

17-4 PH STAINLESS STEEL

UNS S17400



- High Strength
- Good Corrosion Resistance
- Good Properties Up To 600°F (316°C)

Applications Potential

AK Steel 17-4 PH® is the most widely used of all the precipitation-hardening stainless steels. Its valuable combination of properties gives designers opportunities to add reliability to their products while simplifying fabrication and often reducing costs. This valuable alloy is widely used in the aerospace, chemical, petrochemical, food processing, paper and general metalworking industries.

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

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PRODUCT DESCRIPTION

AK Steel 17-4 PH is a martensitic precipitation-hardening stainless steel that provides an outstanding combination of high strength, good corrosion resistance, good mechanical properties at temperatures up to 600°F (316°C), good toughness in both base metal and welds, and short-time, low-temperature heat treatments that minimize warpage and scaling.

Composition

	%
Carbon	0.07 max.
Manganese	1.00 max.
Phosphorus	0.040 max.
Sulfur	0.030 max.
Silicon	1.00 max.
Chromium	15.00-17.50
Nickel	3.00-5.00
Copper	3.00-5.00
Columbium	
plus Tantalum	0.15-0.45

Available Forms

AK Steel produces 17-4 PH Stainless Steel sheet and strip in thicknesses from 0.015" to 0.125" (0.38 to 3.18 mm). In these forms, the alloy is supplied in Condition A, ready for fabrication and subsequent hardening by the user. Since the material transforms to martensite on cooling to room temperature, flatness requirements should be considered and discussed as part of the order.

Metric Practice

The values shown in this bulletin were established in U.S. customary units. The metric equivalents of U.S. customary units shown may be approximate. Conversion to the metric system, known as the International System of Units (SI) has been accomplished in accordance with ASTM E 380.

The newton (N) has been adopted by the SI as the metric standard unit of force. The term for force per unit of area (stress) is the newton per square meter (N/m²). Since this can be a large number, the prefix mega is used to indicate 1,000,000 units and the term meganewton per square meter (MN/m²) is used. The unit (N/m²) has been designated a pascal (Pa). The relationship between the U.S. and the SI units for stress is: 1000 pounds/in² = 1 kip/in² (ksi) = 6.8948 meganewtons/m² (MN/m²) = 6.8948 megapascals (MPa).

Standard Heat Treatments

As supplied from the Mill in Condition A, AK Steel 17-4 PH Stainless Steel can be heat treated at a variety of temperatures to develop a wide range of properties. Eight standard heat treatments have been developed. The following chart outlines the times and temperatures required.

This alloy exhibits useful mechanical properties in Condition A. Tests at Kure Beach, NC, after 14 years show excellent stress corrosion resistance. Condition A ma-

terial has been used successfully in numerous applications. The hardness and tensile properties fall within the range of those for Conditions H 1100 and H 1150.

However, in critical applications, the alloy is used in the precipitation-hardened condition, rather than Condition A. Heat treating to the hardened condition, especially at the higher end of the temperature range, stress relieves the structure and may provide more reliable resistance to stress corrosion cracking than in Condition A.

Condition A

Standard Heat Treatments

	Condition	Heat To	Time at Temperature, hours	Type of Cooling
		$\pm 15^{\circ}\text{F}$ (8.4°C)		
Condition A Solution Treated $1900^{\circ}\text{F} \pm 25^{\circ}\text{F}$ $(1038^{\circ}\text{C} \pm 14^{\circ}\text{C})$ Air cool below 90°F (32°C)	H 900	900°F (482°C)	1	Air
	H 925	925°F (496°C)	4	Air
	H 1025	1025°F (551°C)	4	Air
	H 1075	1075°F (580°C)	4	Air
	H 1100	1100°F (593°C)	4	Air
	H 1150	1150°F (621°C)	4	Air
	H 1150+1150	1150°F (621°C)	4	Air
		1150°F (621°C)	<i>followed by</i> 4	Air
	H 1150-M	1400°F (760°C)	2	Air
		1150°F (621°C)	<i>followed by</i> 4	Air

Mechanical Properties

AK Steel 17-4 PH Stainless Steel provides excellent mechanical properties. For applications requiring high strength and hardness plus corrosion resistance, this

alloy is an outstanding choice. In addition, it is more cost effective than many high-nickel, non-ferrous alloys.

Table 1

Typical Mechanical Properties*

Property	Condition						
	A	H 900	H 925	H 1025	H 1075	H 1150	H 1150-M
UTS, ksi (MPa)	160 (1103)	210 (1448)	200 (1379)	185 (1276)	175 (1207)	160 (1103)	150 (1034)
0.2% YS, ksi (MPa)	145 (1000)	200 (1379)	195 (1345)	170 (1172)	165 (1148)	150 (1034)	130 (896)
Elongation, % in 2" (50.8 mm)	5.0	7.0	8.0	8.0	8.0	11.0	12.0
Hardness, Rockwell	C35	C45	C43	C38	C37	C35	C33

*Cold-flattened sheets and strip.

Table 2

Properties Acceptable for Material Specification*

Property	Condition						
	A	H 900	H 925	H 1025	H 1075	H 1100	H 1150
UTS, ksi (MPa)	185 max. (1276)	190 min. (1310)	170 min. (1172)	155 min. (1069)	145 min. (1000)	140 min. (965)	135 min. (931)
0.2% YS, ksi (MPa)	160 max. (1103)	170 min. (1172)	155 min. (1069)	145 min. (1000)	125 min. (862)	115 min. (790)	105 min. (724)
Elongation, % in 2" (50.8 mm)	3 min.	5 min.	5 min.	5 min.	5 min.	5 min.	8 min.
Hardness, Rockwell	C38 max.	C40-48	C38-46	C35-43	C31-40	C31-40	C28-38

*Sheets and strip.

Table 3

Pin Bearing Properties of Sheet*

Condition	e/D [†] = 1.5		e/D = 2.0		Tensile Strengths***	
	Bearing Yield Strength** ksi (MPa)	Bearing Strength ksi (MPa)	Bearing Yield Strength** ksi (MPa)	Bearing Strength ksi (MPa)	0.2% YS ksi (MPa)	UTS ksi (MPa)
H 925	273 (1882)	304 (2096)	308 (2124)	401 (2765)	190 (1310)	191 (1317)
H 1025	242 (1669)	270 (1862)	288 (1986)	359 (2475)	172 (1186)	172 (1186)
H 1100	233 (1606)	257 (1772)	262 (1806)	337 (2324)	160 (1103)	160 (1103)
H 1150	203 (1400)	234 (1613)	236 (1627)	313 (2158)	146 (1007)	150 (1034)
A	211 (1455)	226 (1558)	276 (1903)	296 (2041)	158 (1089)	158 (1089)

*Average of duplicate tests on one heat of 0.065" (1.65 mm) sheet material

** Offset equals 2% of pin diameter.

*** Yield equals ultimate tensile strengths due to rounding.

† e/D = Distance from edge of specimen to edge of hole ÷ hole diameter.

Elevated Temperature Properties

Mechanical properties of AK Steel 17-4 PH Condition H 1150 after long-time exposure at elevated temperatures are shown in Table 4. When tested at room temperature after exposure, a slight loss of toughness and gain in strength can be noted. However, H 1150 properties can be restored by heat treating at 1150°F (621°C) for four hours after original exposure. By taking advantage of this re-aging treatment, the service life of parts exposed at elevated temperature to 750°F (339°C) can be extended indefinitely.

Elevated temperature properties for short-time exposures were determined for Conditions H 900 and H 1150. Specimens were heated rapidly by resistance methods and reached exposure temperatures within two seconds. Specimens were then held at temperature for the times indicated and tested both at exposure temperature and at room temperature. (See Tables 5, 6 and 7).

Table 4

Effect of Elevated Temperature Exposure on Mechanical Properties – Condition H 1150

Exposure Temperature °F (°C)	Time hours	Test Temperatures									Precracked Charpy	
		Room Temperature			600°F (316°C)			750°F (399°C)			W/A, in-lb/in ² (mm•N/mm ²)	
		UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong % in 2" (50.8 mm)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong % in 2" (50.8 mm)	UTS ksi (MPa)	0.2% YS ksi (MPa)	Elong % in 2" (50.8 mm)	75°F (24°C)	-75°F (-60°C)
600 (316)	1000	151 (1041)	142 (979)	13	123 (848)	118 (814)	6	115 (793)	110 (758)	5	1882 (329)	2062 (361)
	7000	157 (1082)	150 (1034)	11	128 (882)	123 (848)	8	120 (827)	117 (807)	5	1956 (342)	1653 (289)
	7000*	141 (972)	119 (820)	13	113 (779)	107 (738)	7	107 (738)	103 (710)	6	2168 (379)	2242 (392)
650 (343)	1000	155 (1069)	149 (1027)	13	128 (882)	124 (855)	6	121 (834)	116 (800)	5	1940 (340)	2018 (353)
	7000	168 (1159)	162 (1117)	11	138 (952)	135 (931)	7	132 (910)	128 (882)	5	1624 (284)	1597 (279)
	7000*	141 (972)	119 (820)	12	115 (793)	108 (745)	7	108 (745)	102 (703)	7	2264 (396)	2398 (420)
700 (371)	100	152 (1048)	144 (993)	13	125 (862)	120 (827)	6	118 (814)	112 (772)	4	1874 (328)	1973 (345)
	1000	162 (1117)	155 (1069)	11	134 (924)	130 (896)	7	130 (896)	124 (855)	6	1841 (322)	1801 (315)
	7000	179 (1234)	174 (1200)	9	148 (1020)	144 (993)	6	142 (979)	137 (945)	5	1215 (213)	667 (117)
	7000*	140 (965)	117 (807)	13	114 (786)	108 (745)	7	108 (745)	103 (710)	6	2153 (377)	2260 (396)
750 (399)	100	154 (1062)	147 (1014)	13	128 (882)	122 (841)	6	121 (834)	115 (793)	4	1807 (316)	1836 (321)
	1000	171 (1179)	165 (1138)	11	140 (965)	135 (931)	7	135 (931)	129 (889)	6	1309 (229)	1231 (215)
	7000	185 (1276)	178 (1227)	10	149 (1027)	144 (993)	7	144 (993)	138 (952)	8	987 (173)	420 (74)
	7000*	140 (965)	117 (807)	13	113 (779)	107 (738)	7	105 (724)	101 (696)	7	2308 (404)	2320 (406)
None	None	148 (1020)	134 (924)	13	121 (834)	115 (793)	5	116 (800)	111 (765)	4	2087 (365)	2124 (372)

*Re-aged at 1150°F (621°C) for 4 hours after exposure.

Table 5

Effect of Short-Time Elevated Temperature Exposure on Mechanical Properties – Condition H 900
Tested at Room Temperature

Exposure Temperature °F (°C)	Property	Exposure Time, seconds						
		5	10	30	60	90	300	600
1000 (538)	UTS, ksi (MPa)	213 (1469)	210 (1448)	210 (1448)	210 (1448)	207 (1437)	205 (1414)	201 (1386)
	0.2% YS, ksi (MPa)	197 (1358)	189 (1303)	193 (1331)	194 (1338)	187 (1290)	192 (1324)	188 (1297)
	Elong., % in 2" (50.8 mm)	8.0	8.0	7.0	7.0	6.0	5.5	5.0
1100 (593)	UTS, ksi (MPa)	201 (1386)	204 (1407)	197 (1359)	191 (1317)	192 (1324)	176 (1214)	178 (1228)
	0.2% YS, ksi (MPa)	183 (1262)	184 (1269)	178 (1228)	175 (1207)	180 (1241)	170 (1172)	167 (1152)
	Elong., % in 2" (50.8 mm)	7.5	8.5	7.0	6.0	5.5	5.0	6.0
1200 (649)	UTS, ksi (MPa)	187 (1290)	187 (1290)	179 (1234)	181 (1248)	165 (1138)	164 (1131)	163 (1124)
	0.2% YS, ksi (MPa)	173 (1193)	176 (1118)	167 (1151)	168 (1159)	163 (1124)	149 (1027)	148 (1020)
	Elong., % in 2" (50.8 mm)	8.0	8.0	7.0	8.0	6.5	6.0	6.0
1300 (704)	UTS, ksi (MPa)	172 (1186)	172 (1186)	165 (1138)	162 (1115)	160 (1103)	155 (1069)	154 (1062)
	0.2% YS, ksi (MPa)	146 (1007)	154 (1062)	137 (945)	143 (986)	134 (924)	112 (772)	131 (903)
	Elong., % in 2" (50.8 mm)	9.0	8.0	8.0	6.0	6.5	7.0	7.0
1400 (760)	UTS, ksi (MPa)	165 (1138)	164 (1131)	161 (1110)	162 (1115)	159 (1096)	160 (1103)	157 (1082)
	0.2% YS, ksi (MPa)	132 (910)	123 (848)	124 (855)	120 (827)	127 (876)	125 (862)	118 (814)
	Elong., % in 2" (50.8 mm)	8.5	8.0	7.0	6.0	6.0	5.0	6.0
1600 (871)	UTS, ksi (MPa)	167 (1152)	165 (1138)	165 (1138)	165 (1138)	161 (1110)	162 (1117)	—
	0.2% YS, ksi (MPa)	121 (834)	121 (834)	122 (841)	121 (834)	126 (869)	128 (882)	—
	Elong., % in 2" (50.8 mm)	6.0	5.0	5.0	5.0	4.5	4.5	—
1800 (982)	UTS, ksi (MPa)	161 (1110)	159 (1096)	158 (1089)	157 (1082)	—	—	—
	0.2% YS, ksi (MPa)	119 (820)	119 (820)	114 (786)	118 (814)	—	—	—
	Elong., % in 2" (50.8 mm)	6.0	6.0	5.5	6.0	—	—	—
2000 (1093)	UTS, ksi (MPa)	161 (1110)	161 (1110)	158 (1089)	—	—	—	—
	0.2% YS, ksi (MPa)	127 (876)	116 (800)	109 (752)	—	—	—	—
	Elong., % in 2" (50.8 mm)	6.0	5.0	5.0	—	—	—	—

Control Sample: UTS – 215.9 ksi (1489 MPa)
0.2% YS – 196 ksi (1352 MPa)
Elong., % in 2" (50.8 mm) – 8.5

Table 6

Effect of Short-Time Exposure at 1400°F (760°C) on Mechanical Properties – Condition H 1150

Test Temperature °F (°C)	Property	Exposure Time, seconds						
		5	10	30	60	90	300	600
Room Temperature	UTS, ksi (MPa)	154 (1062)	151 (1041)	151 (1041)	149 (1027)	150 (1034)	150 (1034)	147 (1014)
	0.2% YS, ksi (MPa)	130 (896)	127 (876)	122 (841)	115 (793)	112 (772)	117 (807)	105 (724)
	Elong., % in 2" (50.8 mm)	12.0	9.0	9.0	9.0	8.5	8.0	8.0
1400 (760)	UTS, ksi (MPa)	46.0 (317)	43.4 (297)	47.5 (327)	47.5 (327)	46.8 (332)	44.5 (306)	44.3 (305)
	0.2% YS, ksi (MPa)	45.2 (311)	42.6 (293)	46.0 (317)	46.2 (318)	45.3 (312)	43.5 (298)	42.3 (292)
	Elong., % in 2" (50.8 mm)	27.0	29.0	21.0	19.0	18.0	23.0	21.0

Control Sample: UTS – 157 ksi (1082 MPa)
0.2% YS – 143 ksi (986 MPa)
Elong., % in 2" (50.8 mm) – 12.0

Table 7

Effect of Elevated Temperature Exposure for 30 Seconds on Mechanical Properties – Condition H 1150

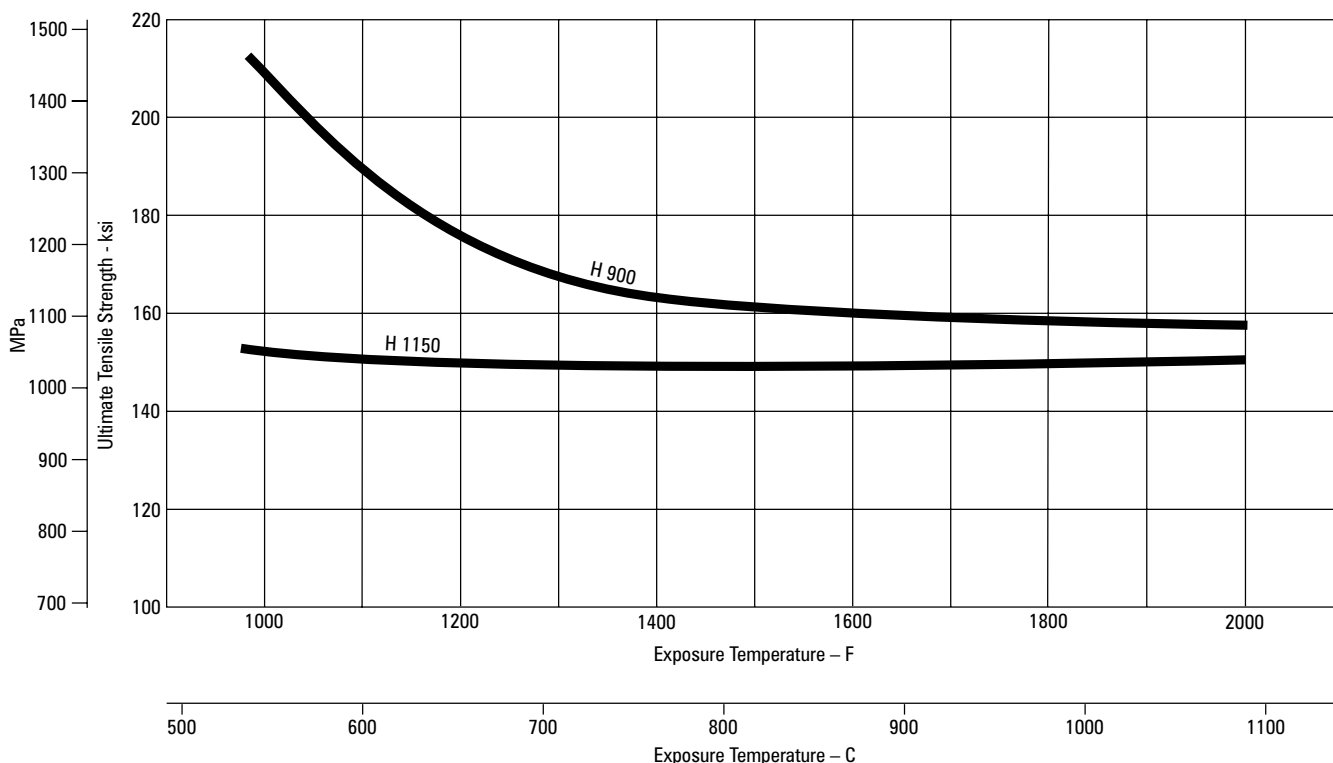
Test Temperature °F (°C)	Property	Exposure Temperature, °F (°C)					
		1000 (538)	1200 (649)	1400 (760)	1600 (871)	1800 (982)	2000 (1093)
Room Temperature	UTS, ksi (MPa)	155 (1069)	154 (1062)	151 (1041)	155 (1069)	155 (1069)	157 (1082)
	0.2% YS, ksi (MPa)	141 (972)	136 (938)	122 (841)	117 (807)	108 (745)	113 (779)
	Elong., % in 2" (50.8 mm)	10.0	11.0	9.0	7.5	6.0	4.5
Exposure Temperature	UTS, ksi (MPa)	128 (882)	76.6 (528)	47.5 (327)	38.0 (262)	26.6 (183)	15.1 (103)
	0.2% YS, ksi (MPa)	108 (745)	71.6 (493)	46.0 (317)	37.4 (258)	26.0 (179)	12.7 (87)
	Elong., % in 2" (50.8 mm)	6.0	13.0	21.0	26.0	28.0	48.0

Control Sample: UTS – 157 ksi (1082 MPa)
 0.2% YS – 143 ksi (986 MPa)
 Elong., % in 2" (50.8 mm) – 12.0

Figure 1

Elevated Temperature Properties

(Exposed for 30 Seconds at Temperature and Tested at Room Temperature)



NOTE: These tests represent instant heating of the entire cross section of the test specimens. Under actual conditions, heating rates would depend on heat source, surface conditions and thermal conductivity of

AK Steel 17-4 PH Stainless Steel (see Physical Properties). Times and temperatures shown in the tables apply only after parts have reached temperatures.

Physical Properties

Table 8

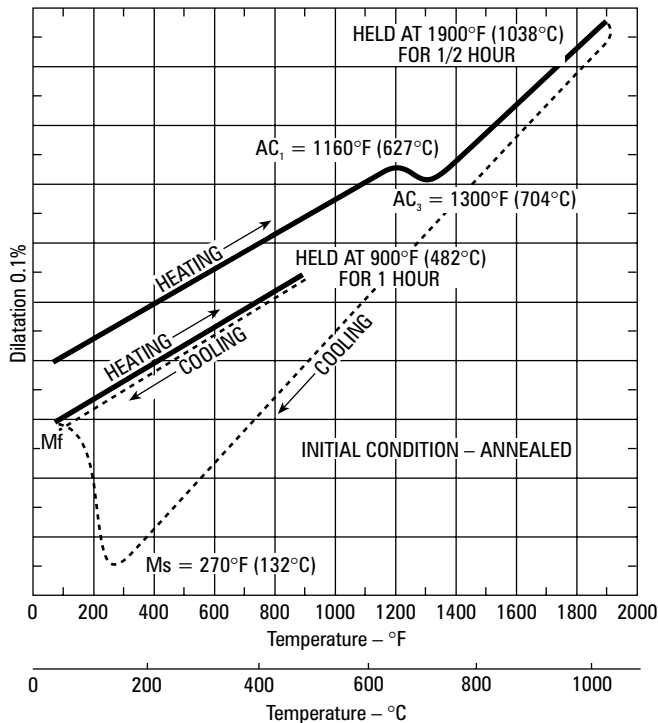
	Condition A (Magnetic)	Condition H 900 (Magnetic)	Condition H 1075 (Magnetic)	Condition H 1150 (Magnetic)
Density, lbs/in ³ (g/cm ³)	0.28 (7.78)	0.282 (7.80)	0.283 (7.81)	0.284 (7.82)
Electrical Resistivity, microhm-cm	98	77	—	—
Specific Heat Btu/lb/°F (32 - 212°F) kJ/kg•K (0 - 100°C)	0.11 (0.46)	0.11 (0.46)		
Thermal Conductivity BTU/hr/ft ² /in/°F (W/m•K)				
300°F (149°C)		124 (17.9)		
500°F (260°C)		135 (19.5)		
860°F (460°C)		156 (22.5)		
900°F (482°C)		157 (22.6)		
Mean Coefficient of Thermal Expansion in/in/°F (μm/m•K)				
−100 - 70°F (−73 - 21°C)	—	5.8 x 10 ^{−6} (10.4)	—	6.1 x 10 ^{−6} (11.0)
70 - 200°F (21 - 93°C)	6.0 x 10 ^{−6} (10.8)	6.0 x 10 ^{−6} (10.8)	6.3 x 10 ^{−6} (11.3)	6.6 x 10 ^{−6} (11.9)
70 - 400°F (21 - 204°C)	6.0 x 10 ^{−6} (10.8)	6.0 x 10 ^{−6} (10.8)	6.5 x 10 ^{−6} (11.7)	6.9 x 10 ^{−6} (12.4)
70 - 600°F (21 - 316°C)	6.2 x 10 ^{−6} (11.2)	6.3 x 10 ^{−6} (11.3)	6.6 x 10 ^{−6} (11.9)	7.1 x 10 ^{−6} (12.8)
70 - 800°F (21 - 427°C)	6.3 x 10 ^{−6} (11.3)	6.5 x 10 ^{−6} (11.7)	6.8 x 10 ^{−6} (12.2)	7.2 x 10 ^{−6} (13.0)
70 - 900°F (21 - 482°C)	—	—	—	7.3 x 10 ^{−6} (13.1)
Modulus of Elasticity, psi (MPa)		28.5 x 10 ⁶ (197 x 10 ³)		
Modulus of Rigidity, in Torsion, ksi (MPa)	9.68 x 10 ³ (67 x 10 ³)	11.00 x 10 ³ (76 x 10 ³)	—	10.10 x 10 ³ (70 x 10 ³)
Poisson's Ratio (all conditions)		0.272		

Dimensional Change in Hardening

As indicated by the density values, AK Steel 17-4 PH Stainless Steel undergoes a volume contraction when it is hardened. This produces a predictable change in dimensions that must be taken into consideration if parts made of this alloy must be manufactured to close tolerances.

The dimensional contraction in hardening Condition A material to Condition H 900 amounts to 0.0004 - 0.0006 inches per inch (0.0004 - 0.0006 mm per mm). Hardening to Condition H 1150 produces a contraction of 0.0008 - 0.0010 inches per inch (0.0008 - 0.0010 mm per mm). Dimensional changes for other conditions are related to the hardening temperature used.

Figure 2
Dimensional Change in Hardening



Corrosion Resistance

AK Steel 17-4 PH Stainless Steel provides excellent corrosion resistance. It withstands corrosive attack better than any of the standard hardenable stainless steels and is comparable to Type 304 in most media. This has been confirmed by actual service in a wide variety of corrosive conditions in the petrochemical, petroleum, paper, dairy and food processing industries, and in applications such as boat shafting. Additional proof of its durability is the replacement of chromium-nickel stainless steels and high-alloy non-ferrous metals by this alloy for a broad range of parts requiring excellent resistance to corrosion.

Laboratory Tests

Hundreds of laboratory corrosion tests have been conducted on AK Steel 17-4 PH Stainless Steel to provide data for comparison with other stainless steels. As chemically pure reagents were used, the data are useful as a guide to the comparative ranking of this alloy with the other materials, but are not a measure of their performance under actual operating conditions. Typical corrosion rates for the material in a variety of media are listed in the following table along with comparable data for Type 304.

In general, the corrosion resistance of AK Steel 17-4 PH Stainless Steel is similar to Type 304 in the media tested, depending on heat-treated conditions. For specific applications, see the details of Table 9 or conduct pilot corrosive tests.

Table 9

Corrosion Rates of AK Steel 17-4 PH in Various Chemical Media

Chemical Medium	Concentration %	Temp. °C	Corrosion Rate, mils per year (a)				
			H 925	AK Steel 17-4 PH (b)			Type 304 (b) Annealed
H ₂ SO ₄	1	35	Nil	Nil	Nil	Nil	28
	2		Nil	Nil	Nil	Nil	57
	5		4	7	11	9	240
	1	80	1	1	1	1	350
	2		8	9	13	17	480
	98	35	Nil	Nil	Nil	Nil	—
	98	80	5	5	7	6	—
HCl	1/2	35	2	2	3	16	33
	1		35	174	518	650	240
HNO ₃	25	Boiling	14	6	7	8	2
	50		70	35	47	31	4
	65		125	85	107	79	10 (c)
Formic Acid	5	80	3	1	1	2	81
	10		2	3	3	5	100
Acetic Acid	33	Boiling	6	6	4	4	300
	60		2	2	2	2	250
H ₃ PO ₄	2-1/2	Boiling	Nil	Nil	Nil	Nil	Nil
	20		1	1	1	2	2
	50		4	4	3	5	7 (c)
	70		86	57	60	119	32 (c)
NaOH	30	80	5	5	7	8	Nil
	50		3	3	4	5	1
	30	Boiling	8	7	11	11	68 (1)
	50		480 (1)	450 (1)	560 (1)	560 (1)	80 (1)
Ammonium Hydroxide	10	Boiling	Nil	Nil	Nil	Nil	Nil
10% HNO ₃ - 1% HF	—	35	1500	1500	1500	1500	380
10% HNO ₃ - 3% HF	—		4300	4300	4300	4300	840
Cola Soft Drink Syrup	Concentrated	35	Nil	Nil	Nil	Nil	Nil
Salt-Sugar-Vinegar	—	Boiling	Nil	Nil	Nil	Nil	Nil

(a) Rates were determined by total immersion of 5/8" (15.8 mm) diameter x 5/8" (15.8 mm) long cylindrical test specimens for five 48-hour periods. Specimens were electrolytically activated for the last three periods except for the boiling 65 percent nitric acid test and also for Type 304 bar in boiling sodium hydroxide. For Type 304 bar, passive periods were not averaged. In most cases, where rates of replicates varied, the highest is given. Other exceptions to all of foregoing are marked. (b) Numbers in parentheses indicate the number of periods in testing. Nil - indicates rates of less than 1 mil/year. (c) Rates increase from period to period. Rate is average of 5 periods.

Data Reference: J. J. Halbig & O. B. Ellis, "Observations on Corrosion Resistance of High Strength Stainless Steels for Aircraft," *Corrosion*, Vol 14., pp. 389t-395t (1958)

Atmospheric Exposure

In rural and mild industrial atmospheres, AK Steel 17-4 PH Stainless Steel has excellent resistance to general corrosion in all heat-treated conditions. It is equivalent to Type 304 stainless steel in these environments. The alloy exposed to seacoast atmosphere will gradually develop overall light rusting and pitting in all heat-treated conditions. It is almost equal to Type 304 and much better than the standard hardenable stainless steels in this environment.

Seawater Exposure

The combination of high mechanical strength and good corrosion resistance makes this alloy well suited for many marine applications such as valve and pump parts. However, in common with other stainless steels, the material is subject to crevice attack if exposed to stagnant seawater for any length of time. If equipment exposed to seawater is not operated continuously, cathodic protection is highly desirable to prevent such attack.

Stress Corrosion Cracking

Stress corrosion cracking, although occurring infrequently, can be a source of failure in stainless steels. It usually takes place in highly stressed parts that are exposed under conditions that permit local concentration of chlorides.

Tests using smooth bent beam specimens stressed up to the 0.2% yield strength of the material and exposed to marine atmosphere on the 80-foot lot at Kure Beach, North Carolina, show that AK Steel 17-4 PH Stainless Steel is quite susceptible to stress corrosion cracking when in Condition H 900. In Condition A, and when hardened at temperatures of 1025°F (552°C) and higher; the alloy is highly resistant to stress corrosion cracking. In addition, many years of service experience in marine atmospheres and in high-purity water at high temperatures demonstrate the resistance of the alloy to this type of failure.

For maximum resistance to chloride stress corrosion cracking, the alloy should be hardened at the highest aging temperature that will yield required properties, but not less than 1025°F (552°C).

Another set of smooth bent beam specimens involving welded 17-4 PH Stainless Steel in Conditions H 900, H 1025, H 1075 and H 1150 were stressed at 90% of the 0.2% yield strength of the material and exposed to a marine atmosphere on the 80-foot lot at Kure Beach, North Carolina. The samples were divided into three groups:

1. Not Welded (Solution Treated + Aged)
2. Solution Treated + Welded + Aged
3. Welded + Solution Treated + Aged

All specimens in Condition H 900 failed in 68 days or less, regardless of whether welded or not. None of the other specimens failed after more than 25 years in test.

In addition, welded specimens were made by fusing 2" (50.8 mm) diameter circular weld beads onto one face of 1/4" (6.35 mm) thick AK Steel 17-4 PH plate. After welding and final heat treatment, the surfaces were ground to a smooth finish. The internal stresses caused by welding are very high and can equal or exceed the yield strength of the material. These specimens were exposed to quiet seawater at Wrightsville Beach, North Carolina. The welding and heat-treating conditions were as follows:

1. Solution Treated + Aged to Conditions H 1025, H 1075, H 1150 + Welded.
2. Welded + Solution Treated + Aged to Conditions H 1025, H 1075, H 1150.
3. Solution Treated + Welded + Aged to Conditions H 1025, H 1075, H 1100.

Careful examination showed there was no evidence of stress corrosion cracking in any of the test specimens after one year in test.

Table 10

Stress Corrosion Cracking*

Condition	Applied Stress, ksi (MPa)		Time to Failure**
A (Heat 2)	124	(855) – 100% YS	3NF
	93	(641) – 75% YS	3NF
H 900 (Heat 2)	187	(1289) – 100% YS	2-21 days, 1-37 days
	140	(965) – 75% YS	1-21 days, 1-28 days, 1-35 days
H 925 (Heat 2)	173	(1193) – 100% YS	1-61 months, 1-139 months, 1NF
	130	(896) – 75% YS	1-53 months, 1-52 months, 1NF
H 975 (Heat 2)	168	(1158) – 100% YS	3NF
	126	(869) – 75% YS	1-78 months, 2 NF
H 1025 (Heat 1)	140	(965) – 90% YS	5NF
	116	(800) – 75% YS	5NF
H 1075 (Heat 1)	135	(931) – 90% YS	5NF
	113	(779) – 75% YS	5NF
H 1150 (Heat 1)	102	(703) – 90% YS	5NF
	85	(586) – 75% YS	5NF

*Smooth bent beam strip specimens were exposed on the 80' lot at Kure Beach, NC. Five replicates of 0.090" (2.3 mm) thick strip from Heat 1 were exposed on May 23, 1960. Samples of 0.062" (1.6 mm) thick strip from Heat 2 were exposed in triplicate in each heat-treated condition shown on June 5, 1973.

**NF indicates No Failure as of September 1985.

Hydrogen Embrittlement

Hydrogen embrittlement is a potential threat to all high-strength martensitic steels wherever the reduction of hydrogen ions to atomic hydrogen may occur. Common-place examples are aqueous corrosion, cathodic protection to prevent corrosion, galvanic coupling with less noble metals and electroplating.

When exposed to 18% HCl-1% SeO₂ solution and stressed to 100,000 psi (690 MPa) in direct tension, AK Steel 17-4 PH Stainless Steel aged at temperatures ranging from 900 to 1050°F (482 to 566°C) failed from hydrogen embrittlement within four hours. Aging at temperatures above 1100°F (593°C) conferred immunity to cracking, while at 1100°F (593°C) a borderline situation existed, with material sometimes resistant to cracking and sometimes not.

Despite the susceptibility of AK Steel 17-4 PH Stainless steel to hydrogen embrittlement that is shown by this severe test, only a few isolated instances of its failure

in service by this mechanism have been recorded. Apparently, under nearly all conditions of use, this alloy possesses adequate resistance to hydrogen embrittlement. Where this problem is acute and strength requirements permit, the alloy should be aged at temperatures of 1100°F (593°C) or higher to ensure freedom from cracking.

Sulfide Stress Cracking

Laboratory tests run in synthetic sour well solution (5% sodium chloride + 1/2% acetic acid saturated with hydrogen sulfide) in accordance with NACE Test Method TM-01-77 show that, for best resistance to this aggressive medium, the alloy should either be in Condition H 1150-M or aged at 1150°F (620°C) for two 4-hour periods. In either of these heat-treated conditions, AK Steel 17-4 PH Stainless Steel is considered by NACE as acceptable for use in sour (sulfide) service and is included in MR-01-75.

Formability

Because AK Steel 17-4 PH Stainless Steel in Condition A is hard, forming normally should be limited to mild operations. However, formability can be greatly improved by heat treating before cold working or by use of hot-forming methods.

Overaging for Cold Forming

Aging by various heat treatments can be used to improve formability in certain operations such as stretch forming. This is indicated by the percent elongation values reported in Table 1. It should be noted, however, in Table 11, that Olsen cup values (used as a relative comparison of drawability) did not show any improvement in overaged samples.

Table 11

Properties and Formability of AK Steel 17-4 PH at Room Temperature

Condition	Property				
	0.2% YS ksi (MPa)	UTS ksi (MPa)	Elongation % in 2" (50.8 mm)	Hardness Rockwell C	Olsen Cup Draw inches (mm)
A	110.0 (758)	156.5 (1078)	6.7	33.0	0.330 (0.838)
H 900 (1 hour)	181.7 (1248)	200.5 (1380)	10.5	44.5	0.250 (0.635)
H 1150 (4 hours)	132.8 (916)	144.5 (996)	13.2	32.5	0.330 (0.838)
Aged at 1300°F (704°C) 2 hours	103.5 (714)	142.7 (983)	9.5	30.0	0.248 (0.630)
Aged at 1400°F (760°C) 2 hours	117.0 (807)	148.5 (1024)	8.7	32.0	0.309 (0.785)
H 1150-M	108.5 (748)	131.0 (903)	16.2	27.5	0.327 (0.830)

The mechanical properties in Table 11 can be used as a guide in selecting the type of cold forming operation to be used for various conditions. In biaxial operations, such as drawing, Condition A may be just as satisfactory as an overaged condition. However, for stretch forming and similar operations, test data indicate an overaged condition such as H 1150 or H 1150-M is preferred.

It should be recognized, also, that when parts are cold formed in an overaged condition, they must be re-solution treated at 1900°F (1038°C) after forming, and

prior to aging to any of the higher strength conditions such as H 900 – *if* the high strength developed by such a heat treatment is needed. If extremely high strength is not needed, AK Steel 17-4 PH Stainless Steel still offers attractive properties as formed in Condition H 1150 or H 1150-M. Yield strength, for example, would be more than twice that obtained in an austenitic grade such as Type 304. However, when severe forming is done in an overaged condition, it is recommended that the formed part be re-aged to relieve residual stresses and restore toughness.

Bend Properties

Table 12 is a summary of bend test data from tests conducted on flat sheets and strip ranging in thickness from 0.015 to 0.109 inches (0.38 to 2.7 mm).

Table 12

Bend Test Data
Minimum Bend Radius*

Condition	90°		135°		180°	
	L	T	L	T	L	T
A	3T	4T	3T	5T	6T	9T
H 900	3T	4T	3T	6T	5T	9T
H 925	2T	4T	3T	6T	5T	9T
H 1025	2T	4T	3T	6T	4T	7T
H 1075	2T	4T	3T	4T	4T	7T
H 1150	2T	2T	2T	3T	4T	6T

* Expressed as function of sheet thickness. Minimum radius to make indicated bend with no fissuring when viewed under a 10X magnifying glass.

Hot Forming

As indicated by the high elongation shown in Table 13, AK Steel 17-4 PH Stainless Steel can be formed quite readily by first solution treating (austenitizing) at 1900°F (1038°C), then forming during cooling from this temperature while the steel is still austenitic. The preferred temperature range for such forming is at 650 - 900°F (343 - 482°C), which is well above the M_s temperature of the steel (M_s approximately 270°F (132°C)). Mechanical properties of hot-formed parts subsequently hardened are not significantly different from those obtained by standard heat treatments.

Table 13

Mechanical Properties of AK Steel 17-4 PH
Heated to 1900°F (1038°C)
Tests at Temperature During Cool Down

Test Temp. °F (°C)	0.2% YS ksi, (MPa)	UTS ksi, (MPa)	Elongation % in 2" (50.8 mm)	Hardness – RC	
				Cooled to RT	Aged at 900°F (482°C)
400 (204)	20.2 (139)	143.5 (990)	8.0	35.0	43.0
500 (260)	23.0 (159)	125.5 (865)	24.0	37.0	44.0
550 (288)	25.7 (177)	122.8 (847)	27.0	36.5	43.5
600 (316)	25.1 (173)	122.0 (841)	26.5	37.0	44.0
650 (343)	25.6 (176)	108.0 (745)	42.5	36.5	44.0
700 (371)	25.7 (177)	101.2 (698)	51.0	37.0	44.0
750 (399)	24.9 (171)	87.2 (600)	63.0	36.5	43.5
800 (427)	24.6 (649)	94.2 (649)	85.0	37.0	43.0
900 (482)	24.1 (166)	63.0 (434)	43.0	35.0	42.5

Table 14

Room Temperature Properties of AK Steel 17-4 PH
Stretched on Cooling from Solution Treatment Temperature

Hot Forming Test Temp. °F (°C)	% Stretch in 2" (50.8 mm)	Aging Temperature (4 hrs) °F (°C)	0.2% YS ksi (MPa)	UTS ksi (MPa)	Elongation % in 2" (50.8 mm)
500 (260)	9.0	900 (482)	198.0 (1365)	202.2 (1393)	9.0
650 (343)	16.0	900 (482)	168.7 (1152)	190.8 (1314)	9.0
650 (343)	20.0	900 (482)	171.8 (1185)	190.5 (1313)	9.0
650 (343)	33.5	None	133.6 (921)	162.4 (1117)	6.0
650 (343)	35.0	900 (482)	181.4 (1248)	194.6 (1338)	7.5
650 (343)	35.0	1050 (566)	155.0 (1069)	160.0 (1103)	7.5
800 (427)	22.0	900 (482)	166.6 (1146)	178.4 (1232)	11.0
800 (427)	42.0	None	116.0 (800)	155.8 (1073)	7.0
800 (427)	47.5	900 (482)	176.0 (1214)	190.0 (1310)	8.0
Standard H 900	—	—	173.8 (1194)	195.0 (1345)	11.0

Olsen cup values for AK Steel 17-4 PH Stainless Steel are given in Table 15 at room temperature as well as hot forming temperatures. Also included for comparison are properties for AK Steel 17-7 PH Stainless Steel in Condition A

(a readily formed precipitation-hardening stainless steel developed by AK Steel). The benefits of hot forming AK Steel 17-4 PH Stainless Steel are quite apparent.

Table 15

Olsen Cup Draw Tests on AK Steel 17-4 PH and AK Steel 17-7 PH Stainless Steels
at Room and Elevated Temperatures

Grade	Condition	Thickness inches (mm)	Test Temperature	Depth of Olsen Cup Draw inches (mm)
17-4 PH	A	0.030 (0.076)	R. T.	0.260 to 0.290 (6.6 to 7.4)
17-4 PH	Aged at 1200°F (649°C)	0.030 (0.076)	R. T.	0.240 (6.1)
17-4 PH	A	0.030 (0.076)	Hot*	0.350 to 0.400 (8.9 to 10.0)
17-7 PH	A	0.030 (0.076)	R. T.	0.350 to 0.380 (8.9 to 9.6)

*Solution treated at 1900°F (1038°C), then transferred hot to Olsen machine for cup test. Strip temperature at start of test approximately 1000°F (538°C).

Weldability

The precipitation hardening class of stainless steels is generally considered to be weldable by the common fusion and resistance techniques. Special consideration is required to achieve optimum mechanical properties by considering the best heat-treated conditions in which to weld and which heat treatments should follow welding. This particular alloy is the most common member of the class and is generally considered to have the best weldability. When a weld filler is needed, AWS E/ER 630 is most often specified. AK Steel 17-4 PH Stainless Steel is well known in reference literature and more information can be obtained in the following ways:

1. ANSI/AWS A 5.9, A 5.22, and A 5.4 (filler metals, minimum UTS and elongation).
2. "Welding AK Steel Stainless Steels," FDB #SF-1.

Heat Treatment

For maximum hardness and strength, material in the solution-treated condition is heated for one hour at $900^{\circ}\text{F} \pm 15^{\circ}\text{F}$ ($482^{\circ}\text{C} \pm 8.4^{\circ}\text{C}$) and air cooled to room temperature. If the material is purchased in the solution-treated condition (Condition A) and not subsequently hot worked, the hardening treatment can be performed without solution treating before hardening.

Where ductility in the hardened condition is of importance, better toughness can be obtained by raising the temperature of the hardening heat treatment. Unlike regular hardenable materials that require hardening plus a tempering or stress relieving treatment, this alloy can be hardened to the final desired properties in one operation. By varying the heat-treating procedure between $900 - 1150^{\circ}\text{F}$ ($482 - 621^{\circ}\text{C}$) for one to four hours, a wide range of properties can be attained.

If the alloy is not sufficiently ductile in any given hardened condition, it can be reheated at a higher hardening temperature to increase impact strength and elongation. This can be accomplished without a solution treatment prior to final heat treatment. However, strength will be reduced.

For hot-worked or overaged material, a solution treatment at $1875 - 1925^{\circ}\text{F}$ ($1024 - 1052^{\circ}\text{C}$) for three minutes for each 0.1" (2.5 mm) of thickness, followed by cooling to at least 90°F (32°C) must be done prior to hardening. The solution treatment refines the grain size and makes hardened material more uniform.

When fabricating AK Steel 17-4 PH Stainless Steel, it is important to keep in mind the low temperatures at which the start of transformation to martensite (M_s) and the completion of the martensite transformation (M_f) occur. These temperatures are approximately 270°F (132°C) and 90°F (32°C) respectively.

Because of this characteristic, it is necessary to cool parts in process at least to 90°F (32°C) prior to applying subsequent heat treatments if normal final properties are to be obtained. This practice is essential to assure grain refinement and to assure good ductility.

Descaling

Hardening treatments produce only a light heat tint on surfaces. This tint can be removed easily by mechanical means such as wet grit blasting or with a short pickle in 10% nitric - 2% hydrofluoric acid (by volume) at 110 - 140°F (43 - 60°C). Where pickling is undesirable, heat tint may be removed by a light electro-polishing operation. The latter two treatments also clean and passivate the surfaces for maximum corrosion resistance.

Where solution treating is performed, the following pickling method satisfactorily removes surface scale. The use of molten salts such as sodium hydride or Kolene processes to descale is limited since these methods partially harden solution-treated material.

Procedure	Acid Bath	Temperature °F (°C)	Time at Temperature Minutes	Rinse
Step 1	Caustic Permanganate	160 - 180 (71 - 82)	60	Water rinse
Step 2	10% Nitric Acid + 2% Hydrofluoric Acid	110 - 140 (43 - 60)	2 - 3	Hot water, high-pressure water, or brush scrub

In pickling operations, close control of time and temperature is necessary to obtain uniform scale removal without over-etching. Scale softening methods may be used on material that has been solution treated (not pickled) and precipitation hardened.

Specifications

The following specifications are listed without revision indications. Contact ASTM Headquarters for latest ASTM revision. For AMS revision, contact AMS Division of SAE.

AMS 5604 Sheet, Strip and Plate
ASTM A 693 Plate, Sheet and Strip
(Listed as Grade 630 - UNS S17400)



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