CLIFFS

15-5 PH®
STAINLESS STEEL

Aerospace

Chemical

Food Processing

Metalworking

Paper Industries

Cleveland-Cliffs **15-5 PH® STAINLESS STEEL** offers a combination of high strength and hardness, good corrosion resistance and excellent transverse mechanical properties. Cleveland-Cliffs 15-5 PH Stainless Steel is the ferrite-free version of Cleveland-Cliffs 17-4 PH® Stainless Steel. Both alloys are widely used in the aerospace, chemical, petrochemical, food processing, paper and general metalworking industries.

Product Description

Cleveland-Cliffs 15-5 PH Stainless Steel 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) and good toughness in both the longitudinal and transverse directions in both base metal and welds. Short-time, low-temperature heat treatments minimize distortion and scaling.

This alloy is air melted and AOD refined. For data not available on this alloy, use the Cleveland-Cliffs 17-4 PH® Stainless Steel sheet data as a guideline when available.

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)	14.00 – 15.50
Nickel	(Ni)	3.50 – 5.50
Copper	(Cu)	2.50 – 4.50
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 15-5 PH Stainless Steel is produced in sheet and strip, in thicknesses from 0.015 – 0.125 in. (0.38 – 3.18 mm). Material 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 5862
- ASTM A693 Plate, Sheet and Strip
  (Listed as Grade XM-12 – UNS S15500)

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 15-5 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 table outlines the times and temperatures required.

This alloy exhibits useful mechanical properties in Condition A. Tests conducted at an exposed marine atmosphere 82 ft. (25 m) from the waterline, show excellent stress corrosion resistance for close to 20 years. 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.

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 15-5 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)	186 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 – SHEET CHARPY IMPACT RESISTANCE*

Condition	Impact Energy, in.•lbs./in.² (J/cm²)**	
	Room Temperature	-65 °F (-54 °C)
A	3265 (57.2)	2669 (46.7)
H 900	2857 (50.0)	2361 (41.3)
H 1025	3974 (69.6)	3378 (59.2)
H 1150	4626 (81.0)	4248 (74.4)
H 1150-M	5616 (98.4)	5049 (88.4)
Pressed Notch Tests		
H 900	2184 (38.2)	1360 (23.8)
H 1150	3406 (59.6)	2557 (44.8)

**Average of triplicate tests for two heats.*
***Samples were 0.093 in. (2.36 mm) thick with a depth beneath the notch of 0.314 in. (7.98 mm)*

Physical Properties

TABLE 5 – MODULUS OF ELASTICITY

	Condition			
	H 900	H 1025	H 1075	H 1150
Modulus in Tension, psi. (MPa)	28.5×10^6 (196×10^3)	—	—	—
Modulus in Torsion, psi. (MPa)	11.2×10^6 (77×10^3)	11.0×10^6 (76×10^3)	10.0×10^6 (69×10^3)	10.0×10^6 (69×10^3)

Data represent average of two tests from one heat.

The modulus of elasticity of Cleveland-Cliffs 15-5 PH Stainless Steel at elevated temperatures can be expressed conveniently as percent of room temperature modulus. At temperatures ranging from room to 600 °F (315 °C), this material showed the following:

TABLE 6 – EFFECT OF TEMPERATURE ON MODULUS OF ELASTICITY

Temperature °F (°C)	Modulus of Elasticity*, (% of Room Temperature Modulus)
72 (22)	100.0
100 (38)	99.6
200 (93)	97.8
300 (149)	96.2
400 (204)	94.7
500 (260)	93.0
600 (315)	91.4

*Poisson's Ratio in all hardened conditions is 0.272. *Data represent average of two tests from one heat.*

TABLE 7 – PHYSICAL PROPERTIES

	Condition			
	A	H 900	H 1075	H 1150
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)	0.10 (0.42)	—	—
Thermal Conductivity, BTU/hr./ft.²/°F (W/m/K)				
300 °F (149 °C)	—		—	—
500 °F (260 °C)	—		—	—
860 °F (460 °C)	—		—	—
900 °F (482 °C)	—		—	—
Mean Conefficient 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)

Dimensional Change

DIMENSIONAL CHANGE IN HARDENING

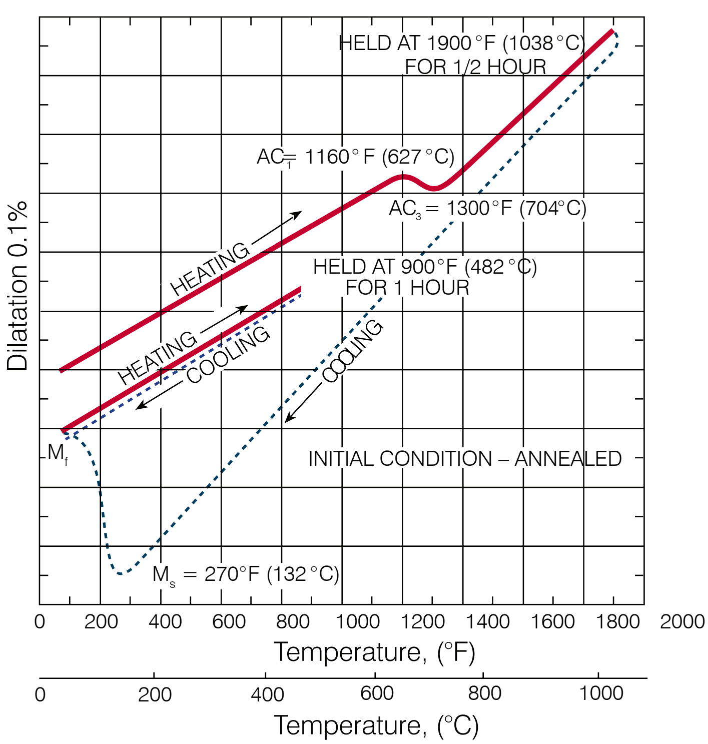
On hardening Cleveland-Cliffs 15-5 PH Stainless Steel, a dimensional change will take place. Typical dimensional changes are shown in Table 8. They can vary from heat to heat.

TABLE 8 –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 average of two tests from one heat.

FIGURE 1 – DIMENSIONAL CHANGE IN HARDENING



Corrosion Resistance

The general level of corrosion resistance of Cleveland-Cliffs 15-5 PH Stainless Steel exceeds that of Types 410 and 431, and is approximately equal to that of Cleveland-Cliffs 17-4 PH Stainless Steel. This is indicated by laboratory tests in both strongly oxidizing and reducing media, as well as by atmospheric exposures. In all heat-treated conditions, this alloy exhibits very little rusting after 500 hours of exposure to 5% salt fog at 95 °F (35 °C).

When exposed to seacoast atmospheres for long periods of time, the material gradually develops a superficial layer of rust like other precipitation-hardening stainless steels. The general level of corrosion resistance is best in the fully-hardened condition, and decreases slightly as the aging temperature is increased.

TABLE 9 – CORROSION RATES IN VARIOUS MEDIA

Corrosive Media	Time	Condition	Corrosion Rate
65% HNO_3	Average 5 –48 hour periods	H 900 H 1025 H 1150	0.0083 IPM* (0.210 mm) 0.0106 IPM (0.269 mm) 0.0083 IPM (0.210 mm)
1% HCl, 95 °F (35 °C)	Average 5 –48 hour periods	H 900 H 1025 H 1150	0.0025 IPY** (0.635 mm) 0.0825 IPY (2.159 mm) 0.730 IPY (18.542 mm)
Commercial bleach 93 °F (35 °C)	7 days	H 900 H 1025 H 1150	0.0016 IPY (0.040 mm) 0.013 IPY (0.330 mm) 0.0083 IPY (0.211 mm)

*Inches per month **Inches per year*

TABLE 10 – STRESS CORROSION CRACKING TEST RESULTS OF CLEVELAND-CLIFFS 15-5 PH*

Heat	Heat Treatment	0.2% YS, ksi. (MPa)	Time to Failure, days under stress of	
			100% YS	75% YS
F	Condition A	133 (917)	NF, NF, NF	NF, NF, NF
E F	H 900	180 (1241) 173 (1193)	22, 22, 22 21, 21, 21	22, 22, 22 21, 21, 21
E F	H 925	172 (1186) 166 (1145)	22(1), 22(1), 22(1) 23(1), 23(1), 23(1)	22(1), 22(1), 22(1) 23(1), 23(1), 23(1)
E F	H 975	163 (1124) 159 (1096)	NF, NF, NF NF, NF, NF	NF, NF, NF NF, NF, NF
E	H 1025	159 (1096)	NF, NF, NF	NF, NF, NF

**NF indicates no failure. (1) Cracked at code numbers that were stamped near the ends of specimens. Materials Performance Vol. 26, No. 2 (1987).*

TABLE 11 – 5% SALT FOG EXPOSURE FOR 10 DAYS

Condition	Rating
H 900	A+ (0% rust and stain covered)
H 1025	A (0 – 5% rust and stain covered)
H 1150	A (0 – 5% rust and stain covered)

FORMABILITY

Because Cleveland-Cliffs 15-5 PH Stainless Steel in Condition A is strong, forming normally should be limited to mild operations. However, fabrication can be improved greatly by heat-treating before cold-working. Table 12 indicates minimum bend radii for forming this material.

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 10X magnifying glass.

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 equivalent weldability to the most common alloy of this stainless class, Cleveland-Cliffs 17-4 PH Stainless Steel. When a weld filler is needed, AWS E/ER 630 is most often specified. Cleveland-Cliffs 15-5 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 15-5 PH Stainless Steel, it is important to keep in mind the low temperatures at which the start of transformation to martensite (Ms) and the completion of the martensite transformation (Mf) 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.

In pickling operations, time and temperature should be controlled closely 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.

TABLE 13

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

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.

CLIFFS

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