CLIFFS

17-4 PH®

STAINLESS STEEL

Aerospace

Food Processing

Petrochemical

Metalworking

CLEVELAND-CLIFFS 17-4 PH® STAINLESS STEEL 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.

Product Description

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

Composition		(wt %)
Carbon	(C)	0.07 max.
Manganese	(Mn)	1.00 max.
Phosphorus	(P)	0.040 max.
Sulfur	(S)	0.030 max.
Silicon	(Si)	1.00 max.
Chromium	(Cr)	15.00 – 17.50
Nickel	(Ni)	3.00 – 5.00
Copper	(Cu)	3.00 – 5.00
Niobium*	(Nb)	0.15 – 0.45

**ASTM A693 requirements call for Niobium plus Tantalum (Ta) = 0.15 – 0.45. Cleveland-Cliffs makes no intentional Ta addition.*

AVAILABLE FORMS

Cleveland-Cliffs 17-4 PH Stainless Steel is produced in sheet and strip thicknesses from 0.015 – 0.125 in. (0.38 – 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.

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 A693 Plate, Sheet and Strip
(Listed as Grade 630 - UNS S17400)

METRIC PRACTICE

The values shown in this bulletin were established in U.S. customary units. The metric equivalents may be approximate.

Standard Heat Treatments

As supplied from the Mill in Condition A, Cleveland-Cliffs 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 conducted at an exposed marine atmosphere on an 80 ft. (24.4 m) lot, 82 ft. (25 m) from the waterline, show excellent stress corrosion resistance. Condition A material 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.

TABLE 1 – STANDARD HEAT TREATMENTS

Condition A Solution Treated at 1900 °F ± 25 °F (1038 °C ±14 °C)
or Air cool below 90 °F (32 °C)

Condition	Heat To ± 15 °F (8.4 °C)	Time at Temperature, hrs.	Type of Cooling
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) 1150 °F (621 °C)	4 followed by 4	Air Air
H 1150-M	1400 °F (760 °C) 1150 °F (621 °C)	2 followed by 4	Air Air

Mechanical Properties

Cleveland-Cliffs 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 2 – TYPICAL MECHANICAL PROPERTIES

Transverse Property	Condition						
	A	H 900	H 925	H 1025	H 1075	H 1150	H 1150-M
UTS, ksi. (MPa)	160 (1103)	200 (1379)	190 (1310)	170 (1172)	165 (1138)	150 (1034)	137 (945)
0.2% YS, ksi. (MPa)	115 (793)	185 (1275)	175 (1207)	165 (1138)	160 (1103)	130 (896)	111 (765)
Elongation % in 2 in. (50.8 mm)	5	9	9	10	11	12	17
Rockwell Hardness, C	35	45	43	38	37	33	31

TABLE 3 – PROPERTIES ACCEPTABLE FOR MATERIAL SPECIFICATION*

Property	Condition						
	A	H 900	H 925	H 1025	H 1075	H 1150	H 1150-M
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 in. (50.8 mm)	3 min.	5 min.	5 min.	5 min.	5 min.	5 min.	8 min.
Rockwell Hardness, C	38 max.	40 – 48	38 – 46	35 – 43	31 – 40	31 – 40	28 –38

Sheets and strip.

TABLE 4 – 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)	Bearing Yield Strength**, ksi. (MPa)	Bearing Strength**, 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 in. (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.

Mechanical Properties

ELEVATED TEMPERATURE PROPERTIES

Mechanical Properties of Cleveland-Cliffs 17-4 PH Stainless Steel 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 6, 7, and 8).

TABLE 5 – EFFECT OF ELEVATED TEMPERATURE EXPOSURE ON MECHANICAL PROPERTIES – CONDITION H 1150

Exposure Temp. °F (°C)	Time hrs.	Test Temperatures: Room Temperature			Test Temperatures: 600 °F (316 °C)			Test Temperatures: 750 °F (399 °C			Prenotched Charpy W/A, in.•lbs/in². (N/mm²)	
		UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elong % in 2 in. (50.8 mm)	UTS, ksi. (MPa)	0.2% YS ksi. (MPa)	Elong % in 2 in. (50.8 mm)	UTS, ksi. (MPa)	0.2% YS ksi. (MPa)	Elong % in 2 in. (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 (1021)	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.*

Mechanical Properties

TABLE 6 – 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 (1488)	210 (1488)	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 in. (50.88 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 in. (50.88 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 in. (50.88 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 in. (50.88 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 in. (50.88 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 (1100)	162 (1117)	–
	0.2% YS, ksi. (MPa)	121 (834)	121 (834)	122 (841)	121 (834)	126 (869)	128 (882)	–
	Elong. % in 2 in. (50.88 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 in. (50.88 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 in. (50.88 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 in. (50.8 mm) – 8.5

TABLE 7 – EFFECT OF SHORT-TIME EXPOSURE AT 1400 °F (760 °C) ON MECHANICAL PROPERTIES – CONDITION H 1150

Exposure 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 in. (50.88 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 in. (50.88 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 in. (50.8 mm) – 12.0

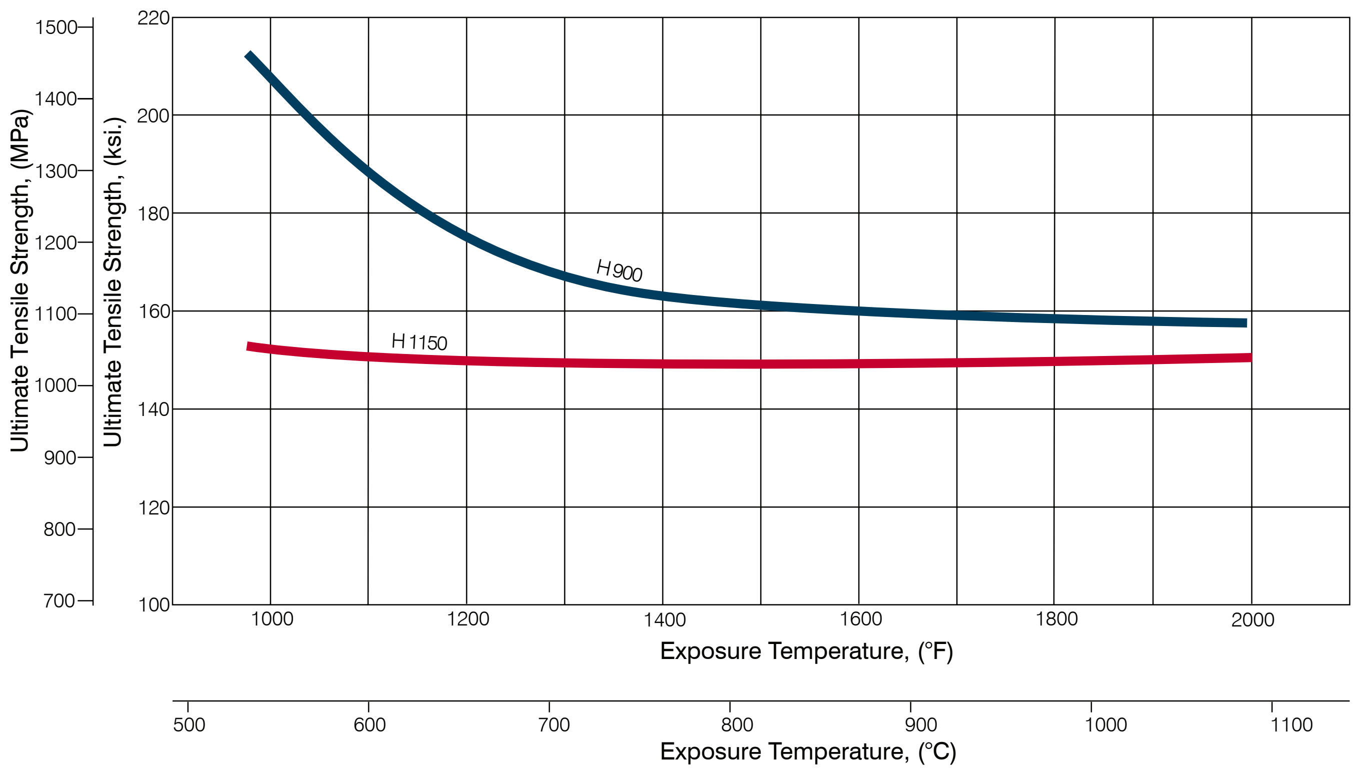
Mechanical Properties

TABLE 8 –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 in. (50.88 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)	26.6. (179)	12.7 (87)
	Elong. % in 2 in. (50.88 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 in. (50.8 mm) – 12.0

FIGURE 1 – EFFECT OF 30 SECOND ELEVATED TEMPERATURE EXPOSURE ON ROOM TEMPERATURE PROPERTIES



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

TABLE 9 – PHYSICAL PROPERTIES

	Condition			
	A (Magnetic)	H 900 (Magnetic)	H 1075 (Magnetic)	H 1150 (Magnetic)
Density, lbs./in³ (g/cm³)	0.28 (7.78)	0.282 (7.80)	0.283 (7.81)	0.284 (7.82)
Electrical Resistivity, μΩ•cm	98	77	–	–
Specific Heat, BTU/lbs./°F (kJ/kg/K) 32 – 212 °F (0 – 100 °C)	0.11 (0.46)	0.11 (0.46)	–	–
Thermal Conductivity, BTU/hr./ft²/°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)	–	5.8×10^{-6} (10.4)	–	6.1×10^{-6} (11.0)
70 – 200 °F (21 – 93 °C)	6.0×10^{-6} (10.8)	6.0×10^{-6} (10.8)	6.3×10^{-6} (11.3)	6.6×10^{-6} (11.9)
70 – 400 °F (21 – 204 °C)	6.0×10^{-6} (10.8)	6.0×10^{-6} (10.8)	6.5×10^{-6} (11.7)	6.9×10^{-6} (12.4)
70 – 600 °F (21 – 316 °C)	6.2×10^{-6} (11.2)	6.3×10^{-6} (11.3)	6.6×10^{-6} (11.9)	7.1×10^{-6} (12.8)
70 – 800 °F (21 – 427 °C)	6.3×10^{-6} (11.3)	6.5×10^{-6} (11.7)	6.8×10^{-6} (12.2)	7.2×10^{-6} (13.0)
70 – 900 °F (21 – 482 °C)	–	–	–	7.3×10^{-6} (13.1)
Modulus of Elasticity, ksi. (MPa)	–	28.5×10^{6} (197×10^{3})	–	–
Modulus of Rigidity, in Torsion, ksi. (MPa)	9.68×10^{3} (67×10^{3})	11.00×10^{3} (76×10^{3})	–	10.10×10^{3} (70×10^{3})
Poisson's Ratio (all conditions)	–	0.272	–	–

Dimensional Change

DIMENSIONAL CHANGE IN HARDENING

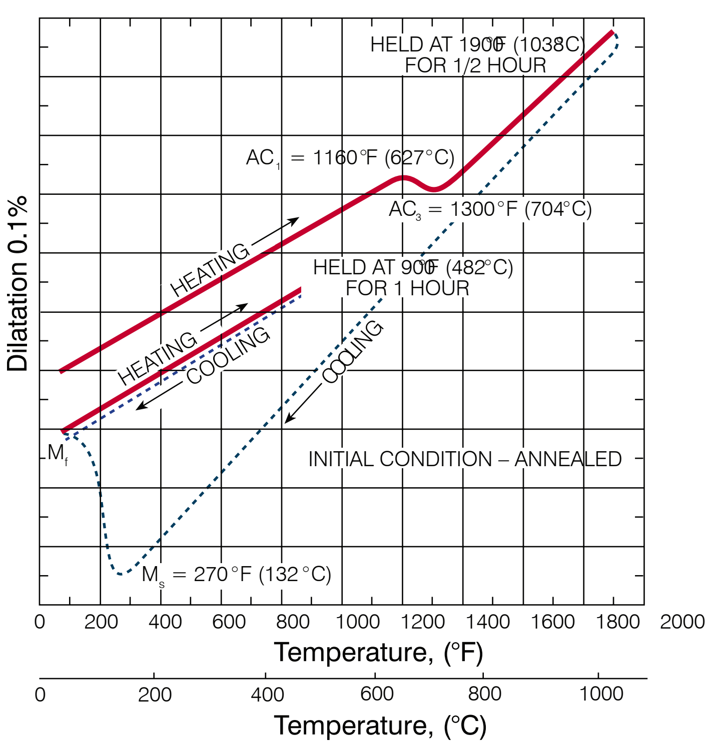
As indicated by the density values, Cleveland-Cliffs 17-4 PH Stainless Steel undergoes a volume contraction when it is hardened. This produces a predictable change in dimensions that must be taken into consideration if parts made of this alloy must be manufactured to close tolerances.

TABLE 10 – CONTRACTION FROM HEAT TREATMENT

Condition	Contraction, in./in. (mm/mm)
H 900	0.00045
H 925	0.00051
H 1025	0.00053
H 1100	0.0009
H 1150	0.0022
H 1150-M	1400 ——> 0.00037
	1150 ——> 0.00206
	∴1400 + 1150 ——> 0.00243

Data represent single tests from one heat.

FIGURE 2 – DIMENSIONAL CHANGE IN HARDENING



Corrosion Resistance

CORROSION RESISTANCE

Cleveland-Cliffs 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 Cleveland-Cliffs 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 Table 11 along with comparable data for Type 304.

In general, the corrosion resistance of Cleveland-Cliffs 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 11 or conduct pilot corrosive tests.

ATMOSPHERIC EXPOSURE

In rural and mild industrial atmospheres, Cleveland-Cliffs 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

TABLE 11 – CORROSION RATES OF CLEVELAND-CLIFFS 17-4 PH STAINLESS STEEL IN VARIOUS CHEMICAL MEDIA

Chemical Medium	Concentration, %	Temp., °C	Corrosion Rate, mils per year (a)				
			Cleveland-Cliffs 17-4 PH SS (b)				Type 304 (b)
			H 925	H 1025	H 1075	H 1150	Annealed
H_2SO_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	0.5	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_3PO_4	2.5	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	450	560	560	80 (1)
			(1)	(1)	(1)	(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 0.625 in. (15.8 mm) diameter x 0.625 in. (15.8 mm) long cylindrical test specimens for five 48-hr 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)

Corrosion Resistance

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 ft. (24.4 m) lot, 82 ft. (25 m) from the waterline, show that Cleveland-Cliffs 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 Cleveland-Cliffs 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 ft. (24.4 m) lot, 82 ft. (25 m) from the waterline. 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 in. (50.8 mm) diameter circular weld beads onto one face of 1/4 in. (6.35 mm) thick Cleveland-Cliffs 17-4 PH Stainless Steel 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 12 – STRESS CORROSION CRACKING*

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

*Smooth bent beam strip specimens were exposed on the 80 ft. (24.4 m) lot, 82 ft. (25 m) from the waterline. Five replicates of 0.090 in. (2.3 mm) thick strip from Heat 1 were exposed. Samples of 0.062 in. (1.6 mm) thick strip from Heat 2 were exposed in triplicate in each heat-treated condition.
**NF indicates No Failure after 15 years of exposure.

Corrosion Resistance

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. Commonplace examples are aqueous corrosion, cathodic protection to prevent corrosion, galvanic coupling with less noble metals and electroplating.

When exposed to 18% HCl-1% SeO_2 solution and stressed to 100,000 ksi. (690 MPa) in direct tension, Cleveland-Cliffs 17-4 PH Stainless Steel aged at temperatures ranging from 900 – 1050 °F (482 – 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 Cleveland-Cliffs 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, Cleveland-Cliffs 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 Cleveland-Cliffs 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 2. It should be noted, however, in Table 13, that Olsen cup values (used as a relative comparison of drawability) did not show any improvement in overaged samples.

TABLE 13 – PROPERTIES AND FORMABILITY OF CLEVELAND-CLIFFS 17-4 PH STAINLESS STEEL AT ROOM TEMPERATURE*

Condition	0.2% YS, ksi. (MPa)	UTS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)	Rockwell Hardness, C	Olsen Cup Draw, in. (mm)
A	110.0 (758)	156.5 (1078)	6.7	33	0.330 (0.838)
H 900 (1 hr.)	181.7(1248)	200.5 (1380)	10.5	45	0.250 (0.635)
H 1150 (4 hrs.)	132.8 (916)	144.5 (996)	13.2	33	0.330 (0.838)
Aged at 1300 °F (704 °C) 2 hrs.	103.5 (714)	142.7 (983)	9.5	30	0.248 (0.630)
Aged at 1400 °F (760 °C) 2 hrs.	117.0 (807)	148.5 (1024)	8.7	32	0.309 (0.785)
H 1150-M	108.5 (748)	131.0 (903)	16.2	28	0.327 (0.830)

**Average of duplicate tests.*

The mechanical properties in Table 13 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, Cleveland-Cliffs 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.

Properties

BEND PROPERTIES

Table 14 is a summary of bend test data from tests conducted on flat sheets and strip ranging in thickness from 0.015 – 0.109 in. (0.38 – 2.7 mm).

TABLE 14 – BEND TEST DATA MINIMUM BEND RADIUS*

Condition	90°		135°		189°	
	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 10X magnifying glass.*

HOT FORMING

As indicated by the high elongation shown in Table 15, Cleveland-Cliffs 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 15 – MECHANICAL PROPERTIES OF CLEVELAND-CLIFFS 17-4 PH STAINLESS STEEL

Heated to 1900 °F (1038 °C)
Tests at Temperature During Cool Down

Test Temperature, °F (°C)	0.2% YS, ksi. (MPa)	UTS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)	Rockwell Hardness, C	
				Cooled to RT	Aged at 900 °F (482 °C)
400 (204)	20.2 (139)	143.5 (990)	8.0	35	43
500 (260)	23.0 (159)	125.5 (865)	24.0	37	44
550 (288)	25.7 (177)	122.8 (847)	27.0	37	44
600 (316)	25.1 (173)	122.0 (841)	26.5	37	44
650 (343)	25.6 (176)	108.0 (745)	42.5	37	44
700 (371)	25.7 (177)	101.2 (698)	51.0	37	44
750 (339)	24.9 (171)	87.2 (600)	63.0	37	44
800 (427)	24.6 (649)	94.2 (649)	85.0	37	44
900 (482)	24.1 (166)	63.0 (434)	43.0	35	43

Properties

TABLE 16 – ROOM TEMPERATURE PROPERTIES OF CLEVELAND-CLIFFS 17-4 PH STAINLESS STEEL

Stretched on Cooling from Solution Treatment Temperature

Hot Forming Test Temp., °F (°C)	% Stretch in 2 in. (50.8 mm)	Aging Temperature, (4 hrs) °F (°C)	0.2% YS, ksi. (MPa)	UTS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)
500 (260)	9.0	900 (482)	198.0 (1365)	202.2 (1339)	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 Cleveland-Cliffs 17-4 PH Stainless Steel are given in Table 17 at room temperature as well as hot forming temperatures. Also included for comparison are properties for Cleveland-Cliffs 17-7 PH Stainless Steel in Condition A (a readily formed precipitation-hardening stainless steel developed by Cleveland-Cliffs). The benefits of hot forming Cleveland-Cliffs 17-4 PH Stainless Steel are quite apparent.

TABLE 17 – OLSEN CUP DRAW TESTS ON CLEVELAND-CLIFFS 17-4 PH AND CLEVELAND-CLIFFS 17-7 PH STAINLESS STEELS AT ROOM AND ELEVATED TEMPERATURES

Grade	Condition	Thickness, in. (mm)	Test Temperature	Depth of Olsen Cup Draw, in. (mm)
Cleveland-Cliffs 17-4 PH SS	Aged at 1200 °F (649 °C)	0.030 (0.076)	RT	0.240 (61)
Cleveland-Cliffs 17-4 PH SS	A	0.030 (0.076)	RT	0.260 – 0.290 (6.6 – 7.4)
Cleveland-Cliffs 17-4 PH SS	A	0.030 (0.076)	Hot*	0.350 – 0.400 (8.9 – 10.0)
Cleveland-Cliffs 17-7 PH SS	A	0.030 (0.076)	RT	0.350 – 0.380 (8.9 – 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).*

Properties

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. Cleveland-Cliffs 17-4 PH Stainless Steel is well known in reference literature and more information can be obtained in the following ways:

1. ANSI/AWS A5.9, A5.22, and A5.4 (stainless steel filler metals, welding electrode specifications).
2. "Welding of Stainless Steels and Other Joining Methods," SSINA (www.ssina.com).

HEAT TREATMENT

For maximum hardness and strength, material in the solution-treated condition is heated for one hour at 900 °F ± 15 °F (482 °C ± 8.4 °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 °F (482 – 621 °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 °F (1024 – 1052 °C) for three minutes for each 0.1 in. (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 Cleveland-Cliffs 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 electropolishing 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.

TABLE 18 – METHOD FOR POST HEAT TREAT DESCALING

Procedure	Acid Bath	Temperature, °F (°C)	Time at Temperature Minutes	Rinse
Step 1	Caustic Permanganate	160 – 180 (71 – 82)	60	Water
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.

About Cleveland-Cliffs Inc.

Cleveland-Cliffs is the largest flat-rolled steel producer in North America. Founded in 1847 as a mine operator, Cliffs also is the largest manufacturer of iron ore pellets in North America. The Company is vertically integrated from mined raw materials and direct reduced iron to primary steelmaking and downstream finishing, stamping, tooling, and tubing. The Company serves a diverse range of markets due to its comprehensive offering of flat-rolled steel products and is the largest steel supplier to the automotive industry in North America. Headquartered in Cleveland, Ohio, Cleveland-Cliffs employs approximately 25,000 people across its mining, steel and downstream manufacturing operations in the United States and Canada.

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