(UNS S21800)

NITRONIC® 60
STAINLESS STEEL
PRODUCT FORMS

PUMPS
VALVES
FITTINGS

INGOTS
BILLETS
BARS
PIGS
WELD WIRE
PLATE

FIGHTS WEAR AND GALLING

- **Best galling resistance of all stainless steels**
- **Corrosion resistance and strength superior to Type 304**
- **Pitting resistance better than Type 316**

Product Data Bulletin E-60
Revised 11-2013

Electralloy
ELECTRALLOY

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Plate Products

ELECTRALLOY

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NITRONIC® 60

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Product Description

Electralloy 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, Electralloy Nitronic® 60 Stainless Steel provides excellent high-temperature oxidation resistance and low-temperature impact resistance.

Composition

Composition	% Min.	% Max
Carbon	0.060	0.080
Manganese	7.50	8.50
Phosphorus	---	0.040
Sulfur	---	0.030
Silicon	3.70	4.20
Chromium	16.00	17.00
Nickel	8.00	8.50
Molybdenum	---	0.75
Copper	---	0.75
Nitrogen	0.10	0.18
Titanium	---	0.050
Aluminum	---	0.020
Boron	---	0.0015
Columbium	---	0.10
Tin	---	0.050
Vanadium	---	0.20
Tungsten	---	0.15

Available Forms

Electralloy Nitronic® 60 Stainless Steel is available in bar, master alloy, pigs, ingots and forging billets. Forms available from other manufacturers using Electralloy melt include sheet and strip, castings, extrusions, seamless tubing and plate. Electralloy Nitronic® 60 Stainless Steel was originally covered by U.S. Patent 3,912,503.

Heat Treatment

Electralloy Nitronic® 60 Stainless Steel is not hardenable by heat treatment. Annealing at 1950° F (1066° C) followed by water quenching is recommended.

Specifications

Electralloy 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 A240 – Heat-Resisting Chromium and Chromium-Nickel Stainless Sheet Plate, Sheet and Strip for Pressure Vessels
- 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 Applications (Grade CF 10SMnN)
- AMS 5848 – Bars, Forgings, Extrusions, Tubing and Rings
- ASME Design Allowables Listed in Table UHA-23 of Section VIII, Division 1
- ASME Design Valves Listed in Section III, Division 1, Table 1-72

Applications Potential

Outstanding galling and wear resistance, and excellent corrosion resistance, of Electralloy's Nitronic® 60 make it a valuable material for infrastructure projects such as bridge pins and expansion joint hangers and wear plates for highway construction; and stems and wicket gate wear rings for hydro-electric dams. Alloy finds application in foods processing and pharmaceuticals in sanitary equipment where lubricants cannot be used. Nitronic® 60 is also used in oil and gas production and chemical and petrochemical plants for valve stems, seats and trim, pump wear rings, seals, bushings and the like. Nitronic® 60 weld wire is used to make wear and galling resistant weld overlays.

Nitronic® alloys are produced by Electralloy under license from AK Steel.

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 designed 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.

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The information and data in this product data bulletin are accurate to the best of our knowledge and belief, but are intended for general information only. Applications suggested for the materials are described only to help readers make their own evaluations and decisions, and are neither guarantees nor to be construed as express or implied warranties for suitability for these or other applications.

Data referring to mechanical properties and chemical analyses are the result of test performed on specimens obtained from specific locations of the products in accordance with prescribed sampling procedures; any warranty thereof is limited to the values obtained at such locations and by such procedures. There is no warranty with respect to values of the materials at other locations.

Atlas Impeller Casting of Nitronic® 60 Stainless Steel.

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.

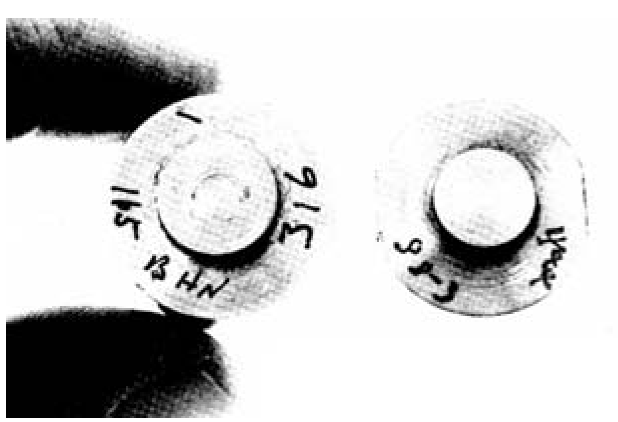
A "button and block" galling test was used to rank alloys for their galling tendencies. In the test procedure, a dead-load weight is applied in a floor model Brinell Hardness Tester on two flat, polished surfaces (10-20 micro-inches). The 0.5-inch (12.7 mm) diameter button is slowly rotated by hand 360° 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.

Table 1 **Unlubricated Galling Resistance of Stainless Steels Threshold Galling Stress in ksi (MPa) (Stress at which galling began)**

Conditions and Normal Hardness (Brinell)	Type 410	Type 416	Type 430	Type 440C	Type 303	Type 304	Type 316	17-4PH	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 (352) 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 15-5 PH (H 1150)	50+ (345)
Nitronic® 60 (205) vs. Inconel 718 (306)	50+ (345)
Nitronic® 60 (205) vs. CP Titanium (185)	47+ (324)
Nitronic® 60 (205) vs. Ni Resist Type 2 (145)	50+ (345)

cont.

Couple – (Brinell Hardness)	Threshold Galling Stress ksi (MPa) (Stress at which galling began)
Nitronic® 60 (205) vs. Stellite 21 (295)	43+ (296)
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 2205 (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 + H1150) (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

Elevated Temperature Galling Applications

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). 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.

Table 3 **Cryogenic Galling Resistance***

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

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

Wear Resistance

Data shown in Tables 4 through 16 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 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 4 **Wear Compatibility of Self-Mated Austenitic Stainless Steels**

Alloy	Hardness Rockwell	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 5 **Wear Compatibility of Self-Mated Martensitic and Ferritic Stainless Steels**

Alloy	Hardness Rockwell	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 6 **Wear Compatibility of Self-Mated Cast Alloys and Coatings**

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

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
H 13 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	Weight Loss, mg/1000 cycles						
	Type 304	Type 316	17-4PH	Nitronic® 32	Nitronic® 50	Nitronic® 60	Type 440C
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 VS	Weight Loss, mg/1000 cycles		
	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 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 Nitronic® 60 Stainless Steel and Waukesha 88 in Contact with Stainless Steels

	Weight Loss, mg/1000 cycles	
Alloy VS	Nitronic® 60	Waukesh 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 Compatibility 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

Table 13 Wear Compatibility of Miscellaneous Dissimilar Couples (cont.)

Couple (Rockwell Hardness)	Couple Weight Loss, mg/1000 cycles
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				
HBR 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

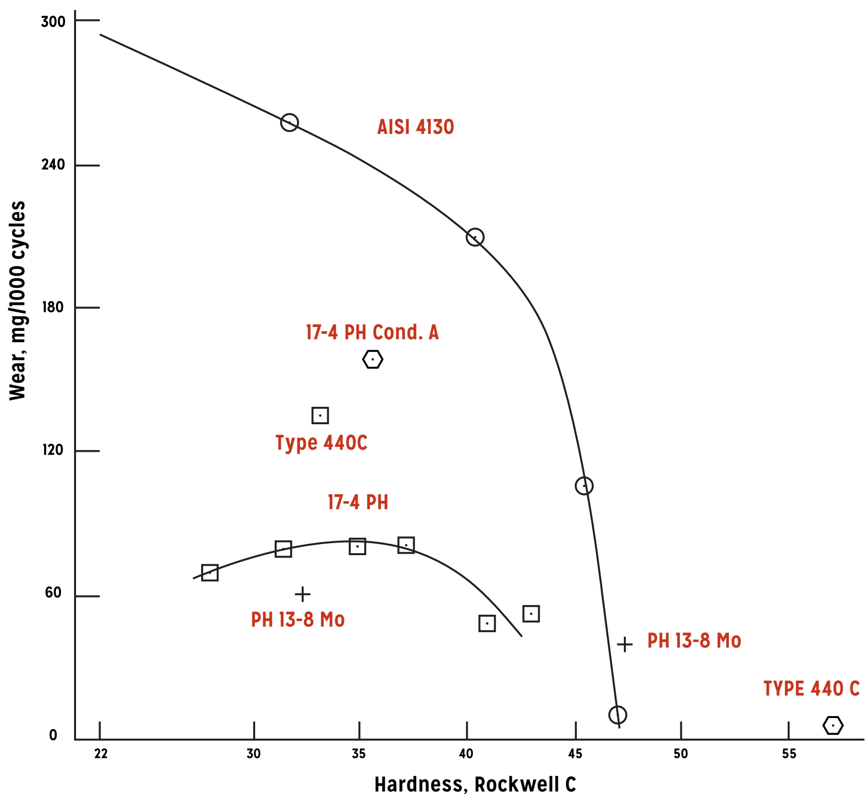


FIGURE 2 **Effect of Load on the Wear of Nitronic® 60 and Stellite 6B-Taber Met-Abrader, 0.5” (12.7 mm) ø Crossed Cylinders, Self-Mated, 27.6 cm/sec. (415 RPM), 10,000 Cycles, Dry, in Air**

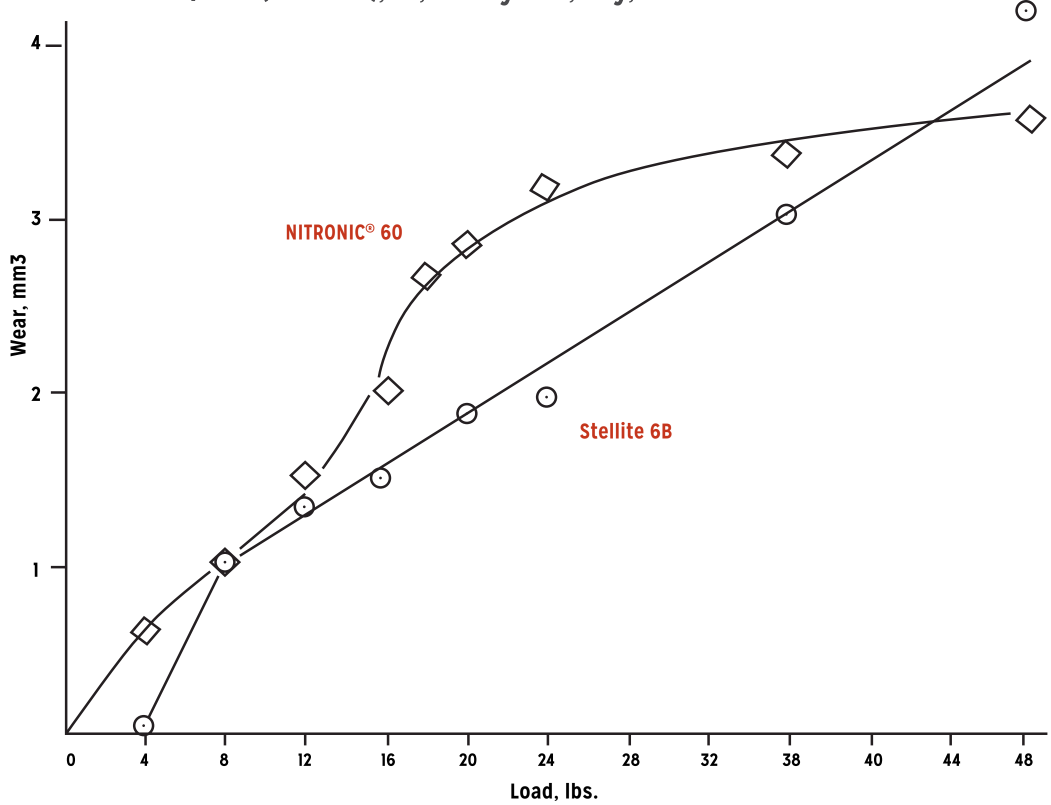


FIGURE 3 **Effect of Speed on Wear 16 lbs. (71 N), 10,000 Cycles, Self-Mated 0.5” (12.7 mm) Crossed Cylinders Corrected for Density Differences**

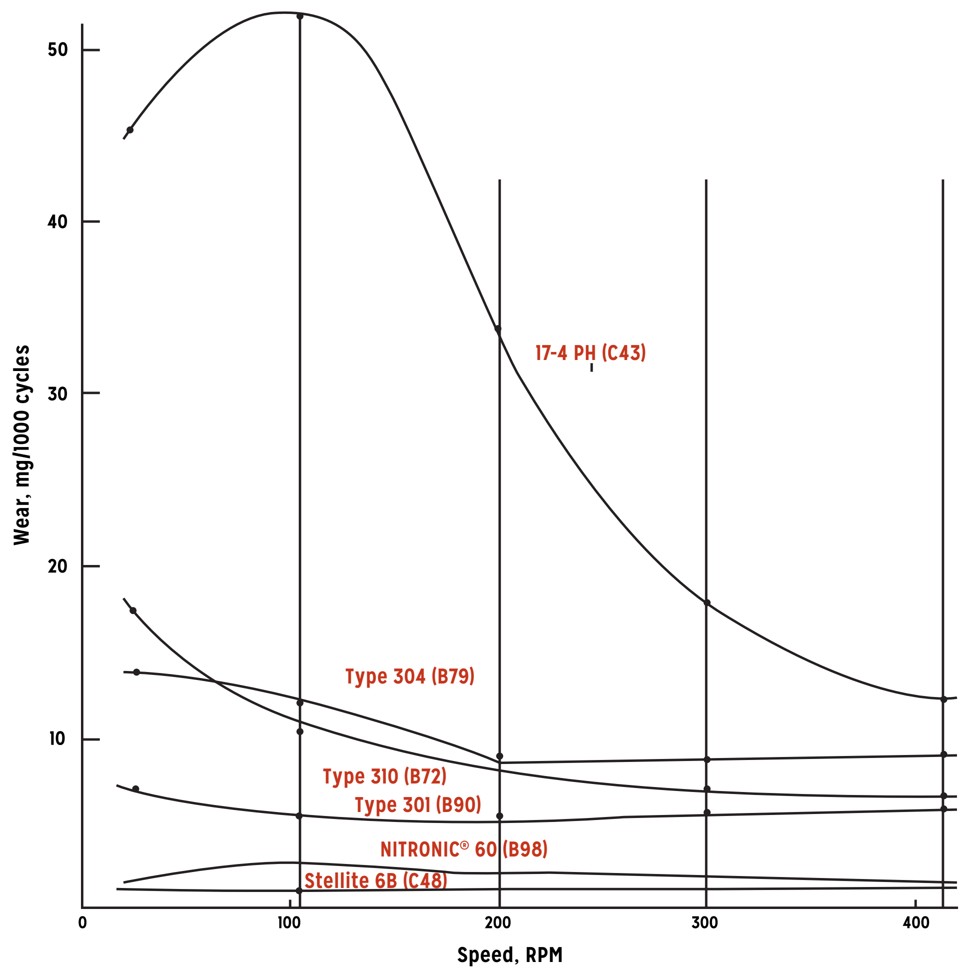
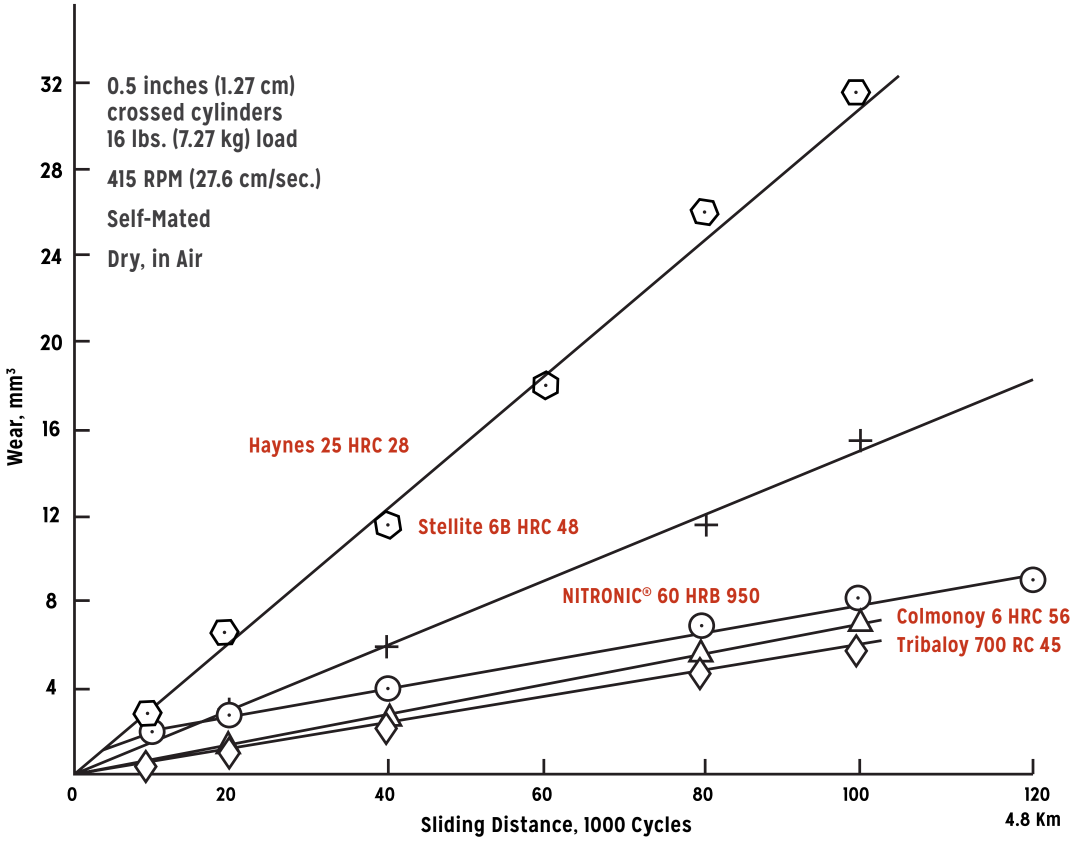


FIGURE 4 **Effect of Distance on Wear Resistance of Nitronic® 60 Compared to Nickel and Cobalt Alloys**



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**

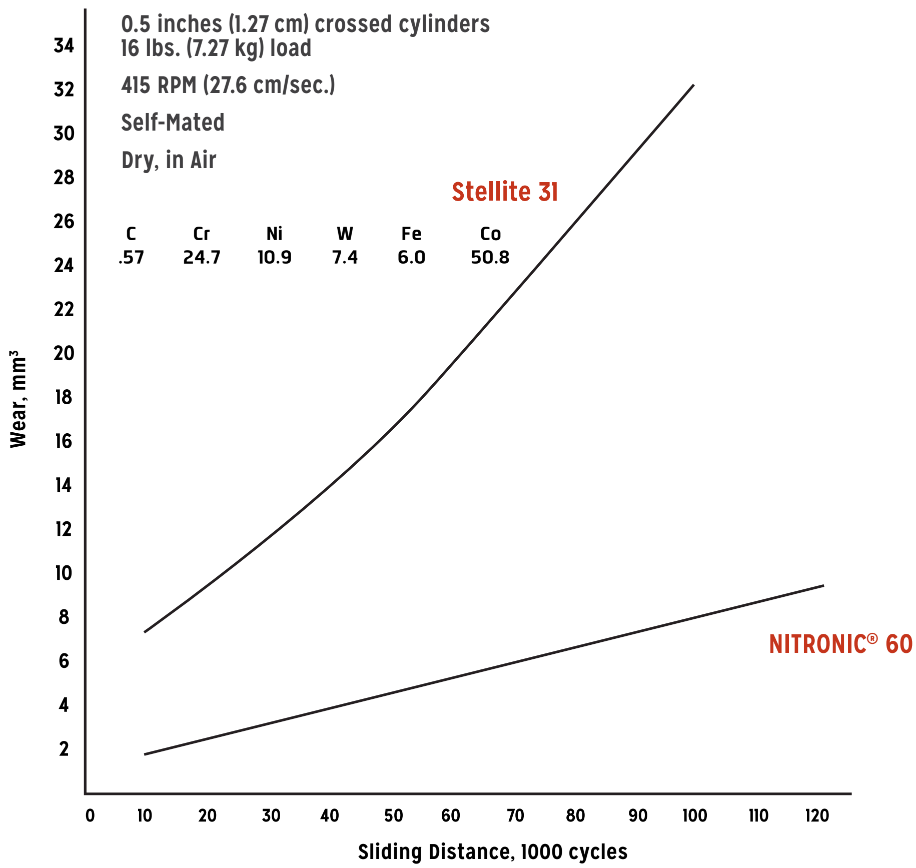


Table 17 **High Temperature Wear Resistance of Nitronic® 60***

Alloy	Atmosphere	Volume Loss, mm³	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)

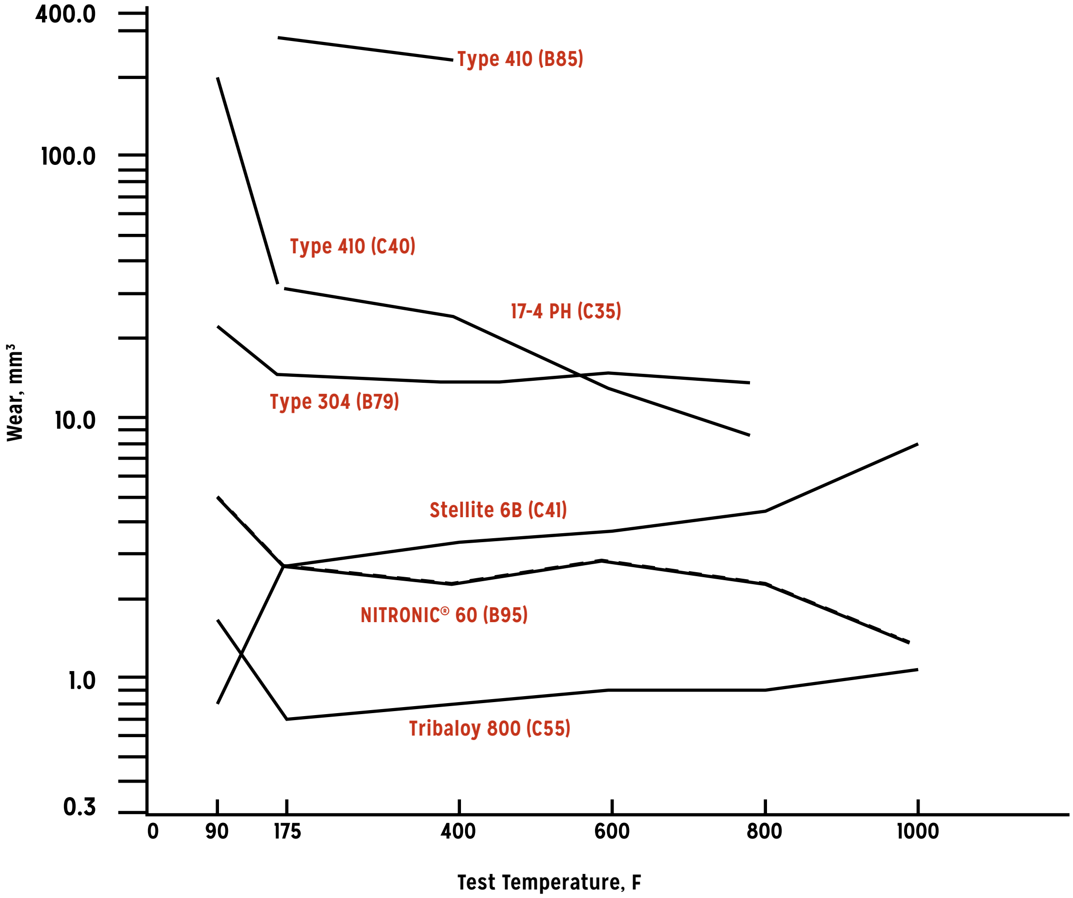
*Test Conditions: Self-mated thrust washers, 500° F (260° C), 500 RPM, 110 lbs (489 N), 4000 cycles.
Tested at the U.S. Bureau of Mines.

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

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. 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.

FIGURE 6 **Effect of Temperature on Wear**



Test conditions – 16 lbs. load, 20,000 rev., 415 RMP, self-mated, stationary specimen only heated to test temperature.

Fretting Wear

Fretting wear is caused by high loads at very small slip amplitudes (40µm) 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.

Nitronic® 60 Stainless Steel has proven highly successful for wear rings in vertical centrifugal pumps. The combination of Nitronic® 60 and Nitronic® 50 Stainless Steels has replaced cobalt wear alloys in some cases, and offers outstanding wear and corrosion protection. Nitronic® 60 Stainless Steel also has been cast up to 8550 lbs. for water pump impellers where CA-6NM has proved inadequate. It is anticipated that the excellent galling resistance, cavitation erosion resistance, and good castability of Nitronic® 60 Stainless will make it an ideal choice for turbine runners, especially with integrally cast wear rings.

Table 18 **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 255 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 Vibration Test Method

20kHz, 80° F (27° C) H_2O, 0.002" (0.05 mm) amplitude.

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

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.

Corrosion Resistance

The general corrosion resistance of 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 then Type 316 in laboratory conditions. Corrosion tests are not normally performed on Nitronic® 60 HS.

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

Alloy	Hardness Rockwell	Alloy Wear, mm^3** 10,000 cycles @ 105 RPM	Alloy Wear, mm^3** 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

Alloy	Hardness Rockwell	Alloy Wear, mm^3** 10,000 cycles @ 105 RPM	Alloy Wear, mm^3** 40,000 cycles @ 415 RPM
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, mm^3 10,000 cycles @ 105 RPM	Alloy Wear, mm^3 10,000 cycles @ 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

Alloy	Hardness Rockwell	Alloy Wear, mm^3 10,000 cycles @ 105 RPM	Alloy Wear, mm^3 10,000 cycles @ 415 RPM
Type 316	B76	22.41	15.59
Type 304	B79	25.23	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.

Table 22 **Corrosion Properties***

Media	Annealed NITRONIC® 60	Annealed Type 304	Annealed Type 316	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	Nitronic® 60 exhibited resistance to general rusting comparable to Type 304.			

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

Seawater Corrosion Resistance

When exposed for 6 months in quiet seawater at ambient temperature, Nitronic® 60 stainless exhibits 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.

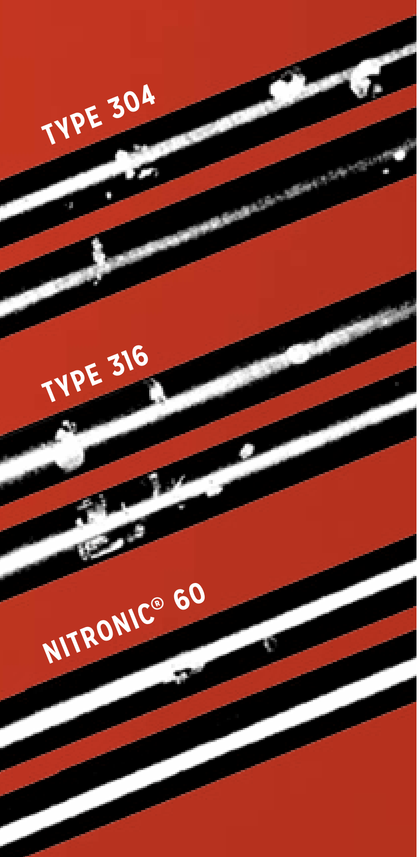


Table 23 **Chloride Pitting Resistance***

Media	Annealed NITRONIC® 60	Annealed Type 304	Annealed Type 316	17-4 PH (H 925)
10% $FeCl^3$ @ RT (pitting test) 50 hours	0.004 gm/in^2 No Pits	0.065 gm/in^2 Pitted	0.011 gm/in^2 Pitted	0.154 gm/in^2 Pitted
10% $FeCl^3$ @ RT with artificial crevices 50 hours	0.024 gm/in^2 Slight	0.278 gm/in^2 Heavy	0.186 gm/in^2 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

Table 25 **Sulfide Stress Cracking Resistance***

17-4 PH (H 1150-M)

0.2% YS ksi (MPa)	Stress Applied Expressed as a % YS	Time to Failure Hours
108.7 (749)	90.6	8.9
108.7 (749)	85.0	19.5
108.7 (749)	81.6	21.9
108.7 (749)	72.8	26.7
108.7 (749)	60.7	50.1
108.7 (749)	44.9	104.5
110.5 (762)	34.6	214.6
110.5 (762)	28.0	572.1
110.5 (762)	22.0	720 (No Failure)

Nitronic® 60 (Annealed)

0.2% YS ksi (MPa)	Stress Applied Expressed as a % YS	Time to Failure Hours
55.3 (381)	110	720 (NF)
58.7 (405)	110	720 (NF)
52.8 (365)	100	720 (NF)
54.3 (374)	100	720 (NF)
55.3 (385)	100	720 (NF)
58.7 (405)	100	720 (NF)
58.7 (405)	85	720 (NF)

Passed NACE requirements of 720 hours stressed at 100% of 0.2% YS without 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°)	214	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

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) 25 minutes heat, 5 minutes cool- duplicate tests	RA 330	+ 3.4	+ 4.9	+ 6.4	---	---	---
	Type 310	+ 4.0	+ 6.7	- 22.7	---	---	---
	Type 309	+ 3.0	- 41.6	- 100.4	---	---	---
	Nitronic® 60	+ 1.5	- 69.2	- 167.6	---	---	---
	Type 316	- 473.0	- 970.8	- 1287.0	---	---	---
		Weight Loss, mg/cm²					
1900° F (1038° C) 35 minutes heat, 30 minutes cool-	Type 446	---	---	---	1.47	1.72	1.97
	Type 310	---	---	---	2.70	15.95	17.22
	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*
(See Table 36 for acceptable specification values)

Condition	Size	Hardness	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 4XD	Reduction of Area %
Annealed	1" (25.4 mm) ø	95 HRB	103 (710)	60 (414)	64	74
Annealed	1-3/4" (44.4 mm) ø	100 HRB	101 (696)	56 (386)	62	73
Annealed	2-1/4" (57.2 mm) ø	100 HRB	101 (696)	60(414)	60	76
Annealed	3" (76.2 mm) ø	97 HRB	113 (779)	65 (448)	55	67
Annealed	4-1/8" (104.8 mm) ø	95 HRB	106 (731)	56 (386)	57	67
10% Cold Drawn	.442" (11.2 MM) ø Start Size	24 HRC	120 (827)	91 (627)	51	68
20% Cold Drawn		31 HRC	140 (965)	112 (772)	35	65
30% Cold Drawn		34 HRC	161 (1110)	132 (910)	26	62
40% Cold Drawn		37.5 HRC	195 (1344)	153 (1055)	20	57
50% Cold Drawn		41 HRC	217 (1496)	174 (1200)	15	53
60% Cold Drawn		43 HRC	240 (1655)	195 (1344)	12	48
70% Cold Drawn		46 HRC	263 (1813)	217 (1496)	10	40

*Data based on duplicate tests.
(1) CG bar

Table 31 Typical Bearing Properties ASTM E 238

Condition	Bearing Strength ksi (MPa)	Bearing Yield Strength ksi (MPa)	UTS ksi (MPa)	0.2% YS ksi (MPa)	% El in 2"	Hardness (R)
Annealed	190.5 (1313)	79.5 (548)	104.9 (723)	52.2 (360)	49.2	B90
10% Cold Rolled	212 (1462)	132.8 (916)	123.1 (849)	90.6 (625)	40.0	C26

Table 32 Typical Room Temperature Torsion and Shear Properties*

Condition	Size	Hardness HRB	Torsional Modulus, G ksi (MPa)	0.2% Torsional YS ksi (MPa) γ	0.2% Torsional YS ksi (MPa) ϵ_ε	Modulus of Rupture ksi (MPa)	Double Sheer Strength ksi (MPa)
Annealed	1" ø (25.4 mm)	95	8.83 x 10^3 (61 x 10^3)	48.9 (337)	50.7 (350)	124 (855)	---
Annealed	3/8" ø (9.6 mm)	95	---	---	---	---	86 (593)

*Data based on duplicate tests.

Table 33 Double Shear Strength*
(Cold Drawn 0 .0442" [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 34 Fatigue Strength
(R.R. Moore Machine)

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

FIGURE 7 **Typical Engineering Stress-Strain Curve of Nitronic® 60 in Tension**

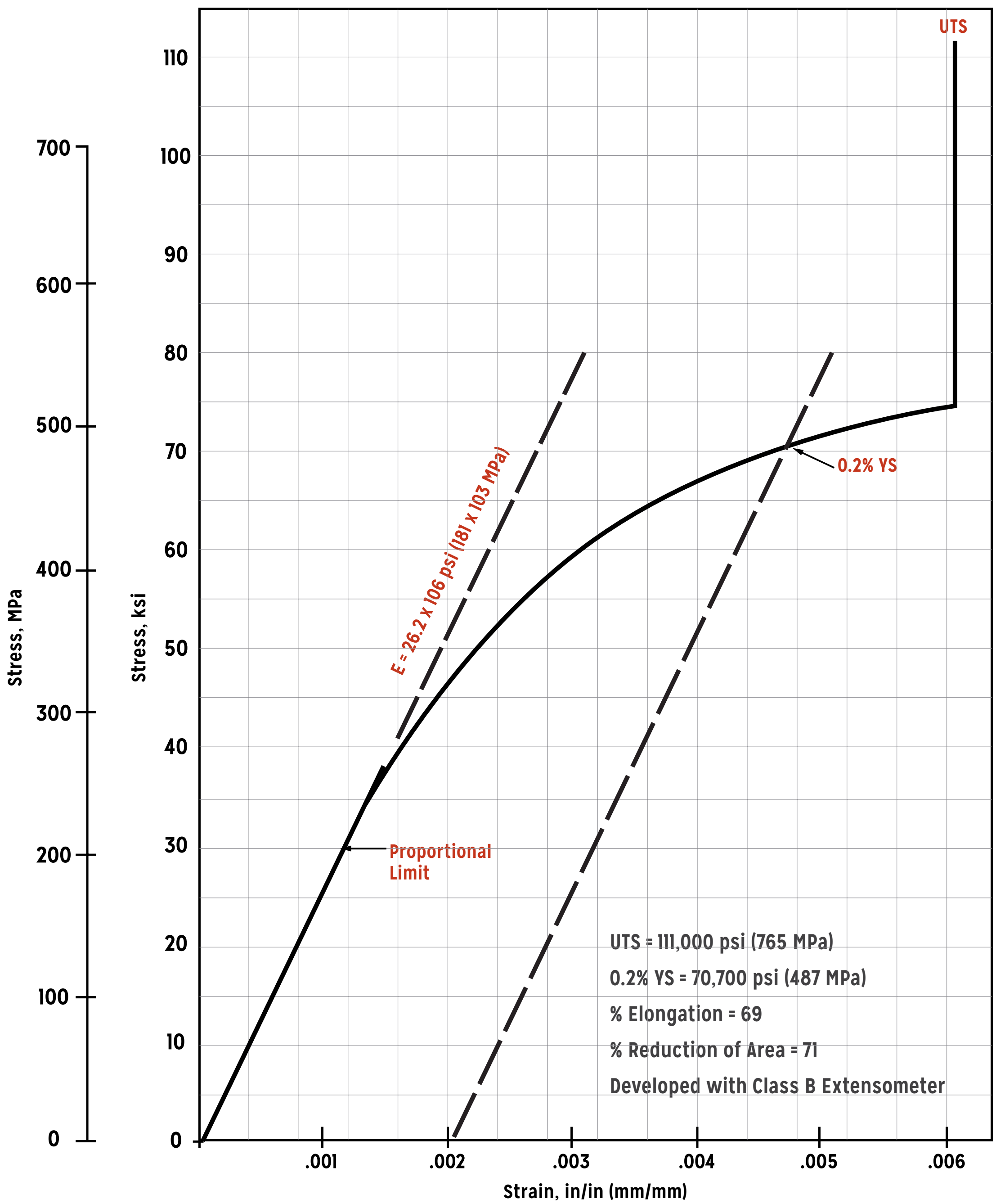


Table 35 **Room Temperature Compression Strength**

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 36 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 HRB
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 37 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 test of 2 heats and single tests of 1 heat. **Single tests of 1 heat.

Table 38 Elevated Temperature Tensile Properties

(Cold Swaged 54% to 0.700" [17.8 mm] ø)

Test Temperature °F (°C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 4XD	Reduction of Area %
Room Temperature	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 39 Elevated Temperature Stress Rupture Strength

(Annealed Bars 5/8" to 1" [16.0 to 25.4 mm] Diameter)

		Stress Rupture Strength, ksi (MPa)		
Temperature °F (°C)	**Number of Heats**	**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 40 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 41 Low Temperature Mechanical Properties of Nitronic® 60 Stainless Steel Longitudinal Tensile Specimens*

Test Temp. °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 x 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 x 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 x 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 x 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 x 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 x 10^6 (171.000)	133	---

*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.

High Strength (HS) Bar Properties

Nitronic® 60 Stainless Steel Bars are also available in a high-strength condition attained by special thermo-mechanical processing techniques. Because the high strength is achieved by mill processing, and not heat treatment, hot forging or welding operations cannot be performed on this material without loss of strength. Aqueous corrosion resistance is lessened to varying degrees, depending upon environment, and susceptibility to intergranular attack is degraded.

Table 42 **Impact Properties****

Condition	Size	Test Temperature °F (°C)	Charpy V-Notch Impact ft-lbs (J)
Annealed	1" ø (25.4 mm)	Room Temperature -100 (-73) -320 (-196)	240* (325) 229 (310) 144 (195)
Annealed	2-1/4" ø (54.2 mm)	Room temperature -100 (-73) -320 (-196)	240* (325) 240* (325) 160 (217)
Cold Swaged 18% Hardness Rc 29	.923" ø (23.7 mm)	-320 (-196)	67 (91)
Cold Swaged 40% Hardness Rc 37	.795" ø (20.2 mm)	-320 (-196)	40 (54)
Cold Swaged 54% Hardness Rc 42	.700" ø (17.8 mm)	-320 (-196)	26 (35)
Cold Swaged 18% Hardness Rc 29	.932" ø (23.7 mm)	-200 (-129)	90 (122)
Cold Swaged 40% Hardness Rc 37	.795" ø (20.2 mm)	-200 (-129)	44 (60)
Cold Swaged 54% Hardness Rc 42	.700" ø (17.8 mm)	-200 (-129)	30 (41)

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

Table 43 **Room Temperature Properties Nitronic® 60 HS Bars**
(Special Hot Working Practice)

Diameter in. (mm)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8mm)	Reduction of Area %	Hardness Rockwell
3.5"-6.0" incl	130 (896)	100 (690)	20	45	C20
6"-8"	110 (758)	90 (621)	20	45	C20

Table 44 **Typical Mechanical Properties Nitronic® 60 H Bars***

Diameter in. (mm)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8mm)	Reduction of Area %
3.5" (88.9 mm)	120 (827)	93 (641)	21	27

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

Table 45 **Effect of Temperature on Tensile Properties* Nitronic® 60 HS**

Test Temperature °F (°C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8mm)	Reduction of Area %
-320 (-196)	211 (1455)	132 (910)	28	16
-100 (-73)	165 (1138)	108 (745)	50	58
Room Temperature	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 46 **Typical Sub-Zero Impact Strength Nitronic® 60 HS Bars (3.5" [88.9 mm] Diameter)**

Test Temperature °F (°C)	Charpy V-Notch Impact, ft-lbs (J)	
	Longitudinal	Transverse
Room Temperature	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 47 **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 (C29) – 17-4 PH (C43)	47+ (324)	
Nitronic® 60 HS (C29) – Nitronic® 50 (C23)	49+ (338)	
Nitronic® 60 HS (C29) – Type 316 (B85)	36 (248)	
Nitronic® 60 HS (C29) – 17-4 PH (C34) (H 1150 + H1150)	37 (255)	

*Metal-to-metal wear-crossed cylinders.

Table 48 **Sulfide Stress Cracking of HS Bars***

Applied Stress ksi (MPa)	% Yield Strength	Location	Time to Failure Hours
97 (699)	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 50
Physical Properties

Density at 75° F (24° C) – 7.622 gm/cm^3

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 **Chloride Stress Corrosion Cracking Resistance Nitronic® 60 HS***

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

*U-Bends, 1-1/4" (6.96 mm) 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.

Table 51 **Mean Coefficient of Thermal Expansion**

Temperature, °F (°C)	in/in/°F (εm/m/°C)
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 52 **Magnetic Permeability**

Condition	Magnetic Permeability
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***

	Field Strength, Oersteds (Ampere/Meters)			
Bar Location	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	1.0059
Central	1.0013	1.0024	1.0033	1.0031

*ASTM A342, Method 4.

Table 54 **Dynamic Coefficient of Friction**

	Dynamic Coefficient of Friction* Test Stress Level, N/mm^2					
Alloy	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 55 **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.

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

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 reaming. Type C-3 for finishing.

Side and Slot Milling Roughing –

0.250" depth – 0.007"/tooth feed – 125 SFM

Finishing – 0.050" depth – 0.009"/tooth feed – 140 SFM

Machinability

Table 56 **Machinability***

AISI B 1112	Type 304	Nitronic® 60
100%	45%	23%

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

Welding

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 are shown in Table 57.

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.

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

Table 57 **Comparative Properties of Base Metal vs. Weld Metal**

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

+Did not gall.

Forging

The following practice should be followed when forging Electralloy Nitronic® 60 stainless sections 13" (330 mm) or smaller:

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

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

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

4) Reheat as necessary.

Casting

Electralloy Nitronic® 60 Stainless Steel may be cast by all conventional casting techniques. Casting parameters: Liquidus – 2536° F (1391° C) Solidus – 2465° F (1352° C). Estimated shrinkage – 5/16 in/ft. Finished Allowance-1/8 in.

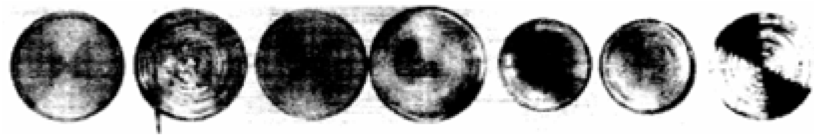
Electralloy Nitronic® 60 Stainless Steel Castings may be partially stress relieved at 1050° F (566° C) +25° F (14° C) for 2 hours followed by air cooling and still pass ASTM A262-E for intergranular corrosion resistance. This heat treatment has been used to minimize distortion during the fabrication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

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

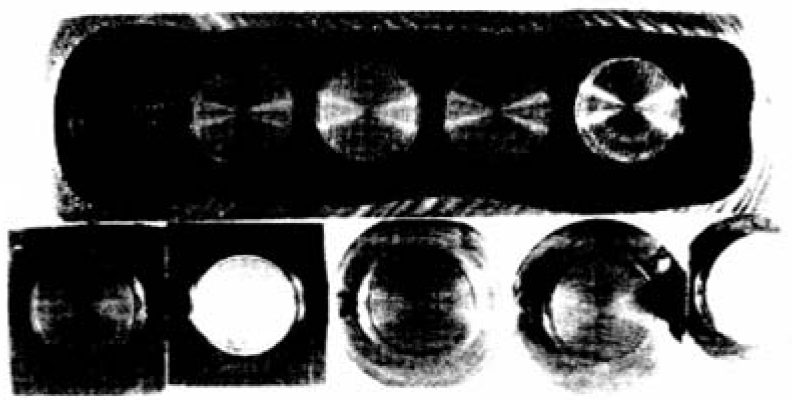
Nitronic® 60
Galling Block

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

Table 58 Intergranular Corrosion Resistance of Nitronic® 60 Weld Overlay on Type 304*

Condition	Corrosion Rate, inches/month
As-deposited	0.0016
1700° F (927° C) - 1 hr - WQ (stress relief)	0.0020
1700° F (927° C) - 1 hr - AC (stress relief)	0.0063

*2 layers of Nitronic® 60 Stainless, gas metal-arc process. ASTM A262 Practice B (Ferric Sulfate).

Intergranular corrosion per ASTM A262 – applicable to annealed material.

Table 59 Typical Elevated Temperature Properties* Cast Nitronic® 60 (CF10SMnN) Annealed

Test Temperature °F (°C)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)	Reduction of area %
75 (24)	96 (662)	47 (324)	54	55
200 (93)	85 (586)	37 (255)	61	61
400 (204)	72 (496)	28 (193)	62	64
600 (316)	67 (462)	24 (165)	60	60
800 (427)	63 (434)	23 (159)	58	64
1000 (538)	61 (421)	23 (159)	57	64
1200 (649)	55 (379)	23 (159)	50	57

*Average of 4 tests.

Table 60 Stress Rupture Strength* Cast Nitronic® 60 (Annealed)

Test Temperature °F (°C)	UTS ksi (MPa)	Time to Failure (Hours)	Elongation % in 2" (50.8 mm)	Reduction of area %
1200 (649)	25 (172)	348	32	53
	30 (207)	108	29	48
	35 (241)	34	23	31

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

Table 61 Typical Room Temperature Mechanical Properties 6" (152 mm) Square Cast Nitronic® 60 Stainless Steel

Condition	Location	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)	Reduction of area %	Hardness HRB	CVN Impact ft-lbs. (J)
As-Cast	Surface	98 (676)	49 (338)	43	34	91	37 (50)
As-Cast	Intermediate	73 (503)	49 (338)	12	15	89	27 (37)
Annealed (Surface)	2000° F (1093° C)	101 (696)	48 (331)	62	67	91	162 (220)
Annealed (Intermediate)	2000° F (1093° C)	96 (662)	46 (317)	54	56	89	---

Table 62 Typical Impact Strength Simulated Slow Cool in Mold Study*

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

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

Learn more about our Nitronic® 60 products at
www.electralloy.com

Failing Bridge Pins – a Critical Problem, a Superior Solution

When the I-95 bridge in Connecticut collapsed in the late 1980's, it high lighted a serious potential problem of rusting and/or seizing of pin and hanger expansion joints of bridges subject to exposure to deicing salts. Recent inspections of other bridge pins have shown the corrosion failure to occur due to locking of the pin to the hanger.

This serious problem has a ready solution in Electralloy Nitronic® 60 Stainless Steel (ASTM A276, UNS 21800). Compared to A36 and A588 carbon steels, Nitronic® 60 Stainless Steel delivers:

- **Corrosion resistance 40 times greater.**
- **A metallurgical grain structure that gives more than 25 times greater resistance to galling, tearing and freezing-up when in contact with other steel surfaces.**
- **A yield strength of 50,000 psi and tensile strength of 100,000 psi.**
- **Far superior toughness, especially at low temperatures.**
- **High Charpy values, about 200 ft-lbs.**
- **Excellent wear resistance.**

This means Electralloy Nitronic® 60 Stainless Steel is the ideal material to replace pin and hanger assemblies to solve the problem of failing carbon steel pins and provide a far greater level of safety for critical components. And each part can be ultrasonically tested at the mill for an additional margin of safety.

Several state transportation departments and turnpike authorities are using Nitronic® 60 pins for replacement of critical bridge pins, including those bridges shown in the photographs.

Electralloy is North America's exclusive licensed producer of all NITRONIC® ingot, billet, bar, coil rod, master alloy pigs as well as plate, weld wire and weld consumables.

Delaware Memorial Bridge, Wilmington, Delaware

Severn River Bridge, Annapolis, Maryland

Newport, Rhode Island Bridge

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