



ARMCO 17-7 PH and PH 15-7 Mo

**Stainless Steel
Sheet and Strip**

Composition

Specifications

Properties for Specification

Metallurgy

Mechanical Properties

Physical Properties

Corrosion Resistance

Testing

Fabrication

ARMCO 17-7 PH AND PH 15-7 Mo STAINLESS STEEL SHEET AND STRIP

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COMPOSITION

The following composition ranges are acceptable in specifications for Armco 17-7 PH and Armco PH 15-7 Mo stainless steels in sheet and strip form:

Element	17-7 PH	PH 15-7 Mo
	%	%
Carbon	.09 max	.09 max
Manganese	1.00 max	1.00 max
Phosphorus	.04 max	.04 max
Sulfur	.04 max	.04 max
Silicon	1.00 max	1.00 max
Chromium	16.00-18.00	14.00-16.00
Nickel	6.50-7.75	6.50-7.75
Aluminum	.75-1.50	.75-1.50
Molybdenum	residual	2.00-3.00
Iron	balance	balance

SPECIFICATIONS

Armco 17-7 PH and PH 15-7 Mo stainless steels are covered by the following specifications*:

AMS 5520—Armco PH 15-7 Mo Sheet, Strip and Plate

AMS 5528—Armco 17-7 PH Sheet, Strip and Plate

AMS 5529—Armco 17-7 PH Sheet, Strip and Plate

MIL-S-25043—Armco 17-7 PH Sheet and Strip

ASTM A 693—Armco PH 15-7 Mo and Armco 17-7 PH Plate, Sheet and Strip

* Consult issuing agency for latest revision of these specifications.

The information and data in this manual are accurate to the best of our knowledge and belief, but are intended for general information only. Applications suggested for the materials described herein are made solely to permit the reader to make his own evaluation and decision, and are not to be construed as either express or implied warranties of fitness for these or other applications. The data reported herein have been developed through tests conducted by or for Armco. They are not guarantees. Data referring to minimum and maximum mechanical properties are the result of tests performed on specimens obtained from specific locations of the product in accordance with prescribed sampling procedures, and any warranty thereof obviously is limited to the values obtained at such locations and by such procedures.

MECHANICAL PROPERTIES ACCEPTABLE FOR MATERIAL SPECIFICATIONS (Sheet, Strip & Light Plate)

Condition	Armco 17-7 PH						
	A ₇₇	TH 1050	TH 1050	RH 950	RH 950	C	CH 900
Thickness, in. (mm)	ALL	.0015-.1874 (.04-4.76)	.1875-.6250 (4.76-15.88)	.0015-.1874 (.04-4.76)	.1875-.6250 (4.76-15.88)	.0015-.050 (.04-1.27)	.0015-.050 (.04-1.27)
UTS, ksi (MPa)	150 max (1034)	180 (1241)	180 (1241)	210 (1448)	200 (1379)	200 (1379)	240 (1655)
0.2% YS, ksi (MPa)	55 max ⁽¹⁾ (379)	150 (1034)	150 (1034)	190 (1310)	180 (1241)	175 (1207)	230 (1586)
Elong, % in 2" (50.8 mm)							
over .6250" (15.88 mm)	20	—	—	—	—	—	—
.1875-.6250" (4.76-15.88 mm)	20	—	7	—	6	—	—
.036-.1874" (.91-4.76 mm)	20	6	—	5	—	1	1
.020-.0359" (.51-.91 mm)	20	6	—	4	—	1	1
.010-.0199" (.25-.51 mm)	20	5	—	3	—	1	1
.005-.0099" (.13-.25 mm)	20	4	—	2	—	1	1
.0015-.0049" (.04-.13 mm)	20	3	—	1	—	1	1
Red. in Area, %	—	—	28	—	20	—	—
Hardness,							
Rockwell	B92 max	C38	C38	C44	C43	C41	C46
Brinell	—	—	352	—	404	—	—

Condition	Armco PH 15-7 Mo						
	A	TH 1050	TH 1050	RH 950	RH 950	C	CH 900
Thickness, in. (mm)	ALL	.0015-.1874 (.04-4.76)	.1875-.6250 (4.76-15.88)	.0015-.1874 (.04-4.76)	.1875-.6250 (4.76-15.88)	.0015-.050 (.04-1.27)	.0015-.050 (.04-1.27)
UTS, ksi (MPa)	150 max (1034)	190 (1310)	190 (1310)	225 (1551)	225 (1551)	200 (1379)	240 (1655)
0.2% YS, ksi (MPa)	65 max (448)	170 (1172)	170 (1172)	200 (1379)	200 (1379)	175 (1207)	230 (1586)
Elong, % in 2" (50.8 mm)							
over .6250" (15.88 mm)	25	—	—	—	—	—	—
.1875-.6250" (4.76-15.88 mm)	25	—	4	—	4	—	—
.036-.1874" (.91-4.76 mm)	25	5	—	4	—	1	1
.020-.0369" (.51-.91 mm)	25	5	—	4	—	1	1
.010-.0199" (.25-.51 mm)	25	4	—	3	—	1	1
.005-.0099" (.13-.25 mm)	25	3	—	2	—	1	1
.0015-.0049" (.04-.13 mm)	25	2	—	1	—	1	1
Red. in Area, %	—	—	20	—	20	—	—
Hardness,							
Rockwell	B100 max	C40	C40	C46	C45	C41	C46
Brinell	—	—	372	—	426	—	—

⁽¹⁾Material .010" (.25 mm) and thinner will have yield strength of 65 ksi (448 MPa).

Note: All testing in the transverse direction. All values minimum unless otherwise noted.

**METALLURGY OF ARMCO
17-7 PH AND 15-7 Mo
STAINLESS STEELS**

Physical Metallurgy

CLASSIFICATION

Armco 17-7 PH and PH 15-7 Mo are semi-austenitic precipitation-hardening stainless steels. These steels are essentially austenitic at room temperature in the annealed or solution-treated condition, but can be transformed to martensite by a series of thermal treatments or by cold work. They are then further hardened by thermal treatment to strengths in excess of 200,000 psi (1379 MPa).

The elements present in 17-7 PH and PH 15-7 Mo stainless steels may be divided into two groups, ferrite formers and austenite stabilizers. Table I lists these elements in order of their relative potency.

Table I

FERRITE FORMERS	AUSTENITE STABILIZERS
Aluminum	Carbon
Silicon	Nickel
Chromium	Manganese
Molybdenum	

Carbon has a strong influence on the stability of austenite. When in solid solution, carbon stabilizes the austenitic structure of 17-7 PH and PH 15-7 Mo stainless steels. Precipitation of a significant portion of this carbon as chromium carbide (Cr_{23}C_6) during the austenite conditioning treatment lowers the stability of the austenite permitting the transformation to martensite.

This is the reason for the dual nature of these steels. They are austenitic for easy fabrication prior to transformation to martensite, and can be treated to high strengths after fabrication. The basic steps in heat treatment of these alloys are:

1. Solution heat treat (anneal at 1950 F [1066 C])*
2. Austenite condition
3. Transform to martensite
4. Precipitation harden

*Armco 17-7 PH and PH 15-7 Mo are generally supplied in the solution-treated condition (Condition A)

The austenite-conditioning and precipitation-hardening treatments can be varied, within specified limits, to accommodate specific processing techniques and to obtain a wide range of properties.

Maximum strength is developed by the precipitation hardening of martensite formed by cold working. Condition C is achieved by a 60% cold reduction of the solution-treated steel. This develops a martensitic structure that has limited formability. Condition C material is then precipitation hardened by a single heat treatment. The basic steps in developing maximum mechanical properties follow:

1. Transform to martensite (cold reduce 60% to produce Condition C)
2. Precipitation harden (age at 900 F [482 C] to produce Condition CH 900)

Intermediate temper conditions, 1/2 C, 3/4 C, can be produced by cold rolling less than the 60% necessary for Condition C. In these conditions, martensite is formed in amounts corresponding to the degree of rolling. This allows use of the single CH aging treatment to obtain mechanical properties corresponding to those obtained in the TH and RH conditions. Since the 1/2 C and 3/4 C conditions are lower in strength, their formability is better than that of Condition C. The effect of cold reduction on the mechanical properties of cold rolled 17-7 PH stainless steel is illustrated in Table II.

Table II

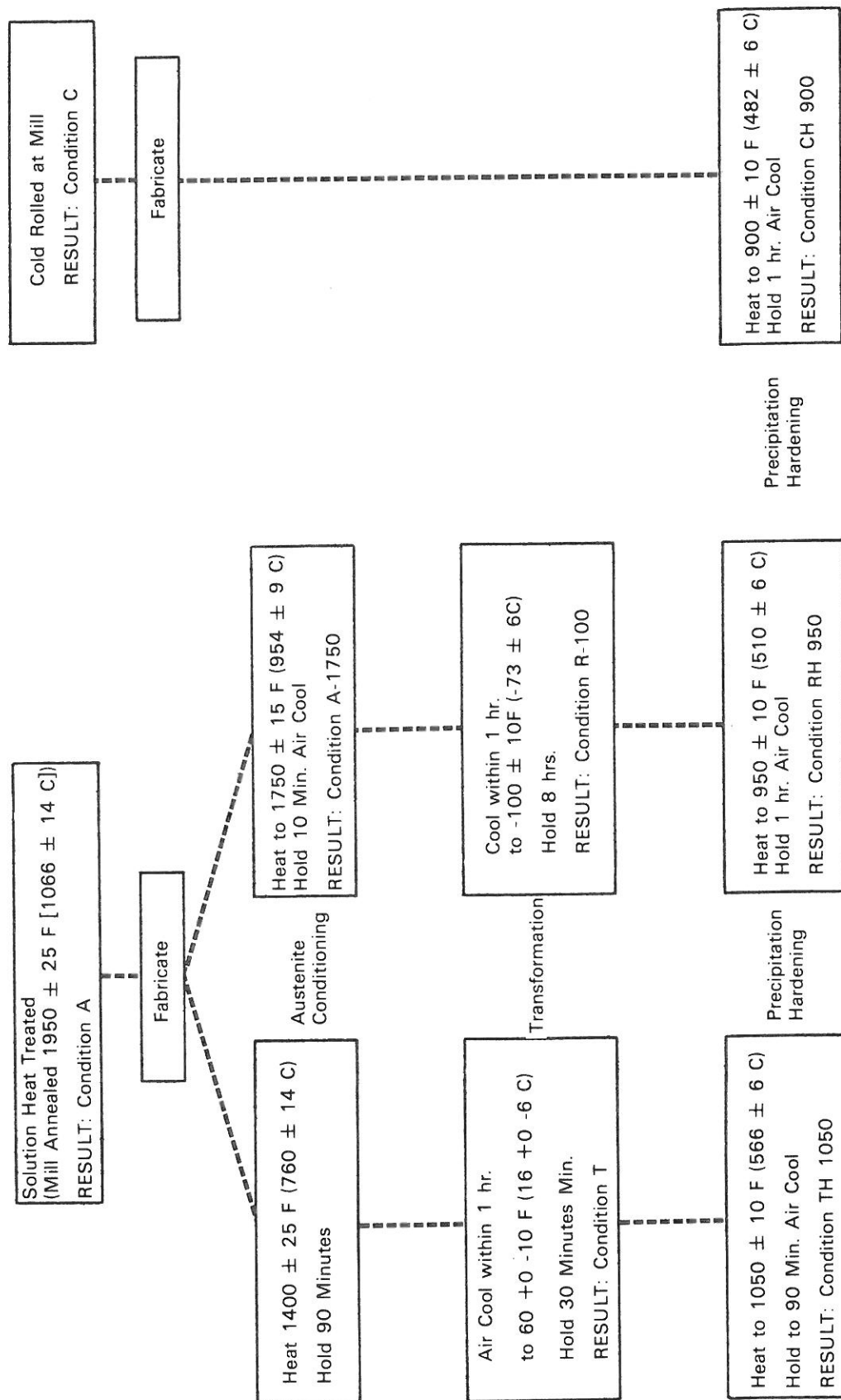
TYPICAL PROPERTIES OF INTERMEDIATE TEMPER ARMCO 17-7 PH STAINLESS STEEL

Condition	% Cold Reduction	As-Rolled Transverse Direction			
		UTS, ksi (MPa)	0.2% YS, ksi (MPa)	Elongation % in 2" (50.8 mm)	Hardness R _C
1/2 C	30	178 (1227)	115 (793)	10	36
3/4 C	45	201 (1386)	148 (1020)	8	40
C	60	220 (1517)	190 (1310)	5	43
Precipitation Hardened @ 900 ± 10 F 1 Hr					
1/2 CH 900	30	191 (1317)	176 (1213)	13	43
3/4 CH 900	45	233 (1606)	229 (1579)	5	48
CH 900	60	265 (1827)	260 (1793)	2	49

Table III

STANDARD HEAT TREATMENTS

ARMCO 17-7 PH AND PH 15-7 Mo STAINLESS STEELS



SOLUTION HEAT TREATMENT

17-7 PH and PH 15-7 Mo are solution heat treated (annealed) at 1950 F (1066 C). Carbon is taken into solution and held by rapid cooling, resulting in a stable austenitic structure. The structure in this condition contains from 10 to 20% delta ferrite occurring

as stringers. See Figures 1, 2, and 3. The hardness in Condition A is approximately Rockwell B88. In this form, 17-7 PH and PH 15-7 Mo stainless steels have fabricating characteristics similar to Type 301 stainless steel. Because cold working causes transformation of austenite to martensite, intermediate anneals may be necessary where fabrication involves severe deformation.

Photomicrographs of Armco 17-7 PH and Armco PH 15-7 Mo Stainless Steels in Condition A

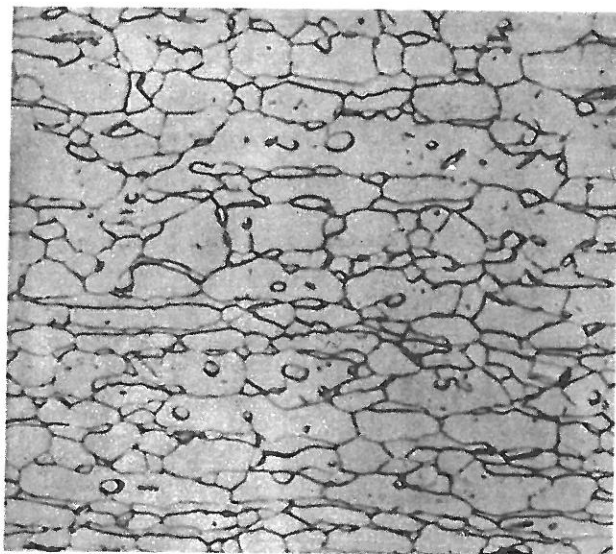


Figure 1 Austenite Matrix with Ferrite Stringers
Etch: (1) Nitric-Acetic, Electrolytic
(2) 10% Oxalic, Electrolytic
Magnification: 1,000X—Optical

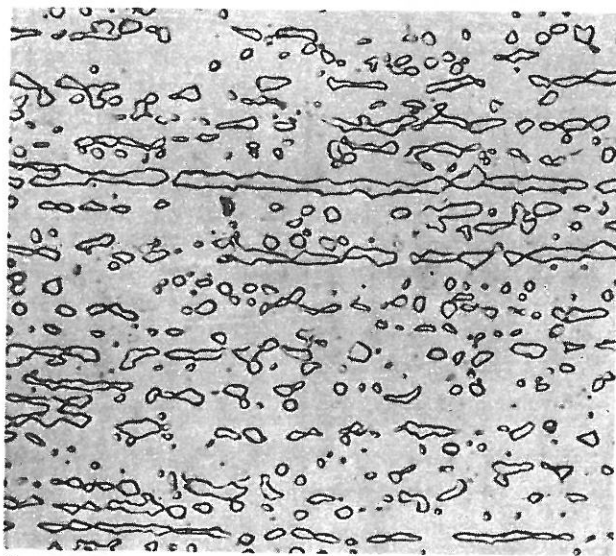


Figure 2 Delineation of Ferrite Stringers in Austenite Matrix
Etch: 10% NaCN, Electrolytic
Magnification: 1,000X—Optical

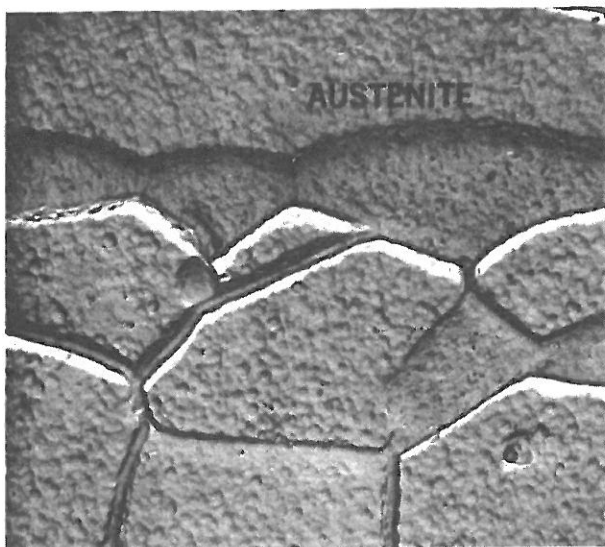


Figure 3 A Ferrite Stringer in the Austenite Matrix

Etch: (1) Nitric-Acetic, Electrolytic

(2) 10% Oxalic, Electrolytic

Magnification: 18,000X Electron Micrograph—Plastic Replica Technique

AUSTENITE CONDITIONING AND TRANSFORMATION TO MARTENSITE

In order to develop high strengths, the austenitic structure of Condition A must be transformed to martensite and precipitation hardened.

This is accomplished by conditioning the austenite (heating to a temperature which allows carbon to precipitate). Subsequent cooling causes the martensitic formations of Condition T or Condition R-100 with hardnesses of Rockwell C30-35 (Fig. 4).

The transformation to Condition T results from removing carbon from solution in the austenite when heating at 1400 F (760 C). Chromium carbides (Cr_{23}C_6) first form at the ferrite stringer—austenite interface. If the carbon content is on the high side of

the specification, carbides will also form in the grain boundaries, see Figure 5. Removal of carbon and chromium from the austenite matrix makes austenite unstable and results in transformation to martensite during cooling to $55\text{ F} \pm 5\text{ F}$ ($13\text{ C} \pm 3\text{ C}$).

The mechanism of forming Condition R-100 is similar to that of producing Condition T. However, at the austenite conditioning temperature of 1750 F (954 C), fewer carbides are precipitated than at 1400 F (760 C). Consequently, the M_s temperature (the temperature at which transformation starts) is lower (approx. 75 F [24 C]) than when austenite is conditioned at 1400 F (760 C) ($M_s \approx 175\text{ F}$ [79 C]). To obtain complete transformation following conditioning at 1750 F (954 C), it is necessary to cool to about -100 F (-73 C).

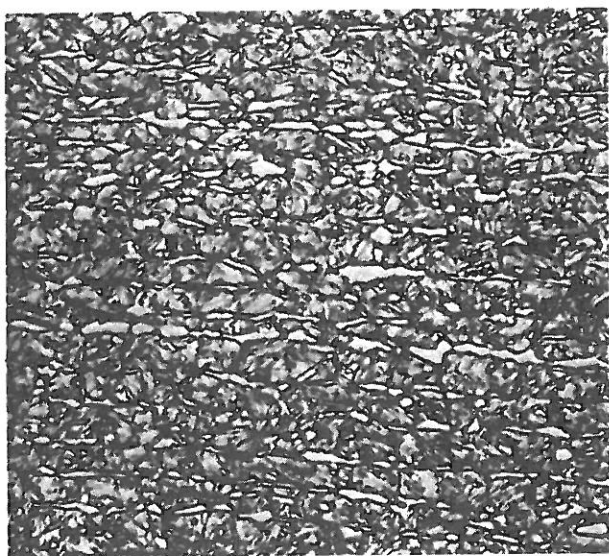


Figure 4 Austenite transformed to Martensite. Representative of Conditions T, R-100, TH 1050, and RH 950

Etch: (1) Nitric-Acetic, Electrolytic

(2) 10% Oxalic, Electrolytic

Magnification: 1,000X—Optical

Photomicrographs of Armco 17-7 PH and PH 15-7 Mo Stainless Steels Transformed to Martensite

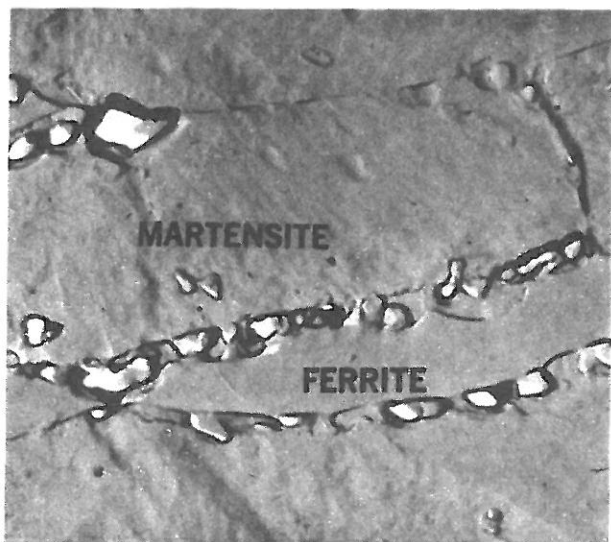


Figure 5 Condition T (transformed) showing carbides at ferrite-martensite interface. Condition R-100 is similar with fewer carbides.
Etch: Vilella's
Magnification: 18,000X—Electron Micrograph—Plastic replica technique

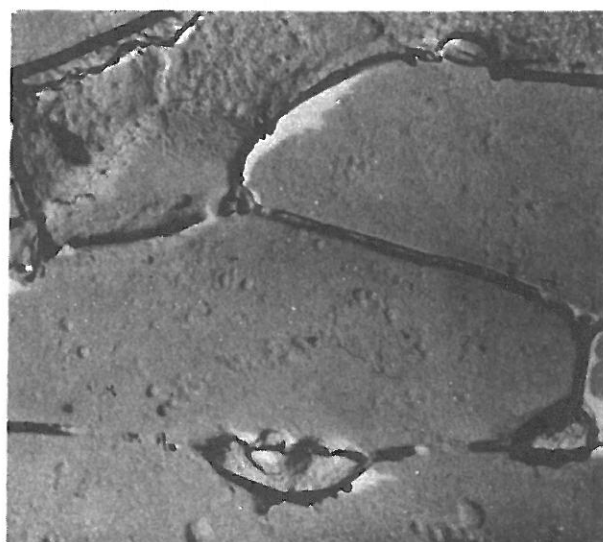


Figure 6 Condition R-100 (transformed) showing carbides and grain boundaries. More heavily etched than Fig. 5. Note fewer carbides.
Etch: (1) Nitric-Acetic, Electrolytic
(2) 10% Oxalic, Electrolytic
Magnification: 18,000X—Electron Micrograph—Plastic replica technique

Figures 5 and 6 show the carbide distribution after conditioning at 1400 F (760 C) and 1750 F (954 C).

Figure 7 shows the effect of austenite conditioning temperature variation on the M_s temperature.

The phase transformation from austenite to martensite is accompanied by a substantial increase in magnetic permeability, and produces a dimensional expansion of about 0.0045"/in. (0.0045 mm/mm).

Figure 7
Effect of Austenite Conditioning Temperature on the M_s Point

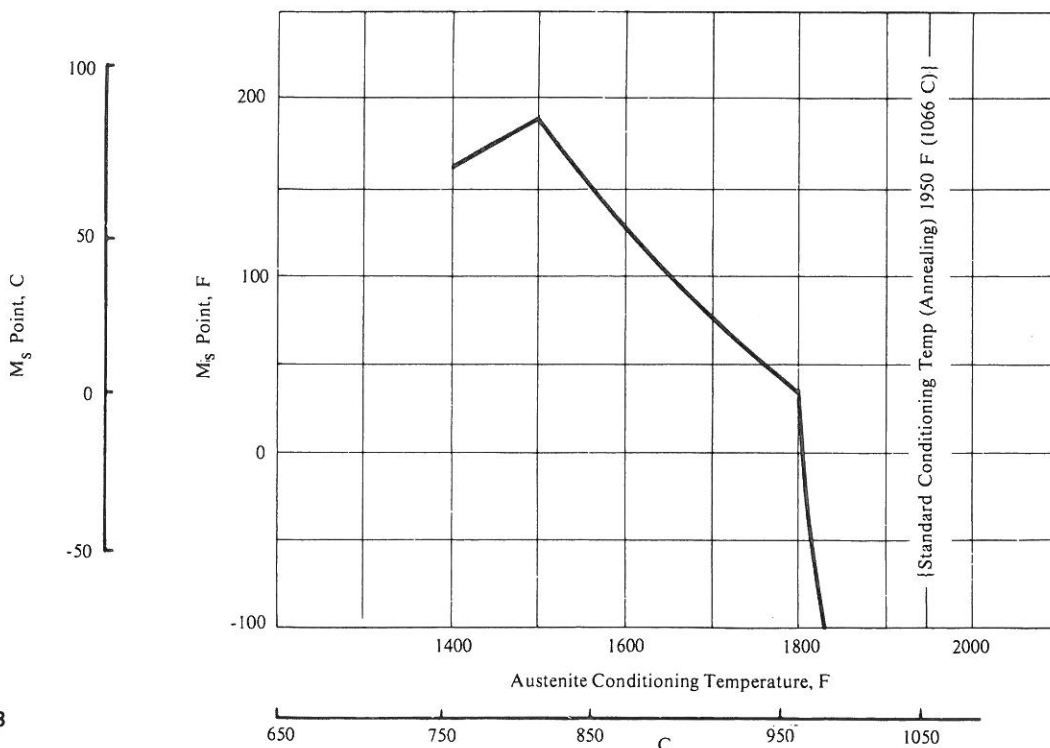
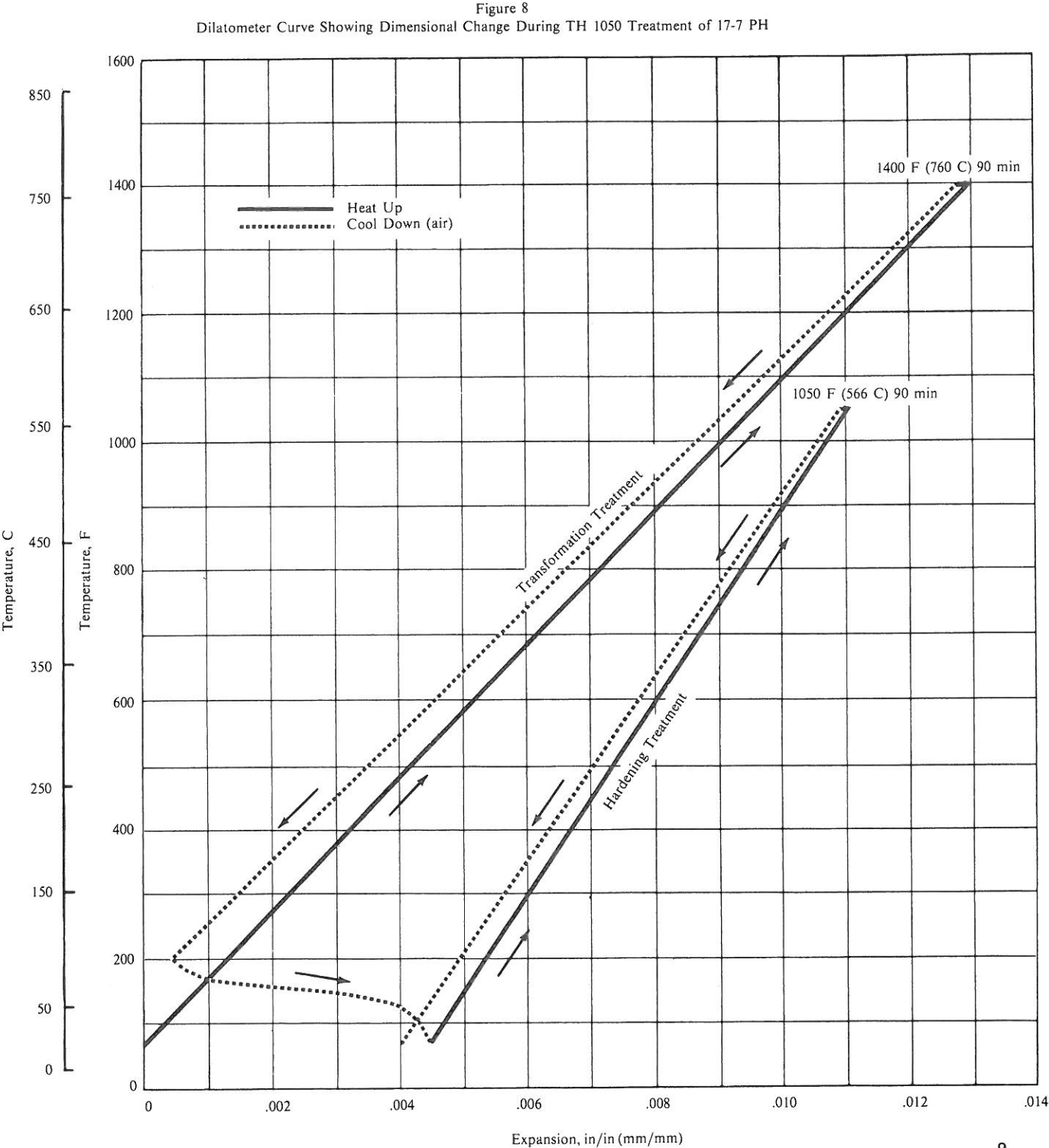


Figure 8 relates temperature to dimensional change for the complete TH 1050 heat treating cycle. It shows the 0.0045"/in. (0.0045 mm/mm) expansion during transformation from face-centered cubic

austenite to body-centered cubic martensite as well as the 0.0005"/in. (0.0005 mm/mm) contraction resulting from precipitation hardening.



Properties in TH and RH Conditions

ROOM TEMPERATURE PROPERTIES

TRANSVERSE TENSILE PROPERTIES⁽¹⁾

Condition	0.2% YS, ksi (MPa)	UTS, ksi (MPa)	Elong % in 2" (50 mm)	Hardness Rockwell ⁽⁴⁾	0.2% Comp. YS, ksi (MPa)
17-7 PH					
A	55 max ⁽²⁾ (379) 40 (276)	150 max (1034) 130 (896)	20 min 35	B92 max B85	— —
T	100 (689)	145 (1000)	9	C31	—
TH 1050	150 min (1034) 185 (1276)	180 min (1241) 200 (1379)	note ⁽³⁾ 9	C38 min C43	— 195
A 1750	42 (290)	133 (917)	19	B85	—
R-100	115 (793)	175 (1207)	9	C36	—
RH 950	190 min (1310) 220 (1517)	210 min ⁽⁵⁾ (1448) 235 (1620)	note ⁽³⁾ 6	C44 min C48	— 227
PH 15-7 Mo					
A	65 max (448) 55 (379)	150 max (1034) 130 (896)	25 min 35	B100 max B88	— —
T	90 (621)	145 (1000)	7	C28	—
TH 1050	170 min (1172) 200 (1379)	190 min (1310) 210 (1448)	note ⁽³⁾ 7	C40 min C44	— 217
A 1750	55 (379)	150 (1034)	12	B85	—
R-100	125 (862)	180 (1241)	7	C40	—
RH 950	200 min (1379) 225 (1551)	225 min ⁽⁵⁾ (1551) 240 (1655)	note ⁽³⁾ 6	C46 min C48	— 243

⁽¹⁾ Values designated as minimum or maximum are acceptable for material specifications. These values are based upon the heat treatments shown in Table III on page 5 and do not apply to any other treatment. All other values are typical.

⁽²⁾ Max YS 65 ksi (448 MPa) for Condition A material .010" (.254 mm) and thinner.

Material	Elongation, % in 2" (50.8 mm)				
	Thickness, in. (mm)				
	.0015-.0049 (.0038-.0124)	.005-.0099 (.1270-.2515)	.010-.0199 (.250-.500)	.020-.0359 (.518-.912)	.036-.1874 (.912-4.759)
17-7 PH TH 1050	3	4	5	6	6
RH 950	1	2	3	4	5
PH 15-7 Mo					
TH 1050	2	3	4	5	5
RH 950	1	2	3	4	4

⁽⁴⁾ Applies to material .010" (.254 mm) and thicker. Where necessary, superficial hardness readings are converted to Rockwell B or C.

⁽⁵⁾ As shown on page 70, 17-7 PH and PH 15-7 Mo in Condition RH 950 have relatively low fracture toughness. When a combination of high strength and high fracture toughness is required, PH 14-8 Mo should be used.

BEND TEST DATA ⁽¹⁾ — 17-7 PH

	Min T Ratio in 145° Bend ⁽²⁾		Transverse Properties ⁽³⁾			
Condition	Transverse	Longitudinal	UTS, ksi (MPa)	0.2% YS, ksi (MPa)	Elong. % in 2" (50.8 mm)	Hardness Rockwell
.049" (1.24 mm) Thick Specimens						
A	180° Flat Bend	180° Flat Bend	132 (910)	45 (310)	32.0	B85
T	3.18	1.90	148 (1020)	103 (710)	6.75	C31
TH 1050	7.65	3.18	202 (1393)	196 (1351)	4.5	C44
R-100	3.18	1.90	164 (1131)	125 (862)	6.0	C37
RH 950	7.65	3.18	230 (1586)	217 (1496)	5.5	C47
.014" (.36 mm) Thick Specimens						
A	180° Flat Bend	180° Flat Bend	131 (903)	57 (393)	31.5	C89
T	4.43	1.64	144 (993)	106 (731)	5.75	C27
TH 1050	6.64	3.29	197 (1358)	189 (1303)	4.5	C40
R-100	5.57	2.22	161 (1110)	120 (872)	4.75	C32
RH 950	6.64	4.43	222 (1531)	210 (1448)	4.5	C45
.005" (.13 mm) Thick Specimens						
A	180° Flat Bend	180° Flat Bend	133 (917)	52 (359)	35.5	—
T	180° Flat Bend	180° Flat Bend	161 (1110)	113 (779)	5.5	—
TH 1050	3.0	180° Flat Bend	182 (1255)	166 (1145)	3.75	—
A 1750	180° Flat Bend	180° Flat Bend	152 (1048)	40 (276)	12.0	—
R-100	3.0	180° Flat Bend	175 (1207)	132 (910)	4.75	—
RH 950	4.6	3.0	225 (1551)	214 (1475)	3.25	—

⁽¹⁾Bend tests were made at room temperature to a 145° angle in matched punch and dies which were chromium plated.

⁽²⁾Minimum T Ratio (min bend radius ÷ specimen thickness) accepted only after samples bend successfully three times.

⁽³⁾All tensile values represent average of two tests with the exception of hardness which represents one test.

DATA — COURTESY THE BUDD CO., PHILADELPHIA, PA.

BEND TEST DATA ⁽¹⁾ — PH 15-7 Mo

	Min T Ratio in 145° Bend ⁽²⁾		Transverse Properties ⁽³⁾			
Condition	Transverse	Longitudinal	UTS, ksi (MPa)	0.2% YS, ksi (MPa)	Elong. % in 2" (50.8 mm)	Hardness Rockwell
.049" (1.24 mm) Thick Specimens						
A	180° Flat Bend	180° Flat Bend	136 (938)	53 (365)	32	B90
T	3.18	1.9	157 (1082)	117 (807)	6.75	C32
TH 1050	7.66	3.18	220 (1517)	214 (1475)	4	C47
R-100	3.18	1.9	171 (1179)	127 (876)	6.5	C37
RH 950	7.66	4.45	244 (1682)	221 (1524)	6.5	C49
.008" (.20 mm) Thick Specimens						
A	180° Flat Bend	180° Flat Bend	132 (910)	59 (407)	39.5	—
T	1.88	1.88	158 (1089)	132 (910)	4.5	—
TH 1050	3.8	1.88	204 (1407)	198 (1365)	4.25	—
A 1750	1.88	180° Flat Bend	162 (1117)	60 (414)	6.25	—
R-100	2.88	1.88	180 (1241)	136 (938)	4.5	—
RH 950	3.88	2.88	246 (1696)	226 (1558)	3.5	—
.004" (.10 mm) Thick Specimens						
A	180° Flat Bend	180° Flat Bend	133 (917)	64 (441)	37.5	—
T	180° Flat Bend	180° Flat Bend	164 (1131)	119 (820)	4	—
TH 1050	3.75	180° Flat Bend	209 (1441)	202 (1393)	3	—
A 1750	180° Flat Bend	180° Flat Bend	165 (1138)	51 (352)	11.0	—
R-100	3.75	180° Flat Bend	185 (1276)	141 (972)	4	—
RH 950	3.75	3.75	252 (1737)	235 (1620)	2.5	—

⁽¹⁾Bend tests were made at room temperature to a 145° angle in matched punch and dies which were chromium plated.

⁽²⁾Minimum T Ratio (min bend radius ÷ specimen thickness) accepted only after samples bend successfully three times.

⁽³⁾All tensile values represent average of two tests with the exception of hardness which represents one test.

DATA — COURTESY THE BUDD CO., PHILADELPHIA, PA.

SHORT-TIME ELEVATED TEMPERATURE PROPERTIES

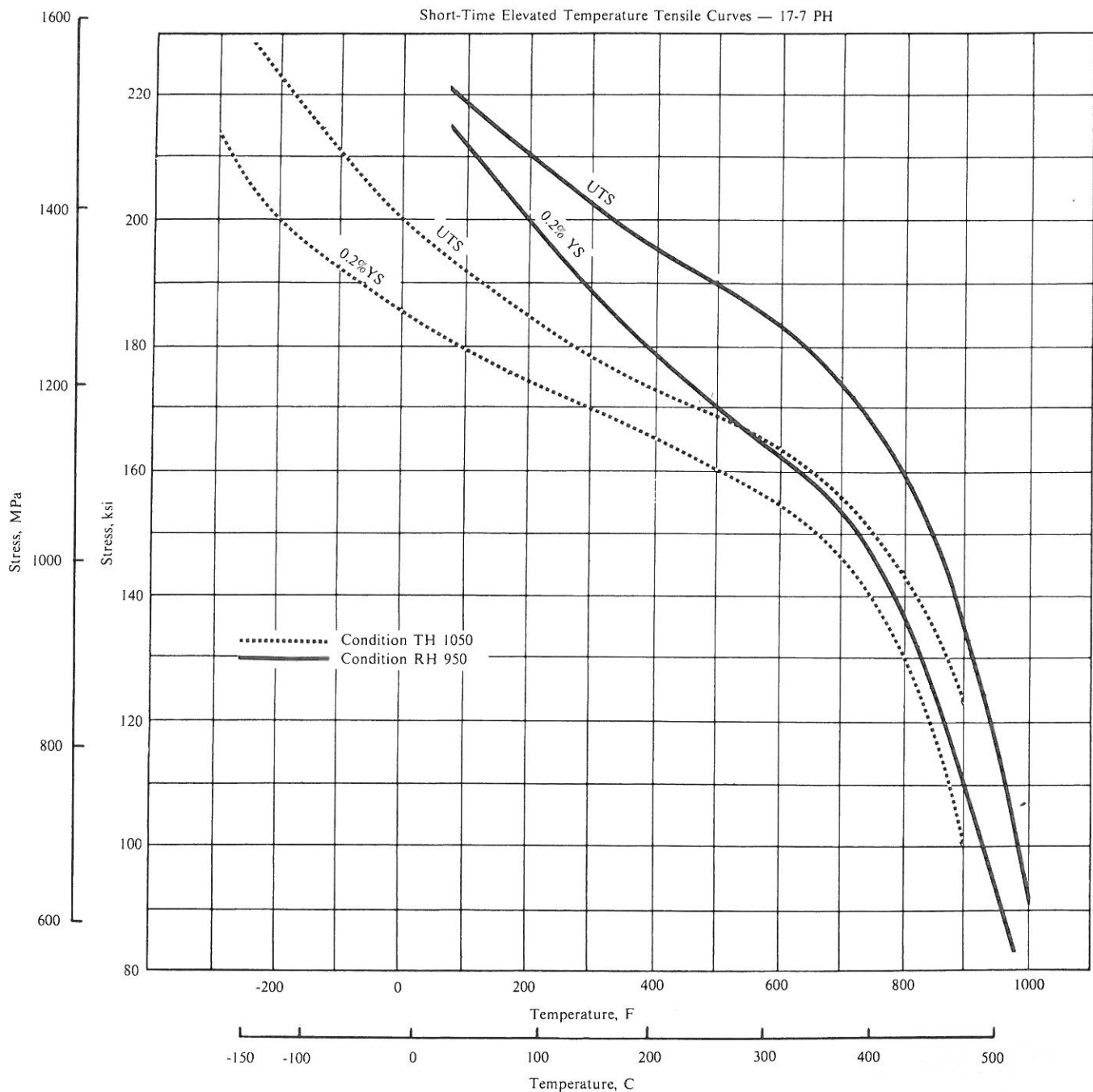
Armco 17-7 PH and PH 15-7 Mo stainless steels in Condition TH 1050 retain a high percentage of their room temperature strength up to 800 F (427 C). On a strength-weight ratio comparison up to this temperature, they are superior to the standard stainless steels, and low alloy steels. Furthermore, they compare favorably with the titanium alloys currently available.

The short-time tensile properties of 17-7 PH and PH 15-7 Mo stainless steels in condition RH 950 are superior to those obtained by the TH 1050 heat treatment. It is noteworthy that tensile and yield

strengths at 600 F (316 C) are well above the minimum room temperature properties for Condition TH 1050. In addition, minimum room temperature tensile and yield strength of RH 950 are over 16% higher than those of TH 1050.

For applications involving service up to 600 F (316 C), design strength can be based on short-time elevated temperature properties since stresses below the yield strength will produce only negligible creep rates.

For service above 600 F (316 C), design must often be based on stress-rupture and creep data.



Note: Sub-zero data courtesy North American Aviation. Other data from Armco Research Laboratories and represent typical response.

NOTCHED TENSILE PROPERTIES

To explore notch sensitivity, tests were performed at 75 F (24 C) and 350 F (177 C) on sheet specimens having 1/16" (1.59 mm) and 1/4" (6.35 mm) holes opened to the edges of the test specimen. Although theoretical stress concentration factors varied from 3.4 to 1.9, tensile strength was only 7 to 14% greater than that of unnotched specimens.

The actual test data are shown in the following table:

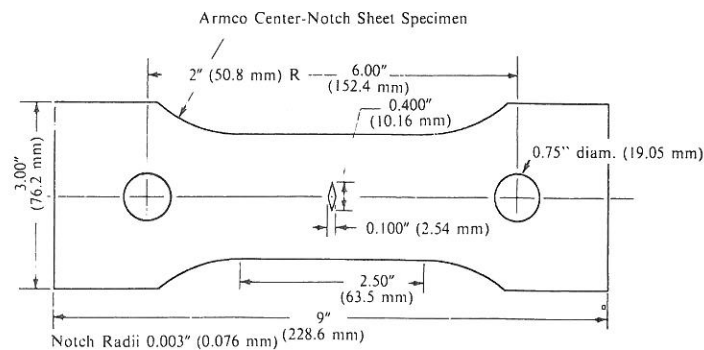
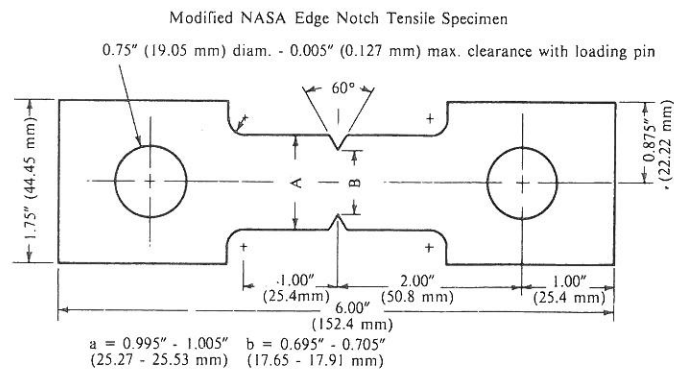
NOTCHED TENSILE PROPERTIES
17-7 PH CONDITION RH 950

Test Temp. F (C)	Sheet Direction	Ultimate Tensile Strength K = 1	Notched Tensile Strength K = 1.9	Notched Tensile Strength K = 3.4
		ksi (MPa)	1/4" [6.35 mm] hole ksi (MPa)	1/8" [1.59 mm] hole ksi (MPa)
75 (24)	L	229 (1579)	256 (1765)	249 (1717)
	T	228 (1572)	254 (1751)	249 (1717)
75 (24)	L	240 (1655)	269 (1855)	266 (1834)
	T	239 (1648)	268 (1848)	262 (1806)
350 (177)	L	213 (1469)	232 (1600)	227 (1565)
	T	203 (1400)	232 (1600)	218 (1503)
350 (177)	L	220 (1517)	246 (1696)	247 (1703)
	T	210 (1448)	242 (1669)	231 (1593)

Data is average of tests from two heats. Tests on 0.050" (1.27 mm) specimens. Toughness properties have also been developed by using three different test methods:

(1) NASA—Edge Notch Tensile, (2) Center Notch Fatigue Crack Tensile and (3) the Srawley Hydrogen Embrittlement Method.

These data have found considerable use in the design of pressure vessels.



CENTER NOTCH — FATIGUE CRACKED TEST
2" (50.8 mm) WIDE X 0.050" (1.27 mm) THICK
TESTED IN TRANSVERSE DIRECTION

Material	Condition	0.2% YS, ksi (MPa)	UTS ksi (MPa)	K _c ksi in.	Notch Strength, ksi (MPa)	NS/YS	NS/UTS
PH 15-7 Mo	TH 1050	207 (1427)	214 (1475)	116	125 (862)	.60	.58
	RH 950	221 (1524)	241 (1662)	102	104 (717)	.47	.43
	RH 1075	205 (1413)	211 (1455)	132	135 (931)	.66	.64
	CH 900	269 (1855)	274 (1889)	127	141 (972)	.52	.51
	CH 1050	249 (1717)	257 (1772)	151	152 (1048)	.61	.59

NASA EDGE NOTCH — 1" (25.4 mm) WIDE — .0007" (.018 mm) MAX ROOT RADIUS

Material	Condition	0.2% YS, ksi (MPa)	UTS ksi (MPa)	Notch Strength, ksi (MPa)	NS/YS	NS/UTS
17-7 PH (.020" [.51 mm])	RH 950	220 (1517)	236 (1627)	120 (827)	.55	.51
	RH 1000	205 (1413)	224 (1544)	107 (738)	.52	.48
	RH 1050	185 (1276)	205 (1413)	160 (1103)	.86	.78
	RH 1100	135 (931)	175 (1207)	157 (1082)	1.18	.90
PH 15-7 Mo (.063" [1.60 mm])	RH 950	228 (1572)	247 (1703)	108 (745)	.47	.44
	RH 1000	230 (1586)	243 (1675)	140 (965)	.61	.58
	RH 1050	220 (1517)	227 (1565)	162 (1117)	.74	.71
	RH 1100	182 (1255)	192 (1324)	174 (1200)	.96	.91

Data: Courtesy NASA — Lewis Labs. Samples tested in the transverse direction.

SRAWLEY HYDROGEN EMBRITTLEMENT METHOD

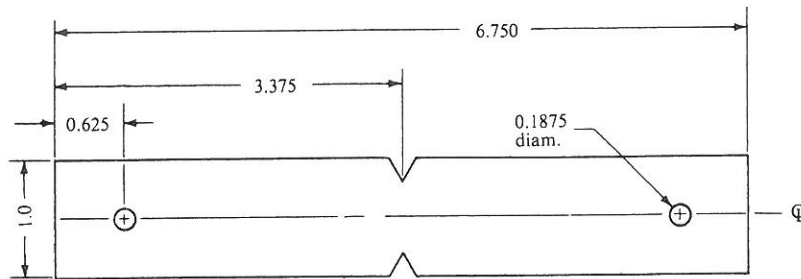
Material	Condition	Thickness inches (mm)	0.2% YS, ksi (MPa)	UTS, ksi (MPa)	F _{net}	F _{net} F _{tu}
17-7 PH	TH 1050	.020 (.51)	184 (1269)	198 (1365)	168	.85
		.036 (.91)	179 (1234)	208 (1434)	155	.74
	RH 950	.020 (.51)	210 (1448)	221 (1524)	146	.66
		.036 (.91)	212 (1462)	246 (1696)	141	.57
PH 15-7 Mo	TH 1050	.040 (1.02)	196 (1351)	205 (1413)	195	.73
	RH 950	.040 (1.02)	213 (1469)	235 (1620)	171	.87
	RH 1050	.040 (1.02)	194 (1338)	207 (1427)	180	.95
	CH 900	.043 (1.09)	237 (1634)	250 (1724)	202	.81
	CH 1050	.043 (1.09)	257 (1772)	267 (1841)	203	.71
	CH 1090	.043 (1.09)	293 (2020)	298 (2055)	182	.61

Samples tested in the transverse direction.

NOTCHED & UNNOTCHED TENSILE PROPERTIES AT SUB-ZERO TEMPERATURES

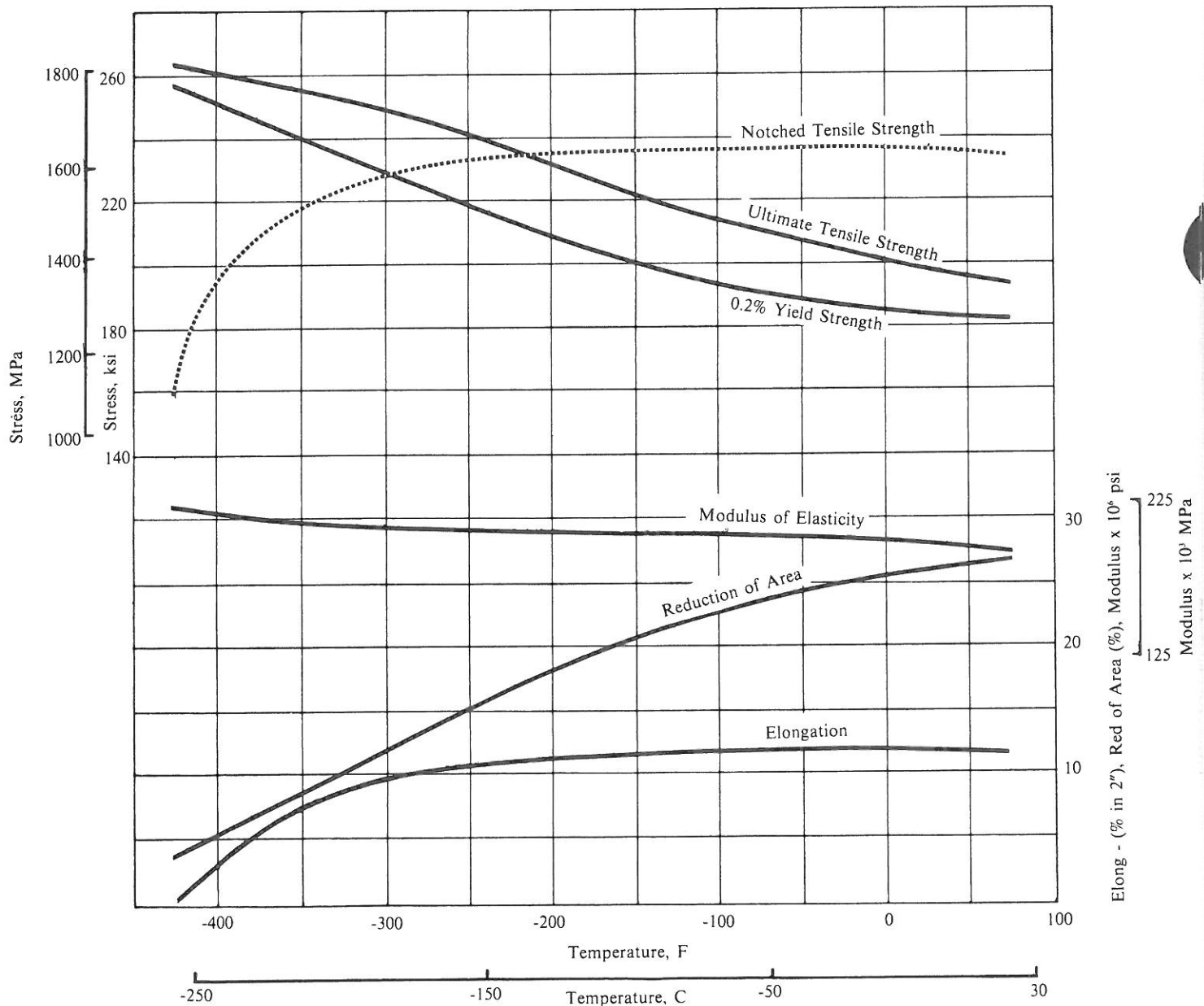
Test data below is representative of both bar and sheet stock. Testing was done at temperatures from

75 to -420 F (24 to -251 C). The diagram below shows the type of notched sheet test specimens used.



Type 10 Specimen from Sheet Stock. 60 V-notches, 0.500" in. (12.7 mm) root width, notch radius 0.040" (1.02 mm).

17-7 PH Condition TH 1050



Data Reference: WADC Technical Report No. 58-386, pp 6, 13, 22 and 31. Data represents triplicate tests from one heat. Stress concentration factor, $K_t = 2.9$

BEARING STRENGTH

Material	Condition	Sheet Thickness, in. (mm)	Test Direction	E/D	2% Bearing Yield Strength, ksi (MPa)	Ult. Bearing Strength, ksi (MPa)
17-7 PH	TH 1050 ⁽¹⁾	0.050 (1.27)	—	—	270 (1862)	354 (2441)
	RH 950	0.050 (1.27)	T ⁽²⁾	1.99	392 (2702)	455 (3137)
			T ⁽²⁾	1.97	365 (2517)	470 (3240)
PH 15-7 Mo	TH 1050	0.064 ⁽³⁾ (1.62)	L	1.5	339 (2337)	402 (2772)
				2.0	345 (2379)	497 (3427)
			T	1.5	325 (2241)	410 (2827)
				2.0	378 (2606)	463 (3192)
		0.050 ⁽³⁾ (1.27)	L	1.5	316 (2179)	418 (2882)
				2.0	342 (2358)	501 (3454)
			T	1.5	343 (2365)	427 (2944)
				2.0	342 (2358)	504 (3475)
	RH 950	0.064 ⁽³⁾ (1.62)	L	1.5	350 (2413)	455 (3137)
				2.0	390 (2689)	543 (3744)
			T	1.5	366 (2523)	471 (3247)
				2.0	372 (2565)	507 (3496)
		0.050 ⁽³⁾ (1.27)	L	1.5	344 (2372)	470 (3241)
				2.0	405 (2792)	564 (3889)
			T	1.5	346 (2386)	476 (3282)
				2.0	349 (2406)	487 (3358)

⁽¹⁾ Tests average of two heats.

⁽²⁾ Average of three tests on each of two heats.

⁽³⁾ Each value represents average of three tests. Each gage from a different heat.

Tests conducted at room temperature

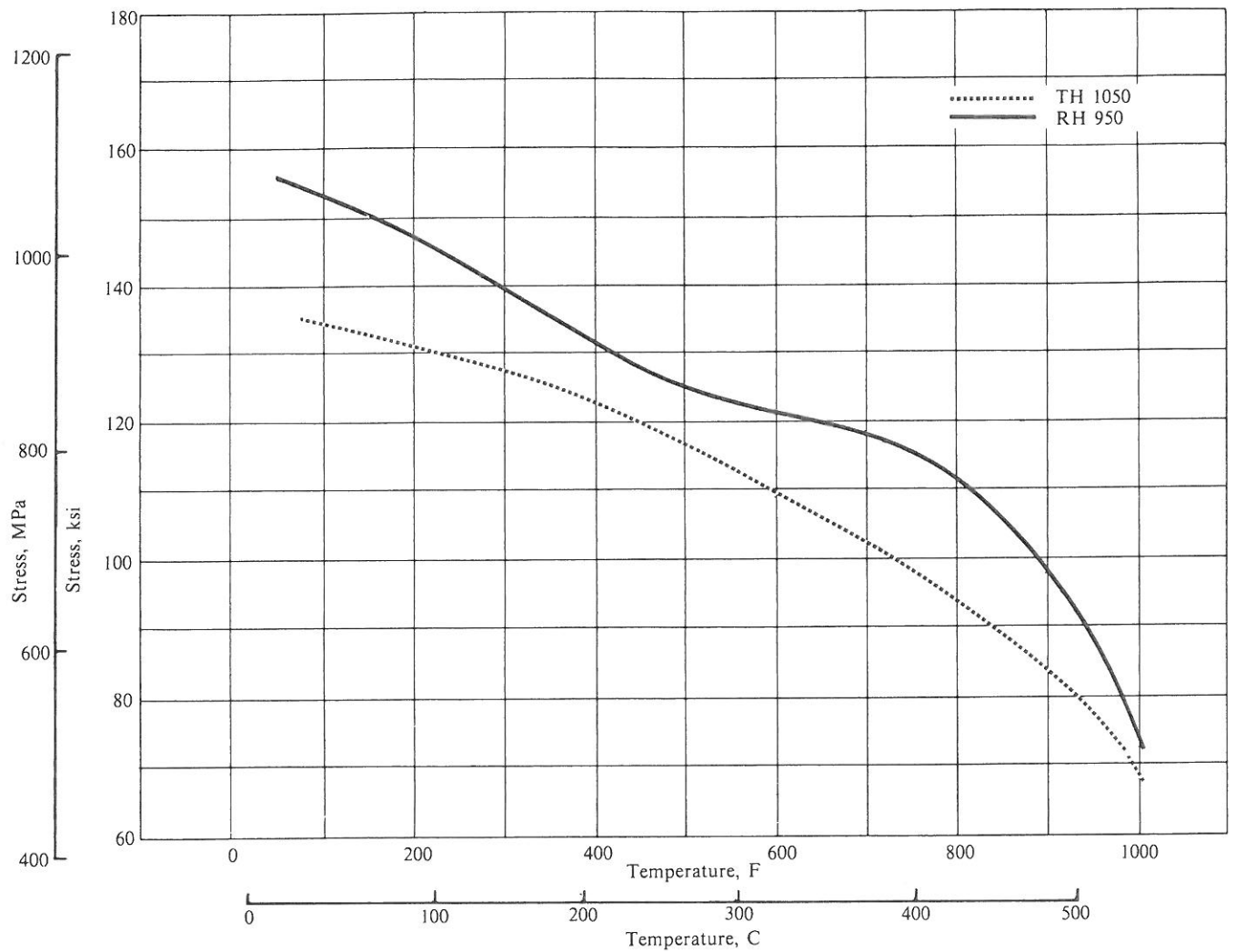
$E/D = \frac{\text{Distance from edge of specimen to edge of hole}}{\text{Diameter of hole}}$

Bearing pin diameter = $\frac{3}{16}$ " (9.52 mm)

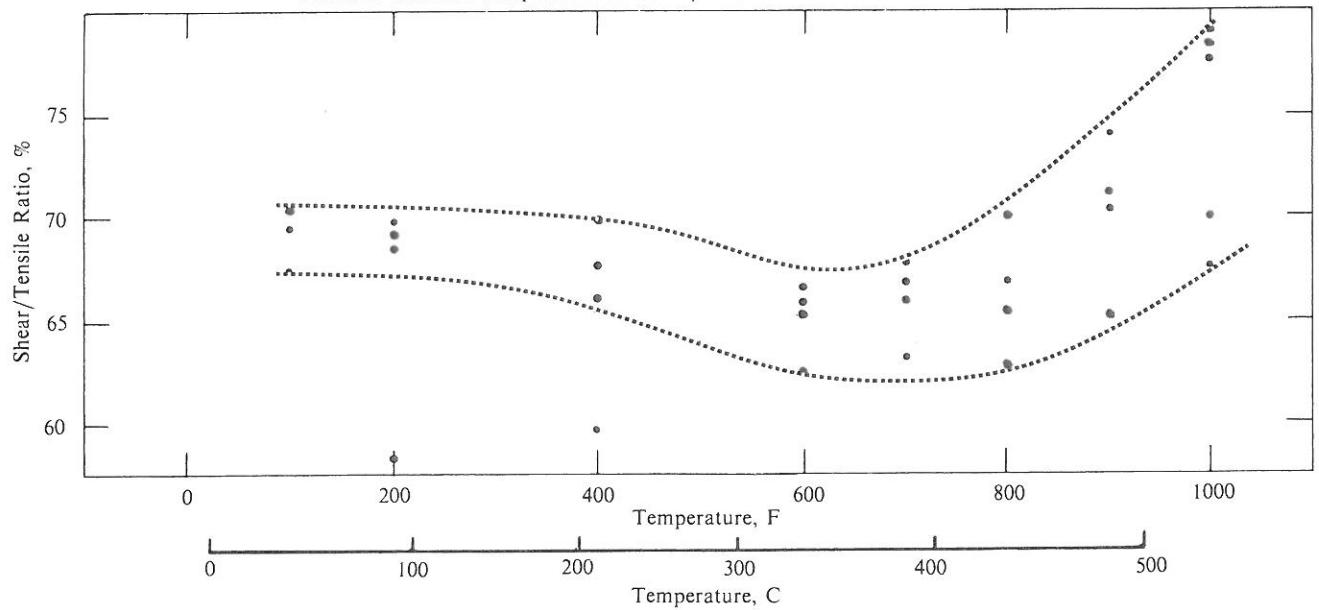
Data Reference: Armco Research Center Record Book 2620.

SHEAR STRENGTH (SINGLE SHEAR)

17-7 PH



Effect of Elevated Temperature on Shear/Tensile Ratio 17-7 PH



FATIGUE STRENGTH

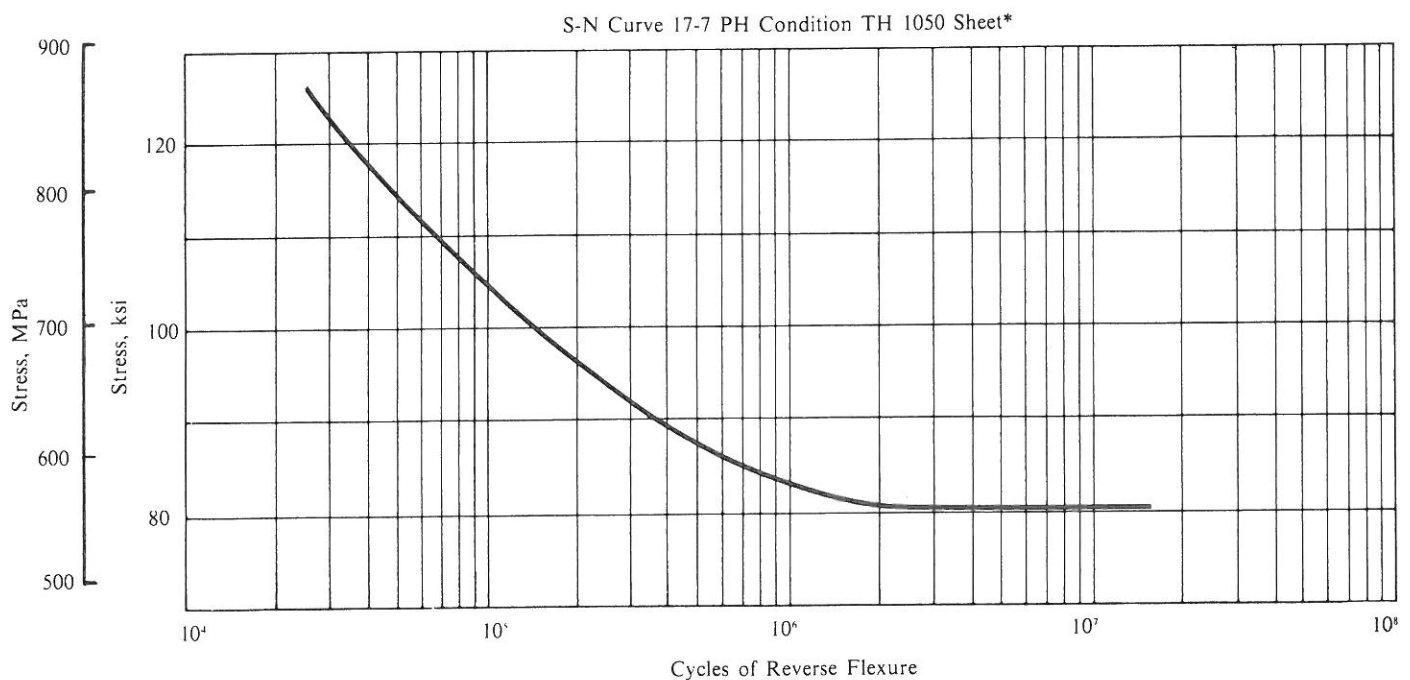
17-7 PH Condition TH 1050

Endurance limit of Condition TH 1050 in sheet form and in several finishes has been determined on sheet specimens in reversed bending. This table represents

one heat. However, other heats have indicated similar ratios of endurance limit to tensile strength.

SHEET SPECIMENS IN REVERSED BENDING

Thickness inches (mm)	Surface Condition	Test Direction	UTS ksi (MPa)	Endurance Limit 15 x 10 ⁶ Cycles, ksi (MPa)	Ratio of Endur- ance Limit to UTS
.062 (1.575)	Not Descaled	Longitudinal	183 (1262)	58 (400)	.318
.062 (1.575)	Pickled	Longitudinal	175 (1207)	55 (379)	.313
.062 (1.575)	Vapor Blasted	Longitudinal	183 (1262)	75 (517)	.411
.060 (1.524)	Polished 120 grit	Longitudinal	182 (1255)	80 (552)	.442



*Polished surface (120 grit), reversed bending in longitudinal direction. All tests from one heat.

Reverse bend fatigue tests on Armco 17-7 PH stainless steel, in Condition TH 1050, show the material has some notch sensitivity when the stress concentration factor (K) is above 1.3.

Observed stress concentration factors are all lower than theoretical values derived from the geometry of the stress raiser. Consequently, endurance limits are higher than would be expected on a theoretical basis.

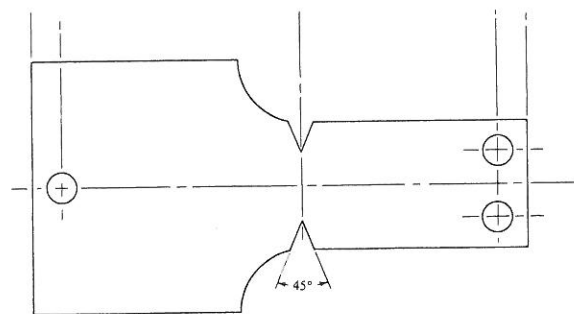
The graphs on the following page show how

Endurance limit variation resulting from theoretical stress concentration factors is also shown.

	Ultimate Tensile Strength ksi (MPa)	0.2% Yield Strength ksi (MPa)	Elongation % in 2" (50.8 mm)
Longitudinal	192 (1324)	179 (1234)	9
Transverse	188 (1296)	174 (1200)	9

Technical drawing of a mechanical part with the following dimensions and labels:

- Overall width: 3.6875
- Distance from left edge to center of first hole: 2.00
- Distance from center of first hole to center of second hole: 0.1875
- Overall height: 2.00
- Distance from top edge to center of first hole: 1.00
- Distance from center of first hole to center of second hole: 1.00
- Distance from center of second hole to center of third hole: 0.1875
- Distance from center of third hole to center of fourth hole: 0.1875
- Distance from center of fourth hole to right edge: 0.938
- Distance from center of second hole to center of third hole: 0.500
- Distance from center of third hole to center of fourth hole: 0.500
- Labels: "No. 11 Hole", "P", "R", "0.1875 diam."



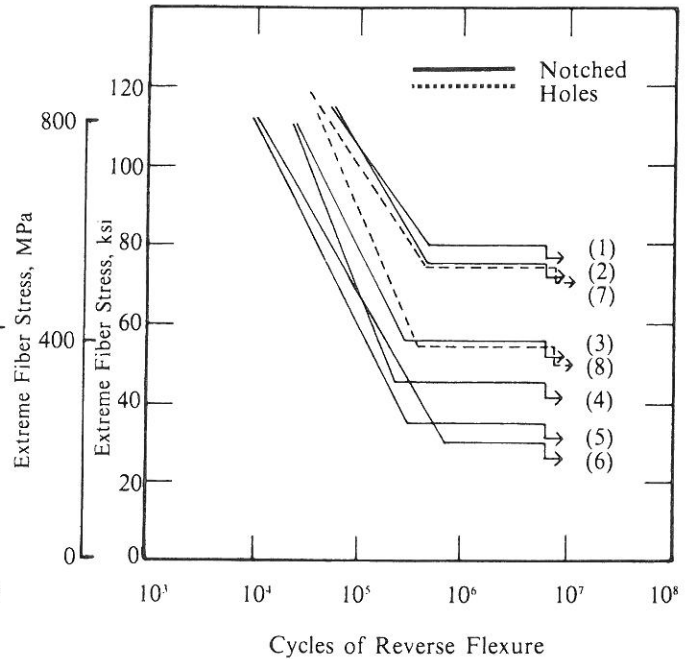
- (3) Specimens were machined from .062-.063" (1.57 - 1.60 mm) thick material. Heat treating scale was not removed before testing.

**S-N Curves for Specimens
Tested in Longitudinal Direction
(Specimens not descaled)**

STRESS CONCENTRATION FACTOR

Curve	Theoretical K	Observed K	Notch Radius or Hole Diam, in (mm)	Endurance Limit ksi (MPa)
1	1.00	1.00	Constant Strength Beam	80 (552)
2	1.33	1.07	.500 (12.70)	75 (517)
3	2.00	1.45	.100 (2.54)	55 (379)
4	2.62	1.74	.050 (1.27)	46 (317)
5	3.65	2.21	.025 (0.64)	36 (248)
6	4.94	2.66	.010 (0.25)	30 (207)
7	2.28	1.08	.500 (12.70)	74 (510)
8	2.68	1.48	.156 (3.96)	54 (372)

Test from one heat—machined, heat treated to TH 1050 (192 ksi [1324 MPa] UTS—longitudinal).



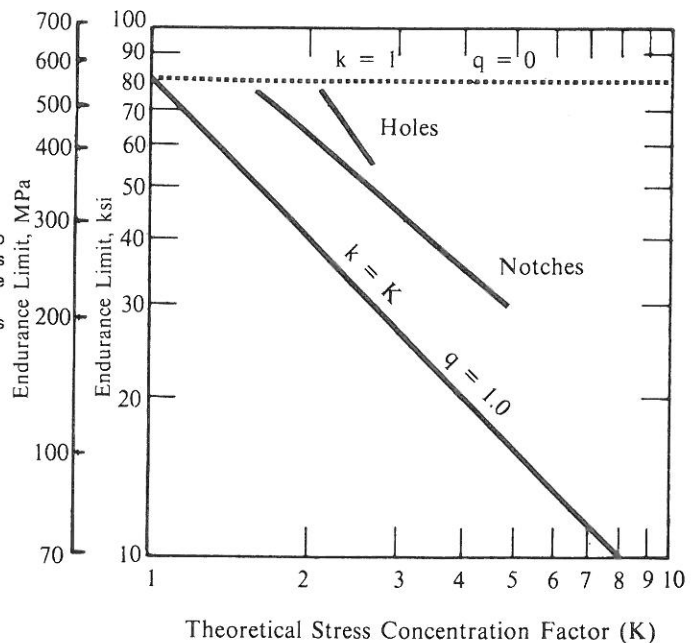
Endurance Limit vs. Theoretical Stress Concentration Factor 17-7 PH Condition TH 1050

$$K = \frac{\text{maximum stress}}{\text{nominal stress}} = \text{theoretical stress concentration factor}$$

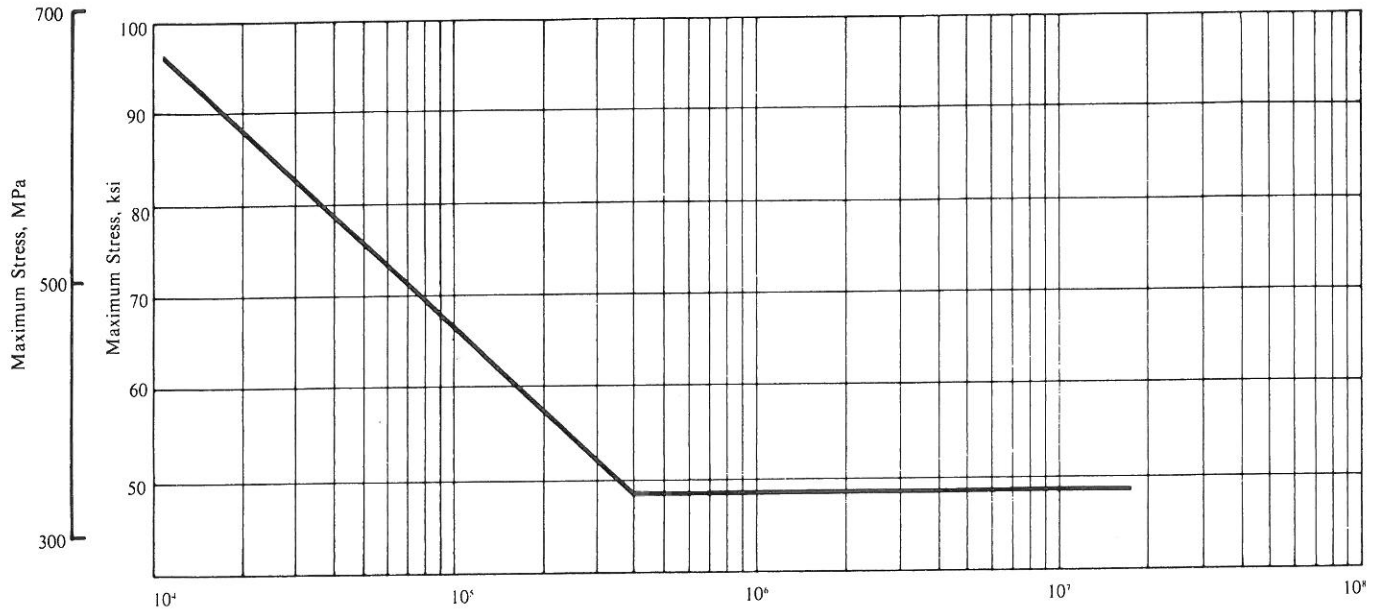
$$k = \frac{\text{measured endurance limit (unnotched)}}{\text{measured endurance limit (notched)}} = \text{measured stress concentration factor}$$

$$q = \frac{k-1}{K-1} = \text{stress concentration index}$$

Notes: (1) The horizontal line, $q=0$, represents the condition of no reduction of endurance limit due to notches or other stress raisers. The 45° line, $q=1$, gives the reduction of endurance limit if full theoretical effect of stress raiser is obtained. (2) As shown above, holes do not reduce endurance limit as much as external notches except for high values of K .

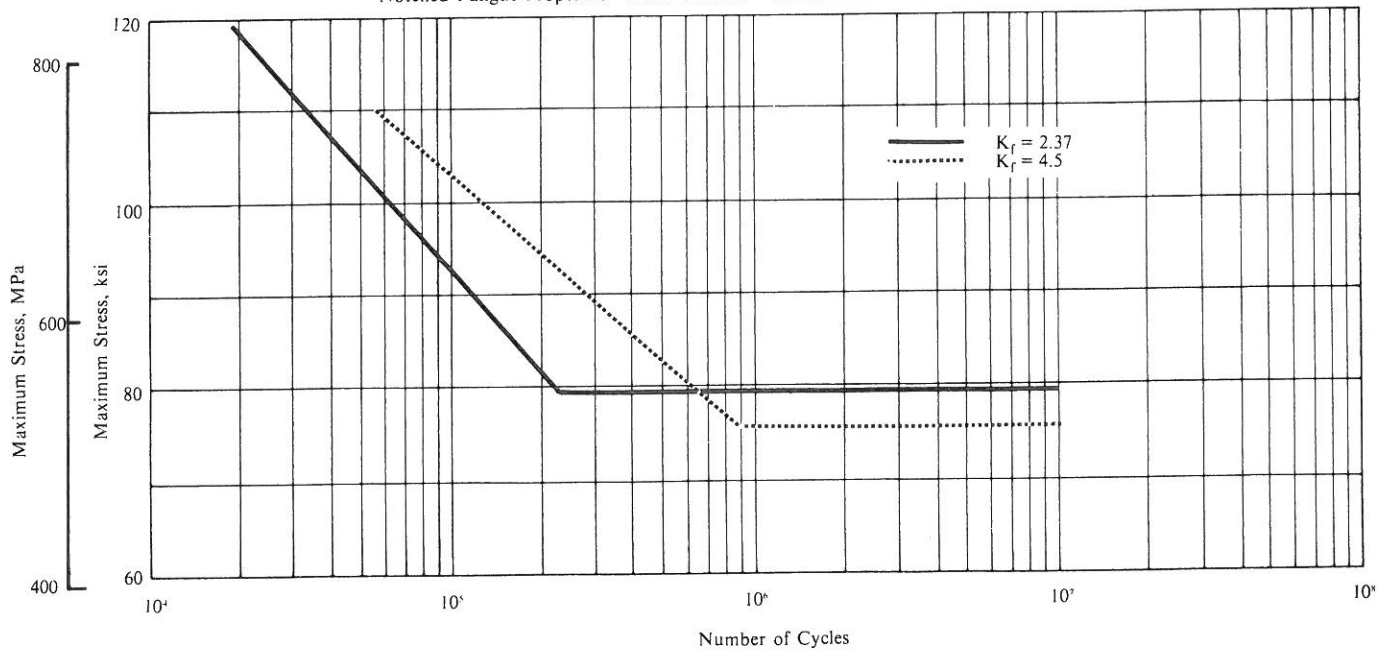


Notched Fatigue Properties - Axial Tension - Tension Tests 17-7 PH Condition TH 1050



- Notes: (1) $K_f = 3.27$
 (2) Stress Ratio = $\frac{\text{min stress}}{\text{max stress}} = + 1/10$
 (3) Specimen thickness - .0765 to .1000" (1.94 to 2.54 mm)

Notched Fatigue Properties - Axial Tension - Tension Tests 17-7 PH Condition RH 950



- Notes: (1) Stress Ratio = $\frac{\text{min stress}}{\text{max stress}} = + 1/10$
 (2) Specimen thickness - .048" (1.22 mm)

EFFECT OF VARIATIONS IN HEAT TREATMENT

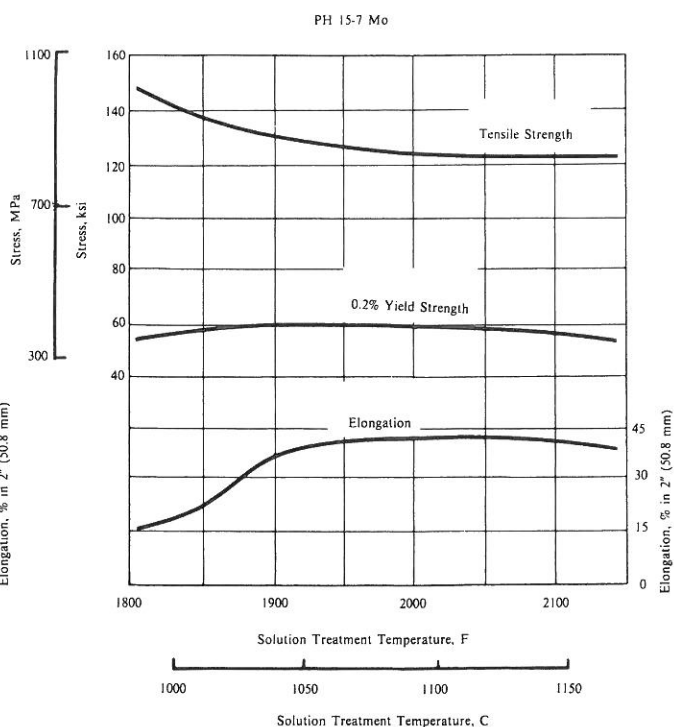
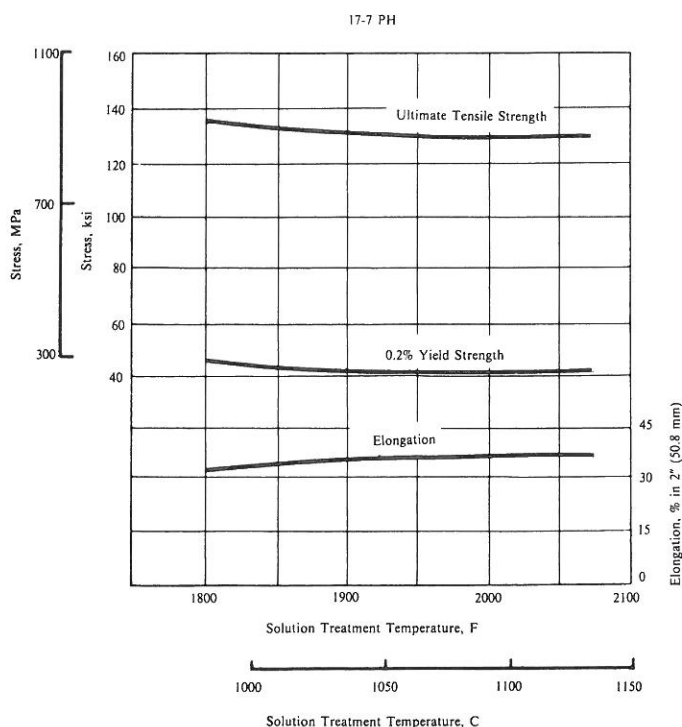
Solution Treatment

The recommended solution-treating temperature for 17-7 PH stainless steel is 1950 ± 25 F (1066 ± 14 C). Material should be held at temperature 3 minutes for each 0.1" (2.54 mm) of thickness. This treatment gives the best combination of properties for formability in Condition A and strength in Conditions TH 1050 and RH 950.

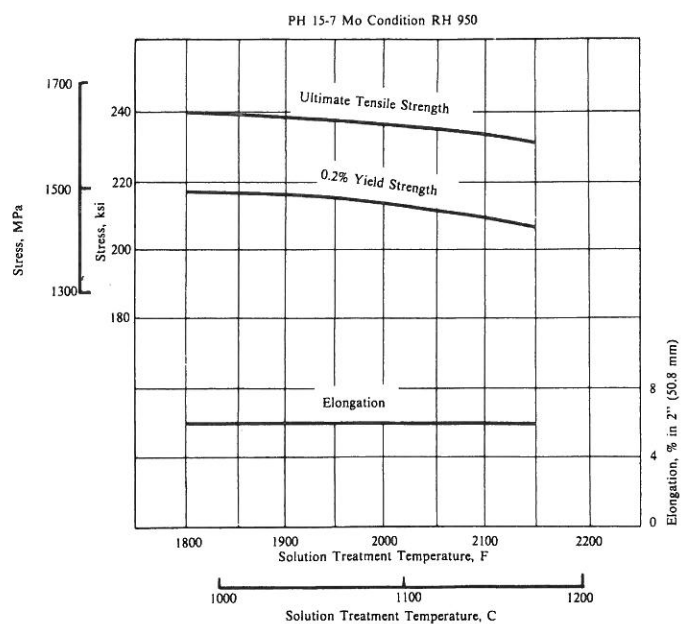
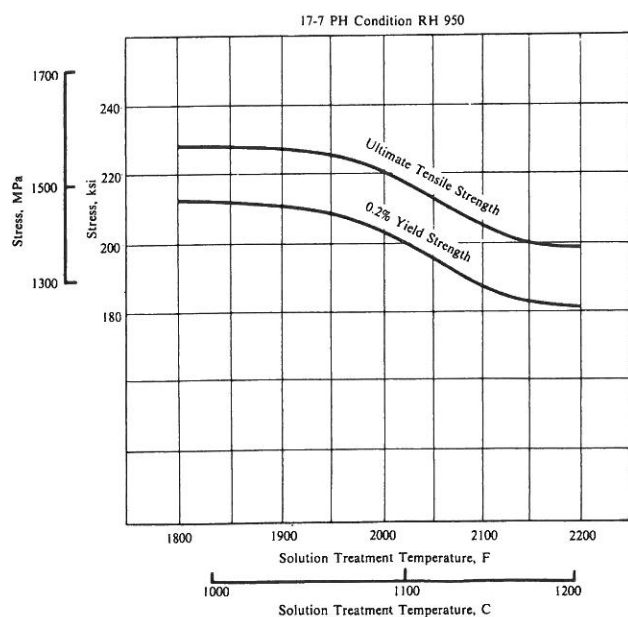
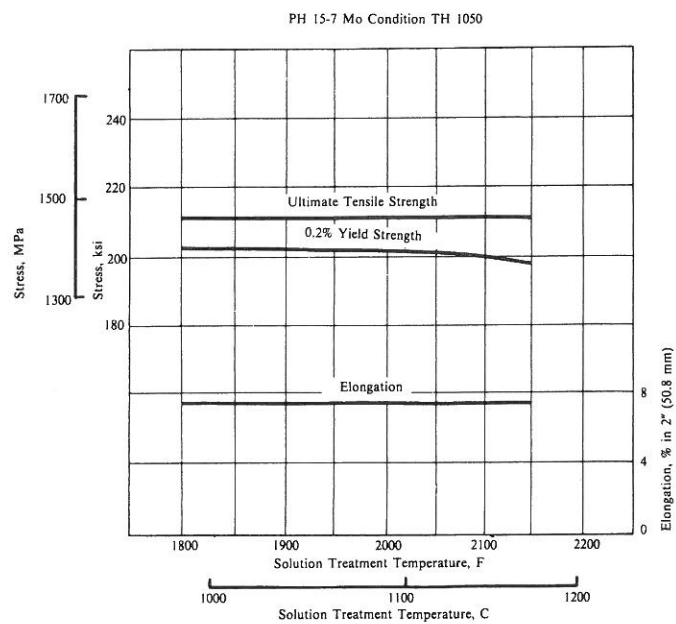
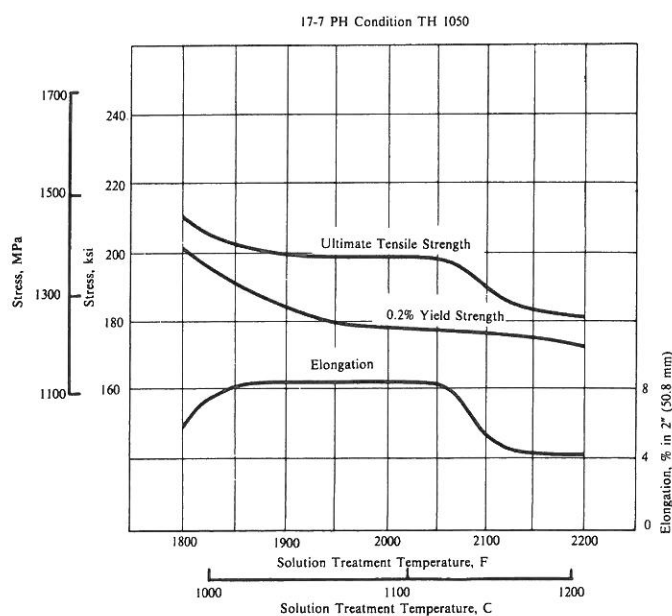
With large furnace loads, longer soaking time may be required to assure the entire load reaches temperature. After soaking, cool in air. Heavy furnace loads may require spreading or heavy plates may require forced cooling to avoid cooling too slowly.

The effects of variation in annealing temperature on mechanical properties in Conditions A, TH 1050, and RH 950 are shown in the following graphs.

Effect of Solution-Treatment Temperature on Condition A Properties



Effect of Solution-Treatment Temperature on Hardened Properties



Data Reference: Armco Research Center Record Books 2564, 2551, 1807. Data are averages of 4 to 10 heats.

Effect of Solution-Treatment Cooling Rate on Properties of 17-7 PH Condition A

Sol. Treat. Time, min	Cooling Time to 1000 F (538 C), min	0.2% YS ksi (MPa)	UTS ksi (MPa)	Elong, % in 2" (50.8 mm)	Hardness Rockwell
2	Air	39.2 (270)	122.6 (845)	41.5	B 85
20	Air	36.9 (254)	124.7 (860)	39.0	B 84
2	9.5	38.0 (262)	133.4 (919)	28.5	B 86
5	27.0	38.0 (262)	135.8 (937)	17.7	B 91
15	110.0	54.6 (376)	138.1 (951)	12.7	B100

Note: Slow cooling rates reduce elongation. For this reason, cooling rates to 1000 F (538 C) should be as rapid as obtained in normal air cooling if satisfactory Condition A properties are desired. Cooling is particularly critical when intermediate annealing prior to additional cold working. Data Reference: Armco Research Center Record Books 2620, 2659, 1917. Data is average from two typical heats.

Variation in Transformation Treatment

Many of the transformation characteristics of 17-7 PH and PH 15-7 Mo stainless are similar to those of other hardenable steels. The major difference is the temperature range in which the transformation from austenite to martensite occurs. For other hardenable steels, this range is generally between 200 F and 700 F (93 C and 371 C). For 17-7 PH and PH 15-7 Mo it may be considerably lower.

The metallurgical principles of "transformation" are discussed in the Metallurgy Section. Two standard heat treatments, TH 1050 and RH 950, are used for 17-7 PH and PH 15-7 Mo; however, it is recognized that it is often necessary to alter the times, temperature and cooling rates of these prescribed heat treatments. Most common reasons for variations are compatibility with brazing cycles, limitations of heat treating equipment, size of parts, assemblies consisting of dissimilar metals, and cases where strength higher or lower than standard are desired. Therefore, the following data are intended as a guide in anticipating the effects in

varying the austenite conditioning temperature, time at temperature, cooling rate after austenite conditioning, and finally, time and temperature held to effect transformation.

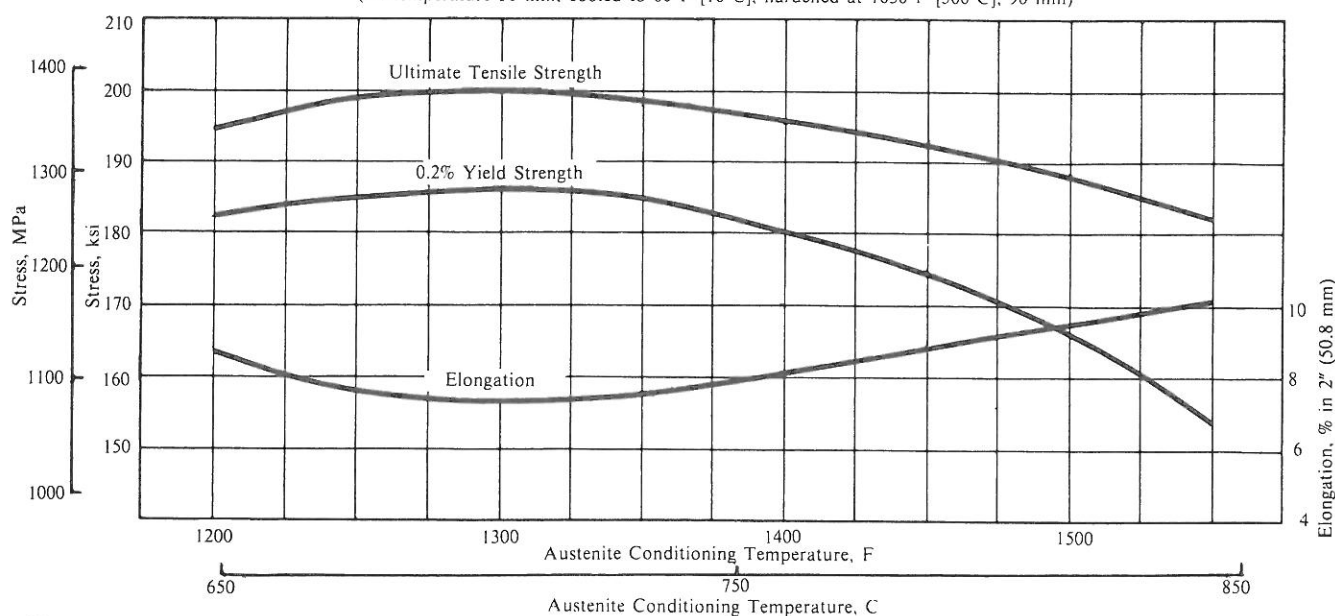
Austenite conditioning and transformation for Condition TH 1050 has been standardized to:

Heat to 1400 F \pm 25 F (760 C \pm 14 C) for 1-1/2 hours; cool to 60 F (16 C) \pm 0-10 F (\pm 0-6 C) within one hour after removal from the furnace and hold for 30 minutes. The steel in this condition is designated "Condition T."*

*See note on page 61.

Austenite conditioning temperature and time at temperature are not too critical. Satisfactory design properties can be obtained over a wide range of temperature and time. Higher strength is obtained from the 1300 F (704 C) conditioning temperature, but this is accompanied by lower elongation. Austenite conditioning at 1400 F (760 C) provides the best combination of strength and ductility after subsequent hardening, from heat to heat.

Effect of Variation in Austenite Conditioning Temperature on Mechanical Properties of 17-7 PH Condition TH 1050
(At temperature 30 min, cooled to 60 F [16 C], hardened at 1050 F [566 C], 90 min)



Time at austenite conditioning temperature should be 30 to 60 minutes to obtain maximum strength after subsequent hardening. However, 1-1/2 hours is recommended for better uniformity, particularly in larger batch operations.

Cooling rates from the austenite conditioning temperature affect the temperature at which transformation occurs, and, therefore, affect final properties. Quenching to 60 F (16 C) may give the highest strength after subsequent hardening treatment, but may cause distortion. Also, if cooling delays should occur, and the metal does not reach 60 F (16 C) within one hour, it may be desirable to employ a refrigeration treatment to obtain sufficient transformation to get the reported strengths. But, this may impair the tensile elongation slightly. Both these effects are shown below.

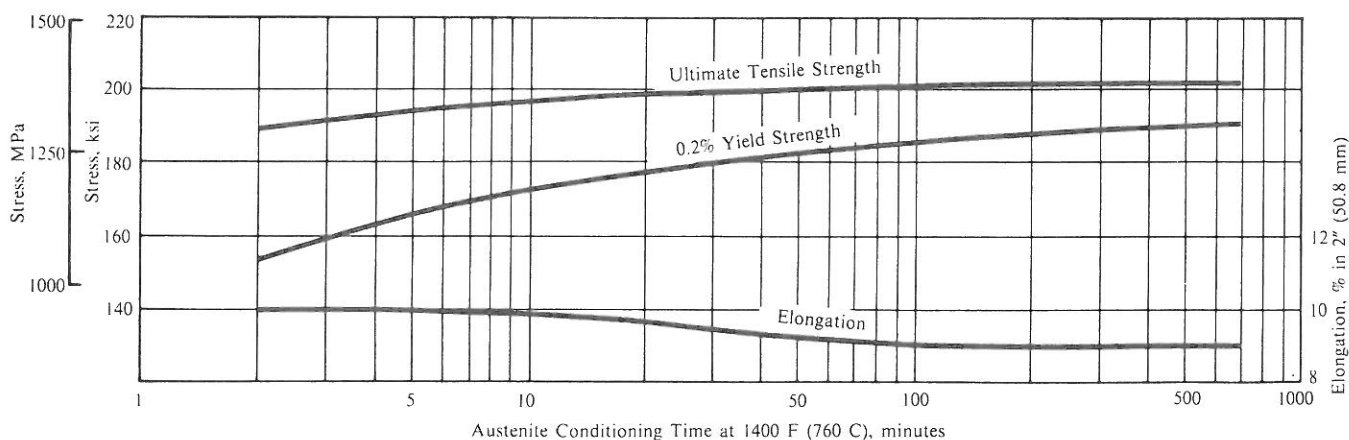
Austenite conditioning and transformation for Condition RH 950 has been standardized to:

Heat to 1750 F \pm 15 F (954 \pm 9 C) for 10 minutes; air cool to room temperature and within one hour cool to -100 F \pm 10 F (-73 \pm 6 C). Hold for 8 hours. The steel in this condition is designated "Condition R-100."*

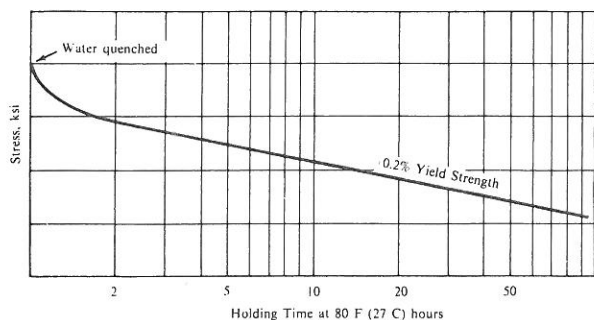
The transformation during the RH 950 heat treatment is very similar to that of the TH 1050 treatment. The major difference is the lower M_s temperature resulting from the higher austenite conditioning temperature of 1750 F (954 C).

The austenite conditioning temperature and time at temperatures are not too critical; however, variations from the standard treatment will affect properties as shown below.

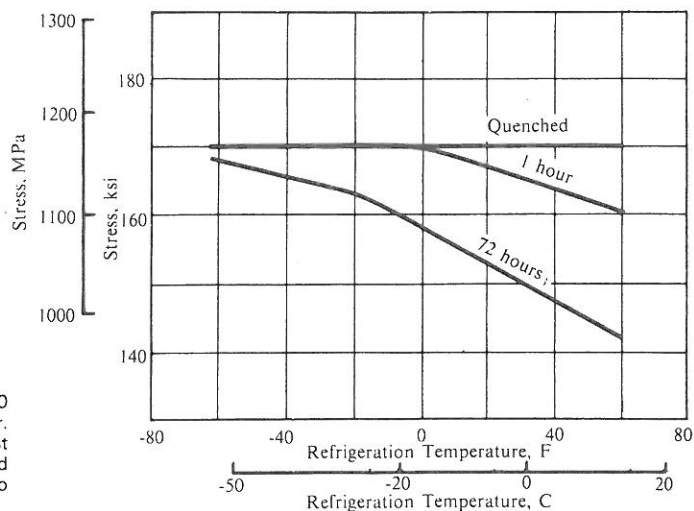
Effect of Variation in Time at Austenite Conditioning Temperature on Mechanical Properties of 17-7 PH Condition TH 1050 (At 1400 F [760 C] for time shown, cooled to 60 F [16 C], hardened at 1050 F [566 C], 90 min.)



Effect of Cooling Time from Austenite Conditioning Temperature to Room Temperature on 0.2% Yield Strength — 17-7 PH — Condition TH 1050, (1400 F [760 C] -90 min, air cooled to 80 F [27 C], held as indicated below, water quenched to 60 F [16 C], hardened 1050 F [566 C] -90 min.)



Effect of Refrigeration Treatment During Transformation on Yield Strength of 17-7 PH. Cond. TH 1050. (1400 F [760 C] -90 min, air cooled to 80 F [27 C] for indicated time — cooled to indicated temperature, hardened at 1050 F [566 C] -90 min.)

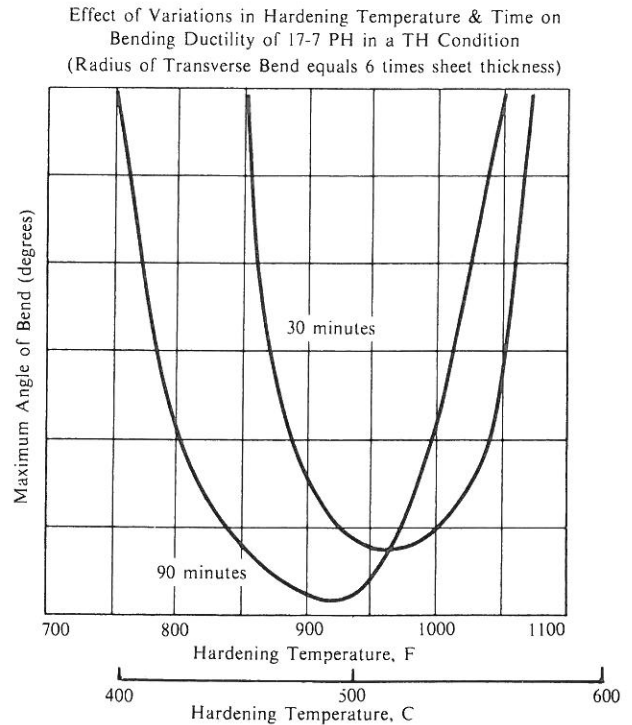
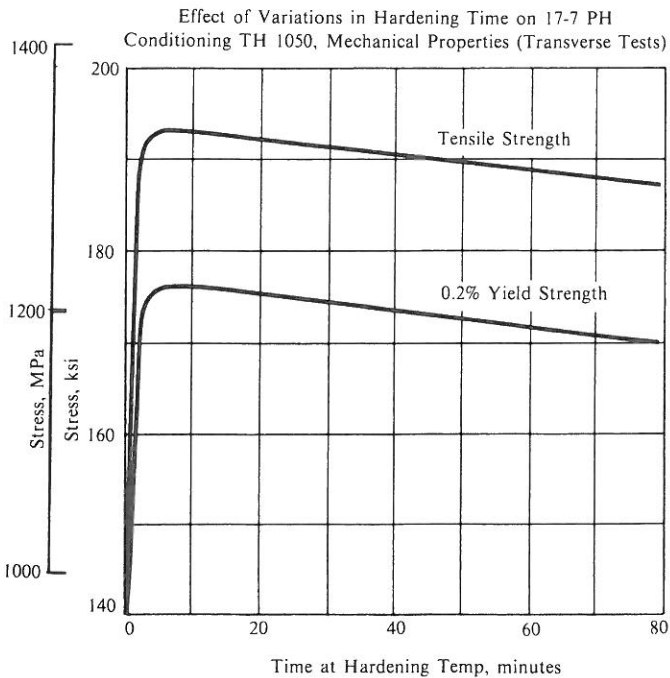
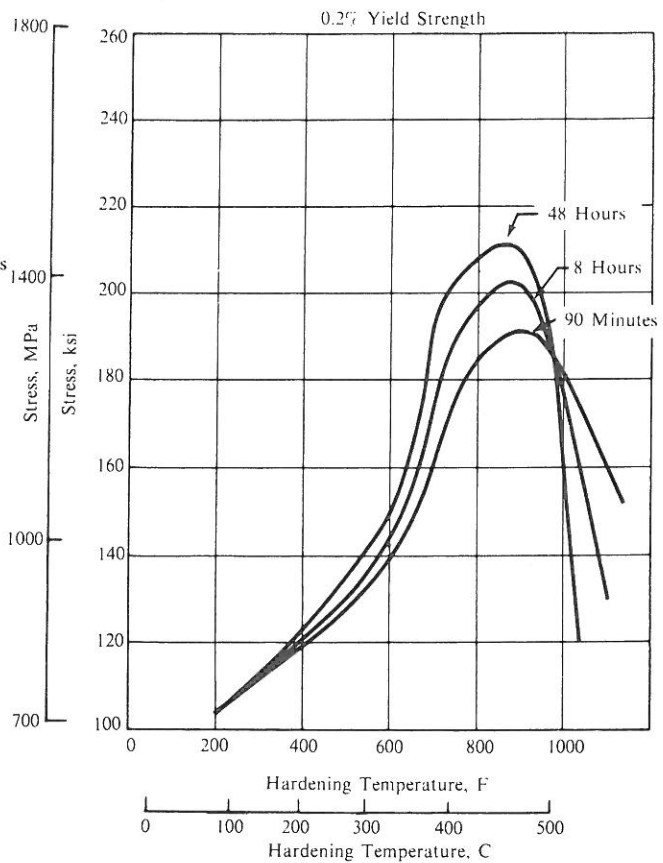
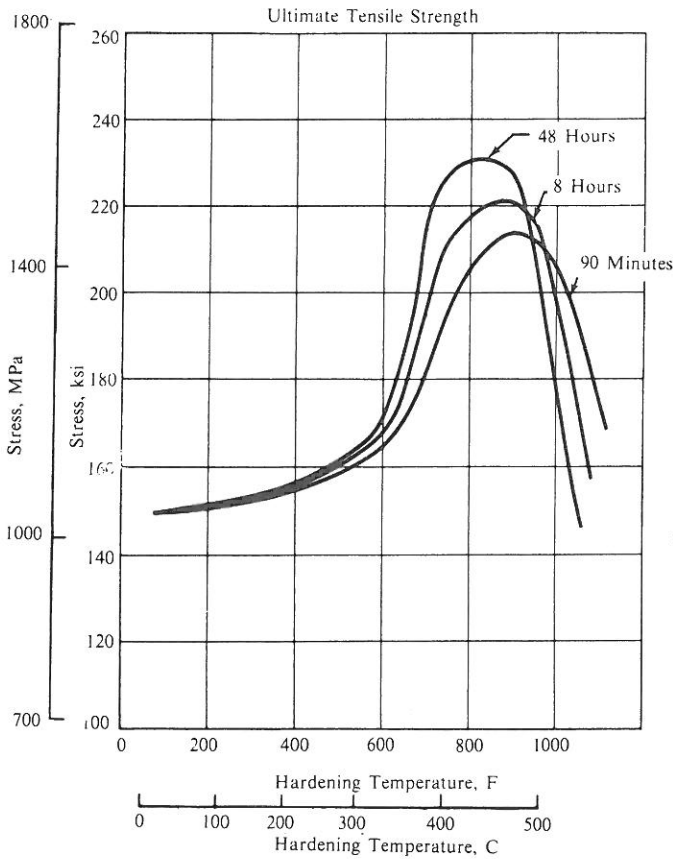


*It has been indicated that cooling to 60 F (16 C) (Condition T) or -100 F (-73 C) (Condition R-100) must be completed within one hour. Technically, this means that once transformation begins (M_s) it must be cooled to 60 F (16 C) or -100 F (-73 C) within one hour. Prolonged holding times above the M_s but below 1000 F (538 C) have no adverse effect on mechanical properties.

Variation in Hardening Treatment

Effect of Hardening Time and Temperature on Mechanical Properties of 17-7 PH in TH Conditions

1400 F (760 C), 1-1/2 hours, air cool to room temperature and water quench to 60 F (16 C). Harden as shown below.



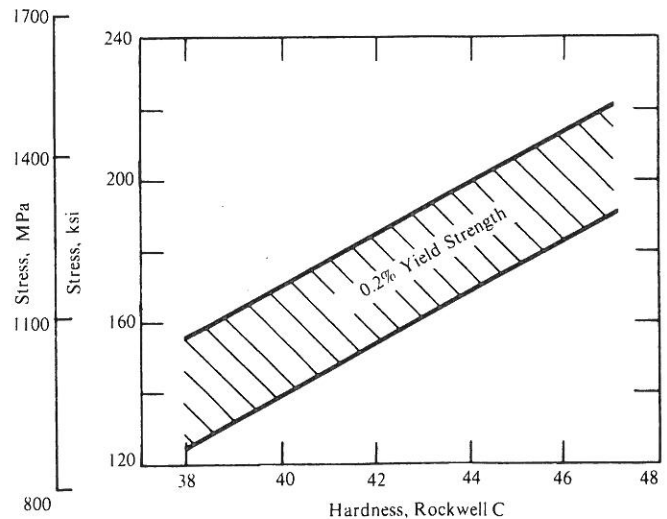
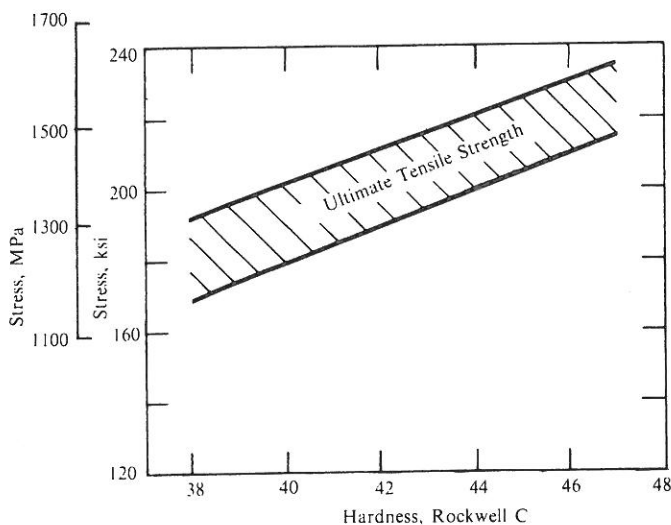
A substantial increase in strength and hardness is obtained by a precipitation-hardening treatment following transformation. The hardening effect takes place over a wide range of temperature. It is discernible at 200 F (93 C), gradually increases to a maximum at 900-950 F (482-510 C), then tapers off as 1400 F (760 C) is approached.

Maximum strength obtained at 900-950 F (482-510 C) is accompanied by lowest ductility. Hardening temperatures below and above this range result in considerably better ductility as measured by bend tests. The strength drops fairly fast with increasing temperatures above the maximum strength range (900-950 F [482-510 C]) and a tolerance of ± 10 F (± 6 C) is recommended. However, hardening at temperatures below 900 F (482 C) is not recommended since there is insufficient stress relief.

The effect of time at hardening temperatures is

also important. For example, when hardening at a temperature of 1050 F (566 C) for Condition TH 1050, maximum strength and hardness are developed in the first five minutes at temperature. Thereafter, strength decreases very gradually with time. These effects are shown in the graphs.

Because there is a relationship between strength and hardness, many manufacturers prefer to use hardness values as a specification control rather than yield or ultimate tensile strength. However, hardness does not offer an exact control since a single Rockwell point can represent a variation of as much as 35,000 psi (241 MPa) in strength. Generally speaking, once the strength-hardness relation has been established for a specific heat, a change in hardness of one Rockwell point represents approximately 8000 psi (55 MPa) strength. Note the strength vs. hardness relationship shown below.



EFFECT OF HARDENING TEMPERATURE AND OF REHARDENING TREATMENTS ON MECHANICAL PROPERTIES

Precipitation Hardening Treatment	PH 15-7 Mo				17-7 PH		
	0.2% YS ksi (MPa)	UTS ksi (MPa)	Elong. % in 2" (50.8 mm)	Hardness R _C	0.2% YS ksi (MPa)	UTS ksi (MPa)	Elong. % in 2" (50.8 mm)
TH 900 (30 min)	201 (1386)	220 (1517)	8.0	46.3	—	—	—
TH 950 (30 min)	209 (1441)	224 (1544)	7.5	47.0	—	—	—
TH 1000	220 (1517)	231 (1593)	6.7	48.2	—	—	—
TH 1050	205 (1413)	216 (1489)	6.2	46.5	188 (1296)	202 (1393)	10.0
TH 1050 + 1100 F (593 C)	179 (1234)	188 (1296)	10.0	41.5	—	—	—
TH 1050 + 1075 F (579 C)	—	—	—	—	159 (1096)	175 (1207)	11.0
TH 1050 + 1075 F + 1100 F (579 C + 593 C)	—	—	—	—	142 (979)	162 (1117)	13.0
TH 1050 + 1050 F (566 C)	201 (1386)	206 (1420)	6.7	44.8	169 (1165)	181 (1248)	10.5
TH 1050 + 1050 F + 1000 F (566 C + 538 C)	—	—	—	—	171 (1179)	183 (1262)	11.0
TH 1050 + 1050 F + 1000 F + 950 F (566 C + 538 C + 510 C)	—	—	—	—	175 (1207)	184 (1269)	10.5
TH 1050 + 1000 F (538 C)	209 (1441)	219 (1510)	5.7	46.0	—	—	—
TH 1050 + 950 F (510 C)	213 (1469)	222 (1531)	5.7	46.5	—	—	—
TH 1050 + 950 F (510 C) (30 min)	—	—	—	—	190 (1310)	206 (1420)	10.0
TH 1050 + 900 F (482 C)	212 (1462)	222 (1531)	6.0	46.5	—	—	—
TH 1050 + 900 F (482 C) (65 hrs)	223 (1538)	234 (1631)	5.2	48.0	—	—	—
TH 1100	181 (1248)	189 (1303)	8.0	41.5	—	—	—
TH 1100 + 1100 F (593 C)	168 (1158)	182 (1255)	10.3	39.7	—	—	—
TH 1100 + 1050 F (566 C)	182 (1255)	191 (1317)	9.3	41.7	—	—	—
TH 1100 + 1000 F (538 C)	186 (1282)	194 (1338)	8.8	42.5	—	—	—
TH 1100 + 950 F (510 C)	188 (1296)	195 (1344)	8.3	42.5	—	—	—
TH 1100 + 900 F (482 C)	188 (1296)	195 (1344)	9.7	42.3	—	—	—
TH 1100 + 900 F (482 C) (65 hrs)	202 (1393)	210 (1448)	8.5	44.7	—	—	—

All hardening times 1½ hours except as noted. All values from one heat (17-7 PH) — average values from 3 heats (PH 15-7 Mo).
Data reference (PH 15-7 Mo): Armco Research Center Record Books 1807, 2620.

EFFECT OF HARDENING TEMPERATURE AND REHARDENING TREATMENTS ON MECHANICAL PROPERTIES

Precipitation Hardening Treatment	17-7 PH			PH 15-7 Mo			
	0.2% YS ksi (MPa)	UTS ksi (MPa)	Elong. % in 2" (50.8 mm)	0.2% YS ksi (MPa)	UTS ksi (MPa)	Elong. % in 2" (50.8 mm)	Hardness R _C
RH 900	—	—	—	211 (1455)	237 (1634)	7	48
RH 950	206 (1420)	222 (1531)	10	217 (1496)	241 (1662)	6	49
RH 950 + 1100 F (593 C)	—	—	—	194 (1338)	201 (1386)	7	43
RH 950 + 1050 F (566 C)	—	—	—	218 (1503)	229 (1579)	5	47
RH 950 + 1050 F (566 C) (15 min)	188 (1296)	205 (1413)	11	—	—	—	—
RH 950 + 1050 F (566 C) (5 min)	194 (1338)	210 (1448)	11	—	—	—	—
RH 950 + 1000 F (538 C)	—	—	—	218 (1503)	241 (1662)	5	48
RH 950 + 1000 F (538 C) (15 min)	201 (1386)	214 (1475)	11	—	—	—	—
RH 950 + 1000 F (538 C) (5 min)	201 (1386)	215 (1482)	11	—	—	—	—
RH 950 + 950 F (510 C) (15 min)	207 (1427)	222 (1531)	8	—	—	—	—
RH 950 + 950 F (510 C) (5 min)	209 (1441)	222 (1531)	11	—	—	—	—
RH 950 + 900 F (482 C) (8 hrs)	—	—	—	225 (1551)	251 (1731)	6	50
RH 950 + 900 F (482 C) (65 hrs)	—	—	—	232 (1600)	255 (1758)	5	51
RH 950 + 900 F (482 C) (500 hrs)	—	—	—	230 (1586)	242 (1669)	5	50
RH 1000	—	—	—	221 (1524)	238 (1641)	6	48
RH 1050	—	—	—	211 (1455)	224 (1544)	5	46
RH 1050 + 950 F (510 C)	—	—	—	218 (1503)	232 (1600)	5	48
RH 1050 + 900 F (482 C) (8 hrs)	—	—	—	224 (1544)	236 (1627)	5	49
RH 1050 + 900 F (482 C) (65 hrs)	—	—	—	234 (1613)	245 (1689)	4	49
RH 1100	—	—	—	188 (1296)	196 (1351)	9	43

Hardening time 1 hour unless noted otherwise. PH 15-7 Mo values are average from 3 heats.
Data Reference: Armco Research Center Record Books 1807, 2620.

EFFECT OF HARDENING TEMPERATURE ON NOTCH STRENGTH*

Precipitation Hardening Treatment	0.2% YS ksi (MPa)	UTS ksi (MPa)	Notch Str. ksi (MPa)	NS YS	NS UTS
PH 15-7 Mo					
RH 950	228 (1572)	247 (1703)	108 (745)	.47	.44
RH 1000	230 (1586)	243 (1675)	140 (965)	.61	.58
RH 1050	220 (1517)	227 (1565)	162 (1117)	.74	.71
RH 1100	182 (1255)	192 (1324)	174 (1200)	.96	.91
17-7 PH					
RH 950	220 (1517)	236 (1627)	120 (827)	.55	.51
RH 1000	205 (1413)	224 (1544)	107 (738)	.52	.48
RH 1050	185 (1276)	205 (1413)	160 (1103)	.86	.78
RH 1100	135 (931)	175 (1207)	157 (1082)	1.18	.90

*PH 15-7 Mo specimens .063" (1.60 mm) and 17-7 PH specimens .020" (.51 mm).
All 1" (25.4 mm) wide. .0007" (.018 mm) Max Root Radius. All tests in transverse direction.
Data courtesy of NASA — Lewis Lab.

As the aging temperature is increased, the notch strength to yield strength and to ultimate tensile strength ratios are increased. This gain in notch toughness has been an important design considera-

tion in pressure vessel applications, with most pressure vessels using an aging temperature between 1070 F (579 C) and 1150 F (621 C). This applies to both the RH and TH type heat treatments.

EFFECT OF COLD WORK ON CONDITION TH 1050 PROPERTIES

Cold working in Condition A results in a loss of strength in the hardened condition TH 1050 as indicated below:

% Reduction in Thickness (by Rolling)	Properties of 17-7 PH following TH 1050 Heat Treatment				Properties of PH 15-7 Mo following TH 1050 Heat Treatment			
	0.2% YS ksi (MPa)	UTS ksi (MPa)	Elong. % in 2" (50.8 mm)	Hardness R _C	0.2% YS ksi (MPa)	UTS ksi (MPa)	Elong. % in 2" (50.8 mm)	Hardness R _C
0	184 (1269)	200 (1379)	8.7	44	188 (1296)	199 (1372)	9.5	44.5
20	167 (1151)	176 (1213)	8.6	—	163 (1124)	191 (1317)	10.8	43.0
30	155 (1069)	170 (1172)	9.9	—	150 (1034)	189 (1303)	11.4	42.5

A modified TH 1050 heat treatment has been developed to compensate for cold working when TH 1050 properties are desired. This treatment is outlined below:

Austenite Condition Air Cool & Refrigerate Precipitation Harden
 1550 F ± 25 F (843 C ± 14 C) 90 min 0 F ± 10 F (-18 C ± 6 C) 4 hrs 1050 F ± 10 F (566 C ± 6 C) 90 min

As shown below this treatment overcomes the loss in strength caused by cold work. The equivalent of regular TH 1050 properties can be obtained.

% Reduction in Thickness	Heat Treatment	Properties of 17-7 PH following Heat Treatment				Properties of PH 15-7 Mo following Heat Treatment			
		0.2% YS ksi (MPa)	UTS ksi (MPa)	Elong. % in 2" (50.8 mm)	Hardness R _C	0.2% YS ksi (MPa)	UTS ksi (MPa)	Elong. % in 2" (50.8 mm)	Hardness R _C
0	Std.	174.5 (1203)	187.5 (1292)	10.5	41.5	195 (1344)	205 (1413)	8.5	45.0
30	Std.	165.5 (1141)	183.8 (1268)	11.8	41	178 (1227)	198 (1365)	11.0	44.0
0	Mod.	179.0 (1234)	190.0 (1310)	10	41.5	198 (1365)	208 (1434)	8.5	45.0
30	Mod.	176.2 (1214)	187.8 (1294)	11	41	194 (1338)	204 (1407)	9.5	44.5

Std. = Standard TH 1050 Heat Treatment; Mod. = Modified TH 1050 Heat Treatment.
Note: Data represents tests from a minimum of three typical heats per table.
Data Reference: Armco Research Center Record Books 1788, 2519, 2530, 2536, 2557, 2582.

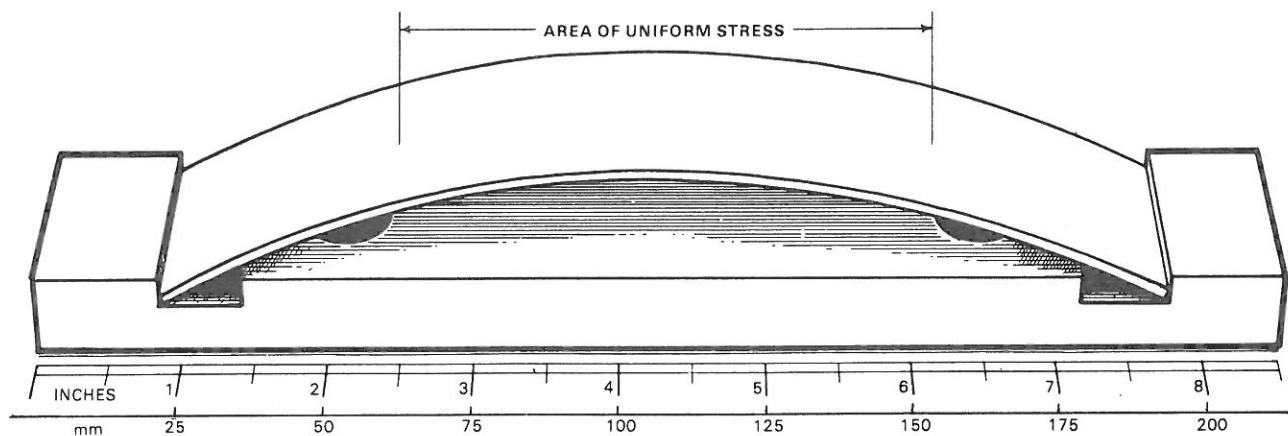
Stress-Cracking of Armco 17-7 PH and PH 15-7 Mo Stainless Steels in Marine Environments

The hardenable chromium stainless steels are known to be subject to spontaneous fracture when stressed and exposed to some corrosive environments. Likewise, the precipitation-hardening stainless steels may, under some conditions, also fail by stress cracking. The tendency appears to be associated with the type of stainless, its hardness, the level of applied tension stress, and the environment.

Armco has conducted stress-cracking tests on the precipitation-hardening alloys in the marine environment at Kure Beach, North Carolina. Careful consideration was given to the design of sheet specimen for stress-cracking studies. It was recognized that there were limitations in the usefulness of the stress specimens which have been used by many investigators. A beam-type specimen with three point

loading provides only a line of maximum stress at the midpoint. Horseshoe-type specimens proved to be unsatisfactory for light gage sheet material because it was not possible to confine the area of maximum stress to the desired portion of the horseshoe.

Studies were made on sheet specimens bent into an arc with the ends held in the rigid jig. (See illustration.) Measurements with strain gages indicated that with a 7" (177.8 mm) chord length about 4" (101.6 mm) of the center portion of the specimen was uniformly stressed in tension at the external fibers. Our work indicates that this type of specimen is relatively easy to prepare in large numbers. More important, the data are reasonably reproducible.



Armco-developed specimen and jig for testing resistance of stainless steel sheet to stress-corrosion cracking.

The data reported here are the results of multiple specimens exposed at stress levels of 50 and 75% of the actual yield strength of the materials tested. Test specimens were 0.050" (1.27 mm) thick heat treated to Conditions TH 1050 and RH 950. Specimens in Condition CH 900 were .041" (1.041 mm) thick. The long dimension of all specimens was cut transverse to the rolling direction.

Final heat treating scales were removed by wet grit blasting using a mixture of #100 Pangbornite and 240 grit alumina. The surface roughness was measured to be RMS 25-30. Subsequent work has indicated that pickling specimens after the 1750 F (954 C) heat

treatment adversely affects results.

When comparing the various heat-treated conditions, the data show that both 17-7 PH and PH 15-7 Mo stainless steels have the greatest resistance to stress cracking in Condition CH 900. Likewise, Condition TH 1050, although somewhat less resistant than Condition 900, appears to be more resistant to stress cracking than Condition RH 950.

The tables summarize the test data. In addition, in the mild industrial atmosphere at Middletown, Ohio, specimens stressed at 90% of their yield strength had not broken after 730 days of exposure.

TRANSVERSE ROOM TEMPERATURE MECHANICAL PROPERTIES OF SPECIMENS TESTED

Alloy	Condition	Hardness R _C	0.2% YS psi (MPa)	UTS psi (MPa)	Elong. % in 2" (50.8 mm)
17-7 PH	TH 1050	46	199,600 (1376)	214,400 (1478)	8.0
17-7 PH	TH 1050	42	178,800 (1233)	190,600 (1314)	9.0
17-7 PH	RH 950	49	216,900 (1495)	237,600 (1638)	5.0
17-7 PH	RH 950	48	217,500 (1499)	230,200 (1587)	5.0
17-7 PH	RH 1000	48	215,900 (1488)	228,100 (1573)	6.5
17-7 PH	RH 1000	46.5	205,800 (1419)	216,100 (1490)	6.0
17-7 PH	CH 900	52	269,600 (1859)	279,300 (1926)	0.5
PH 15-7 Mo	TH 1050	45.5	204,600 (1411)	213,800 (1475)	5.5
PH 15-7 Mo	TH 1050	46	208,600 (1438)	218,300 (1505)	7.0
PH 15-7 Mo	RH 950	50	219,800 (1516)	244,600 (1686)	4.0
PH 15-7 Mo	RH 950	50	220,800 (1523)	246,200 (1497)	4.5
PH 15-7 Mo	RH 1000	49.5	226,200 (1559)	244,400 (1684)	2.5
PH 15-7 Mo	RH 1000	49.5	227,100 (1565)	244,800 (1688)	4.0
PH 15-7 Mo	CH 900	51	251,600 (1735)	261,800 (1806)	2.0

Data shown represent average values from 5 tests on each of two heats.

SUMMARY OF STRESS-CRACKING FAILURES AT KURE BEACH — 800 FOOT LOT

Material and Heat Treatment	Stressed at 50% of the 0.2% YS			Stressed at 75% of the 0.2% YS		
	Stress psi (MPa)	Days to Failure	Range Days	Stress psi (MPa)	Days to Failure	Range Days
17-7 PH						
TH 1050	100,800 (695)	No Failures in 746 days	16-49	151,300 (1043)	100 ^{[2]*}	82-118**
TH 1050	89,000 (620)	No Failures in 746 days		133,600 (921)	No Failures in 746 days	
RH 950	111,600 (769)	30.2		167,500 (1154)	7.4	
RH 950	110,200 (759)	116 ^{[1]*}		165,400 (1141)	51.6	
CH 900	142,800 (985)	No Failures in 746 days		214,200 (1476)	No Failures in 746 days	
PH 15-7 Mo						
TH 1050	107,400 (742)	No Failures in 746 days	112-385	161,000 (1110)	103 ^{[3]*}	75-118**
TH 1050	109,200 (753)	No Failures in 746 days		163,900 (1130)	39.8	
RH 950	115,800 (799)	169.4		173,700 (1198)	68.8	
RH 950	116,800 (806)	98.8		175,200 (1208)	14.2	
CH 900	131,000 (904)	No Failures in 746 days		196,600 (1355)	No Failures in 746 days	

*[1] Number in brackets indicates number of failed specimens. Remainder of 5 specimens unbroken after 746 days.

** Range of broken specimens only. Remainder of 5 specimens unbroken after 746 days.

Note: All tests made in transverse direction.

Data Reference: Armco Research Laboratory Record Books 1307, 2433, 2502.

Tests discontinued after 746 days.

SUMMARY OF STRESS-CRACKING EXPOSURE TESTS AT KURE BEACH — PH 15-7 Mo

Condition	Heat	Original Properties			Stressed 60% Fty			Stressed 40% Fty		
		F _{tu} ksi (MPa)	F _{ty} ksi (MPa)	Elong. %	Stress ksi (MPa)	Days To Failure		Stress ksi (MPa)	Days To Failure	
						80' (24.38 m) Lot	800' (240.4 m) Lot		80' (24.38 m) Lot	800' (240.4 m) Lot
TH 1050	A	222 (1531)	212 (1462)	6.0	127 (876)	182	NF	85 (586)	NF	NF
	B	217 (1496)	209 (1441)	7.0	125 (862)	73 ^[4]	NF	84 (579)	NF	NF
	C	215 (1482)	206 (1420)	5.5	124 (855)	71 ^[2]	NF	82 (565)	NF	NF
RH 950	A	243 (1675)	218 (1503)	6.7	131 (903)	28.2	179 ^[4]	87 (600)	92 ^[3]	346 ^[1]
	B	243 (1675)	220 (1517)	6.0	132 (910)	22.2	126 ^[4]	88 (607)	74 ^[4]	NF
	C	239 (1648)	218 (1503)	6.0	131 (903)	19	164 ^[4]	87 (600)	82 ^[1]	NF
RH 1050	B	227 (1565)	219 (1510)	6.5	131 (903)	14 ^[4]	NF	88 (607)	NF	NF
	C	222 (1531)	215 (1482)	4.5	129 (889)	21.2 ^[2]	NF	86 (593)	NF	NF
SIMULATED BRAZE*	B	252 (1737)	234 (1613)	5.0	140 (965)	24.2	236.2	93 (641)	49.6	NF
	C	252 (1737)	235 (1620)	4.7	140 (965)	44.2	101.4	94 (648)	61.6	265 ^[2]

NF Denotes no failures after 400 days.

[1] Denotes number of specimens failed at average time shown. Remainder of 5 specimens not failed after 400 days.

*Simulated braze heat treatment: Simulate braze at 1675 F (913 C) for 20 minutes, cool to 1000 F (538 C) within 40-45 minutes, cool to room temperature, cool to -100 F (-73 C) and hold for 8 hours, harden at 900 F (482 C) for 24 hours, cool to room temperature.

**FABRICATION OF ARMCO
17-7 PH AND PH 15-7 Mo
STAINLESS STEELS**

Cutting

Cutting operations such as blanking, punching, perforating, shearing, sawing, abrasive wheel cutting, and torch cutting are generally performed on Armco 17-7 PH and PH 15-7 Mo stainless steels in Condition A. The procedures commonly used for other chromium-nickel stainless steels also apply in fabricating 17-7 PH and PH 15-7 Mo stainless steels.

Dimensional changes resulting from heat treatment should be anticipated and allowance made in laying out dimensions of parts on Condition A sheets. (See dilatometer curves in Physical Properties Section.)

BLANKING AND PUNCHING

High grade tool steel dies are required. Dies must be kept sharp and more rigidly backed up than those used for mild steel.

Armco 17-7 PH and PH 15-7 Mo stainless steels are stronger than mild steel and increased power and slower speeds are necessary.

Closer punch and die clearance than used for mild steel is required. For example, 20 gage sheet (.037" [9.39 mm]) and thinner requires punch clearance equal to 1/20th of material thickness. For 19 gage (.043" [1.092 mm]) sheet and thicker, a maximum punch clearance of approximately .002" (.051 mm) to .003" (.076 mm) may be used.

Accurate punch and die adjustment is necessary, otherwise metal will tend to draw and work harden, causing strain on tools and blanking presses.

PERFORATING

The same general procedures as outlined for blanking and punching apply to perforating 17-7 PH and PH 15-7 Mo stainless steels.

Hole diameter generally should not be less than twice sheet thickness.

The use of a thin stainless drawing compound or cutting oil is helpful in perforating, especially when the work is done with wire size punches.

SHEARING

Because 17-7 PH and PH 15-7 Mo have higher strength, they require about twice the power needed for shearing mild steel of the same thickness. Therefore, the capacity of a shear will be only 50 to 70 percent of its capacity for mild steel.

High speed steel blades are recommended. And clearance for light gage sheet should be 0.001" to 0.0015" (0.0254 to 0.0381 mm), for heavier gage sheet 0.0015" to 0.002" (0.0381 to 0.0508 mm).

SAWING

For hand sawing use high speed hacksaw blades with tooth count per inch suitable for thickness of section to be cut. In cutting light gage sheets, blades with at least 32 teeth per inch (1.26 teeth/mm) are recommended.

Power band sawing and high-speed friction cutting can be used to cut 17-7 PH and PH 15-7 Mo using the same practices recommended for Type 302.

TORCH CUTTING

The flux-injection oxyacetylene torch cutting method, commonly used for cutting stainless steel, can be used. However, torch cutting sections greater than 2-1/2" (63.5 mm) thick is limited.

ABRASIVE WHEEL CUTTING

Use the procedures normally employed for Type 302.

DIMPLING

Armco 17-7 PH and PH 15-7 Mo stainless steels can be dimpled easily in Condition A. However, the dimensional change which occurs during heat treatment creates some difficulty in aligning holes. For this reason, it is necessary to dimple material in the transformed or fully hardened condition.

In Condition TH 1050 or RH 950 it is difficult to dimple with conventional ram-type equipment. However, tests indicate that good results can be obtained by a method based on high frequency impact plus spinning.* Dimpling by this method is done without the addition of heat. Results can be changed by varying the number and length of strokes, stroke pressure, hold-down pressure, length of time, and hammer pressure.

Armco 17-7 PH in Conditions TH 1050 and RH 950 has been dimpled successfully by this method in thicknesses from 0.020" to 0.120" (0.508 to 3.048 mm).

PIERCING

Piercing has been done successfully on 17-7 PH in Condition RH 950. Holes 3/16" (4.76 mm) in diameter have been pierced in .031" (7.87 mm) material with piercing equipment similar to that described above for dimpling (different dies were used). Examination of the area around pierced holes indicates no cracking occurs and that very little stress is placed in the metal during the piercing operation.

* Developed by the Lemert Engineering Co., Plymouth, Indiana

Drawing and Forming

Armco 17-7 PH and PH 15-7 Mo in Condition A have forming and drawing characteristics similar to the austenitic stainless steels such as Type 301. However, consideration of the mechanical properties of these alloys will be helpful in tool design and fabrication.

Elongation in Condition A is approximately 35% (% in 2" [50.8 mm]) as compared to 55% for annealed Type 301.

In drawing and severe forming operations, considerable work hardening will occur in localized areas. This causes a non-uniform condition that may not be completely eliminated during heat treatment but is not usually objectionable. However, if complete uniformity is required in critical parts that have been severely cold worked, annealing after fabrication and before heat treatment is recommended.

If parts are to be fabricated in Condition A and subsequently hardened by heat treatment, allowance should be made for the dimensional change that occurs in heat treating. An expansion occurs during the transformation treatment and a slight contraction during the hardening treatment. Refer to Physical Metallurgy Section for data on these dimensional changes.

There is an important fabrication advantage obtained with the RH 950 Condition. In the TH 1050 treatment, the structure is martensitic at room temperature following austenite conditioning at 1400 F (760 C). In this condition (T), it has limited ductility and has experienced dimensional growth. In the RH 950 treatment, however, cooling to room temperature from 1750 F (954 C) normally retains ductile austenite. Therefore, restriking can be done at room temperature after austenite conditioning and prior to transformation. Restriking eliminates distortion that may occur during austenite conditioning and may be done in the forming dies.

Another advantage of the RH 950 treatment is that its 1750 F (954 C) conditioning treatment relieves stresses induced during forming better than 1400 F (760 C) temperature used in TH 1050.

BRAKE FORMING

Brake forming equipment used for annealed austenitic stainless steels has adequate capacity for 17-7 PH and PH 15-7 Mo in Condition A. Material in Condition A, in free bending, will bend 180 degrees over one times the sheet thickness. In V-Block bending, material .187" (4.75 mm) and thinner in Condition A may be bent 135 degrees over one times the material thickness. For thicknesses over .187" (4.75 mm), it can be bent 135 degrees over three times material thickness.

Material in the transformed or fully hardened condition, requires liberal minimum bend radii. For this reason, it is highly desirable to form material in Condition A whenever possible.

Springback in Condition A is comparable to that encountered with annealed Type 301.

STRETCH FORMING

Stretch formed parts are regularly produced on standard equipment. Parts are usually formed in Condition A, but where only moderate forming is involved, they have been formed in the transformed condition. However, common practice is to form initially in Condition A and straighten by re-stretching in the transformed or fully hardened condition.

The shape of the part usually determines whether size compensation made in forming tools is adequate, or whether re-stretching operations are needed to control material growth during heat treatment. In some cases, a combination of both may be required. It is sometimes helpful to stretch almost to final size, anneal, and then re-stretch to final size before transforming and hardening.

Typical parts made by stretch forming are as follows:

PART	FORMED IN CONDITION	THICKNESS OF MATERIAL, in. (mm)
Contoured Zee Section	A	.025-.063 (0.635-1.600)
Zees	A	.008-.040 (0.203-0.041)
Rocket Venturi	A	.043 (1.092)
Frames	A & T	.020-.062 (0.051-1.575)
Channels	A & T	.020-.125 (0.051-3.175)
Angles	A & T	.008-.125 (0.203-3.175)
Skins	A & T	.020-.125 (0.051-3.175)
Hats	A & T	.020-.125 (0.051-3.175)
Zees	A & T	.020-.125 (0.051-3.175)
Channels	A, T & TH 1050	.020-.090 (0.051-2.286)
Ring Segments	A, T & TH 1050	.020-.090 (0.051-2.286)
Angles	A, T & TH 1050	.020 (0.051)

DRAWING

Many useful shapes can be developed in Armco 17-7 PH using single-operation draws. Although material in Condition A will not withstand as severe single operation draws as are possible with standard austenitic stainless steels, intermediate annealing can be used for difficult shapes. Multiple draws without intermediate annealing are possible only when the work done in each stage is not too extensive.

The design of dies and selection of die material, equipment, speeds and lubricants follow normal practice with annealed Type 301. Use of Ampco No. 22 draw rings and high film strength lubricants contribute to successful drawing operations.

A slight distortion which may occur during heat treatment can be compensated for in the forming tools or by re-striking. The latter can be done with best results when material is in Conditions T, A 1750 or R-100.

HYDROFORMING AND MARFORMING

Hydroforming and Marforming operations can readily be performed on 17-7 PH and PH 15-7 Mo in Condition A. Typical parts reported by aircraft manufacturers are as follows:

PART	THICKNESS OF MATERIAL, in. (mm)	TYPE OF OPERATION
Formers	.051 (1.295)	Hydroform ⁽¹⁾
Cups	.032-.063 (0.813-1.600)	Hydroform
Flanges	.032 (0.813)	Hydroform
Angles	.032 (0.813)	Hydroform
Domes	.032 (0.813)	Hydroform
Hat Section	.032 (0.813)	Marform ⁽²⁾
Frames	.032 (0.813)	Marform
Zee Stiffeners	.032 (0.813)	Marform
Duct Halves	.032 (0.813)	Marform
Cup Shape	.020-.050 (0.508-1.27)	Marform
Box Shape	.020-.050 (0.508-1.27)	Marform

Dimensional expansion in heat treatment is ordinarily compensated for by making allowances in forming tools.

⁽¹⁾Trade name for process developed by the Cincinnati Milling Machine Co.

⁽²⁾Trade name for process developed by the Glenn L. Martin Co.

GUERIN PROCESS

The Guerin process has been used quite successfully to form 17-7 PH in Condition A, and some firms have reported success in using the process on moderately formed parts in Conditions T and TH 1050. Following are typical parts that have been formed by the Guerin process:

PART	CONDITION	THICKNESS OF MATERIAL, in. (mm)
Zee Sections	A	.005-.094 (0.127-2.388)
Bulkheads	A	.020-.040 (0.508-1.016)
Formers	A	.032-.051 (0.813-1.295)
Frames	A	.020-.094 (0.508-2.388)
Beaded Panels	A	.025 (0.635)
Flanged Parts	A	.062 (1.575)
Webs	A	.020-.094 (0.508-2.388)
Tail Ribs	A	.032 (0.813)
Angles	A & T	.008-.060 (0.203-1.524)
Channels	A, T & TH 1050	.020-.090 (0.508-2.286)
Gussets	A, TH 1050	.020-.090 (0.508-2.286)
Clips	A, TH 1050	.020-.090 (0.508-2.286)

Most forming is done while material is in Condition A and then heat treated. When close tolerances are required, parts may be re-sized by re-striking or hand-benching in the transformed or fully hardened conditions.

SPINNING

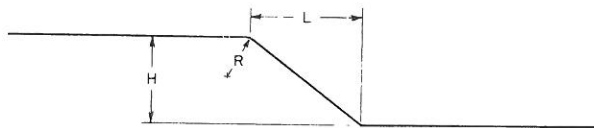
Spinning 17-7 PH and PH 15-7 Mo in Condition A is similar to spinning Type 301. However, more frequent annealing may be required when spinning difficult shapes.

Because of their high elevated-temperature properties, 17-7 PH and PH 15-7 Mo are especially suitable as a material for cold-spun missile casings. The strength developed during cold working is principally dependent upon the amount of cold work and the temperature at which it is done.

The data on pages 101 and 102 shows the effect of various amounts of cold work at several cold working temperatures on the mechanical properties of PH 15-7 Mo and 17-7 PH in various conditions.

JOGGLING

Jogging operations have been made successfully on 17-7 PH in a wide range of thicknesses. Typical joggles made by aircraft companies are as follows:



CONDITION	JOGGLE DIMENSIONS in. (mm)			THICKNESS OF MATERIAL, in. (mm)
	H	R	L	
A	.25 (6.35)	.06 (1.52)	.25 (6.35)	.08 max (2.03)
A	.281 (7.14)	.036 (0.91)	1.124 (28.55)	.018 min (0.46)
A	.281 (7.14)	.250 (6.35)	1.124 (28.55)	.125 max (3.18)
A	.09 (2.29)	.06 (1.52)	.375 (9.52)	.020 max (0.51)
A	.25 (6.35)	.125 (3.18)	.50 (12.70)	.125 max (3.18)
A	.07 (1.78)	.125 (3.18)	.250 (6.35)	.051 min (1.29)
A	.125 (3.18)	.093 (2.36)	.875 (22.22)	.032 min (0.81)
A	.125 (3.18)	.125 (3.18)	.343 (8.71)	.016 min (0.41)
A	.375 (9.52)	.125 (3.18)	1.062 (26.97)	.062 max (1.57)
A016-.063 (0.41-1.60)
T	.09 (2.29)	.09 (2.29)	.540 (13.72)	.020 min (0.51)
T	.125 (3.18)	.25 (6.35)	.75 (19.05)	.125 max (3.18)
T	.125 (3.18)	.187 (4.75)	.875 (22.22)	.062 min (1.57)
TH 1050	.120 (3.05)	.09 (2.29)	.30 (7.62)	.06 max (1.52)

*L = 6H (for sheet metal and formed sections)

L = 6H to 10H (for shallow joggles in high sections)

Machining

This section contains data only on drilling, reaming, tapping, and milling, the operations usually performed on flat-rolled material.

Armco 17-7 PH and PH 15-7 Mo in Condition A have better machining characteristics than annealed Type 302 even though cutting rates are about the same. Type 302 produces long stringy chips but 17-7 PH and PH 15-7 Mo produce chips that break up.

Material in Conditions T, A 1750 and R-100 may be machined in about the same manner as Condition A. Conditions TH 1050 and RH 950 have chip characteristics similar to Condition A, but because they are considerably harder, lower cutting speeds must be used.

If machining is done on material in Condition A, allowance must be made for the dimensional changes that occur in heat treatment. Also, oxidation during the 1400 or 1750 F (760 or 954 C) transformation treatments will impair surface finish and close tolerances.

For these reasons, material is usually machined in Conditions T or R-100. The final hardening treatment will then cause only a slight contraction which can be compensated for in close tolerance work or ignored if tolerances are greater than 0.0005" (0.127 mm) per inch. Furthermore, the light discoloration that occurs during final hardening will not appreciably affect surface finish or tolerances.

In all types of machining operations, definite cuts should be made and tools should not be allowed to "ride." This is necessary to prevent work-hardening, especially when machining material in the annealed condition.

Suggested practices for drilling, milling, reaming, and tapping are essentially the same as for Type 302, with emphasis on the factors mentioned.

DRILLING

High speed steel drills are preferred. Carbide tipped drills are often advantageous but close control is necessary.

Webs should be thinned as much as possible without causing excessive breakage.

Drills should be as short as possible to provide best rigidity.

Included tip angle of 130 degrees gives better results than standard 118-degree angle.

For relatively large holes in light gage material, a fly-cutter grind with a pilot in the center is recommended. Best adapted for drills 1/4" to 1" (6.35 to 25.4 mm), this type grind is of limited use on smaller drills because of difficulty in grinding the center pilot. Although tool life is not as good, this grind produces much cleaner holes.

Sulfur-base oil is recommended as a lubricant, but it must be completely removed before heat treating.

When drilling sheets under 1/16" (1.588 mm) thickness, back-up sheets of cast iron or plain steel should be used. These allow the drill to cut all the way through the material, prevent burring on the underside and possible drill breakage.

Typical feeds and speeds using high speed steel drills are as follows:

	Conditions	
	A, A 1750, R 100, T	TH 1050, RH 950 C, CH 900
Speed (sfm)*	40-60	20-50
Feed (ipr) under 1/8" (3.175 mm) dia.	.002 & under	.002 & under
over 1/8" (3.175 mm) dia.	up to .007	up to .007

*Speeds may be increased by using carbide drills.

REAMING

High speed steel, spiral fluted reamers with a 30-degree lead or chamfer are preferred. Carbide tipped reamers are excellent for high speeds and best finish.

Parts being reamed should be flooded with sulfurized oil. Water soluble oils are recommended for carbide tipped reamers operating at high speeds.

Typical feeds, speeds and depths of cuts for material which has not been precipitation-hardened are as follows:

Speed (sfm) for sizing	40-80
for finishing	15-40
using carbides)	100-300
Depth of cut	.003-.010" (0.076-0.254 mm)
Feed (ipr)	.003-.0075" (0.076-0.190 mm)

TAPPING

Avoid tapping over 75% thread if possible. A 50% thread is much easier to tap and in many cases, will hold satisfactorily.

A 15-degree hook grind is recommended for taps.

For all through holes, a two-flute tap or gun, or chip-driver tap is recommended.

For large sizes (over 1" [25.4 mm] dia.) collapsible type taps with a 15-20 degree lip hook are preferred.

When shortening a tap for bottom tapping, do not destroy the taper lead.

Typical tapping speeds range from 10 to 30 sfm.

On close tolerance work where class III fit must be held, the following rules should be followed:

1. Use the proper style tap to provide adequate chip clearance: Up to size #6, a two-flute tap; from #6 to 1/2" (12.7 mm), a three-flute tap; and over 1/2" (12.7 mm), a four-flute tap.
2. Drill the tap hole accurately and ream to size. Variation of size in drill holes can cause variation

in the tapped size.

3. Check lead error as well as pitch diameter. Lead error can be caused by improper grade taps (use precision ground taps) or by improper tapping equipment. Precision tapping requires well-designed and balanced equipment; oversize equipment causes lag and drag in the spindle.

MILLING

High speed steels are ordinarily used for milling on standard equipment. However, with modern heavy duty equipment, carbide tools can be used at considerably increased cutting rates.

With high speed steel tools, helical type slab milling cutters are preferred using slow speeds and heavy feeds.

With carbide tooling on modern equipment, step milling and end milling are highly desirable. Feeds should be a minimum of .005" (.127 mm) per tooth and both feed and depth of cut are limited only by available horsepower and chip removal facilities.

Speeds for material which has not been precipitation-hardened should be about 40-60 sfm using high-speed steel tools but may be 100 sfm and higher with carbide tools.

Chemical Milling

Air Force report⁽¹⁾ states that several companies have successfully chem-milled production lots of 17-7 PH and PH 15-7 Mo. No significant problems have been reported and "shearing strength data obtained for 17-7 PH steel in the TH 1075 condition indicated that chemical milling has no significant effect on these properties." Among the 17-7 PH parts described in the report were skin sheets for honeycomb sandwich panels, spun heads, and flat sheet and plate.

As much as 80% of sheet thickness has been removed in production chem-milling of PH 15-7 Mo. Sheets milled down to 0.008" (.203 mm) thickness can be consistently held to ± 0.001 " (.025 mm) thickness tolerances.

⁽¹⁾ Wright Aeronautical Serial Report No. MP .00-178, "Machining Characteristics of High Strength Thermal Resistant Materials, Phase II, Survey of Chemical Milling, Supplement to Interim Engineering Report No. 4," Submitted in Partial Fulfillment of Contract AF 33(600)-35967, Item IV.

Grinding

The Bonded Abrasives Division of the Carborundum Company has conducted grinding tests on PH 15-7 Mo. Their findings are as follows:

1. Armco PH 15-7 Mo appears to offer no major problem in grinding.
2. Conventional grinding wheels at conventional speeds and feeds appear satisfactory.
3. Material in Conditions TH 1050 and RH 950 is easier to grind than annealed (Condition A) material.
4. General starting recommendations are as follows. However, these are general recommendations and would be altered to suit specific operations.

Wheel and Operation	Surface Grinding	Cylindrical Grinding
Grain Grit Grade Bond	Aluminum Oxide 46-60 H-J Vitrified DA60—H9—V20	Aluminum Oxide 46-60 J-K Vitrified DA465—K6—V11
Wheel Speed, sfm Work Speed, sfm Table Speed	5500-6500 — 35-60 FPM	5500-6500 70-90 1/8—1/4 width of wheel per work RPM
Cross Feed	.010-.030" (.254-.762 mm)	—
Grinding Fluid Infeed per Pass	Water Soluble Fluid .002-.005" (.051-.127 mm)	Water Soluble Fluid .001-.002" (.025-.050 mm)

Grinding characteristics of 17-7 PH are comparable to those of PH 15-7 Mo.

Cleaning

BEFORE WELDING OR BRAZING

If dirt or grease is present on surfaces to be welded or brazed, it should be removed to prevent unsound or weak joints. Solvents such as turpentine, naphtha, alcohol or nonleaded gasoline are used for this type of cleaning. Ordinary soap and water or mild abrasive cleaners such as Ajax or Bon Ami can also be used. In addition one part Oakite #33 mixed with two parts water may be used.

Grease or oil alone can be removed by vapor degreasers such as perchlorethylene or trichlorethylene. If dirt also is present, use some sort of mechanical cleaning such as scrubbing with a mild abrasive and water, or with one part Oakite #33 to two parts water. Parts should be thoroughly rinsed with warm water and dried.

Blasting methods also have been used successfully.

After Brazing

If a brazing flux is used it should be removed thoroughly after brazing. This normally can be done by flushing parts thoroughly with water. If flux is not

thoroughly removed, severe corrosion or perforations can result.

Before Heat Treating or Annealing

As with other stainless steels, thorough cleaning of parts or assemblies prior to annealing or heat treatment facilitates scale removal. The removal of oils and drawing lubricants also insures that the steel will not be carburized from this source. *Carburized parts do not develop high strength properties.*

Recommended cleaning procedure is:

1. Vapor degrease or solvent clean. This step will remove oil, grease and drawing lubricants.
2. Mechanically scrub with mild abrasive cleaners, Oakite #33 or similar proprietary cleaners. This is necessary for the removal of dirt or other insoluble materials. All traces of cleaners should be removed by thoroughly rinsing with warm water.

Blasting Methods

Aircraft companies have successfully cleaned Armco 17-7 PH stainless by wet and dry blasting methods. Blasting is used to clean before welding or brazing and helps remove scale after heat treating.

After blasting, any grit left on parts should be removed by scrubbing thoroughly.

Successful methods that have been reported are as follows:

Wet or Dry	Grit Size	Grit Material	Nozzle Size in.	Air Pressure* psi	Nozzle Angle Degrees	Cleaning Speed sq. in.-min.
Dry	#36	—	3/8	40-60	70-90	20
Dry	—	Silica Sand	—	100	—	—
Wet	#220	Jiffy Blast	1/4	25-95	45-60	6-10
Dry	#30	Blastite (Al ₂ O ₃)	1/4	25-95	45-60	12-20
Wet	—	—	—	35-90	—	10-20
Dry	#36	Garnet or Al ₂ O ₃	3/8	35	60	60

* Depends on metal thickness.

Heat Treatment

While selection of heat treating equipment depends to some extent upon the nature of the particular parts to be treated, the heat source, atmosphere, and control of temperature are the primary considerations.

Furnaces fired with *oil* or *natural gas* are not entirely satisfactory for the heat treatment of stainless steels. In such units, it is difficult to control combustion

and eliminate flame impingement on the parts being treated. Electric furnaces or gas fired radiant tube furnaces are generally used for heat treating precipitation-hardening stainless steels.

Air has proven to be a satisfactory furnace atmosphere for heat treating and annealing operations. Controlled reducing atmospheres such as *dissociated ammonia* or *bright annealing gas* introduce the hazard of *nitriding* and *carburizing* or *decarburizing*. Bright annealing may be done in hydrogen, argon or helium atmosphere (dew point approximately -65 F [-54 C]), if a cooling rate approximately that obtained in air cooling can be used. *Dry hydrogen, argon or helium* (dew point approximately -75 F [-59 C]) may be used for the 1750 F (954 C) heat treatment outlined for Condition RH 950 and will provide essentially a scale-free surface. At the heat treating temperatures of 1400 F (760 C) and lower, scale-free heat treatment in dry hydrogen, argon or helium atmosphere is difficult to achieve. For complete freedom from scale or heat discoloration, at lower temperatures, a vacuum furnace is required.

Cooling rate from the annealing temperature to 1000 F (538 C) is important because slow cooling rates can lower the ductility of as-annealed material. This is especially important where intermediate annealing is performed prior to additional cold-working operations. Therefore, *parts should be cooled rapidly (air) from 1950 to 1000 F (1066 to 538 C).* Cooling rate below 1000 F (538 C) is not critical.

When performing the RH heat treatment, it is necessary to cool from 1750 F (954 C) to -100 F (-73 C) within 1 hr and hold for a period of 8 hours. While commercial equipment is available for refrigeration at this temperature, a bath with an excess of dry ice (solid CO₂) in alcohol or acetone maintains a temperature of -100 to -109 F (-73 to -78 C) without control equipment.

Solution annealing (1950 F [1066 C]) or austenite conditioning (1750 or 1400 F [954 or 760 C]) in molten salts is not recommended because of the danger of carburization and/or intergranular penetration. However, hardening heat treatments (900 to 1200 F [482 to 649 C]) have been successfully accomplished in a few salts of the hydride or nitrate types. (See Scale Removal Footnote No. 5.) Investigation on salt bath furnaces is continuing.

Scale Conditioning and Removal

Scale develops during most heat treating operations. The amount and nature vary with the cleanliness of the parts, the furnace atmosphere, and the

temperature and time of heat treatment. A variety of descaling methods may be employed, but wet grit blasting is generally preferred over acid pickling.

NITRIC—HYDROFLUORIC ACID PICKLE

Some degree of intergranular penetration generally occurs during any pickling operation. However, in Conditions A and CH 900, the penetration resulting from pickling is usually slight. Other conditions of heat treatment are more susceptible to intergranular penetration during pickling (10% nitric acid plus 2% hydrofluoric acid). For this reason, pickling methods should be very carefully controlled if they are used for scale removal. For removal of light discoloration or heat tint produced by a final hardening treatment at 900-1200 F (482-649 C), the standard 10% nitric plus 2% hydrofluoric acid bath may be used with care.

DIVERSEY DS-9 BRIGHT DIP

Tests by Armco Research Center indicate that the Diversey DS-9 Bright Dip Process⁽¹⁾ will remove heat treatment scale from Armco 17-7 PH and PH 15-7 Mo without causing intergranular corrosion attack. The following summary of results shows how the Diversey Process compares with vapor blasting and standard pickling in 10% nitric — 2% hydrofluoric acid.

⁽¹⁾ Patent Pending, The Diversey Corp., 1820 Roscoe Street, Chicago 13, Illinois.

Summary of Test Results

1. Diversey DS-9 Bright Dip Process satisfactorily removed scale from heat treated PH steels without producing intergranular attack. The treatment resulted in a smooth dense surface on both 17-7 PH and PH 15-7 Mo in the conditions tested. Short pickling times (for scale removal) tended to produce a somewhat rough surface, but no intergranular attack was observed. Longer treatments produced smooth surfaces. However, this caused higher weight losses and attendant reduction in thickness. Pickling RH 950 treated samples in Diversey DS-9 produced larger losses than on TH 1050 samples. Further, PH 15-7 Mo suffered slightly greater attack than 17-7 PH.
2. It is our opinion that the Diversey DS-9 process can be used on PH stainless steels if the user is cognizant of the metal loss involved. It is our understanding that the Diversey Company is presently developing a scale softening treatment to reduce the pickling time in the DS-9 solution. If this is accomplished, the utility of the treatment will be materially broadened. At present, however, its use will probably be limited to the thicker gages. It should also be noted that an alkaline pre-

clean was absolutely necessary. Whether this is associated only with surface wettability, or whether it had some other effect on the scale was not determined. It should be used, however, as an integral part of the pickling procedure.

OTHER SCALE REMOVAL METHODS

Heat Treatment	Preferred Methods	Secondary Methods
Solution Treatment (Anneal)	Wet grit blast (1)	Scale Condition and pickle (3)
Austenite Condition 1400 F-1700 F (760-927 C)	Wet grit blast (1)	1. Pickle (2) 2. Scale condition and pickle (4) or (5)
Precipitation— Harden 900 F- 1100 F (482-593 C)	Wet grit blast (1)	1. Pickle (2) 2. Scale condition and pickle (3)

1. Wet grit blasting processes are widely used and have been found to be highly satisfactory. These methods eliminate the hazard of intergranular attack from acid pickling. There also are advantages in better fatigue strength and corrosion resistance.
2. 10% HNO₃ + 2% HF at 110-140 F (43-60 C) for 3 minutes maximum. Removal of loosened scale may be facilitated by the use of high pressure water or steam spray. A scale conditioning treatment is not necessary for parts which have been thoroughly cleaned. Uniform pickling of the entire surface is evidence of a well cleaned part. A spotty scale and non-uniform removal is evidence of a poorly cleaned part and a scale conditioning process is a necessity prior to pickling.
3. See Section on Scale Conditioners.
4. Caustic permanganate scale conditioning followed by HNO₃ — HF pickle should be used only for Conditions T, R-100, or fully heat treated steel. Do not use fused salts. The use of fused salts as scale conditioners on 17-7 PH and PH 15-7 Mo in Condition A 1750 will prevent the steel from developing maximum transformation upon subsequent refrigeration.
5. Scale condition and pickle as in #4 above. Because the Virgo and Kolene fused salt baths may be operated at temperatures up to 1100 F (593 C), hardening and scale conditioning treatments may be combined if desired. However, the operation of a salt bath at such temperatures should be checked with the manufacturer before proceeding.

SCALE CONDITIONERS

A number of scale conditioning plus acid pickling methods have been devised to soften and remove heat treating scale from 17-7 PH and PH 15-7 Mo. Details on these methods are as follows:

1. du Pont Sodium Hydride*
 - a. Immerse parts in sodium hydride bath at 700 F (371 C) for 15 minutes.
 - b. Rinse with water.
 - c. Immerse in 10% nitric + 2% hydrofluoric acid at 110-140 F (43-60 C) for 2-3 minutes.
 - d. Rinse with hot water or steam scrub.
2. Hooker-Virgo Process†
 - a. Immerse parts in Virgo bath at 900 F (482 C) for 5 minutes.††
 - b. Rinse with water.
 - c. Immerse in 10% nitric + 2% hydrofluoric acid at 110-140 F (43-60 C) for 2-3 minutes.
 - d. Rinse with hot water or steam scrub.
3. Kolene Solution No. 1**
 - a. Immerse parts in Kolene Solution No. 1 at 800 F (427 C) for 5 minutes.††
 - b. Rinse with water.
 - c. Immerse in 15% phosphoric acid with additives at 140 F (60 C) for 10 minutes.
 - d. Rinse with water.
 - e. Immerse in alkaline permanganate at 190 F (88 C) for 5 minutes.
 - f. Immerse for 10 seconds in same acid as step c.
 - g. Rinse with water.
4. Kolene Solution No. 4**

Same steps as shown in method No. 3 except use times of one minute in (e) and one minute in (f).
5. Caustic Permanganate Method
 - a. Immerse parts in boiling 10% caustic permanganate (10% sodium hydroxide + 3% potassium permanganate) for one hour.
 - b. Rinse with hot water.
 - c. Repeat c in No. 1.
 - d. Repeat d in No. 1.

*Process patented by E. I. du Pont de Nemours & Co., Inc.

† Process patented by Hooker Electrochemical Co.

**Process patented by Kolene Corporation

†† The Hooker Electrochemical Company and the Kolene Corporation state that operating characteristics of their baths are also suitable for operation at 950 or 1050 F (510 or 566 C). This means scale on Condition T or R 100 material can be softened and at the same time, the steel hardened by heat treatment to Condition RH 950 or TH 1050. Time may be adjusted as required to obtain desired properties.

Brazing

Armco 17-7 PH and PH 15-7 Mo can be brazed by either high or low temperature brazing methods. However, brazing temperatures higher than 1975 F

(1079 C) may affect final properties. Data on this effect are presented in the section on Mechanical Properties section — Variation in Annealing Temperature.

Both steels are usually brazed in Condition A, then transformed and aged. However, variations in brazing cycle and heat treating sequence are possible and discussed on pages 109 to 112.

Care should be taken to see that parts are not under tension while the brazing alloy is liquid. This can cause cracking due to intergranular penetration of the brazing alloy.

To obtain the best results, parts should be thoroughly cleaned both before and after brazing.

BRAZING ALLOYS

Selection of brazing alloy depends upon thickness of material, end use of parts being brazed, amount of jiggling required, configuration of parts and method of brazing employed. The following brazing alloys are typical of those being used:

TYPICAL BRAZING ALLOY COMPOSITIONS

Alloy	Ag %	Mn %	Cu %	Other
1	85	15	—	—
2	85	15	—	+ Li
3	95	—	5	+ Li
4	90	—	10	+ Li
5	72	—	28	—
6	72	—	28	+ Li
7	50	—	15.5	15.5 Zn, .16 Cd, 3 Ni

Alloys 1 to 6 have melting temperatures ranging from 1400-1850 F (760-1010 C) and are ordinarily used for high temperature brazing operations. No. 7 is a low temperature alloy that has a flow point of 1270 F (688 C). The lithium addition serves as a flux, deoxidizing surfaces to be brazed. It also lowers the melting point of the brazing alloy.

When furnace-brazed in inert or dry hydrogen atmospheres, alloys Nos. 1, 4 and 6 can be used for bright brazing operation (without flux). Nos. 5 and 7 should always be used with a flux.

Other brazing alloys, such as copper, nickel-base alloys and alloys containing silicon or boron, have a high penetration rate which can cause brittleness. Therefore, brazing alloys of this type should be used with caution, especially with thin sections.

TORCH BRAZING

In torch brazing operations, a flux is always needed. Because most fluxes are highly corrosive, brazing time should be kept to a minimum to prevent over-etching and corrosive attack. This is a disadvantage

of torch brazing that becomes critical when brazing thin sheets.

If 17-7 PH and PH 15-7 Mo are to be heat treated to Condition TH 1050, or RH 950, torch brazing requires a high temperature brazing alloy. The melting point of the alloy must be high enough so that joints will hold together when parts are later transformed at 1400 or 1750 F (760 or 954 C).

FURNACE BRAZING

Fluxes are necessary when furnace brazing in an air atmosphere. However, by using a controlled atmosphere, bright brazing can be done without a flux.

Bright brazing requires an air-tight metal chamber. This can be a retort in a furnace or a box of welded construction inserted into a conventional furnace.

An inert gas, such as argon or helium, is preferred for bright brazing. However, dry hydrogen can be used with special precautions. When using dry hydrogen (or air), *no carbonaceous material should be present within the retort or furnace.* When these atmospheres are in contact with materials containing carbon, carbonaceous gases will be formed that will carburize stainless steel. *Carburization decreases the strength developed by later hardening treatments.*

Even when using helium or argon, care should be taken to prevent contact between parts being brazed and carbonaceous materials. To prevent this, thin slip sheets of stainless steel can be used. These should be a minimum of .005" (0.127 mm) thick and then should be discarded after each use. *Dissociated ammonia should never be used.* It will cause nitriding, which impairs mechanical properties. Some effects of carburization and nitriding on 17-7 PH are shown below:

EFFECT OF CARBURIZATION ON HARDNESS

C %	Hardness in Heat Treated Condition Rockwell
.062	C45
.085	C39
.096	C31
.13	B93

EFFECT OF NITRIDING ON MECHANICAL PROPERTIES

Acid Soluble Nitrogen, %	Thickness of Sample in (mm)	Properties in Heat Treated Condition		
		Tensile Strength ksi (MPa)	0.2% Yield Strength ksi (MPa)	Elong. % in 2" (50.8 mm)
.013	.020 (0.508)	190.6 (1314)	177.8 (1226)	7
.035	.0053 (0.135)	192.0 (1324)	180.3 (1243)	7
.062	.003 (0.076)	191.8 (1323)	182.6 (1259)	3
.077	.0025 (0.064)	174.6 (1214)	168.6 (1162)	2

When bright brazing in a furnace with controlled atmosphere at temperatures of 1850-1975 F (1010-1079 C), the dew point should be maintained at -65 F

(-54 C) or lower. Lower brazing temperatures require corresponding lower dew points. At temperatures below 1650 F (899 C) experience indicates it is difficult to achieve good brazed joints without a brazing alloy containing lithium.

BRAZING CYCLES

Tests have been made in the Armco Research Center simulating various furnace and torch brazing cycles. The results for 17-7 PH are given in the following table:

SIMULATED BRAZING CYCLES FOR 17-7 PH

Heat Treatment*	0.2% Yield Strength ksi (MPa)	Tensile Strength ksi (MPa)	Elongation % in 2" (50.8 mm)	Hardness Rockwell C
1	181 (1248)	190 (1310)	9	42.5
2	172 (1186)	190 (1310)	9	42
3	146 (1007)	172 (1186)	12	39.5
4	141 (972)	174 (1200)	4	43
5	144 (993)	179 (1234)	4	43

*Heat Treatments

- 1300 F (704 C) for 30 min. (brazing and transformation treatment); air cooled for 30 min. and cooled in 60 F (16 C) water for 30 min.; hardened at 1050 F (566 C) for 90 min.
- 1400 F (760 C) for 30 min. (brazing and transformation treatment); air cooled for 30 min. and cooled in 60 F (16 C) water for 30 min.; hardened at 1050 F (566 C) for 90 min.
- 1400 F (760 C) for 30 min.; air cooled for 30 min. and cooled in 60 F (16 C) water for 30 min.; 1400 F (760 C) for 10 min. (brazing operation); air cooled for 30 min. and cooled in 60 F (16 C) water for 30 min.; hardened at 1050 F (566 C) for 90 min.
- 1400 F (760 C) for 30 min.; air cooled for 30 min. and cooled in 60 F (16 C) water for 30 min.; torch brazed; air cooled for 30 min.; hardened at 1050 F (566 C) for 90 min.
- 1400 F (760 C) for 30 min.; air cooled for 30 min. and cooled in 60 F (16 C) water for 30 min.; torch brazed; air cooled for 30 min. and cooled in 60 F (16 C) water for 30 min.; hardened at 1050 F (566 C) for 30 min.

Reheating transformed material for brazing, as in heat treatments 3, 4 and 5, above, results in substantial loss of strength after final heat treatment. This is caused by a stress relieving and softening of the martensite upon reheating to 1400 F (760 C), so that full strength cannot be developed by the final hardening treatment. Therefore, torch brazing or furnace brazing after transformation treatment is not recommended.

VARIATIONS IN BRAZING AND HEAT TREATING SEQUENCE—17-7 PH

With Armco 17-7 PH it is possible to combine the brazing and heat treating cycles and still develop mechanical properties similar to those of the standard heat treatments.

A satisfactory combination of brazing and heat treating cycle is outlined below:

1. Braze 1625-1750 F (885-954 C) for 10 minutes using a Ag-Cu-Li brazing alloy. (Example: 93% silver + 7% copper + lithium)

2. Cool to 1000 F (538 C) as rapidly as possible, preferably within 30 minutes.
3. Cool to -100 F (-73 C) and hold 8 hours.
4. Harden (select the hardening treatment most suitable for the specific application).

Brazing temperatures that differ from the recommended austenite conditioning temperatures (either 1400 F or 1750 F (760 or 954 C) depending on the heat treated condition desired), require modified heat treating procedures. These are necessary to obtain mechanical properties that will approach the properties of the standard TH 1050 and RH 950 heat treatments.

When shelving at 1400 F (760 C) is incorporated into a brazing cycle, cooling time from brazing temperature to 1000 F (538 C) has little effect on mechanical properties after hardening at 1050 F (566 C). This is shown by the test data on the following page.

The rate of cooling from brazing temperature to 1000 F (538 C) can affect ductility when using a heat treating cycle similar to RH 950 (simulated braze at approximately 1750 F [954 C], cool to -100 F [-73 C], harden at 950 F [510 C]). Data are shown and ductility determined by tensile elongation and bend tests. With very slow rates of cooling after brazing, it is possible that a condition similar to TH 950 could be realized. In Condition TH 950, 17-7 PH has shown lower corrosion resistance than in Condition TH 1050 or RH 950. This phenomenon is peculiar to 17-7 PH and does not hold true for PH 15-7 Mo. (See Brazing and Heat Treating Sequence for PH 15-7 Mo.)

**EFFECT OF COOLING TIMES FROM
1825 F (966 C) TO 1000 F (538 C)
ON MECHANICAL PROPERTIES OF HARDENED 17-7 PH ⁽¹⁾**

Cooling Time		0.2% YS psi (MPa)	UTS psi (MPa)	Elong. % in 2" (50.8 mm)	Min Radius to make 180° Bend
1825 F to 1400 F (966 C to 760 C)	1825 F ⁽²⁾ to 1000 F (966 C to 538 C)				
55 min	195 min	185,500 (1279)	193,200 (1332)	4.5	5.4 T
60 min	215 min	183,500 (1265)	192,600 (1326)	5.3	5.2 T
120 min	315 min	185,500 (1279)	194,000 (1338)	5.3	5.0 T

The above data represent average test values from two heats.

Specimen thickness was .050" and .0605" (1.27 and 1.65 mm).

(1) Heat Treating Cycle

1. Heat to 1825 F (966 C) — Hold 10 minutes
2. Cool to 1400 F (760 C) — Hold 90 minutes
3. Cool to RT
4. Cool to 0 F (-18 C) — Hold 16 hours
5. Heat to 1050 F (566 C) — Hold 90 minutes — AC.

(2) Cooling times include 90-minute shelving at 1400 F (760 C).

Data Reference: Armco Research Laboratory Data Book 1513, 2384.

BRAZED HONEYCOMB PANEL DATA — 17-7 PH

Mechanical properties of material used in commercial honeycomb production are shown below. Coupons for these tests were obtained from the extended ends of the various panels. The brazing cycle employed on these sheets follows:

1. Braze at 1650-1675 F (899-913 C) for 10 minutes.
2. Furnace cool to 1400 F (760 C) and hold 90 minutes.
3. Remove from furnace and cool to room temperature.
4. Transform at -20 F (-29 C).
5. Harden at 1050 ± 10 F (566 ± 6 C) for 90 minutes.

Minimum mechanical properties desired:

UTS — 180 ksi (1241 MPa)

0.2% YS — 150 ksi (1034 MPa)

Elong.: Thickness over .025" (0.635 mm) — 5.5%

Over 0.010" to 0.025" (0.254 to 0.635 mm)
incl. — 4.5%

0.005" to 0.010" (0.127 to 0.254 mm) incl.
— 3.5%

Thickness in. (mm)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elongation % in 2" (50.8 mm)
.005 (0.127)	196 (1351)	185 (1276)	4.3
.008 (0.203)	197 (1358)	185 (1276)	4.5
.011 (0.279)	192 (1324)	185 (1276)	4.6
.017 (0.432)	198 (1365)	190 (1310)	4.7
.050-.060 (1.27-1.52)	193 (1331)		7.7

* Determinations not made.

Data courtesy of Aeronca Manufacturing Corporation, Middletown, Ohio.

VARIATIONS IN BRAZING AND HEAT TREATING SEQUENCE — PH 15-7 Mo

Armco has investigated the effect on mechanical properties of PH 15-7 Mo when various cooling times from brazing temperature to 1000 F (538 C) are used in the RH heat treatment. Such variations may occur in brazing operations where the brazing cycle serves as the austenite conditioning treatment.

Slower cooling rates are encountered when making brazed honeycomb panels because of heavy jigs, graphite blocks, and sealed retorts. It is difficult to cool panels from brazing temperatures (1625-1750 F [885-954 C]) to 1000 F (538 C) in times less than 30 minutes. With large panels, this time may extend to one or several hours.

Test data show how mechanical properties of PH 15-7 Mo are decreased by slow cooling from simulated brazing temperatures.

EFFECT OF COOLING TIME FROM 1750 TO 1000 F (954 to 538 C) ON MECHANICAL PROPERTIES⁽¹⁾ OF HARDENED PH 15-7 Mo

Final Hardening Temperature F (C)	Property	Cooling Time—1750 to 1000 F (954 to 538 C), minutes					
		Air Cool ⁽²⁾	4	9	17	35	72
950 (510)	UTS, ksi (MPa)	245.7 (1694)	243.9 (1681)	239.1 (1649)	238.1 (1642)	231.7 (1646)	227.8 (1571)
950 (510)	0.2% YS, ksi (MPa)	224.7 (1549)	225.2 (1553)	221.1 (1525)	220.6 (1521)	210.9 (1454)	209.2 (1442)
950 (510)	Elong., % in 2" (50.8 mm)	4.7	4.4	4.2	4.0	4.3	5.3
950 (510)	Min Bend Radius ⁽³⁾	5.4	5.5	5.4	5.5	5.1	5.0
1000 (538)	UTS, ksi (MPa)	245.1 (1690)	242.2 (1670)	237.8 (1640)	237.0 (1634)	230.1 (1587)	227.3 (1567)
1000 (538)	0.2% YS, ksi (MPa)	227.7 (1570)	228.3 (1574)	223.5 (1542)	222.9 (1537)	216.2 (1490)	212.4 (1465)
1000 (538)	Elong., % in 2" (50.8 mm)	4.4	4.0	3.5	3.3	3.7	3.7
1000 (538)	Min Bend Radius ⁽³⁾	5.4	5.5	5.2	5.2	4.9	5.2
1050 (566)	UTS, ksi (MPa)	226.3 (1560)	225.7 (1556)	222.7 (1536)	217.8 (1502)	214.1 (1476)	212.6 (1466)
1050 (566)	0.2% YS, ksi (MPa)	218.4 (1506)	218.2 (1504)	215.2 (1483)	209.1 (1442)	204.8 (1413)	202.1 (1394)
1050 (566)	Elong., % in 2" (50.8 mm)	3.7	3.9	3.0	3.6	4.0	4.0
1050 (566)	Min Bend Radius ⁽³⁾	4.6	4.7	5.3	4.9	4.6	4.8

(1) Values shown are averages of 10 tests on material ranging in thickness from .026" to .060" (0.660 to 1.524 mm).

(2) Standard RH austenite conditioning treatment.

(3) Value shown in minimum radius (in terms of sheet thickness to make 180° bend).

Heat treating cycles were as follows:

1. Held 1750 F (954 C) for 10 min., cooled to 1000 F (538 C) in times shown.
2. Cooled to -100 F (-73), held 8 hours.
3. Hardened at temperature shown for 1 hour.

Data Reference: Armco Research Laboratory Record Book 2564, 2549.

EFFECT OF COOLING TIME FROM 1675 TO 1000 F (913 TO 538 C) ON MECHANICAL PROPERTIES⁽¹⁾ OF HARDENED PH 15-7 Mo

Property	Standard RH 950 Treatment	Cooling Time—1675 to 1000 F (913 to 538 C), minutes			
		Air Cool	16	70	105
UTS, ksi (MPa)	246.2 (1697)	244.5 (1685)	237.2 (1635)	225.6 (1555)	225.4 (1554)
0.2% YS, ksi (MPa)	225.5 (1554)	222.6 (1535)	218.2 (1504)	210.2 (1449)	208.4 (1437)
Elong., % in 2" (50.8 mm)	5.3	5.1	5.2	6.3	6.7
Elong., % in 1/2" (12.7 mm)	—	13.1	13.1	13.5	13.9
Min Bend Radius ⁽²⁾	—	5.9	6.0	5.9	5.8

(1) Values shown are average of 5 tests made on material from 5 heats ranging in thickness from .026 to .052" (0.660 to 1.524 mm).

(2) Value shown is minimum radius (in terms of sheet thickness) to make 180° bend.

Heat treating cycles were as follows:

1. Held at 1675 F (913 C) for 10 min., cooled to 1000 F (538 C) in times shown.
2. Cooled to -100 F (-73 C), held 8 hours.
3. Hardened at 950 F (510 C), 1 hour.

Data Reference: Armco Research Laboratories Record Book 2564.

**EFFECT OF THE COOLING TIMES FROM 1750 TO 1000 F (954—538 C) ON
MECHANICAL PROPERTIES OF HARDENED 17-7 PH⁽¹⁾**

Property	Thickness in. (mm)	Standard RH 950 Treatment	Cooling Time—1750 to 1000 F (954 to 538 C), minutes		
			4	8	17
UTS, ksi (MPa)	.020-.033 (.508-.838)	238.5 (1644)	232.9 (1605)	234.5 (1616)	238.6 (1645)
	.042-.064 (1.067-1.626)	237.4 (1637)	233.8 (1612)	232.5 (1604)	232.4 (1604)
	.078-.096 (1.981-2.438)	232.3 (1602)	230.6 (1590)	229.5 (1582)	225.3 (1553)
0.2% YS, ksi (MPa)	.020-.033 (.508-.838)	223.9 (1543)	222.2 (1532)	223.0 (1538)	225.4 (1554)
	.042-.064 (1.067-1.626)	218.0 (1503)	217.7 (1501)	219.0 (1510)	220.3 (1519)
	.078-.096 (1.981-2.438)	214.0 (1475)	216.9 (1495)	216.7 (1494)	214.6 (1479)
Elong, % in 2" (50.8 mm)	.020-.033 (.508-.838)	6.0	4.8	4.8	4.7
	.042-.064 (1.067-1.626)	6.7	5.7	4.8	4.4
	.078-.096 (1.981-2.438)	8.0	6.6	5.6	6.2
Min Radius To Make 180° Bend	.020-.033 (.508-.838)	5.5 T	5.8 T	6.1 T	6.2 T
	.042-.064 (1.067-1.626)	4.7 T	6.2 T	6.1 T	6.0 T
	.078-.096 (1.981-2.438)	4.9 T	6.4 T	6.0 T	7.0 T

Values shown above are averages of 5 to 9 tests on each of 4 to 7 heats tested in each thickness range shown.

(1) Heat treating cycles were as follows:

1. Heat to 1750 F (954 C) — Hold 10 minutes.
2. Cool to 1000 F (538 C) as shown + Air Cool to Room Temperature.
3. Cool to -100 F (-73 C) — Hold 8 hours.
4. Harden at 950 F (510 C) — Hold 1 hour + Air Cool.

Data Reference: Armco Research Laboratory Data Book 1513, 2549, 2563.

The data shown below represent tests from an actual PH 15-7 Mo honeycomb panel. Coupons for these tests were taken from spacer sheets placed at various locations on the top side of the panel. The material tested had a nominal thickness of 0.020" (0.508 mm).

The brazing cycle employed was as follows:

1. Braze at 1640-1690 F (893-921 C) for 10 minutes.
2. Cool to 1000 F (538 C) in 75 minutes.
3. Transform at -100 F (-73 C) for 8 hours.
4. Harden at 900 F (482 C) for 8 hours.

The following minimum mechanical property requirements were desired:

UTS 225 ksi (1551 MPa)
0.2% YS 200 ksi (1379 MPa)
Elongation 4% (.020—.036"
[0.508—0.914 mm] thick samples)

Direction of Test	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong, % in 2" (50.8 mm)
Longitudinal*	235.6 (1624)	218.1 (1504)	5.7
Transverse*	241.2 (1663)	223.3 (1540)	4.2

* Average values of 18 tests. Coupons were .020" (0.508 mm) nominal thickness.
Data Reference: Aeronca Manufacturing Corporation, Middletown, Ohio.

Welding

17-7 PH and PH 15-7 Mo offer the welding advantages of regular austenitic chromium-nickel grades of stainless steel. The heat of welding effectively austenitizes and solution treats (anneals) the zone immediately adjacent to the weld. Therefore, regardless of the condition of the base metal prior to welding, the heat-affected zones and the weld metal both possess a soft, tough austenitic structure in the as-welded condition which is not susceptible to cracking as are the conventional hardenable steels.

The steel therefore may be welded in any condition of heat treatment without preheating and without critical control of interpass temperature or post-weld cooling rate. Various sequences of welding and heat treatment can be employed to secure desired properties in the welded joints.

Welded articles ranging from spot-welded masons' trowels to fusion-weld pressure vessels for aircraft and missiles have established the fabricability and reliability of these steels. Welding has been employed to join material ranging in thickness from .001" (.0254 mm) foil to heavy plate and forgings. Tensile and yield strengths of post-weld heat treated joints typically are 90-100% of the strength of the parent metal. To achieve sound weld deposits having useful levels of toughness, consideration should be given to: 1) weld deposit composition, 2) weld practice, and 3) post-weld heat treatment.

IMPORTANCE OF THE WELD STRUCTURE

When cast or deposited as weld metal, the *parent metal* composition of 17-7 PH will produce a microstructure containing approximately 25% delta ferrite in a matrix of austenite. Thus, 17-7 PH weld metal, when formed entirely by melting base metal, will have a substantially greater delta ferrite content than the 10 - 15% normally contained in wrought material. PH 15-7 Mo weld deposits show even more delta ferrite . . . approximately 40% compared to 15% in the base metal.

Columniation

The presence of a large amount of delta ferrite in the weld microstructure promotes columniation of the delta ferrite and the austenite phases. The degree of columniation will vary somewhat with welding conditions; that is, it will become more pronounced with

thicker weld beads, higher welding current, and faster welding speed. Nevertheless, the principal governing factor is the chemical composition of the weld and the amount of delta ferrite which the composition retains in the weld microstructure.

Hot Cracking

A large amount of delta ferrite plus pronounced columniation in the weld microstructure can cause the weld metal to be susceptible to hot cracking. This cracking can develop immediately after solidification and appears as a small hot crack at the starting end and in the weld craters.

Usually the starting end crack occurs as a short, longitudinal fissure in the center of the weld bead and could be easily disposed of through the use of a starting tab. However, if the bead is deposited under considerable restraint, the hot cracking in the weld may become more extensive. Slower weld travel speed and reduced weld current are the most important secondary factors in avoiding hot cracking in welds.

Weld Ductility

In the as-deposited condition, 17-7 PH and PH 15-7 Mo weld metal and the base metal heat-affected zones have moderate strength. While modest increases in strength can be obtained through local refrigeration of the weld joint, more often the entire weldment is subjected to a heat treating procedure to harden the weld metal and base metal heat-affected zones.

Weld metal of 17-7 PH and PH 15-7 Mo in the hardened condition containing a large amount of delta ferrite exhibits a tendency to fail in mechanical testing with a coarse, cleavage fracture. This form of fracture generally is accompanied by only modest values for tensile elongation and reduction of area.

Fusion welds in light gage sheet (less than .037" [.940 mm] thick), made single pass with square butt edges, generally have low ferrite levels that result in good toughness over a range of heat-treated strengths. Welds in intermediate gage sheet (.037" to .093" [.940 to 2.362 mm] thick) are best put into service in an over-aged condition such as RH 1100 or TH 1100 (see tables on pages 114 and 115). For welds in heavy sections where single weld deposits may have excessive ferrite content, multi-pass weld practices should be considered.

Post-weld heat treatment, consisting mainly of special annealing cycles, can accomplish a reduction in ferrite content. However, these treatments seldom are practical for actual weldments. Furthermore, special post-weld heat treatment does not alleviate any cracking susceptibility which may appear in the as-deposited weld for reason of too much delta ferrite. Some data on special heat treatment of PH 15-7 Mo welded joints are shown in the table.

**TYPICAL TENSILE PROPERTIES FOR
TUNGSTEN-ARC INERT-GAS WELDS IN 17-7 PH ⁽¹⁾**

Final Condition of Welded Specimen ⁽²⁾	UTS ksi (MPa)	0.2% YS ksi (MPa)	% Elongation		% Lateral Contraction ⁽³⁾
			2" (50.8 mm)	½" (12.7 mm)	
A, W, TH 1050	205 (1413)	195 (1344)	1.5	6.0	2.6
A, W, A, TH 1050	208 (1434)	195 (1344)	2.5	8.0	3.0
A, W, RH 950	220 (1517)	205 (1413)	2.0	6.0	2.0
A, W, RH 1100	165 (1138)	132 (910)	6.0	14.0	5.0
A, W, TH 1100	160 (1103)	130 (896)	6.0	10.0	5.0
A, W, A, TH 1100	160 (1103)	132 (910)	6.0	12.0	6.0

⁽¹⁾ Average of triplicate values for two heats .0625" (1.58 mm) thick.
Welded in jig over copper backup using helium shielded tungsten-arc torch. Gas flow 60 CFH, travel speed 15 IPM, current DC-SP, 1/16" (1.58 mm) W 17-7 PH wire added at 28 IPM speed. Standard 1/2" (12.7 mm) wide tensile specimen with weld in center of 2" (50.8 mm) gage length transverse to direction of pull. Weld bead reinforcement left intact.

⁽²⁾ A — annealed 1950 F (1066 C)
W — welded

⁽³⁾ % reduction in width of specimen at point of fracture.

**TENSILE PROPERTIES OF WELD JOINTS IN 17-7 PH STAINLESS STEEL
MADE AFTER TH 1075 HEAT TREATMENT***

Welds made by tungsten-arc inert-gas process using W 17-7 PH filler wire

Sheet Thickness inch (mm)	Direction of Testing	Test Temperature F	Tensile Properties			
			Parent Metal		Weld Joint	
			UTS psi (MPa)	Elongation % in 2" (50.8 mm)	UTS psi (MPa)	Elongation % in 2" (50.8 mm)
0.018 (.457)	Transverse	RT	182,600 (1259)	10.8	143,900 (992)	2.1
0.050 (1.270)	Transverse	RT	177,700 (1225)	10.4	140,500 (968)	3.8
0.080 (2.032)	Transverse	RT	187,500 (1292)	9.0	156,700 (1081)	4.7
0.050 (1.270)	Longitudinal	RT	184,200 (1270)	—	151,400 (1044)	4.0
0.078 (1.981)	Longitudinal	RT	189,000 (1303)	—	145,800 (1006)	5.6
0.078 (1.981)	Longitudinal	300	175,800 (1213)	9.1	96,000 (662)	4.9
0.050 (1.270)	Longitudinal	500	161,300 (1112)	4.7	90,100 (622)	2.8
0.050 (1.270)	Longitudinal	700	152,400 (1051)	6.5	92,300 (636)	3.0
0.050 (1.270)	Longitudinal	900	116,700 (805)	22.0	81,200 (559)	3.2

* Courtesy North American Aviation, Inc.

COMPOSITION RANGES, %

Element	Sheet and Strip		Weld Wire	
	17-7 PH	PH 15-7 Mo	W 17-7 PH	W PH 15-7 Mo
C	.09 max.	.09 max.	.09 max.	.09 max.
Mn	1.00 max.	1.00 max.	1.00 max.	1.00 max.
P	.04 max.	.04 max.	.025 max.	.025 max.
S	.03 max.	.03 max.	.025 max.	.025 max.
Si	1.00 max.	1.00 max.	.50 max.	.50 max.
Cr	16.00-18.00	14.00-16.00	16.00-17.25	14.00-15.25
Ni	6.50- 7.75	6.50- 7.75	6.50- 7.75	6.50- 7.75
Al	.75- 1.50	.75- 1.50	.75- 1.25	.75- 1.25
Mo	—	2.00- 3.00	—	2.00- 2.75

Filler wire of W 17-7 PH and W PH 15-7 Mo are regularly used for general purpose welding where a high level of weld metal toughness and ductility are not extremely important requisites. W 17-7 PH and W PH 15-7 Mo serve satisfactorily for most welded articles which are heat treated to the lower levels of strength and hardness; that is, any treatment involving a final hardening temperature of 1100 F (593 C) or higher.

Weld Filler Wires

Control of weld metal ferrite content is important if resistance to weld cracking and good weld ductility in the highly hardened (RH 950) condition are to be obtained. A reduction in weld ferrite content is secured most effectively through modification of weld chemical composition. The ferrite content can be decreased by lowering any of the ferrite-forming elements present (essentially molybdenum, chromium, silicon, and aluminum) and/or by increasing the austenite-forming elements nickel or nitrogen. Yet any modifications of the composition in these directions must leave the weld metal still responsive to the precipitation-hardening heat treatment.

To avoid problems with weld metal cracking or lowered ductility, two specific analyses of precipitation-hardenable welding wire are available for use as electrode or filler rod. These analyses are designated as W17-7 PH and W PH 15-7 Mo. They are manufactured to somewhat different and more restrictive alloying element ranges as shown.

Welds Made with Base Metal Filler Metal or No Filler Metal

When welds are made without any filler metal or with a precipitation-hardening analysis filler, they have precipitation-hardening ability and their response to heat treatment will be similar to that of the parent metal.

However, when welds are heat treated to a high strength condition such as RH 950, the weld metal toughness and ductility normally will be somewhat lower than the parent metal. Overaging to a somewhat lower strength level will greatly improve ductility and toughness.

For example, in the fabrication of missile pressure vessels, it has been found that an overaging treatment

such as RH 1100 greatly increases the burst strength over that obtained with a standard RH 950 heat treatment — even though the strength level as measured by uniaxial tensile tests, is lower in the overaged condition. In applications such as this, or wherever good notch toughness is desired in welds, it is strongly suggested that overaging be considered. This will lower strength somewhat, but at the same time overall load carrying ability should be improved. Leaving the weld bead reinforcement intact, instead of grinding it flush also helps in this regard.

Welds Made with Standard Cr-Ni Filler Metal

Standard grades of austenitic Cr-Ni filler metal can be employed in joining 17-7 PH or PH 15-7 Mo where a very tough, ductile weld metal is desired and strength requirements for the joint are not high. Filler wire of ER-308L, ER-347, ER-308, and ER-309 will serve satisfactorily unless the 17-7 PH base metal is being joined to a dissimilar metal.

Joints made in this manner will not respond to heat treatment in the same manner as the parent metal. Response to heat treatment in a given weld depends on the degree and type of alloying elements present in the filler metal and the amount of dilution of parent metal into weld metal during welding. Fillers containing a high percentage of austenite formers such as carbon, manganese, nickel and nitrogen, would harden less than fillers containing a smaller percentage of such elements. For example, weldments made with an ER-309 analysis (25-12) would not respond nearly as much to heat treatment as would a weldment made with an ER-308 filler (20-10).

Furthermore, as the amount of dilution of parent metal 17-7 PH into the weld metal increases, there is a greater tendency for the weldment to respond to heat treatment. For these reasons, it is difficult to predict the degree to which any given weldment may respond to heat treatment unless the percent dilution

or composition of the weld metal is known. Therefore, some preliminary welding work should be done in selecting filler metal, joint design, heat treatment and welding technique for a given weldment utilizing standard chromium-nickel filler metal.

Generally speaking, however, welds made with a standard chromium-nickel filler metal will be tougher and more ductile after heat treatment although strength levels will be less than obtained by using a PH type filler metal.

Nitrogen-Technique for Welds Made Without Filler Metal

When it is not possible to use filler metal to adjust the composition of the weld, and ductility and toughness are not quite adequate, it may be helpful to add about 20% nitrogen gas to the inert-gas shielding stream. In effect, this adds nitrogen (a strong austenite former) to the weld metal. A very small increase in this element helps reduce the amount of delta ferrite in the weld, thus improving ductility and toughness.

An important precautionary note in connection with use of the nitrogen-technique is that presence of the aluminum nitride particles interferes with the making of sound multi-layer welds. As would be suspected, the particles in an initial bead tend to dissociate as melting occurs under the heat of a successive layer and the gas generated forms porosity in the newly deposited metal. Consequently, the nitrogen-technique appears suitable only for single-pass weld joints.

APPLICABLE WELDING PROCESSES

Standard fusion and resistance welding equipment may be used for joining 17-7 PH and PH 15-7 Mo. No auxiliary units such as a closed welding chamber or plastic canopy over the work are required. Tooling used for jigs or fixtures with standard stainless steels will serve, but it must be realized that 17-7 PH and PH 15-7 Mo may be welded either when austenitic (Condition A) or martensitic (condition as transformed by R or T treatment), and these structural conditions have different coefficients of thermal expansion.

Following are comments on the various processes used. Where available, properties of welded joints also are listed.

Inert-Gas Tungsten-Arc

This is the process most widely used when fusion welding 17-7 PH and PH 15-7 Mo. It provides efficient protection of aluminum in the alloy composition and permits fusion and deposition of sound weld metal having the desired analysis.

Most inert-arc welding operations are performed

with DC-SP power because AC application is hampered by current rectification exerted by the steel. Yet AC power is very desirable for securing a clear, fluid weld pool and has been used to some extent with manual welding. An "aluminum effect" tends to appear on the molten weld pool. The degree to which the film develops depends upon the kind of shielding gas applied and its ability to protect the metal. Its appearance is that of a hazy film on the surface. The film does not necessarily interfere with efforts to make a satisfactory weld and does not represent a significant loss of aluminum, but does require a certain amount of operator experience to gage proper conditions for complete penetration and weld bead formation. Conditions of current, speed, gas flow, etc., must be established specifically for 17-7 PH or PH 15-7 Mo.

Helium gas shielding is preferred over argon because it minimizes the aluminum effect displayed by the molten metal and gives more uniform root penetration. Nevertheless, argon or mixtures of argon and helium can be employed. Somewhat greater quantities of shielding gas are used in welding 17-7 PH and PH 15-7 Mo to insure proper alloy recovery than are used regularly on standard stainless steels. A flow of 50 CFH is typical.

High rates of travel speed should be avoided during inert-gas tungsten-arc welding because this can cause fusion line porosity. Travel speeds typically are on the order of 12 inches per minute. It is preferred that weld current and weld pass sequence be selected to minimize weld deposit size.

Some form of protective backup should be employed for weld joints in which complete penetration occurs. A backup consisting of a copper bar with a shallow groove can be used during inert-gas tungsten-arc welding to avoid undesirable root formation. The introduction of inert gas into the groove is helpful. The use of a deep groove with controlled gas backup also is satisfactory.

Inert-Gas Tungsten-Arc Spot

This method has been used but no data are available on properties of joints welded in this manner.

Inert-Gas Metal-Arc (Consumable Electrode)

To date, only limited work has been done with this process, and little can be said about its applicability.

Covered Electrode Metal-Arc — 17-7 PH

When 17-7 PH is to be welded by this commonly used metal-arc process, the electrode may be a standard austenitic Cr-Ni grade of stainless steel in which case the weld deposit probably will not harden much during post-weld heat treatment.

Covered electrodes of 17-7 PH are not made because the electrode flux coating does not give ade-

quate protection to the aluminum in the steel. A high percentage of aluminum cannot be added to the flux to compensate for this oxidation loss without adversely affecting the chemical balance of the weld metal.

Submerged-Arc

This process has not been employed, at least when making joints with precipitation-hardening capability, due to lack of a suitable flux to prevent oxidation of the aluminum.

Resistance Welding

Resistance spot and seam welding can be performed on 17-7 PH and very good weld properties are achieved by following prescribed sequences of welding and heat treatment. Normally, best results are obtained by welding just before or after the final hardening treatment in order to leave the nugget in a tough austenitic condition. While this has little effect on shear strength, it greatly improves the tension breaking load in spot welds.

Data in the table indicate that spot welds can easily be made to satisfy the requirements of MIL-W-6858B. In addition, all other quality standards such as surface indentation, penetration and freedom from internal defects were acceptable.

Resistance flash-butt welding is not recommended for joints to be heat treated to high strength levels after welding. While the flash-butt joints are sound and will respond to heat treatment to produce high strength and hardness, their ductility is very low because of the unfavorable directionality in the parent metal microstructure at the upset weld area.

Cross-wire spot welds on Armco 17-7 PH and PH 15-7 Mo are similar to spot welds on sheet as regards effect of welding and heat treating sequence on joint strength. Such welds are considerably stronger than similar ones in hard drawn Type 302 stainless wire.

WELDING IN CONDITIONS C AND CH

Condition C (cold worked) sheet is readily welded, but the strength and hardness of the fully hardened (Condition CH 900) material cannot be obtained in and adjacent to the weld because the cold-worked structure is annealed by the heat of welding. After fusion welding, the weld and heat-affected areas consist mainly of a soft austenitic structure which does not respond to the single 900 F (482 C) precipitation-hardening treatment. If the steel is given the 900 F (482 C) treatment prior to welding, softening also occurs in and around the weld.

The circumstances for resistance spot welding Condition C or CH 900 material are more favorable because a soft tough weld nugget is desired for good joint strength.

Inert-Gas Shielded-Arc Welding

Illustrated below are results of tests on 17-7 PH joints made by inert-gas shielded-arc welding .050" (1.27 mm) thick sheet material with W 17-7 PH filler rods:

Heat Treating & Welding Sequence	UTS psi (MPa)	Location of Fracture
Welded (not heat treated)	155,000 (1069)	Weld, or in adjacent base metal
Welded + 900 F (482 C)	155,000 (1069)	Weld, or in adjacent base metal
900 F (482 C) + Welded	155,000 (1069)	Weld, or in adjacent base metal

From the above it is clear that if 17-7 PH Condition C or CH is to be welded, the welding must be done at some location in the assembly where a strength lower than that of the fully hardened metal can be tolerated.

Resistance Spot Welding

The following shows the effect of welding and hardening sequence on the shear strength of 17-7 PH spot welded joints.

	Welded Only	Welded + 900 F (482 C)	900 F (482 C) + Welded
Average breaking load in pounds (N) (triplicate tests)	2952 (13,387)	2755 (12,494)	2090 (9478)

All specimens broke in the weld metal. Sample thickness .051" (1.295 mm).

Welding 17-7 PH to 17-4 PH

Circumstances may arise which require the fusion welding of 17-7 PH Condition A flat rolled to a bar of Armco 17-4 PH. If metal-arc welding is to be employed, a 17-4 PH covered electrode should be deposited. The inert-gas shielded-arc processes could make use of either 17-4 PH or 17-7 PH welding wire if filler metal were required. Regardless of the process employed, a dissimilar metal joint of this kind presents a problem in heat treating to obtain the properties of fully hardened material.

Heat treatment at 1600 F (871 C) appears to be the best compromise temperature for solution treating the 17-4 PH as well as transforming the 17-7 PH.

Care must be exercised to cool the weldment from 1600 F to 0 F (871 C to -18 C) or below to insure transformation. Sub-zero cooling does not appear necessary and possibly may adversely affect ductility. Subsequent heat treatment in the temperature range of 1075-1100 F (579-593 C) will precipitation-harden both grades.

Following is a tabulation of properties that can be expected when welding 17-7 PH to 17-4 PH and a compromise temperature (1600 F [871 C]) is employed for solution treatment (17-4 PH) and transformation treatment (17-7 PH):

TYPICAL MECHANICAL PROPERTIES OF DISSIMILAR JOINTS

*17-4 PH welded to 17-7 PH using W 17-4 PH Filler Wire
by Inert-Gas Tungsten-Arc Process.*

Heat Treatment	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong. % in 2" (50.8 mm)	Red. of Area (%)
1600 F (871 C) 90 min, Cool to 0 F + 1075 F (-18 + 579 C) 90 min	150 (1034)	145 (1000)	3.5	10

With resistance spot and seam welding, the 17-4 PH and 17-7 PH components can be (1) heat treated separately in accordance with the recommended practice for each, then welded together in the final operation, or (2) the 17-7 PH component can be treated to Condition T and welded to the 17-4 PH component which has remained in Condition A, then the assembly is precipitation hardened at a temperature suited for both grades.

STRENGTH OF SPOT WELDED JOINTS⁽¹⁾

Steel Type	Condition in which Welded	Condition in which Tested	Shear Breaking Load lbs./weld (N/weld)		Tension Breaking Load lbs./weld (N/weld)	
			Low Test	20 Test Avg.	Low Test	20 Test Avg.
MIL-W-6858B Minimums:			2125 (9452)	2620 (11,654)	—	—
PH 15-7 Mo	A	TH 1050	2830 (12,587)	3103 (13,802)	370 (1646)	580 (2579)
	T	TH 1050	3075 (13,678)	3438 (15,292)	1360 (6049)	1648 (7330)
	TH 1050	TH 1050	2530 (11,253)	2896 (12,881)	1500 (6672)	2015 (8963)
	A	RH 950	2500 (11,120)	2853 (12,690)	370 (1646)	520 (2313)
	A 1750	RH 950	3115 (13,856)	3426 (15,239)	—	—
	R-100	RH 950	2945 (13,099)	3335 (14,834)	1040 (4626)	1232 (5480)
	RH 950	RH 950	2480 (11,031)	2630 (11,698)	1890 (8407)	2170 (9652)
17-7 PH	A	TH 1050	2720 (12,098)	2790 ⁽²⁾ (12,410)	—	—
	T	TH 1050	2950 (13,122)	2970 ⁽²⁾ (13,214)	—	—
	TH 1050	TH 1050	2250 (10,008)	2610 ⁽²⁾ (11,609)	—	—
	A	RH 950	2300 (10,230)	2556 (11,369)	—	—
	R-100	RH 950	2582 (11,485)	2882 (12,819)	—	—
	RH 950	RH 950	2380 (10,586)	2660 (11,832)	—	—

⁽¹⁾ Spot Welding Conditions:

Welding Pressure	— 1200 lbs (5338 N)
Current	— 7500 amps.
Electrode Dome Radius	— 3" (76.2 mm)
Time	— 10 Hertz
Post Weld Heat	— None
Sheet Condition	— Vapor blasted prior to welding
Sheet Thickness	— PH 15-7 Mo .049" (1.245 mm); 17-7 PH .050" (1.27 mm)

⁽²⁾ Average of three tests.