168 F (76 C), 72 hours	No reaction — Passed			
5% Salt Spray @ 95 F (35 C) (120 hours)	NITRONIC 60 exhibited resistance to general rusting comparable to Type 304.			

*Data based on duplicate tests. Corrosion rates are inches per year.

Table 23
Chloride Pitting Resistance*

Media	Annealed Armco NITRONIC 60	Annealed Type 304	Annealed Type 316	Armco 17-4 PH (H 925)
10% $FeCl_3$ @ RT (pitting test) 50 hours	0.004 gm/in² No Pits	0.065 gm/in² Pitted	0.011 gm/in² Pitted	0.154 gm/in² Pitted
10% $FeCl_3$ @ RT with artificial crevices 50 hours	0.024 gm/in² Slight	0.278 gm/in² Heavy	0.186 gm/in² Heavy	— —

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

Table 24
Stress Corrosion Cracking Resistance
(Boiling 42% $MgCl_2$ — 4 notch tension specimens)

Alloy	Hours to Failure at Various Stress Levels				
	20 ksi (138 MPa)	25 ksi (172 MPa)	30 ksi (207 MPa)	35 ksi (241 MPa)	40 ksi (276 MPa)
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

Seawater Corrosion Resistance

When exposed for 6 months in quiet seawater at ambient temperature, 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.

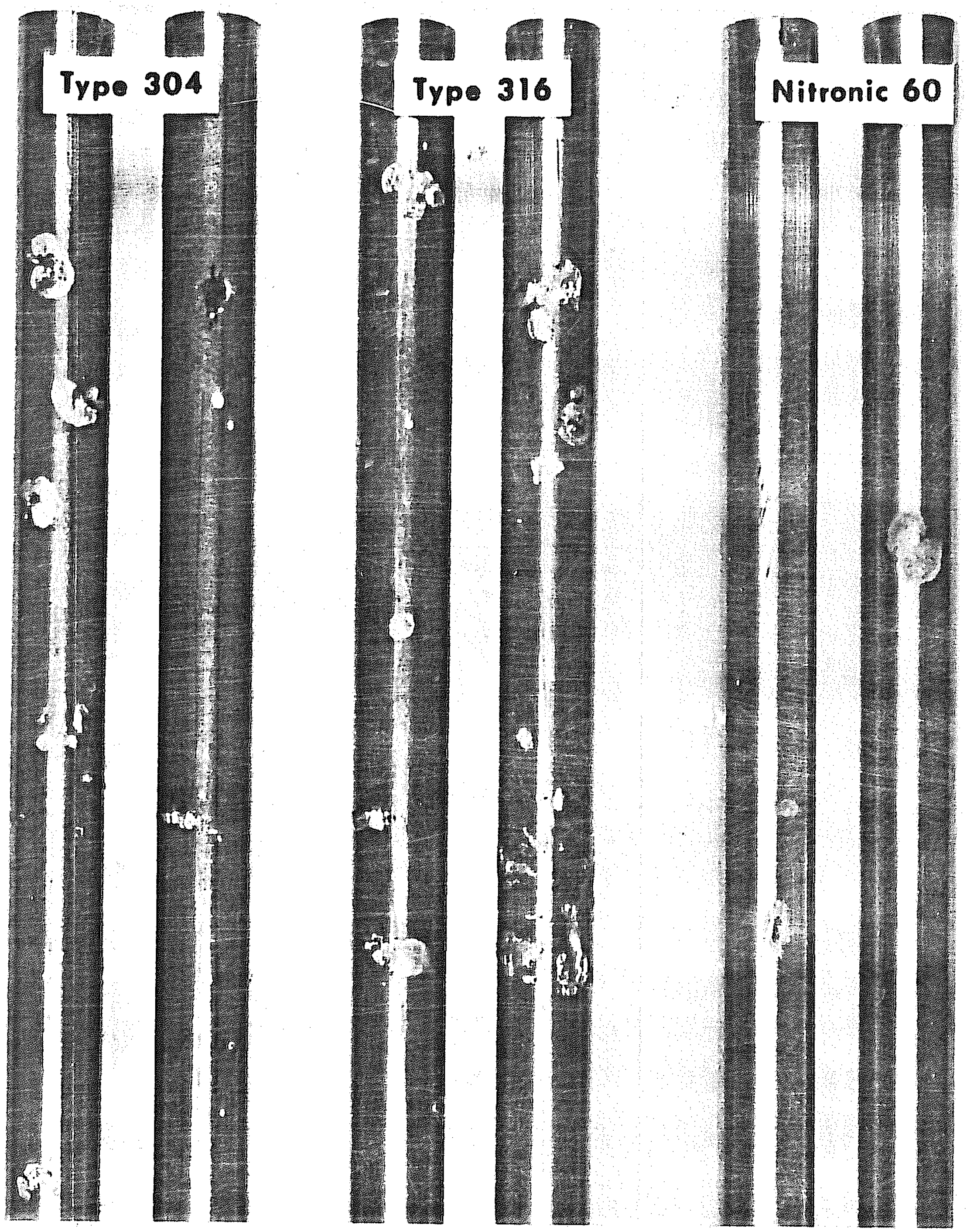


Table 25
Sulfide Stress Cracking Resistance*

17-4 PH (H 1150-M)			NITRONIC 60 (Annealed)		
0.2% YS ksi (MPa)	Stress Applied Expressed as a % YS	Time to Failure Hours	0.2% YS ksi (MPa)	Stress Applied Expressed as a % YS	Time to Failure Hours
108.7 (749)	90.6	8.9	55.3 (381)	110	720 (No Failure)
108.7 (749)	85.0	19.5	58.7 (405)	110	720 (NF)
108.7 (749)	81.6	21.9	52.8 (365)	100	720 (NF)
108.7 (749)	72.8	26.7	54.3 (374)	100	720 (NF)
108.7 (749)	60.7	50.1	55.3 (385)	100	720 (NF)
108.7 (749)	44.9	104.5	58.7 (405)	100	720 (NF)
110.5 (762)	34.6	214.6	58.7 (405)	85	720 (NF)
110.5 (762)	28.0	572.1	Passed NACE requirements of 720 hours stressed at 100% of 0.2% YS without failure.		
110.5 (762)	22.0	720 (No Failure)			

*Tested according to NACE TM-01-77, using Cortest Proof Rings.

Table 26
Sulfidation Resistance*

Test Temperature F (C)	Weight Loss, mg/in²	
	NITRONIC 60	Type 309
1600 (871)	1.40	1.35
1700 (927)	2.14	3745
1800 (982)	3040	Dissolved

*Conditions: Duplicate wire specimens packed in mixture of 90% Na_2SO_4 + 10% KCl for 1 hour 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 27.

Table 27
Carburization Resistance*

Alloy		UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 4XD	Reduction of Area %	Bend 1.5T
NITRONIC 60	Unexposed	116.0 (800)	49.5 (341)	74.0	66.3	180°
	Exposed	91.5 (630)	58.0 (400)	19.0	21.6	100°
Type 316L	Unexposed	76.0 (524)	30.0 (207)	68.0	74.4	180°
	Exposed	65.0 (448)	36.0 (248)	24.0	21.3	110°
Type 309	Unexposed	99.0 (683)	41.0 (283)	54.0	64.7	180°
	Exposed	85.5 (589)	45.5 (313)	14.0	11.9	75°

*Conditions: Duplicate tests exposed at 1800 F (982 C) for 2 hours in packed 90% graphite + 10% sodium carbonate.

Oxidation Resistance

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 28
Static Oxidation Resistance*

Test Temperature, F (C)		Weight Loss, mg/cm² RA 333	Type 310	NITRONIC 60	Type 304
2100 (1149)	Before Descaling	3.1	4.6	16.5	1220
	After Descaling	12.2	15.7	23.2	1284
2200 (1204)	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 29
Cyclic Oxidation Resistance

Cycle	Alloy	Weight Change, mg/in², at number of cycles indicated: 134 cycles	275 cycles	467 cycles	200 cycles	304 cycles	400 cycles
1600-1700 F (871-927 C)	RA 330	+ 3.4	+ 4.9	+ 6.4	—	—	—
25 minutes heat,	Type 310	+ 4.0	+ 6.7	- 22.7	—	—	—
5 minutes cool -	Type 309	+ 3.0	- 41.6	- 100.4	—	—	—
duplicate tests	NITRONIC 60	+ 1.5	- 69.2	- 167.6	—	—	—
	Type 316	-473.0	-970.8	-1287.0	—	—	—
		Weight Loss, mg/cm²					
1900 F (1038 C)	Type 446	—	—	—	1.47	1.72	1.97
30 minutes heat,	Type 310	—	—	—	2.70	15.95	17.22
30 minutes cool	Type 309	—	—	—	22.53	26.34	33.69
	NITRONIC 60	—	—	—	42.99	60.40	74.80
	Type 316	—	—	—	93.04	135.34	178.27

Mechanical Properties

Table 30
Typical Room Temperature Tensile Properties*

Condition	Size	Hardness	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 4XD	Reduction of Area, %
Annealed	1" (25.4 mm) ø	R_B 95	103 (710)	60 (414)	64	74
Annealed	1-3/4" (44.4 mm) ø	R_B 100	101 (696)	56 (386)	62	73
Annealed	2-1/4" (57.2 mm) ø	R_B 100	101 (696)	60 (414)	60	76
Annealed	3" (76.2 mm) ø	R_B 97	113 (779)	65 (448)	55	67
Annealed	4-1/8" (104.8 mm) ø	R_B 95	106 (731)	56 (386)	57	67

HPAlloys MATERIAL Capabilities

High Strength NITRONIC 60

Issued December 22nd, 2003

Strain Hardened Levels

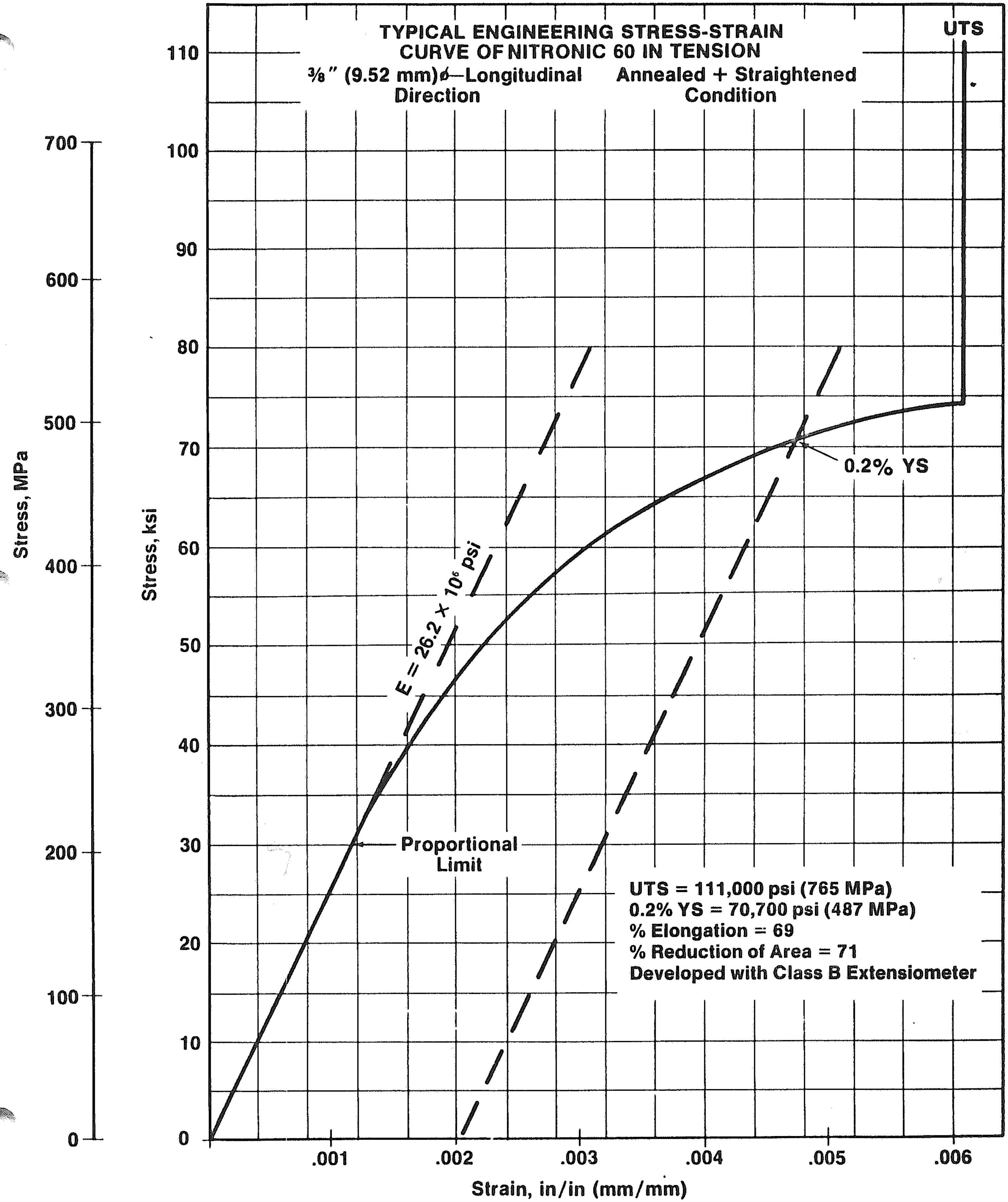
High Strength NITRONIC 60

Minimum specification levels for bar						
Strength Condition	UTS (KSI) Min.	YS (0.2% OS) (KSI) Min.	Elongation in 4xD (%) Min.	Reduction of Area (%) Min.	Hardness Max	Sizes (Inclusive)
Level 1	110	90	35	55	---	0.25" to 4" Dia
Level 2	135	105	20	50	330 BHN	0.25" to 4" Dia
Level 3	160	130	15	45	---	0.25" to 2.4" Dia
Level 4	180	145	12	45	---	0.25" to 2" Dia
Level 5	200	180	10	45	---	0.25" to 1.5" Dia

Questions & Comments: **Tel: 800-472-5569 (inside USA and Canada)**
Tel: 765-675-8871 (outside USA)
Fax: 765-675-7051
Email: service@hpalloy.com

HPAlloy WEB ADDRESS: http://www.hpalloy.com

FIGURE 7



TYPICAL ENGINEERING STRESS-STRAIN
CURVE OF NITRONIC 60 IN TENSION
⅜" (9.52 mm)ϕ—Longitudinal Direction
Annealed + Straightened Condition
UTS
0.2% YS
$E = 26.2 \times 10^6$ psi
Proportional Limit
UTS = 111,000 psi (765 MPa)
0.2% YS = 70,700 psi (487 MPa)
% Elongation = 69
% Reduction of Area = 71
Developed with Class B Extensiometer
Stress, MPa
700
600
500
400
300
200
100
0
Stress, ksi
110
100
90
80
70
60
50
40
30
20
10
0
.001
.002
.003
.004
.005
.006
Strain, in/in (mm/mm)

Table 31
Typical Room Temperature Torsion and Shear Properties*

Condition	Size	Hardness R_B	Torsional Modulus, G ksi (MPa)	0.2% Torsional YS ksi (MPa) γ	0.2% Torsional YS ksi (MPa) ϵ	Modulus of Rupture ksi (MPa)	Double Shear Strength ksi (MPa)
Annealed	1" ø	95	8.83 x 10^3 (57 x 10^3)	48.9 (337)	50.7 (350)	124 (855)	—
Annealed	3/8" ø	95	—	—	—	—	86 (593)

*Data based on duplicate tests

Table 32
Double Shear Strength*
(Cold Drawn — 0.442" [11.23 mm] start size)

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

*Triplicate tests

Table 33
Fatigue Strength
(R.R. Moore Machine)

Condition	Size	Hardness	Endurance Limit, ksi (MPa) 10^8 Cycles
Annealed	1" (25.4 mm) ø	R_B 95	37.5 (258)
Cold Worked 54.6%	0.70" (17.8 mm) ø	R_C 44	72.5 (500)

Table 34
Room Temperature Compression Strength

Condition	Size	0.2% Compressive YS, ksi (MPa)
Annealed	0.500" ø (12.7 mm)	67.6 (466)
Cold Drawn 39%	0.440" ø (11.2 mm)	121.0 (834)

Table 35
Properties Acceptable for Material Specification
(Bar and Wire)

Condition	Size	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 4XD	Reduction of Area, %	Hardness R_B
Annealed	1/2" ø + under (12.7 mm)	105 min (724)	55 min (379)	35 min	55 min	85 min
Annealed	Over 1/2" ø (12.7 mm)	95 min (655)	50 min (345)	35 min	55 min	85 min

Table 36
Typical Elevated Temperature Mechanical Properties*
(Annealed 3/4" and 1" [19.05 and 25.4 mm] Diameter Bar Stock)

Test Temperature F (C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 4XD	Reduction of Area %	Hardness Brinell
Room Temperature	106.5 (734)	56.5 (389)	61.7	71.9	200
200 (93)	98.2 (677)	44.4 (306)	63.3	72.4	187
300 (149)	89.9 (620)	37.8 (260)	64.4	73.7	—
400 (204)	84.4 (580)	32.8 (227)	64.0	73.7	168
500 (260)	82.1 (566)	32.1 (222)	61.5	73.0	—
600 (316)	80.5 (555)	29.7 (205)	59.6	73.1	155
700 (371)	79.5 (548)	29.2 (201)	59.1	72.6	—
800 (427)	78.3 (540)	29.0 (200)	56.5	72.1	148
900 (482)	77.1 (532)	28.3 (195)	53.9	71.6	—
1000 (538)	75.4 (520)	28.0 (193)	52.2	70.4	145
1100 (593)	71.6 (494)	28.7 (198)	48.7	70.0	—
1200 (649)	66.6 (459)	28.1 (194)	48.2	69.6	144
1300 (704)	59.0 (407)	27.5 (189)	41.4	50.0	—
1400 (760)	49.8** (344)	25.3 (174)	47.1	53.9	143
1500 (816)	37.0** (255)	23.8 (164)	72.8	75.0	—
1600 (871)	30.2** (208)	16.4 (113)	72.8	—	110

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

Table 37
Elevated Temperature Tensile Properties
(Cold Swaged 54% to 0.700" [17.8 mm] ⌀)

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

Table 38
Elevated Temperature Stress Rupture Strength
(Annealed Bars 5/8" to 1" [16.0 to 25.4 mm] Diameter)

Temperature F (C)	Number of Heats	Stress Rupture Strength, ksi (MPa)		
		100 hr. life	1000 hr. life	10,000 hr. life
1000 (538)	3	72 (496)	52 (359)	35 (241)
1100 (593)	3	49 (338)	31 (214)	20 (138)
1200 (649)	4	29 (200)	17 (117)	10* (69)
1350 (732)	1	14 (97)	8 (55)	—
1500 (816)	1	6.7 (46)	4 (28)	—

*Extrapolated

Table 39
Cryogenic Tensile Properties*

Condition	Size	Temperature, F (C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 4XD	Reduction of Area, %
Annealed	3/8" (9.5 mm) ø	-100 (-73)	155 (1069)	76 (524)	57	69
	3/8" (9.5 mm) ø	-200 (-129)	170 (1172)	87 (600)	56	71
	1"(25.4 mm) ø	-320 (-196)	213 (1469)	109 (752)	60	67
Cold Swaged 54%	.700" (17.8 mm) ø	-320 (-196)	322 (2220)	272 (1875)	10	53
	.700" (17.8 mm) ø	-200 (-129)	287 (1979)	250 (1724)	13	62

*Duplicate tests

Table 40
Low Temperature Mechanical Properties of NITRONIC 60 Stainless Steel Longitudinal Tensile Specimens*

Test Temperature F (C)	UTS ksi (MPa)	0.2% Offset YS ksi (MPa)	Elongation % in 1" (25.4 mm) or 4XD	Reduction of Area %	Fracture Strength ksi (MPa)	Modulus psi (MPa)	N/U** Tensile Ratio	Charpy V-Notch Impact ft-lbs (J)
75 (24)	109.3 (754)	58.1 (400)	66.4	79.0	336.1 (2317)	24.0×10^6 (165,000)	1.44	231 (310)
0 (-18)	128.1 (883)	67.3 (464)	71.3	79.7	433.4 (2988)	23.7×10^6 (163,000)	1.37	216 (292)
-100 (-73)	148.4 (1023)	77.9 (537)	70.5	80.9	447.1 (3083)	24.2×10^6 (167,000)	1.45	197 (267)
-200 (-129)	167.6 (1155)	87.4 (603)	62.4	78.4	457.0 (3151)	24.2×10^6 (167,000)	1.46	170 (231)
-320 (-196)	217.9 (1502)	101.4 (699)	59.5	65.8	594.0 (4095)	24.8×10^6 (171,000)	1.26	138 (188)
-423 (-253)	203.8 (1405)	125.3 (864)	23.5	26.6	277.6 (1914)	24.8×10^6 (171,000)	1.33	— —

*0.250" (6.35 mm) diameter, machined from a 1" (25.4 mm) 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.

Table 41
Impact Properties**

Condition	Size	Test Temperature, F (C)	Charpy V-Notch Impact, ft-lbs (J)
Annealed	1" ø (25.4 mm)	Room Temperature	240* (325)
		-100 (-73)	229 (310)
		-320 (-196)	144 (195)
Annealed	2-1/4" ø (54.2 mm)	Room Temperature	240* (325)
		-100 (-73)	240* (325)
		-320 (-196)	160 (217)
Cold Swaged 18% Hardness R_C 29	.932" ø (23.7 mm)	-320 (-196)	67 (91)
Cold Swaged 40% Hardness R_C 37	.795" ø (20.2 mm)	-320 (-196)	40 (54)
Cold Swaged 54% Hardness R_C 42	.700" ø (17.8 mm)	-320 (-196)	26 (35)
Cold Swaged 18% Hardness R_C 29	.932" ø (23.7 mm)	-200 (-129)	90 (122)
Cold Swaged 40% Hardness R_C 37	.795" ø (20.2 mm)	-200 (-129)	44 (60)
Cold Swaged 54% Hardness R_C 42	.700" ø (17.8mm)	-200 (-129)	30 (41)

*Data not fracture completely
**Data based on duplicate tests

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 42
Minimum Room Temperature Properties
NITRONIC 60 HS Bars (Rotary Forge Only; Special Practice)

Diameter in (mm)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2″ (50.8 mm)	Reduction of Area %	Hardness Rockwell
2.5-5.0 incl (63.5-127)	110 (758)	90 (621)	20	45	C20
Over 5-6 incl (127-152)	110 (758)	70 (483)	20	45	C20

Table 43
Typical Mechanical Properties
NITRONIC 60 HS Bars*

Diameter	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2″ (50.8 mm)	Reduction of Area %
3.5″ (88.9 mm)	120 (827)	93 (641)	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 44
Effect of Temperature on Tensile Properties*
NITRONIC 60 HS

Test Temperature F (C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2″ (50.8 mm)	Reduction of Area %
-320 (-196)	211 (1455)	132 (910)	28	16
-100 (-73)	165 (1138)	108 (745)	50	58
RT	127 (876)	96 (662)	37	60
200 (93)	118 (814)	87 (600)	44	59
300 (149)	108 (745)	77 (531)	43	61
400 (204)	103 (710)	74 (510)	39	61
600 (316)	99 (683)	71 (490)	41	57
800 (427)	96 (662)	69 (476)	37	63
1000 (538)	91 (627)	68 (469)	31	62
1200 (649)	74 (510)	56 (386)	42	64
1400 (760)	44 (303)	31 (214)	63	83

*Typical values, longitudinal direction, duplicate tests.

Table 45
Typical Sub-Zero Impact Strength
NITRONIC 60 HS Bars (3.5″ [88.9 mm] Diameter)

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

Table 46
Wear and Galling Properties
NITRONIC 60 HS Bars*

Couple (Hardness, Rockwell)	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, ksi (MPa)
NITRONIC 60 HS (C29) — NITRONIC 60 (B95)	41 (283)
NITRONIC 60 HS — 17-4 PH (C43)	47+ (324)
NITRONIC 60 HS — NITRONIC 50 (C23)	49+ (338)
NITRONIC 60 HS — Type 316 (B85)	36 (248)
NITRONIC 60 HS — 17-4 PH (C34) (H 1150 + H 1150)	37 (255)

*Metal-to-metal wear-crossed cylinders.

Table 47
Sulfide Stress Cracking of HS Bars*

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

*NACE TM-01-77, Cortest Proof Rings, Yield Strength = 97 ksi (669 MPa)
**NF—No Failure

Physical Properties

Table 48
Physical Properties

Density at 75 F (24 C)—7.622 gm/cm³
Electrical Resistivity—98.2 microhm-cm
Modulus of Elasticity—26.2 x 10^6 psi (180,000 MPa)
Poisson's Ratio—0.298

Table 49
Mean Coefficient of Thermal Expansion

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

Table 50
Magnetic Permeability

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

Table 51
Magnetic Permeability of HS Bar*

Bar Location	Field Strength, Oersteds (Ampere/Metres) 100 (7958)	200 (15,916)	500 (39,790)	1,000 (79,580)
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 A342-64, Method 4

Table 52
Dynamic Coefficient of Friction

Alloy	Dynamic Coefficient of Friction* Test Stress Level, N/mm² 0.8	5.6	14.0	28.0	56.0	112.0
NITRONIC 60	.50	.35	.38	.44	.44	.44
Stellite 6B	.30	.60	.63	—	—	—
NITRONIC 32	—	—	.45	.53	.65	.58

*Tested in water at 20°C, self-mated.

Table 53
Dynamic Coefficient of Friction
Ring on Block (15-45 lbs [67-200 N])*

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 54
Machinability*

AISI B 1112	Type 304	Armco NITRONIC 60
100%	45%	23%

*1" ⌀ (25.4 mm)—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 NITRONIC 60, machinability is not easy. However, with sufficient power and rigidity, NITRONIC 60 Stainless Steel can be machined. It is suggested that *coated carbides* be considered for machining.

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:

Single Point Turning
Roughing — 0.150" depth — 0.015"/rev feed — 175 SFM
Finishing — 0.025" depth — 0.007"/rev feed — 200 SFM

Side and Slot Milling
Roughing — 0.250" depth — 0.007"/tooth feed — 125 SFM
Finishing — 0.050" depth — 0.009"/tooth feed — 140 SFM

Drilling
1/4" diameter hole — 0.004"/rev feed — 60 SFM
1/2" diameter hole — 0.007"/rev feed — 60 SFM
3/4" diameter hole — 0.010"/rev feed — 60 SFM

Reaming — feed same as drilling — 100 SFM

These rates are suggested for carbide tools, Type C-2 for roughing, drilling, and reading, 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 55.

The use of 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 Armco.

The American Welding Society has included NITRONIC 60W bare wire in AWS A5.9 as ER 218 alloy.

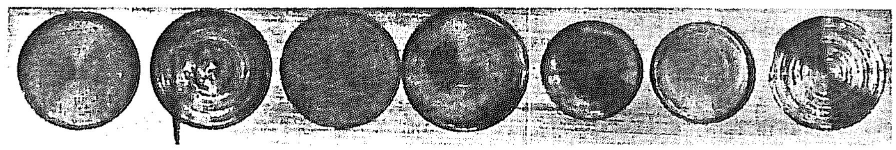
Table 55
Comparative Properties of Base Metal vs. Weld Metal

	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)	Red. of Area %	Hardness Rockwell	Impact Charpy V-Notch ft-lbs (J)		Galling Stress NITRONIC 60 vs. NITRONIC 60 ksi (MPa)
						Temperature, F(C)		
As-Welded Weld Metal G.M.A.	123 (848)	85 (586)	19	22	C25	Room -320 (-196)	54 (73) 11 (15)	40 (276)
Annealed Base Metal	103 (710)	60 (414)	64	74	B95	Room -320 (-196)	240+ (325) 144 (195)	50+ (345)

¹ Did not gall

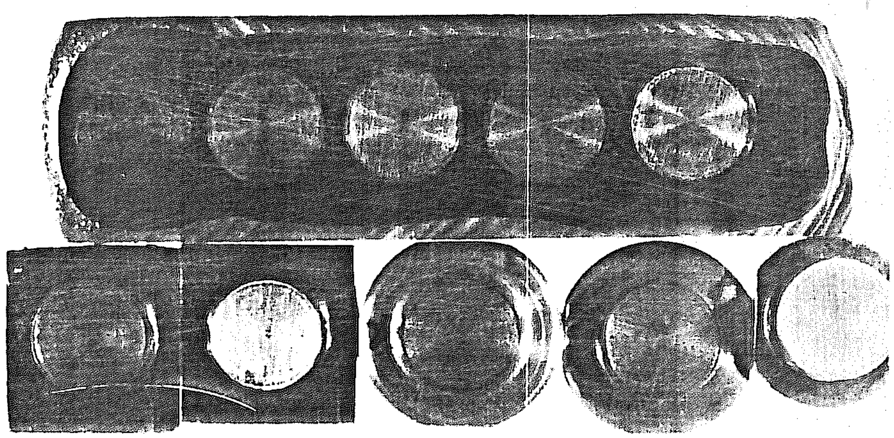
Following are examples of the excellent galling resistance of Armco NITRONIC 60 in the as-deposited, weld overlay condition.

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 ksi (MPa)	40.8 (282) OK	40.0 (276) Galled	40.8 (282) OK	37.7 (260) OK	56.9 (392) OK	58.3 (402) OK	34.3 (236) 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 ksi (MPa)	35.8 (247) OK	52.7 (365) OK	35.8 (247) OK	46.3 (319) OK	47.8 (329) OK

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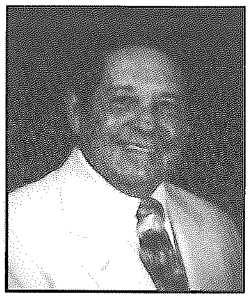
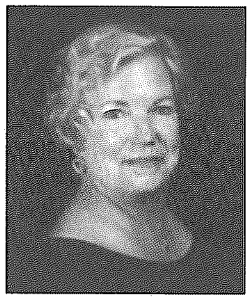


Russ Kirchner, Jr.
President/Metallurgist



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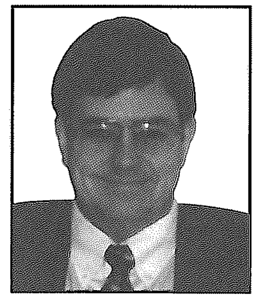
CEO



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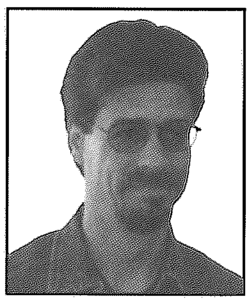

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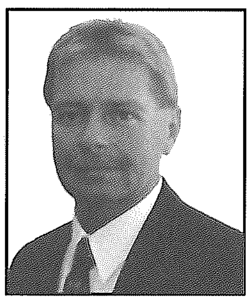

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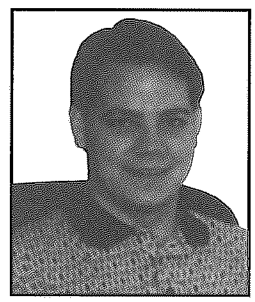

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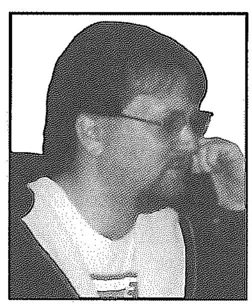

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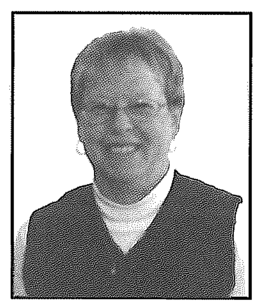
Plant Manager



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