CLIFFS

13-4 SR®
STAINLESS STEEL

Exhaust Components

Grid Resistors

Locomotive Braking Resistors

Resistance Heating Elements

13-4 SR STAINLESS STEEL is a ductile, weldable ferritic with 13% chromium (Cr) and 3.75% aluminum (Al). The high aluminum content results in a base alloy with high electrical resistivity. It is intended for use where electrical energy needs to be dissipated or heat is generated. Good oxidation resistance to 1800 °F (982 °C) permits applications at elevated temperatures. The alloy's wet corrosion resistance is comparable to ferritic alloys Type 409 or Type 430. The alloy is classified as ASTM B603 Class IV and as UNS Alloy K91470.

Product Description

CHEMICAL COMPOSITION

ASTM B603 CHEMICAL REQUIREMENT FOR CLASS IV

Composition Range		Resistivity Range
% Cr	% Al	μohm•cm
12 – 15	2.75 – 3.75	111 – 122

Composition		(wt %)
Carbon	(C)	0.025
Manganese	(Mn)	0.30
Phosphorus	(P)	0.045 max.
Sulfur	(S)	0.030 max.
Chromium	(Cr)	13.00
Nickel	(Ni)	0.25
Aluminum	(Al)	3.75
Titanium	(Ti)	0.30
Iron	(Fe)	Balance

AVAILABLE FORMS

Cleveland-Cliffs produces 13-4 SR Stainless Steel coils in thicknesses ranges of from 0.018 – 0.125 in. (0.457 – 3.175 mm) and widths up to and including 36 in. (914 mm).

For other sizes, contact your Cleveland-Cliffs sales representative.

TABLE 1 – TYPICAL ROOM TEMPERATURE MECHANICAL PROPERTIES

0.2% YS, ksi. (MPa)	UTS, ksi. (MPa)	Elongation % in 2 in.	Rockwell Hardness, B
63 (434)	84 (579)	24	81

TABLE 2 – PHYSICAL PROPERTIES

Temperature vs. Density			
Temperature		Density	
°C	°F	gm/cm³	lbs./in.³
-18	0	7.360	0.266
121	250	7.330	0.265
121	250	7.330	0.265
260	500	7.285	0.263
399	750	7.240	0.261
538	1000	7.195	0.260
677	1250	7.150	0.258
816	1500	7.105	0.256
954	1750	7.050	0.254
1093	2000	7.000	0.253
1232	2250	6.950	0.251

FIGURE 1 – ELECTRICAL RESISTIVITY VS. TEMPERATURE

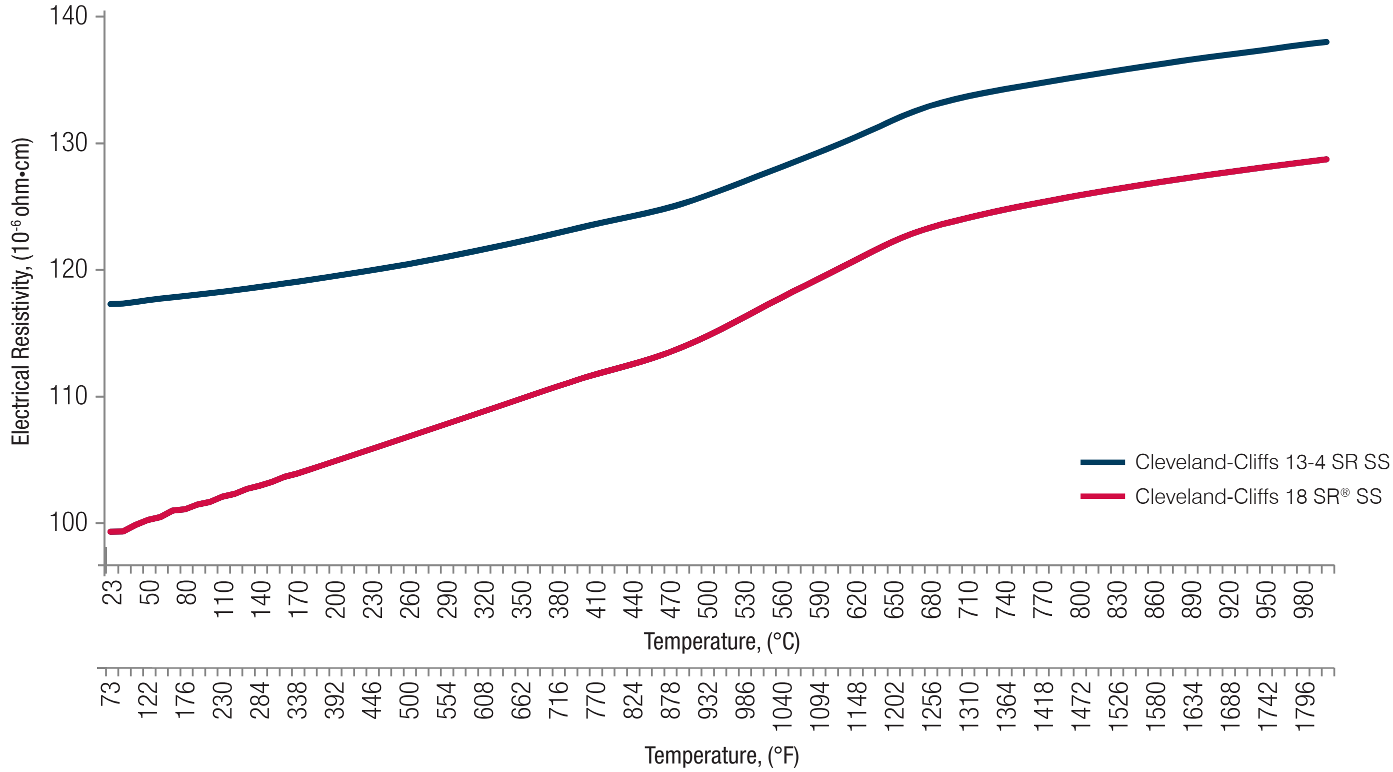
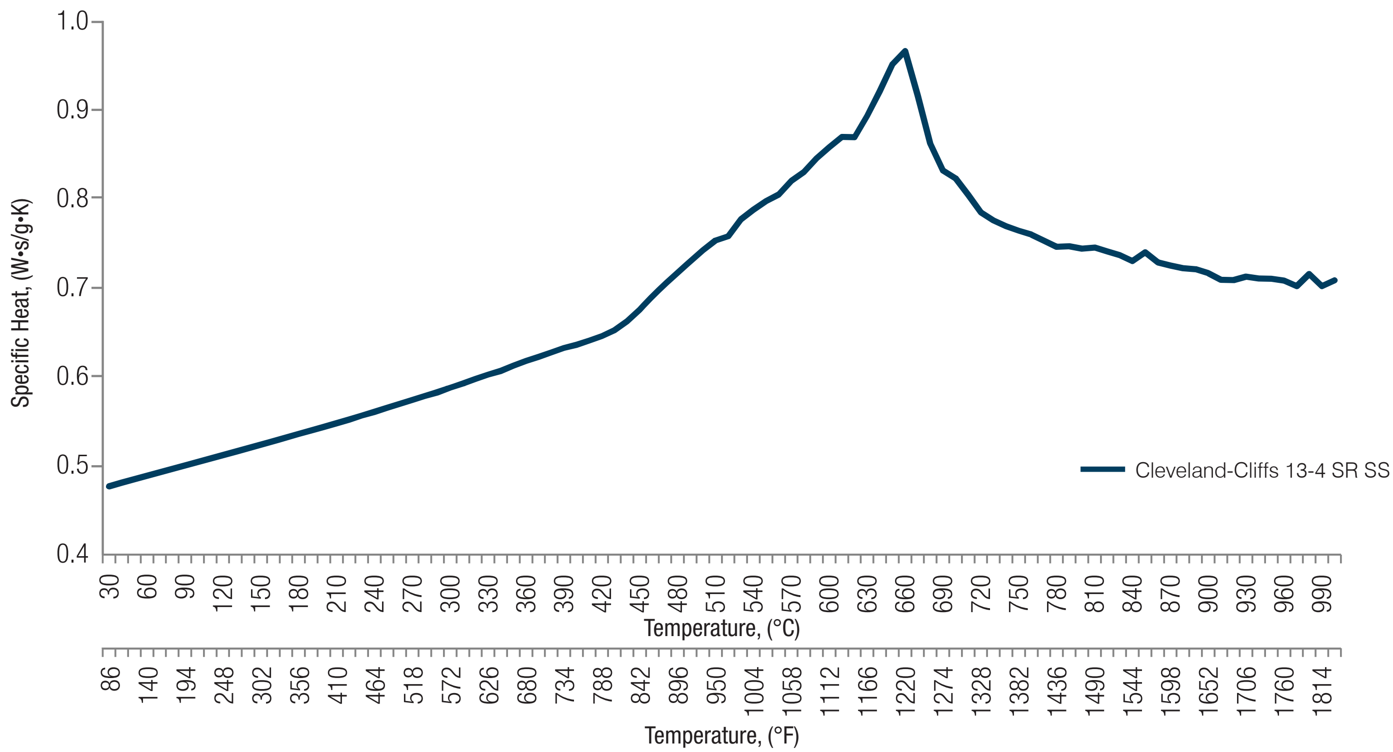


FIGURE 2 – SPECIFIC HEAT VS. TEMPERATURE



Physical Properties

Cleveland-Cliffs 13-4 SR Stainless Steel has a mean coefficient of thermal expansion similar to 17 – 18% chromium alloys Type 439, Cleveland-Cliffs 18 Cr-Cb™ Stainless Steel and Cleveland-Cliffs 18 SR® Stainless Steel. These coefficients are significantly lower than for austenitic 300 series alloys.

TABLE 3 – MEAN COEFFICIENT OF THERMAL EXPANSION

Temperature		CTE
°C	°F	µin./in.°C
100	212	9.79
200	392	10.60
300	572	11.20
400	752	11.65
500	932	12.05
600	1112	12.38
700	1292	12.60
800	1472	12.99
900	1652	13.36
1000	1832	13.66

TABLE 4 – THERMAL CONDUCTIVITY

Temperature		CTE	
°C	°F	W/cm•K	BTU*
23	73	0.137	95.05
50	122	0.142	98.48
100	212	0.150	104.06
200	392	0.166	115.12
300	572	0.182	126.51
400	752	0.198	137.48
500	932	0.228	158.48
600	1112	0.251	173.94
700	1292	0.205	142.54
800	1472	0.240	166.51
900	1652	0.248	172.10
1000	1832	0.262	181.53

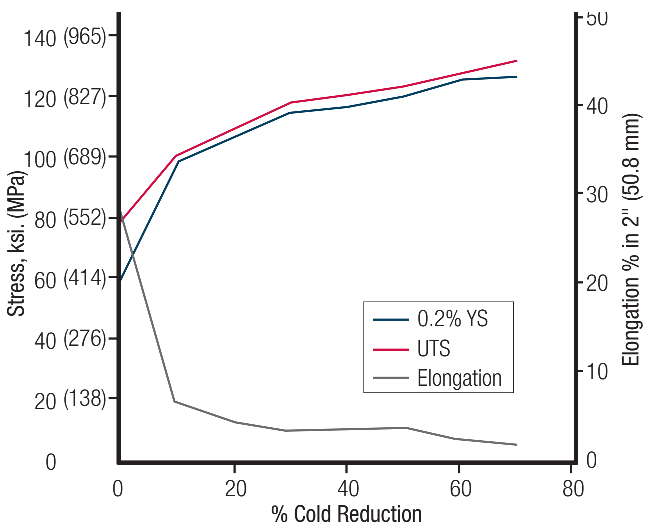
*(BTU·in./hr.·ft.^{2}·°F)

Mechanical Properties

EFFECT OF COLD WORK

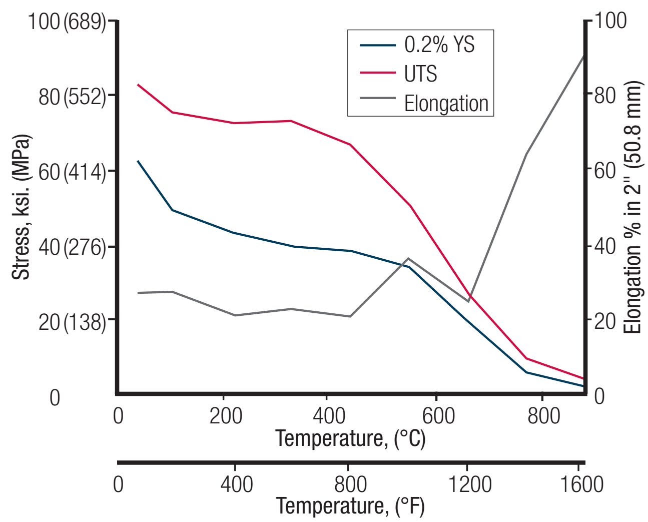
Cold working Cleveland-Cliffs 13-4 SR Stainless Steel leads to a rapid increase in yield and tensile strength and an accompanying loss of ductility. With 10% cold reduction, elongation falls below 10% and yield strength approaches 100 ksi. (690 MPa).

The work hardening rate of Cleveland-Cliffs 13-4 SR Stainless Steel is below that of carbon steel and austenitic stainless alloys. The n-Value, or work hardening coefficient, (measured between 10% strain and the ultimate strength) typically falls in the range of 0.145 – 0.170.



HIGH TEMPERATURE TENSILE PROPERTIES

Strength properties for Cleveland-Cliffs 13-4 SR Stainless Steel decrease with heating showing a rapid decline once temperatures exceed 800 °F (427 °C). Conversely, elongation values remain reasonably unchanged up to 1200 °F (649 °C), but show a rapid increase at higher temperatures.



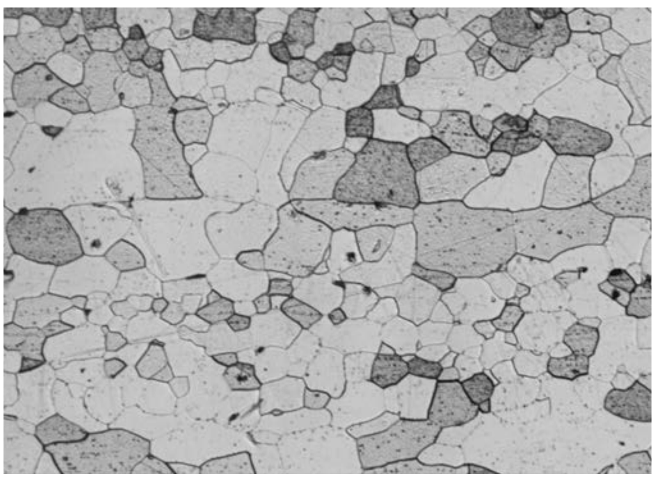
Mechanical Properties

STRESS RUPTURE

Stress rupture strength tested at temperatures for 100 hours and 1000 hours are presented in Table 5. The stress rupture strength of 13-4 SR stainless steel appears similar to that of Cleveland-Cliffs 18 SR Stainless Steel.

TABLE 5 – STRESS RUPTURE STRENGTH

	Stress, psi. (MPa) to Rupture in	
Temp. °C (°F)	100 Hours	1000 Hours
649 (1200)	6750 (46.5)	4500 (31.0)
760 (1400)	2300 (15.9)	1200 (8.3)
871 (1600)	920 (6.3)	540 (3.7)



Cleveland-Cliffs 13-4 SR Stainless Steel annealed grain microstructure. Mixed ferritic grain structure of equiaxed ASTM GS#6 – 7 Etchant: Vilellas Reagent

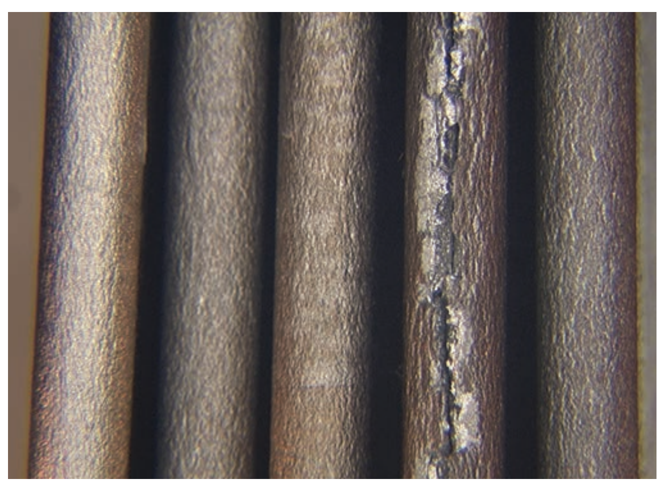
885 °F (474 °C) EMBRITTLEMENT

At temperatures between 750 – 1000 °F (399 – 538 °C), highly-alloyed ferritic stainless steels can become embrittled. Strengths increase while ductility and bendability decrease. The degree of embrittlement increases with time, but can be eliminated with temperature excursions above 1100 °F (593 °C). The properties and bend samples shown below indicate 13-4 SR Stainless Steel can become embrittled with time at 900 °F (482 °C). The alloy will recover much of its ductility with a one-hour exposure to 1150 °F (621 °C).

TABLE 6 – EFFECT OF 900 °F (482 °C) SOAK ON MECHANICAL PROPERTIES

Soak Duration (hrs.)	0.2% YS, ksi. (MPa)	UTS, ksi. (MPa)	Elongation % in 2 in.	Rockwell Hardness	n-Value (10% - Ult.)
0	69 (476)	89 (614)	19.6	B87	0.151
10	71 (490)	90 (621)	19.4	B87	0.150
100	80 (552)	97 (669)	18.5	B91	0.120
1000	116 (800)	129 (889)	10.1	C27	—
1000*	76 (824)	98 (676)	18.5	B89	0.124

**1000 hours at 900 °F (482 °C) and 1 hour at 1150 °F (621 °C)*



Annealed | 900 °F 10 hrs. | 900 °F 100 hrs. | 900 °F 1000 hrs. | 900 °F 1000 hrs. and 1150 °F 1 hr.

Formability

Cleveland-Cliffs 13-4 SR Stainless Steel true stress/true strain curves are provided for the longitudinal and transverse sheet orientations. The transverse properties are somewhat stronger and less ductile.

TOUGHNESS

The ferritic microstructure with 3.75% aluminum makes Cleveland-Cliffs 13-4 SR Stainless Steel more prone to brittle fracturing if impact loaded when cold. The ductile-to-brittle temperature (DBTT) for 0.100 – 0.120 in. (2.5 – 3 mm) thick material falls between 90 – 100 °F (32 – 38 °C). The ductile-to-brittle temperature decreases and fracturing is less prone to occur as the sheet thickness decreases. Stamping and forming operations should be avoided below room temperature.

FIGURE 3 – 13-4 SR STAINLESS STEEL TRUE STRESS/TRUE STRAIN
Longitudinal and Transverse Orientation

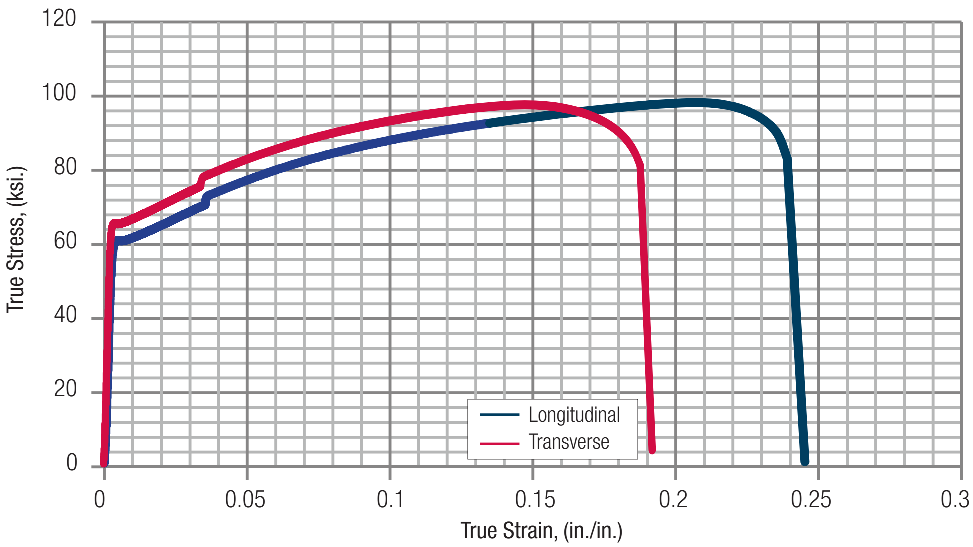


TABLE 7 – LONGITUDINAL ORIENTATION

0.2% YS, ksi. (MPa)	UTS, ksi. (MPa)	Elongation % in 2 in.	Rockwell Hardness, B	n-Value (10% - Ult.)
61 (421)	81 (558)	28	86	0.167

TABLE 8 – TRANSVERSE ORIENTATION

0.2% YS, ksi. (MPa)	UTS, ksi. (MPa)	Elongation % in 2 in.	Rockwell Hardness, B	n-Value (10% - Ult.)
65 (448)	85 (586)	22	86	0.147

Formability

The forming limit diagram is an experimentally developed graphical representation of the amount of biaxial strain or thinning a material can undergo during various forming operations (stretch, plane strain FLCo, and draw) prior to the onset of localized thinning and subsequent fracture. The curves to the right were developed for 0.042 in. (1.1 mm) thick Cleveland-Cliffs 13-4 SR Stainless Steel in both the longitudinal (parallel to the rolling direction) and transverse sample orientations. The FLCo in the transverse direction is 14% versus 24% for the longitudinal. Tensile and stretch r data (lower right) were determined for sheet used to generate forming limit curves.

FIGURE 4 – FORMATTING LIMIT CURVE

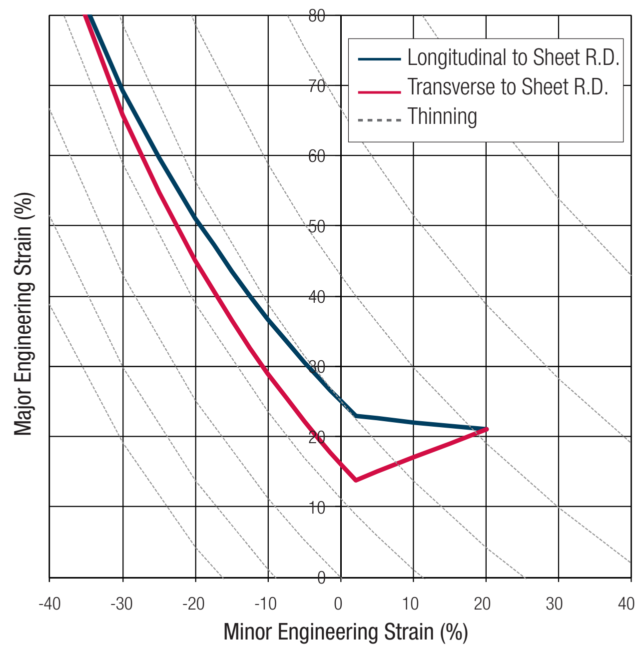


TABLE 9 – FORMING LIMIT DIAGRAM MATERIAL TEST PROPERTIES

Property	Orientation to Sheet R.D.		
	L	D	T
Tensile/Hardness Test (ASTM E8, E694, E18, A370)			
0.2% YS, ksi. (MPa)	61.3	64.6	64.6
UTS, ksi. (MPa)	81.4	84.2	83.7
% El. in 2 in. (man'l)	28.8	24.8	22.8
n-Value (10% – Ult.)	0.168	0.158	0.154
Strength Coeff., ksi. (MPa)	130.2	130.3	132.1
HRBW	86.0		
ASTM Grain Size	6/7		

TABLE 10 – STRETCH R (PLASTIC STRAIN RATIO) AT 18% (ASTM E517)

Property	Orientation to Sheet R.D.		
	L	D	T
r	0.680	0.860	1.140
r_m	0.880		
delta r	0.050		
delta r (max. - min.)	0.610		
Ridge Rating	2.0		
Olsen Cup Height (in.)	0.369		

Oxidation Resistance

Cyclic oxidation comparisons at 1550 – 1600 °F (843 – 871 °C) show Cleveland-Cliffs 13-4 SR Stainless Steel performs similar to higher chromium alloys Type 439, Cleveland-Cliffs 18 Cr-Cb Stainless Steel and Cleveland-Cliffs 18 SR® Stainless Steel and out performs austenitic Type 304. The 100 hour still air oxidation exposures show Cleveland-Cliffs 13-4 SR Stainless Steel compares favorable to Cleveland-Cliffs 18 SR Stainless Steel and superior to ferritic alloys Cleveland-Cliffs 15 Cr-Cb® Stainless Steel, Cleveland-Cliffs 18 Cr-Cb Stainless Steel and austenitic alloy Type 309. Maximum service temperature approaches 1800 °F (982 °C).

TABLE 11 – CYCLIC OXIDATION RESISTANCE 1550 – 1600 °F (843 – 871 °C) WEIGHT CHANGE (mg/cm²)

Alloy	100 Cycles	200 Cycles	300 Cycles	400 Cycles	500 Cycles
Type 304	0.10	-0.07	-4.75	-15.40	-48.90
Type 409	0.39	0.46	0.56	0.61	0.63
Type 439	0.30	0.27	0.19	0.20	0.20
Cleveland-Cliffs 18 Cr-Cb SS	0.32	0.37	0.43	0.48	0.52
Cleveland-Cliffs 18 SR SS	0.06	0.06	0.08	0.10	0.11
Cleveland-Cliffs 13-4 SR SS	0.12	0.13	0.17	0.18	0.18

**Cycle = 25 min. Heat, 5 min. Cool*

TABLE 12 – 100 HR. STILL AIR OXIDATION RESISTANCE WEIGHT GAIN (mg/cm²)

Alloy	Temperature, °F (°C)			
	1600 (871)	1800 (962)	2000 (1093)	2200 (1204)
Cleveland-Cliffs 13-4 SR SS	0.19	0.41	1.02	-3.23
Cleveland-Cliffs 15 Cr-Cb® SS	0.68	2.42	-106.90	NT*
Cleveland-Cliffs 18 Cr-Cb SS	0.59	1.64	76.60	NT
Cleveland-Cliffs 18 SR SS	0.19	0.43	1.01	1.86
Type 309	0.27	1.01	0.80	-144.60

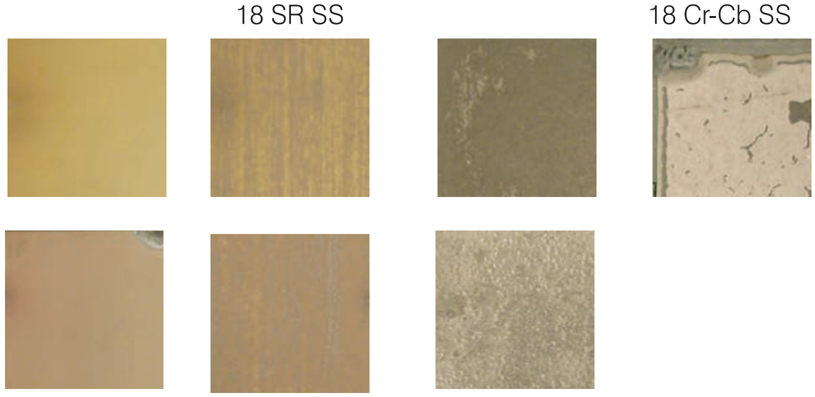
**NT – Not Tested*

100 HOUR OXIDATION SAMPLES

13-4 SR SS | Cleveland-Cliffs 18 SR SS | Type 309 | Cleveland-Cliffs 18 Cr-Cb SS

2000 °F (1093 °C)

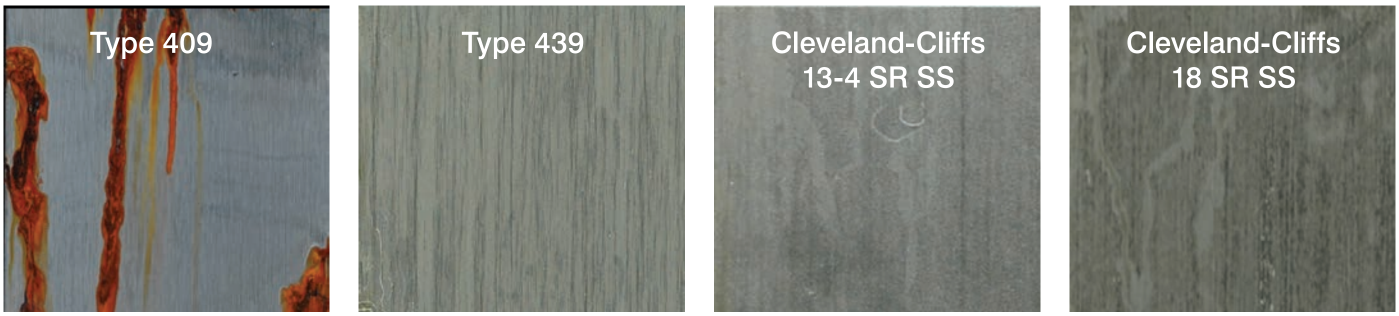
2200 °F (1204 °C)



Corrosion Resistance

Cleveland-Cliffs 13-4 SR Stainless Steel outperforms 11% Cr Type 409 and compares favorably to higher chromium ferritic stainless alloys in salt spray.

ASTM B117 SALT SPRAY 500 HOURS



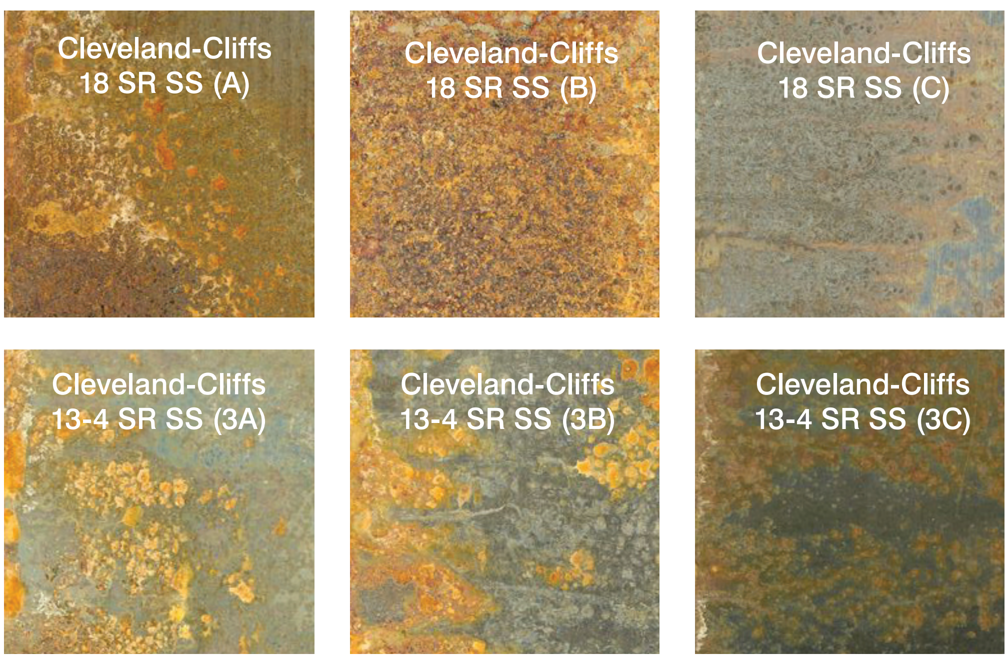
ASTM B117 specifies metallic coupons are inclined at 30° to the vertical and exposed to 5% NaCl solution atomized and continuously sprayed on to specimen surfaces while held at a temperature of 95 °F (35 °C).

FIVE CYCLES IN ASTM G87 MOIST SO_2 TEST – METHOD B*

Moist SO_2 testing consists of an 8-hour exposure to 104 °F (40 °C) condensing humidity containing 2L of sulfur dioxide gas followed by a 16-hour ambient dwell. NOTE: One 24-hour period is equal to one cycle.

Cleveland-Cliffs 18 SR SS

Cleveland-Cliffs 13-4 SR SS



Samples were exposed to all five cycles after heat treatment for 3 minutes at 1770 °F (966 °C).

Samples were exposed to all five cycles without any heat treatment.

Samples were exposed to one cycle before heat treatment for 3 minutes at 1770 °F (966 °C) then an additional 4 cycles.

Cleveland-Cliffs 13-4 SR Stainless Steel performs as well, if not better, than Cleveland-Cliffs 18 SR Stainless Steel in moist SO_2 testing after 5 cycles with or without a 1770 °F (966 °C) oxidation exposure.

**ASTM Standard 2010 Edition Volume 03.02 p. 372 – Alternating 24 Hour Exposure Method*

Cyclic Sodium Chloride Pitting Test

Cyclic NaCl pitting tests consist of wetting coupons with salt solution, allowing the solution to concentrate as droplets, then dry, and remoisten at 85% RH. Heating cycles cause oxide films to form and lower resistance to pitting. Cleveland-Cliffs 13-4 SR Stainless Steel resists corrosion similar to Type 439, better than Type 409 but not up to the level of Cleveland-Cliffs 18 SR Stainless Steel.

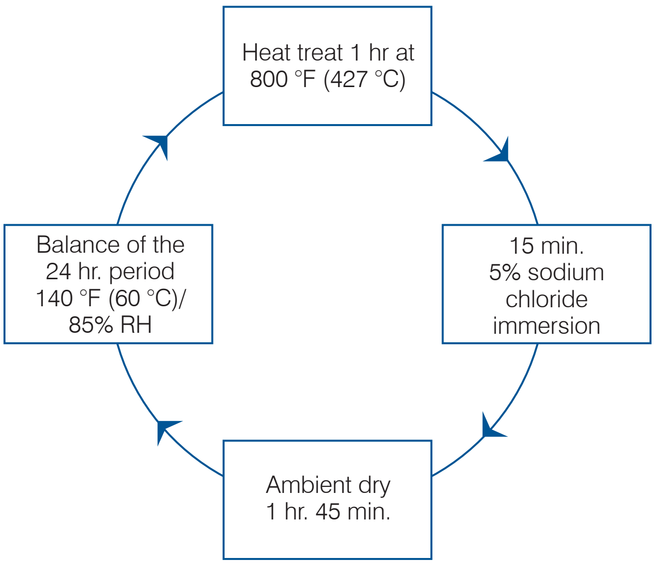


FIGURE 5 – SALT CYCLE MASS LOSS AFTER 28 DAYS (20 CYCLES)

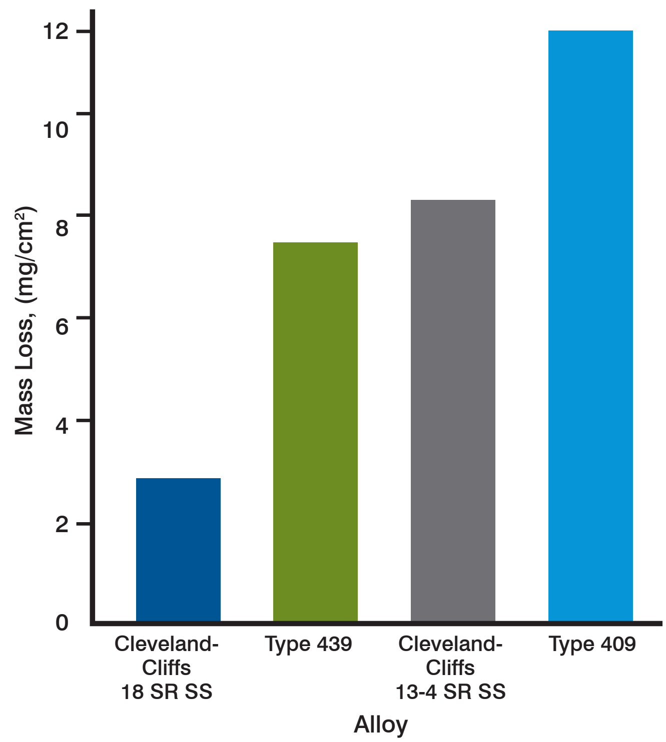
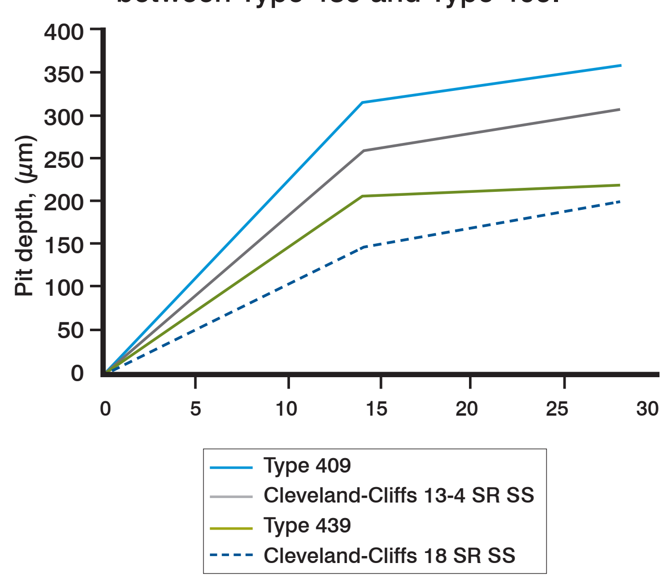


FIGURE 6 – PITTING CORROSION IN EXTERIOR SALT CYCLE TEST

In cyclic salt/humidity exposures Cleveland-Cliffs 13-4 SR Stainless Steel falls between Type 439 and Type 409.



Boiling Condensate Corrosion Test

The boiling condensate test exposes coupons to synthetic automotive exhaust condensate and concentrates the solution by boiling. Deposits are then remoistened in humidity. The sample's corrosion resistance is degraded by a daily 1-hr. heat treatment to 932 °F (500 °C) to that results in heat tint on the surface of the specimens. By virtue of the 4% Al addition, 13-4 SR Stainless Steel in this test performs similar to higher Cr ferritic stainless steels and outperforms 11% Cr Type 409.

In synthetic exhaust condensate Cleveland-Cliffs 13-4 SR Stainless Steel compares favorably to the higher Cr alloys.

TEST SETUP

- Partial immersion of 2 x 4 in. (50.8 x 101.6 mm) coupon in synthetic condensate

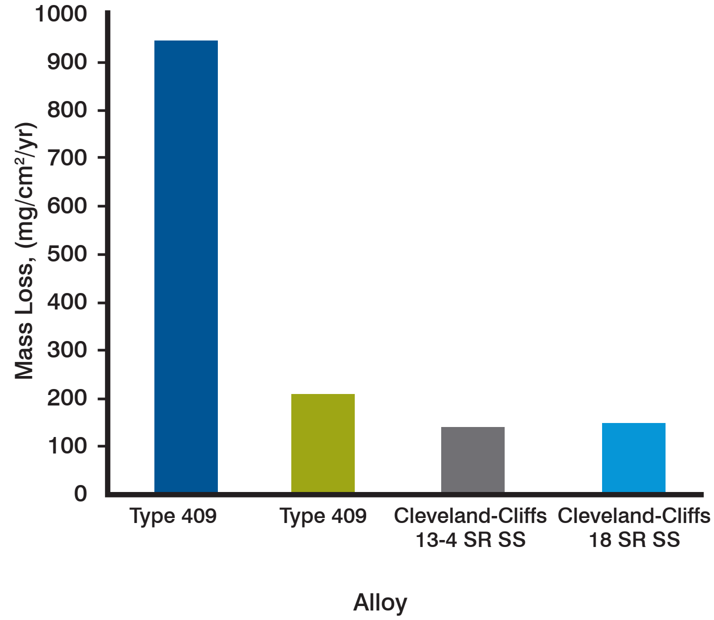
TEST SOLUTION

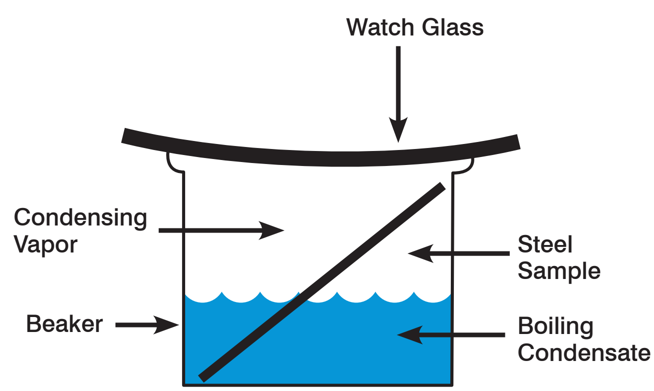
- 5,000 ppm SO_4^{2-}
- 100 ppm Cl^-
- 100 ppm NO_3^-
- 100 ppm Formic Acid
- Solution pH is adjusted to 3.3 – 3.5 using sulfuric acid by adding approximately 300 – 400 ppm SO_4^{2-}

TEST CYCLE PROCEDURE

- Heat 1 hr. at 932 °F (500 °C)
- Humidity exposure for 7 hrs. at 140 °F (60 °C)/85% RH
- 16 hrs. exposed to boiling test solution (boil to dryness)
- 6 weeks of testing

FIGURE 7 – BOILING CONDENSATE CORROSION TEST





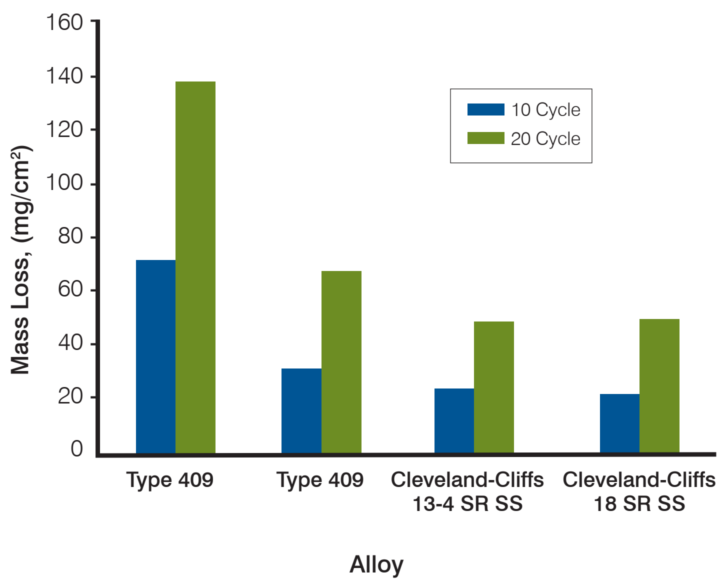
Hot Salt Cycle Test

Cleveland-Cliffs 13-4 SR Stainless Steel outperforms 11% Cr Type 409 and compares favorably to 18% Cr alloys (Cleveland-Cliffs 18 SR Stainless Steel and Type 439) when dipped in aqueous salt solutions and then exposed to 1250 °F (677 °C) temperatures.

TEST SETUP

- 90 min. heat treat at 1250 °F (677 °C)
- 1 min. cold water quench
- 5 min. 5% NaCl soak
- Repeat Cycle – Steps 1 – 3
- Samples in humidity overnight at 140 °F (60 °C) / 85% RH

FIGURE 8 – HOT SALT CYCLE TEST



Weldability

The ferritic class of stainless steels is generally considered to be weldable by common fusion and resistance techniques. Special consideration is required to avoid brittle weld fractures during fabrication by minimizing discontinuities, and maintaining low weld heat input. This particular alloy is generally considered to have slightly poorer weldability than the most common alloy of this stainless class, Type 409. A major difference is that the weld deposits themselves, while possessing reasonable ductility, may not be as ductile as the base metal. Gas Tungsten Arc Welds (GTAW) in 0.042 in. Cleveland-Cliffs 13-4 SR Stainless Steel sheet, both with and without filler, were bend tested according to ASTM E290 around a 0.500 in. diameter bar. All of the weld face and root bend tests passed with no cracking, indicating that the welds do have good ductility. When a weld filler is required, Cleveland-Cliffs 18 Cb filler is suggested for high-temperature service. Care should be taken to avoid forming welds in cold weather.

ER308L filler is suggested for better weld ductility in ambient temperature conditions. The specific alloy selection depends on the application.

Type 409 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 (filler metals, minimum UTS and elongation).
2. "Welding of Stainless Steels and Other Joining Methods", SSINA, (800:982 - 0355).
3. "Welding Stainless Steels", FDB #SF - 71.

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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