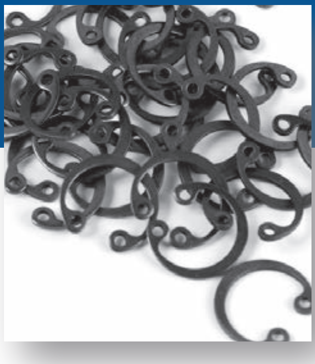
PH15-7 Mo®

STAINLESS STEEL



- **Aircraft Bulkheads**
- **Honeycomb Paneling**
- **Retaining Rings**
- **Springs**

CLEVELAND-CLIFFS PH 15-7 Mo® STAINLESS STEEL is particularly beneficial for a wide range of applications that include retaining rings, springs, diaphragms, aircraft bulkheads, welded and brazed honeycomb paneling and other aircraft components requiring high strength at elevated temperature.

Product Description

Cleveland-Cliffs PH 15-7 Mo Stainless Steel is a semi-austenitic, precipitation-hardening stainless steel that provides high strength and hardness, good corrosion resistance and minimum distortion on heat treatment. It is easily formed in the annealed condition and develops an effective balance of properties by simple heat treatments. For applications requiring exceptionally high strength, Cleveland-Cliffs PH 15-7 Mo Stainless Steel in Condition CH 900 is particularly useful for applications with limited ductility and workability.

In its heat-treated condition, this alloy provides excellent mechanical properties at temperatures up to 900 °F (482 °C). Its corrosion resistance is superior to that of the hardenable chromium types. In some environments, corrosion resistance approximates that of the austenitic chromium-nickel stainless steels. Fabricating practices recommended for other chromium-nickel stain less steels can be used for Cleveland-Cliffs PH 15-7 Mo Stainless Steel.

Composition		(wt %)
Carbon	(C)	0.09 max.
Manganese	(Mn)	1.00 max.
Phosphorus	(P)	0.040 max.
Sulfur	(S)	0.040 max.
Silicon	(Si)	1.00 max.
Chromium	(Cr)	14.00 – 16.00
Nickel	(Ni)	6.50 – 7.75
Molybdenum	(Mo)	2.00 – 3.00
Aluminum	(Al)	0.75 – 1.50

AVAILABLE FORMS

Cleveland-Cliffs PH 15-7 Mo Stainless Steel is produced in sheet and strip in thicknesses from 0.015 – 0.125 in. (0.38 – 3.06 mm). Material is supplied in Condition A, ready for fabrication by the user. Sheet and strip material 0.050 in. (1.27 mm) and thinner may be produced in the hard-rolled Condition C for applications requiring maximum strength.

SPECIFICATIONS

AMS 5520 Sheet, Strip and Plate
ASTM A693 Plate, Sheet and Strip
(Listed as Grade 632 – UNS S15700)

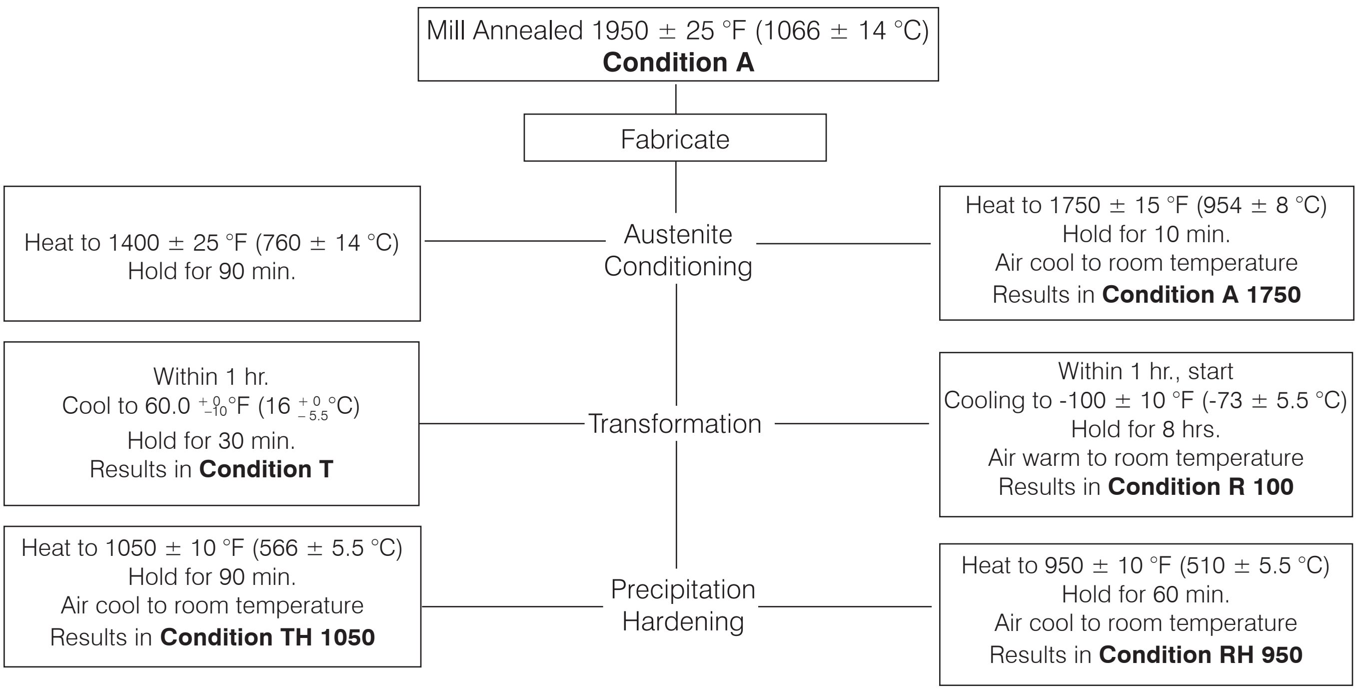
The values shown in this bulletin were established in U.S. customary units. The metric equivalents of U.S. customary units shown may be approximate.

Standard Heat Treatments

Cleveland-Cliffs PH 15-7 Mo Stainless Steel requires three essential steps in heat treating:
1) Austenite conditioning
2) Cooling to transform the austenite to martensite
3) Precipitation hardening

Table 1 presents the procedures for heat treating material in Condition A to Conditions TH 1050 and RH 950.

TABLE 1 – STANDARD HEAT TREATMENTS

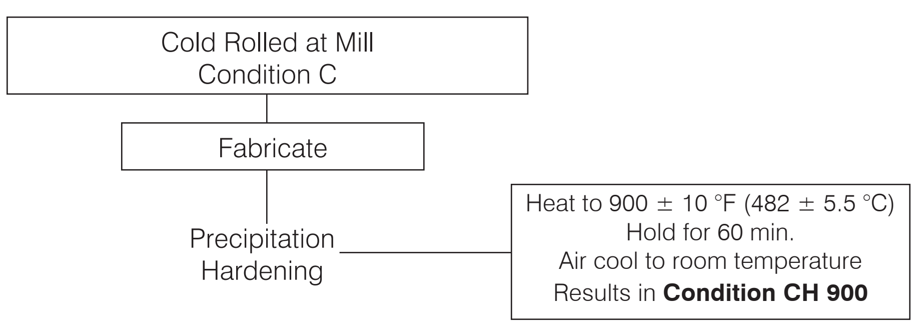


Note: Full TH 1050 properties may not be developed when Cleveland-Cliffs PH 15-7 Mo® Stainless Steel (cold worked) is heat treated to Condition TH 1050. However, full properties will be developed by using one of the following methods:

1) Re-anneal the fabricated part to Condition A and heat treat to Condition TH 1050.
2) Heat treat fabricated part to an RH 1050 Condition.
3) Use a modified TH 1050 heat treatment.
Full strength is developed when heat treating parts to Condition RH 950.

The highest strength levels are obtainable from Cleveland-Cliffs PH 15-7 Mo Stainless Steel. To obtain these properties, Condition A material is transformed to martensite at the mill by cold reduction to Condition C.

Hardening to Condition CH 900 is accomplished with a single, low-temperature heat treatment.



Mechanical Properties

TABLE 2 – TYPICAL MECHANICAL PROPERTIES

Property	Condition							
	A	T	TH 1050	A 1750	R 100	RH 950	C	CH 900
UTS, ksi. (MPa)	130 (896)	145 (1000)	220 (1517)	150 (1034)	180 (1241)	245 (1689)	220 (1517)	265 (1828)
0.2% YS, ksi. (MPa)	55 (372)	90 (620)	205 (1413)	55 (372)	125 (862)	215 (1482)	190 (1310)	260 (1793)
Elongation % in 2 in. (50.8 mm)	33	7	6	12	7	6	5	2
Rockwell Hardness	B88	C28	C45	B85	C40	C49	C45	C50

TABLE 3 – PROPERTIES ACCEPTABLE FOR MATERIAL SPECIFICATION*

Condition	Property					Rockwell Hardness
	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2 in. (50.88 mm)			
			All Gauges	0.020 – 0.1875 in. (0.51 – 4.76 mm)	0.010– 0.0199 in. (0.25 – 0.50 mm)	
A	150 (1034) max.	66 (448) max.	25 min.	—	—	B100 max.
TH 1050	190 (1310) min.	170 (1172) min.	—	5 min.	4 min.	C40 min.
H 925	225 (1552) min.	200 (1379) min.	—	4 min.	3 min.	C46 min.
C	200 (1379) min.	175 (1207) min.	1 min.	—	—	C41 min.
CH 900	240 (1655) min.	230 (1586) min.	1 min.	—	—	C46 min.

**Applies to material 0.010 in. (0.25 mm) and thicker. Selection of hardness scale is determined by material condition and thickness. Where necessary, superficial hardness readings are converted to Rockwell B or C.*

Mechanical Properties

TABLE 4 – TYPICAL ELEVATED TEMPERATURE SHORT-TIME TENSILE PROPERTIES

Property	Temperature °F (°C)						
	75 (24)	300 (149)	600 (316)	700 (371)	800 (427)	900 (482)	100 (538)
UTS, ksi. (MPa)							
Condition TH 1050	212 (1462)	200 (1379)	182 (1255)	175 (1207)	162 (1124)	142 (979)	115 (793)
Condition RH 950	237 (1606)	220 (1517)	200 (1379)	195 (1345)	182 (1255)	160 (1103)	130 (896)
Condition CH 900 Longitudinal	253 (1744)	240 (1655)	220 (1517)	208 (1432)	199 (1372)	184 (1269)	158 (1089)
Transverse	261 (1800)	258 (1778)	238 (1640)	228 (1572)	219 (1510)	202 (1343)	173 (1193)
0.2% YS, ksi. (MPa)							
Condition TH 1050	205 (1404)	195 (1345)	172 (1186)	164 (1131)	150 (1034)	127 (876)	105 (724)
Condition RH 950	220 (1517)	200 (1379)	174 (1200)	165 (1138)	150 (1034)	130 (896)	105 (724)
Condition CH 900 Longitudinal	243 (1675)	225 (1551)	204 (1407)	193 (1331)	181 (1248)	165 (1138)	131 (903)
Transverse	255 (1758)	233 (1607)	211 (1455)	200 (1379)	190 (1310)	175 (1207)	143 (986)
Elongation % in 2 in. (50.8 mm)							
Condition TH 1050	7.0	4.5	4.5	6.0	9.0	14.0	19.0
Condition RH 950	5.0	4.0	5.0	6.0	8.0	10.0	14.0
Condition CH 900	3.0	2.0	1.5	1.5	1.5	2.5	4.0

TABLE 5 – STRESS TO RUPTURE

Property	Temperature °F (°C)			
	600 (316)	700 (371)	800 (427)	900 (482)
In 100 hrs., Stress, ksi. (MPa)				
Condition RH 950	202 (1393)	193 (1331)	174 (1200)	125 (862)
Condition TH 1050	179 (1234)	161 (1110)	139 (958)	108 (745)
In 1000 hrs., Stress, ksi. (MPa)				
Condition RH 950	200 (1379)	191 (1317)	171 (1179)	108 (745)
Condition TH 1050	178 (1227)	159 (1096)	137 (945)	98 (676)

Mechanical Properties

TABLE 6 – CREEP STRENGTH

Stress in ksi. (MPa) to produce	Temperature °F (°C)			
	600 (316)	700 (371)	800 (427)	900 (482)
0.1% permanent deformation in 1000 hrs. Condition RH 950	131.5 (907)	120.5 (831)	95.0 (655)	36.0 (248)
0.2% permanent deformation in 1000 hrs. Condition RH 950	150.1 (1042)	142.0 (979)	109.2 (759)	40.5 (279)

TABLE 7 – ULTIMATE SHEAR STRENGTH

Ultimate shear strength, ksi. (MPa)	Temperature, °F (°C)						
	75 (24)	300 (149)	600 (316)	700 (371)	800 (427)	900 (482)	1000 (538)
Condition TH 1050	143 (986)	130 (896)	116 (800)	110 (758)	104 (717)	96 (662)	80 (552)
Condition RH 950	162 (1117)	145 (1000)	128 (882)	124 (855)	116 (800)	103 (710)	88 (607)

Mechanical Properties

NOTCH TENSILE PROPERTIES

To explore notch sensitivity, tests were performed at 75 °F (24 °C) on sheet specimens. Toughness properties have been developed by using two different test methods: (1) NASA – Edge Notch Tensile and (2) Center Notch Fatigue Crack Tensile. This data has found considerable use in the design of pressure vessels.

FIGURE 1 – MODIFIED NASA EDGE NOTCH TENSILE SPECIMEN

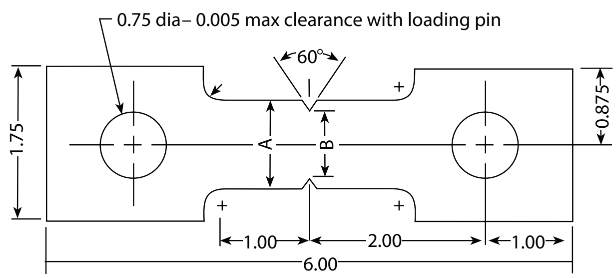


FIGURE 2 – CLEVELAND-CLIFFS CENTER – NOTCH SHEET SPECIMEN

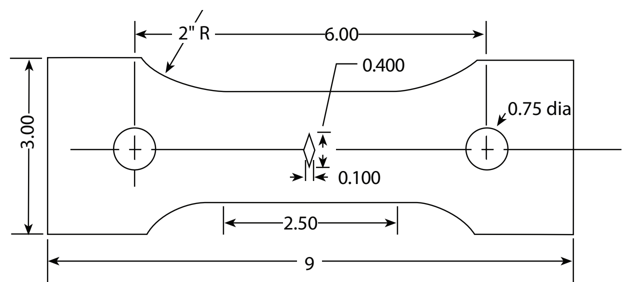


TABLE 8 – CENTER NOTCH – FATIGUE CRACKED TEST*

Condition	0.2% YS, ksi. (MPa)	UTS, ksi. (MPa)	K_c ksi. / in.	Notch Strength, ksi. (MPa)	Notch Strength, YS	Notch Strength, UTS
TH 1050	207 (1420)	214 (1475)	116	125 (862)	0.60	0.58
RH 950	221 (1524)	241 (1662)	102	104 (717)	0.47	0.43
RH 1075	205 (1414)	211 (1455)	132	135 (931)	0.66	0.64
CH 900	269 (1854)	274 (1889)	127	141 (972)	0.52	0.51
CH 1050	249 (1716)	257 (1772)	151	152 (1048)	0.61	0.59

**2 x 0.050 in. (50.8 x 1.27 mm) (wide x thick). Samples tested in the transverse direction.*

TABLE 9 – NASA EDGE NOTCH*

Condition	0.2% YS, ksi. (MPa)	UTS, ksi. (MPa)	Notch Strength, ksi. (MPa)	Notch Strength, YS	Notch Strength, UTS
RH 950	228 (1571)	247 (1703)	108 (745)	0.47	0.44
RH 1000	230 (1586)	243 (1675)	140 (965)	0.61	0.58
RH 1050	220 (1517)	227 (1565)	162 (1117)	0.74	0.71
RH 1100	182 (1255)	192 (1324)	174 (1200)	0.96	0.91

**0.063 in. (1.6 mm) material. 1 in. (25.4 mm) wide, 0.0007 in. (0.018 mm) max. root radius. Data courtesy NASA – Lewis labs. Samples tested in the transverse direction.*

Physical Properties

FORMABILITY

Cleveland-Cliffs PH 15-7 Mo Stainless Steel in Condition A can be formed comparably to Type 301. It work hardens rapidly, and may require intermediate annealing in deep drawing or in forming intricate parts. Springback is similar to that of Type 301.

This alloy is extremely hard and strong in Condition C. Therefore, fabrication techniques for such materials must be used.

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 generally considered to have poorer weldability compared to the most common alloy of this stainless class, Cleveland-Cliffs 17-4 PH Stainless Steel. A major difference is the high Al content of this alloy, which degrades penetration and enhances weld slag formation during arc welding. Also, the austenite conditioning and precipitation hardening heat treatments are both required after welding to achieve high strength levels. When a weld filler is needed, either AMS 5812/UNS S15789 or AMS 5824/UNS S17780 is most often specified

TABLE 10 – PHYSICAL PROPERTIES

	Condition		
	A °C)	TH 1050	RH 950
Density, lbs./in^3 (g/cm^3)	0.282 (7.804)	0.277 (7.685)	0.277 (7.680)
Modulus of Elasticity, ksi. (GPa)	–	29.0 x 10^3 (200)	29.0 x 10^3 (200)
Electrical Resistivity, $\mu\Omega$•cm	80	82	83
Magnetic Permeability, H/m			
@ 25 oersteds	5.1	142	65
@ 50 oersteds	5.2	147	118
@ 100 oersteds	5.1	94	87
@ 200 oersteds	4.7	55	53
Maximum	5.3	150	119
Thermal Conductivity, BTU/hr./ft^2/°F (W/m/K)			
70 °F (21 °C)	–	104 (15.1)	104 (15.1)
200 °F (93 °C)	–	112 (16.2)	112 (16.2)
400 °F (204 °C)	–	124 (17.9)	122 (17.6)
600 °F (316 °C)	–	136 (19.7)	136 (19.7
800 °F (427 °C)	–	146 (21.1)	144 (20.8)
900 °F (482 °C)	–	–	150 (21.7)
1000 °F (538 °C)	–	158 (22.8)	–
Coefficient of Thermal Expansion, in./in./°F (μm/m/K)			
70 – 200 °F (21 – 93 °C)	8.0 x 10^{-6} (14.4)	6.1 x 10^{-6} (11.0)	5.0 x 10^{-6} (9.0)
70 – 400 °F (21 – 204 °C)	8.0 x 10^{-6} (14.4)	6.1 x 10^{-6} (11.0)	5.4 x 10^{-6} (9.7)
70 – 600 °F (21 – 316 °C)	8.5 x 10^{-6} (15.3)	6.1 x 10^{-6} (11.0)	5.6 x 10^{-6} (10.1)
70 – 800 °F (21 – 427 °C)	8.9 x 10^{-6} (16.0)	6.3 x 10^{-6} (11.3)	5.9 x 10^{-6} (10.6)
70 – 900 °F (21 – 482 °C)	9.2 x 10^{-6} (16.6)	6.5 x 10^{-6} (11.7)	6.0 x 10^{-6} (10.8)
70 –1000 °F (21 – 538 °C)	9.4 x 10^{-6} (16.9)	6.6 x 10^{-6} (11.9)	6.1 x 10^{-6} (11.0)

Corrosion Resistance

The general level of corrosion resistance of Cleveland-Cliffs PH 15-7 Mo Stainless Steel in Conditions TH 1050 and RH 950 is superior to standard hardenable types of stainless such as Types 410, 420 and 431, but is not quite as good as Type 304.

ATMOSPHERIC EXPOSURE

Samples exposed to a marine atmosphere show considerably better corrosion resistance than hardened chromium stainless steels such as Type 410. Although there is little difference between any successive two ratings shown in Table 11, samples indicated the following order of corrosion resistance based on general appearance:

1) Type 301
2) PH 15-7 Mo Stainless Steel SS in Condition CH 900
3) PH 15-7 Mo Stainless Steel SS in Condition RH 950
4) PH 15-7 Mo Stainless Steel SS in Condition TH 1050

In all conditions of heat treatment, the alloy, like other types of stainless steel, will develop superficial rust in some environments. For example, in a marine atmosphere, stainless steels show evidence of rusting after relatively short periods of exposure. However, after exposure for one or two years, the amount of rust present is little more than that which was present at six months.

ATMOSPHERIC EXPOSURE

Hundreds of accelerated laboratory corrosion tests have been conducted on the precipitation-hardening stainless steels. Table 11 shows typical corrosion rates for Cleveland-Cliffs PH 15-7 Mo Stainless Steel and Type 304 in seven common reagents. Because chemically pure laboratory reagents were used, the data can only be used as a guide to comparative performance.

TABLE 11 – CORROSION RATES IN VARIOUS MEDIA, MILS PER YEAR*

	PH 15-7 Mo SS		Type 304
	TH 1050	RH 950	Annealed
H_2SO_4 – 95 °F (35 °C)			
1%	273	0.5	0.4
2%	78	0.7	1.3
5%	453	482	7.7
H_2SO_4 – 176 °F (80 °C)			
1%	560	690	22.2
2%	1300	1440	65
HCl – 95 °F (35 °C)			
0.5%	31	0.3	7.1
1%	280	152	3.0
HNO_3 – Boiling			
25%	119	36	1.2
50%	512	128	3.0
65%	748	210	7.2
Formic Acid – 176 °F (80 °C)			
5%	161	7.3	4.1
10%	123	74	18.0
Acetic Acid – Boiling			
33%	3.0	7.6	2.6
60%	33	6.8	10.9
H_3PO_4 – Boiling			
20%	15.4	22.2	1.6
50%	97	52	8.5
70%	600	277	39
NaOH – 176 °F (80 °C)			
30%	4.3	3.3	0.9
NaOH – Boiling			
30%	142	139	17.5

**Rates were determined by total immersion for five 48-hour periods. Specimens were activated during last three test periods in the 65% nitric acid. Rate is average of number of periods indicated in parentheses, if fewer than five periods were run.*

Corrosion Resistance

CORROSION RESISTANCE AND COMPATIBILITY IN ROCK FUELS

Oxygen – While oxygen is highly reactive chemically, liquid oxygen is noncorrosive to most metals. The precipitation hardening stainless steels experience no problem.

Ammonia – Cleveland-Cliffs PH 15-7 Mo Stainless Steel is satisfactory for handling ammonia.

Hydrogen – Liquid hydrogen and gaseous hydrogen at low temperatures are noncorrosive.

Nitrogen Tetroxide – Static tests in nitrogen tetroxide containing 3.2% by weight water lasting from 3 to 27 days, Cleveland-Cliffs PH 15-7 Mo Stainless Steel, Condition RH 950, has shown very low corrosion rates up to 165 °F (74 °C). Under circulating conditions at 79 °F (26 °C) to 88 °F (31 °C) for 100 hours, it has shown no corrosion.

STRESS CRACKING IN MARINE ENVIRONMENTS

The precipitation-hardening stainless steels, like the hardenable chromium stainless steels, may be subject to stress corrosion cracking when stressed and exposed to some corrosive environments. The tendency is associated with the types of stainless, its hardness, the level of applied tension stress and the environment.

Cleveland-Cliffs has conducted stress cracking tests on the precipitation-hardening alloys in a marine atmosphere on a 80 ft. (24.4 m) lot, 82 ft. (25 m) from the waterline, using two-point loaded bent beam specimens.

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 in. (0.125 mm) thick heat treated to Conditions TH 1050 and RH 950. Specimens in Condition CH 900 were 0.041 in. (1.03 mm) thick. The long dimension of all specimens was cut transverse to the rolling direction.

When comparing the various heat-treated conditions, the data show that Cleveland-Cliffs PH 15-7 Mo Stainless Steel has the greatest resistance to stress cracking in Condition CH 900. Likewise, Condition TH 1050, although somewhat less resistant than Condition CH 900, appears to be more resistant to stress cracking than Condition RH 950.

Table 12 summarizes the test data. In addition, in a mild industrial atmosphere in the midwest United States, specimens stressed at 90% of their yield strength had not broken after 730 days of exposure.

TABLE 12 – SUMMARY OF STRESS-CRACKING FAILURES IN COASTAL EXPOSURE*

(Average of 5 tests on each of 2 heats)

Heat Treatment	Stressed at 50% of the 0.2% YS			Stressed at 50% of the 0.2% YS		
	Stress, ksi. (MPa)	Days to Failure	Range Days	Stress, ksi. (MPa)	Days to Failure	Range Days
TH 1050	107.4 (738)	No failures in 746 days	–	161.0 (1110)	103 (3)**	75 – 118***
TH 1050	109.2 (752)	No failures in 746 days	–	163.9 (1131)	39.8	20 – 70
RH 950	115.8 (798)	169.4	112 – 385	173.7 (1195)	68.8	67 – 70
RH 950	116.8 (805)	98.8	10 – 116	175.42 (1207)	14.2	7 – 24
CH 900	131.0 (903)	No failures in 746 days	–	196.6 (1352)	No failures in 746 days	–

**25 m ocean front lot*
***( ) Number in brackets indicates number of failed 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. Tests discontinued after 746 days of exposure.

Heat Treatment

HEAT TREATING AND ANNEALING

For in-process annealing, the alloy should be heated to 1950 ± 25 °F (1066 ± 14 °C) for three minutes for each 0.1 in. 2.5 mm) of thickness, and then air cooled. This treatment may be required to restore the ductility of cold worked material so that it can take additional drawing or forming. Although most formed or drawn parts do not require re-annealing prior to hardening, annealing is required on severely formed or drawn parts to be heat treated to Condition TH 1050 if full response to heat treatment is required. Annealing is unnecessary in the case of the RH 950 heat treatment

EQUIPMENT AND ATMOSPHERE

Selection of heat-treating equipment depends to some extent on the nature of the particular parts to be treated. However, heat source, atmosphere and control of temperatures are the primary considerations.

Furnaces fired with oil or natural gas are difficult to use in the heat treatment of stainless steels, particularly if combustion control is uncertain and if flame impingement on the parts is possible. Electric furnaces or gas-and oil-fired radiant tube furnaces generally are used for heat treating this material.

Air provides 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/or carburizing or decarburizing, and should not be used. Bright annealing may be accomplished in a dry hydrogen, argon or helium atmosphere, with dew point approximately -65 °F (-54°C), if a cooling rate approximately that obtained in an air cool can be used. Dry hydrogen, argon or helium, with 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 an essentially scale-free surface. At heat-treating temperatures of 1400 °F (760 °C) and lower, scale-free heat treatment in a dry hydrogen, argon, or helium atmosphere is difficult to achieve. A vacuum furnace is required for complete freedom from scale or heat discoloration. It is necessary to cool this material to a temperature of -100 °F (-73 °C) for a period of eight hours when heat treating to the RH condition. While commercial equipment is available for refrigeration at this temperature, a saturated bath of dry ice in alcohol or acetone maintains a temperature of -100 to -109 °F (-73 to -78 °C) without control equipment.

Annealing at 1950 °F (1066 °C) or austenite conditioning at 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 at 900 – 1200 °F (482 – 649 °C) has been done successfully with a few salts of the hydride or nitrate types.

CLEANING PRIOR TO ANNEALING OR HEAT TREATING

Thorough cleaning of parts and assemblies prior to heat treatment greatly facilitates scale removal and is necessary for the development of uniform properties. Removal of oils and lubricants with solvents also assures that the steel will not be carburized from this source. Carburized Cleveland-Cliffs PH 15-7 Mo Stainless Steel will not respond properly to heat treatment.

Cleaning may be accomplished by the following two step procedure:

1) Vapor degrease or solvent clean. This step removes oil, grease and drawing lubricants.
2) Mechanical scrubbing with mild abrasive cleaners, Oakite 33 or similar proprietary cleaners, to remove dirt or other insoluble materials. All traces of cleaners should be removed by rinsing thoroughly with warm water.

A light, tightly adherent, uniform-appearing oxide after heat treatment is evidence of proper cleaning.

COATINGS

Protective coatings offer little advantage in reducing oxidation of the metal surface during heat treatments if the parts are thoroughly cleaned. However, when thorough cleaning is impractical, coatings may be beneficial. Extreme caution must be exercised in the use of coatings to provide free air circulation around the coated parts, or carburization may result

Heat Treatment

SCALE REMOVAL

Scale develops during most heat-treating operations. The amount and nature of the scale formation varies 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, and the method chosen often depends upon the facilities available. A tabulation of the recommended scale removal methods after various heat treatments is shown in Table 13.

TABLE 13 – SCALE REMOVAL METHODS

Heat Treated to Condition	Preferred Methods After Heat Treatment	Secondary Methods
A	Wet Grit Blast (1) or Pickle (2)	Scale Condition and Pickle (3)
CH 900	Wet Grit Blast (1) or Pickle (2)	–
A 1750	Wet Grit Blast (1)	Pickle (2) or Scale Condition and Pickle (4)
T and R 100	Wet Grit Blast (1)	Pickle (2) or Scale Condition and Pickle (5)
TH 1050 and RH 950	Wet Grit Blast (1)	Pickle (2) or Scale Condition and Pickle (3)

(1) Wet Grit Blasting processes are widely used and are highly satisfactory. These methods eliminate the hazard of intergranular attack from acid pickling. Added advantages are better fatigue strength and corrosion resistance.

(2) 10% $HN0_3$ + 2% HF at 110 – 140 °F (49 – 60 °C) for three min. maximum. Removal of loosened scale may be facilitated by the use of high-pressure water or steam spray. Scale-conditioning treatment is unnecessary for parts that 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 necessary prior to pickling.

(3) Scale conditioners:
(a) Kolene Process
(b) DuPont Hydride Process
(c) Caustic permanganate (boiling 10% NaOH + 3% $KMn0_4$ for one hr.)

(4) Use caustic permanganate scale conditioning followed by $HN0_3$ – HF pickle only. Do not use fused salts. The use of fused salts on Cleveland-Cliffs PH 15-7 Mo Stainless Steel in Condition A 1750 will prevent the steel from developing maximum transformation upon subsequent refrigeration.

(5) Scale condition and pickle as in footnote (3). The Virgo and Kolene salt baths may be operated at temperatures up to 1100 °F (593 °C) so that the hardening and scale conditioning treatment may be combined if desired. However, the operation of a salt bath at such temperatures should be checked with the manufacturer before proceeding.

Some degree of intergranular penetration occurs during any pickling operation. However, the penetration from the short-time pickling of this material in Condition CH 900 is generally slight. Other conditions are more susceptible to intergranular penetration during pickling. Consequently, pickling should be avoided or carefully controlled if it must be used for such removal.

The standard 10% HN0 + 2% HF acid bath may be used for removal of light discoloration or heat tint produced by the final hardening treatment at 900 – 1200 °F (482 – 649 °C),providing immersion times are kept short (in the order of one min. or fewer).

PH 15-7 Mo® STAINLESS STEEL

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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