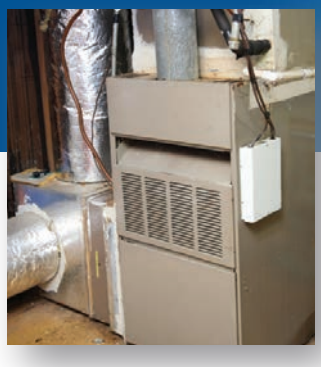
CLIFFS

11 Cr-Cb™

STAINLESS STEEL



- **Automotive Exhaust Tubing**
- **Gas Turbine Silencers**
- **High-Temperature Applications**

Cleveland-Cliffs **11 Cr-Cb™ STAINLESS STEEL** provides oxidation resistance and elevated temperature strength superior to Type 409 and comparable to 18 Cr-Cb™ and Type 439 stainless steels. This makes 11 Cr-Cb a cost-effective material for automotive exhaust tubing, gas turbine silencers and other high-temperature applications. This alloy also should be considered for applications in which Type 409 provides only marginal strength and oxidation resistance.

Product Description

Cleveland-Cliffs 11 Cr-Cb is a ferritic stainless steel that has increased silicon (Si) levels and is dual stabilized with titanium (Ti) and niobium (Nb). In addition to its high-temperature performance, 11 Cr-Cb Stainless Steel provides good forming and welding characteristics. By nature of its lower chromium (Cr) content, it has less wet-corrosion resistance than the higher chromium stainless steels (17 – 18%). However, from the standpoint of creep and oxidation resistance, it is nearly equivalent to these more costly high chromium stainless steel alternatives. Dual stabilized with titanium and niobium gives the alloy resistance to intergranular corrosion.

Composition		(wt %)
Carbon	(C)	0.03 max.
Manganese	(Mn)	1.0 max.
Phosphorus	(P)	0.04 max.
Sulfur	(S)	0.02 max.
Silicon	(Si)	1.00 – 1.75
Chromium	(Cr)	10.5 – 11.7
Nickel	(Ni)	0.05 max.
Titanium	(Ti)	0.10 – 0.30
Nitrogen	(N)	0.03 max.
Niobium (Columbium)	(Nb)	0.25 – 0.45

AVAILABLE FORMS

Cleveland-Cliffs produces 11 Cr-Cb Stainless Steel in coils and cut lengths in thicknesses from 0.030 – 0.115 in. (0.762 – 2.92 mm) and widths up to and including 48 in. (1219 mm). For other thicknesses, contact your Cleveland-Cliffs sales representative.

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.

Mechanical Properties

TABLE 1 – TYPICAL ROOM TEMPERATURE MECHANICAL PROPERTIES

UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)	Rockwell Hardness
73 (503)	49 (338)	30	B80

TABLE 2 – PROPERTIES ACCEPTABLE FOR MATERIAL SPECIFICATION

UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)
68 (469) min.	47 (324) min.	25.0 min.

HIGH TEMPERATURE FATIGUE STRENGTH

Fatigue strength of 11 Cr-Cb Stainless Steel is significantly greater than that of Type 409 and is essentially equal to that of 18 Cr-Cb™ Stainless Steel at 1500 °F (816 °C). This provides an attractive alternative for applications involving high temperatures and cyclic loading.

TABLE 3 – HIGH TEMPERATURE FATIGUE STRENGTH

Alloy	Strength to Surpass 10^7 Cycles, ksi. (MPa)	
	1300 °F (704 °C)	1500 °F (816 °C)
Aluminized Steel Type 1	3.1 (22)	1.5 (10)
Type 409	6.6 (45)	1.0 (7)
18 Cr-Cb SS	7.5 (52)	3.0 (21)
11 Cr-Cb SS	6.5 (44)	3.0 (21)
Type 439	4.0 (28)	1.4 (9)

**Tension/Tension R = 1*

Mechanical Properties

ELEVATED TEMPERATURE PROPERTIES

The synergy of chemistry and processing improves the high-temperature strength of 11 Cr-Cb Stainless Steel. These improved properties are shown in Table 4 and Figure 1.

TABLE 4 – TYPICAL ELEVATED – TEMPERATURE MECHANICAL PROPERTIES

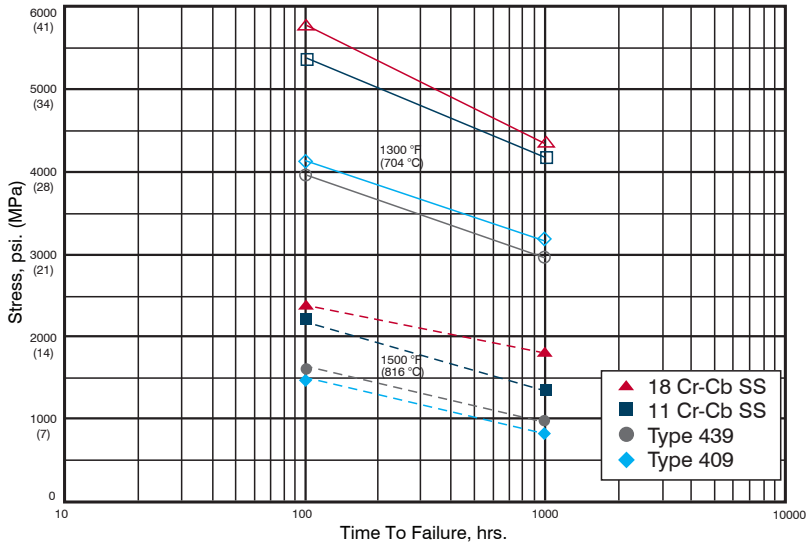
Alloy	Temperature °F (°C)	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)
11 Cr-Cb™ SS	700 (371) 1100 (593) 1500 (816)	59.2 (408) 50.4 (348) 5.9 (41)	33.9 (234) 25.5 (175) 3.8 (26)	25 16 140
18 Cr-Cb™ SS	700 (371) 1100 (593) 1500 (816)	60.5 (418) 58.0 (400) 7.9 (54)	33.5 (232) 25.5 (176) 6.0 (41)	25 16 70
Type 409	700 (371) 1100 (593) 1500 (816)	47.3 (326) 33.4 (231) 4.2 (29)	22.0 (152) 17.2 (118) 2.3 (16)	28 21 140

TABLE 5 – STRESS RUPTURE PROPERTIES OF STAINLESS STEEL AUTOMOTIVE EXHAUST ALLOYS

Alloy	Exposure Temperature			
	1300 °F (704 °C)		1500 °F (816 °C)	
	Stress, ksi. (MPa) for rupture in:			
	100 hours	1000 hours	100 hours	1000 hours
Type 409	4.1 (28.7)	3.2 (22.4)	1.5 (10.5)	0.9 (6.3)
Type 439	4.0 (28.0)	3.0 (21.0)	1.6 (11.2)	1.0 (7.0)
11 Cr-Cb™ SS	5.1 (34.7)	3.7 (25.9)	1.8 (12.6)	1.4 (9.8)
18 Cr-Cb™ SS	5.8 (39.6)	4.4 (30.8)	2.4 (16.8)	1.8 (12.6)
18 SR SS	3.8 (28.6)	2.6 (45.2)	1.7 (11.9)	0.9 (6.3)
Type 304	16.9 (116.3)	11.6 (80.2)	6.2 (41.5)	3.7 (25.9)

*Note: All values are average of duplicate except *denotes a single test.*

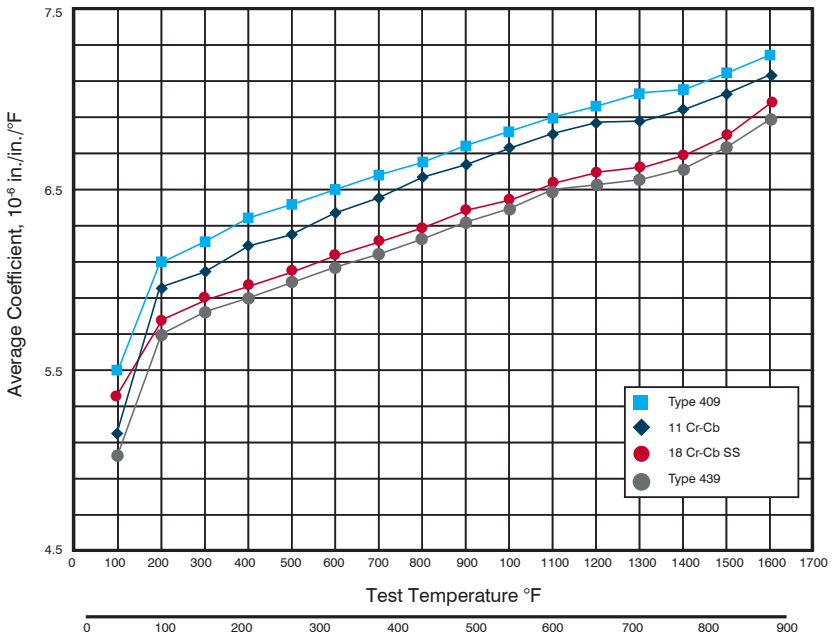
FIGURE 1 – FERRITIC STAINLESS STRESS RUPTURE PROPERTIES



PHYSICAL PROPERTIES

Density, lbs/in³. (g/cm³)	0.275 (7.61)
Electrical Resistivity μΩ•in (μΩ•cm)	31.7 (79.17)

FIGURE 2 – ELEVATED TEMPERATURE THERMAL EXPANSION



Tables

TABLE 6 – YOUNG'S MODULUS VERSUS TEMPERATURE

Temperature °F (°C)	Young's Modulus Versus Temperature, psi x 10^6 (MPa x 10^3)			
	Stainless Grade			
	Type 409	11 Cr-Cb SS	Type 439	18 Cr-Cb SS
70 (21)	29.9 (206)	30.4 (210)	28.4 (196)	29.8 (206)
200 (93)	28.1 (194)	29.7 (205)	27.4 (189)	29.2 (201)
400 (204)	27.5 (190)	28.8 (199)	26.6 (183)	27.9 (192)
600 (316)	26.5 (169)	27.6 (190)	26.2 (180)	26.7 (184)
800 (427)	25.4 (175)	26.0 (179)	24.5 (169)	25.1 (173)
1000 (538)	23.8 (165)	24.8 (161)	22.3 (154)	23.3 (161)
1200 (649)	22.3 (154)	22.2 (153)	20.1 (239)	19.7 (123)
1400 (760)	16.6 (114)	17.8 (123)	16.7 (115)	17.1 (118)
1600 (871)	—	14.9 (103)	—	—

TABLE 7 – THERMAL PROPERTIES

Temperature °F (°C)	Specific Heat, J/kg/K	Thermal Diffusivity, mm^2/s	Thermal Conductivity, W/m/K (BTU/in./hr./ft^2./°F)
73 (23)	451	5.00	17.2 (9.9)
212 (100)	493	5.46	20.5 (11.8)
392 (200)	528	5.50	22.1 (12.8)
572 (300)	560	5.37	22.9 (13.2)
752 (400)	602	5.07	23.2 (13.4)
932 (500)	685	4.74	24.7 (14.3)
1112 (600)	801	4.22	25.7 (14.8)
1292 (700)	990	3.21	24.2 (14.0)

Oxidation Resistance

The balanced chemistry and addition of silicon to 11 Cr-Cb Stainless Steel provides a significant improvement in oxidation resistance compared to Type 409. Oxidation performance in cyclic service at 1650 °F (899 °C) of 11 Cr-Cb Stainless Steel is very similar to that of Type 439 and 18 Cr-Cb Stainless Steel alloys.

TABLE 8 – 1650 °F CYCLIC OXIDATION*

Alloy	Weight Gain mg/in².*	Upper Cyclic Temperature Limit
11 Cr-Cb SS	4.9	1650 °F (899 °C)
Type 409	555	1500 °F (816 °C)
Type 439	6.0	1650 °F (899 °C)
18 Cr-Cb SS	3.4	1650 °F (899 °C)

**325 cycles at 25 minutes heat/5 minutes cool.*

11 Cr-Cb™ STAINLESS STEEL

CORROSION RESISTANCE

The general corrosion resistance of Cleveland-Cliffs 11 Cr-Cb Stainless Steel is similar to Type 409 stainless steel. This alloy has moderate resistance at lower temperatures to chloride and sulfate-rich environments. However, due to the higher silicon, this dual-stabilized alloy has a slight improvement to hot salt attack when compared to Type 409.

FORMABILITY

11 Cr-Cb Stainless Steel has good fabricating characteristics and can be easily cut, blanked and formed. Brake pressing and roll forming normally used on carbon steel can be used on this alloy.

Forming practice indicates that sheet 0.050 – 0.100 in. (1.27 – 2.54 mm) requires a minimum bend radius equal to the metal thickness, 1T.

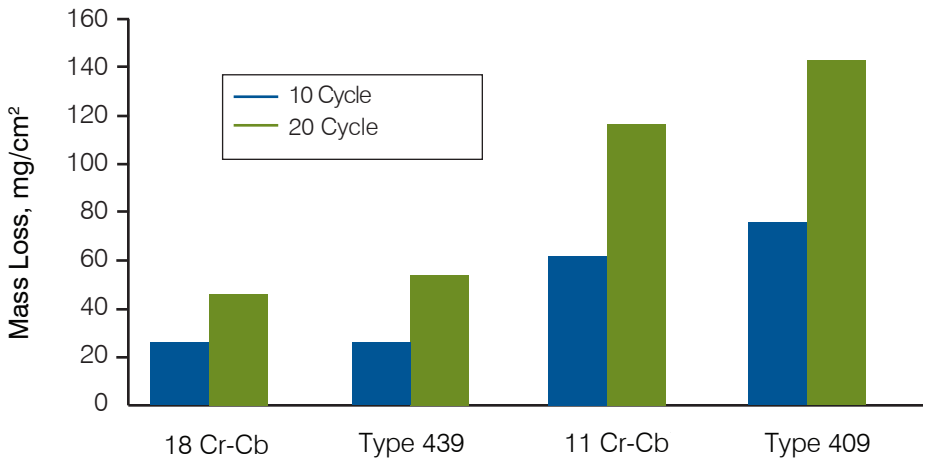
Caution: Cold weather impact loads should be avoided with heavy gauge material, particularly with welds, because the ductile-to-brittle transition temperature (DBTT) could fall close to ambient temperature.

WELDABILITY

11 Cr-Cb Stainless Steel is weldable by the common fusion and resistance welding processes, including laser and high-frequency induction tube welding. This grade is generally considered to have diminished weldability compared to the most common alloy of this stainless class, Type 409. The compositional effects of the high silicon and columbium tend to reduce weld formability. Grain growth and reduced toughness in the heat-affected zone may also occur from the heat of welding. Use of a low heat input weld procedure, minimizing stress concentrations and warming parts slightly prior to forming will reduce the tendency for brittle weld fracture in subsequent processing. When a weld filler wire is required, 18 Cr-Cb Stainless Steel (No AWS Class) and EC439Nb are often recommended for light-gauge high-temperature (>1000 °F) service where thermal cycling is expected. Austenitic filler wire ER309L/EC309L may be used for heavy gauge and low temperature exposure applications. The addition of hydrogen to weld shielding gases for increased welding speed is discouraged, as the ferritic stainless steels are subject to hydrogen embrittlement. More information on the welding of ferritic stainless steels may be obtained from the following sources:

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

FIGURE 3 – HOT SALT CORROSION TEST



1 Cycle in Hot Salt Testing

1. Dip 5 minutes in 5* sodium chloride solution
2. Expose to 1250 °F for 90 minutes
3. WQ 1 minute
4. Run 4 cycles per day with the balance of the 24 hour period held in controlled temperature and humidity chamber set at 140 °F/85% RH
5. Evaluate after 20 cycles
6. Glass peen blast to remove scale
7. Measure mass loss

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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