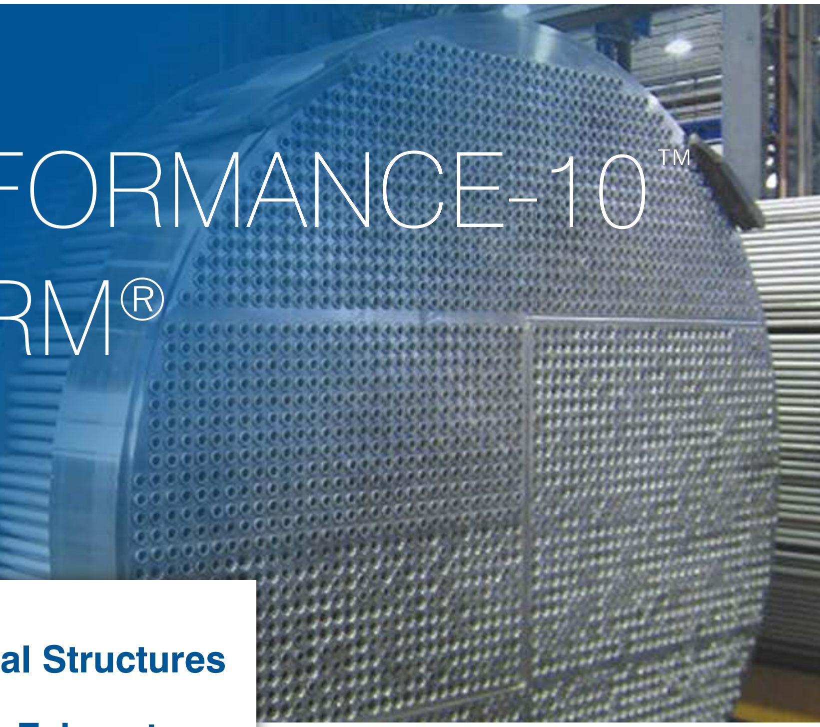
439 HIGH PERFORMANCE-10™
439 ULTRA FORM®
STAINLESS STEEL



Architectural Structures

Automotive Exhaust

Heat Exchangers

Kitchen Equipment

Oxidation resistance and corrosion resistance, superior to Type 409, make Type 439 attractive for numerous automotive exhaust applications. Suggested applications include tubular manifolds and other exhaust system areas where temperatures may exceed the oxidation limit of Type 409 or where aqueous corrosion resistance, particularly to chlorides, is needed. Type 439 performs well in oxidizing environments and resists stress corrosion cracking. The alloy's good weldability, high thermal conductivity and low thermal expansion make it a good choice for many applications. Non-automotive applications include heat exchanger tubing, kitchen equipment, household appliances and architectural structures. Cleveland-Cliffs **439 ULTRA FORM® Stainless Steel** was developed for applications with more severe forming requirements than standard Type 439 stainless steel. The material offers advantages for parts requiring complex shapes.

Product Description

Type 439 is a ferritic stainless steel that outperforms Type 409 in both oxidation resistance and corrosion resistance. Type 439 is stabilized with a titanium (Ti) addition resulting in good weldability. The alloy resists intergranular corrosion and stress corrosion cracking. It has higher thermal conductivity and lower coefficient of expansion than Type 304.

Cleveland-Cliffs 439 ULTRA FORM Stainless Steel provides an outstanding combination of improved forming characteristics over standard Type 439. These benefits are achieved through precise control of chemistry and thermo-mechanical processing from melting to finishing. This provides special advantages when producing difficult-to-form exhaust system components.

Composition		(wt %)
Carbon	(C)	0.03 max.
Manganese	(Mn)	1.00 max.
Phosphorus	(P)	0.04 max.
Sulfur	(S)	0.03 max.
Silicon	(Si)	1.00 max.
Chromium	(Cr)	17.0 – 19.0
Nickel	(Ni)	0.5 max.
Nitrogen	(N)	0.03 max.
Titanium	(Ti)	0.20 + 4(C+N) min., 1.1 max.
Aluminum	(Al)	0.15 max.

AVAILABLE FORMS

Cleveland-Cliffs 439 HIGH PERFORMANCE-10 Stainless Steel is available in thicknesses from 0.015 – 0.10 in. (0.38 – 2.54 mm) in widths up to and including 48 in. (1219 mm). For other sizes, contact your Cleveland-Cliffs sales representative.

Cleveland-Cliffs 439 ULTRA FORM Stainless Steel is available in thicknesses from 0.015 – 0.145 in. (0.38 – 3.68 mm) in widths up to 48 in. (1219 mm). For other sizes, 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 – MECHANICAL PROPERTIES

	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)	Rockwell Hardness, B
Type 439	66 (455)	41 (283)	30	75
Cleveland-Cliffs 439 ULTRA FORM®	66 (455)	41 (283)	33	74
ASTM A240	60 (414) min.	30 (207) min.	22 min.	89 max.

TABLE 2 – EFFECT OF COLD WORK ON MECHANICAL PROPERTIES 439 ULTRA FORM STAINLESS STEEL

Condition	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)	Rockwell Hardness, B
Annealed	63.6 (438)	38.2 (263)	35	73
Cold-worked 5%	70.2 (484)	66.7 (460)	24	85
Cold-worked 10%	79.2 (546)	78.9 (544)	12	89
Cold-worked 15%	89.5 (618)	88.9 (613)	7	92
Cold-worked 30%	103.4 (713)	98.5 (680)	4	96
Cold-worked 50%	113.8 (785)	109.1 (753)	3	97

885° EMBRITTLEMENT

Most 18 chrome ferritic alloys exhibit a significant loss of ductility when exposed to the temperature range of 800 – 1000° F (427 – 538° C). This phenomenon is known as 885° F (474° C) embrittlement.

Tensile results after exposure for 1000 hours at 900° F (482° C) are shown in Table 3.

TABLE 3 – EFFECT OF 900° F (482° C) ON ROOM TEMPERATURE PROPERTIES

Alloy	Condition	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2" (50.8 mm)	Rockwell Hardness, B
Type 439	Annealed	71.1 (491)	44.0 (303)	33.0	B77
	1000 hours @900° F (482° C)	111.4 (768)	98.2 (677)	21.5	C20

Mechanical Properties

TABLE 4 – EFFECT OF 900° F (482° C) PROPERTIES EXPOSURE ON ROOM TEMPERATURE MECHANICAL PROPERTIES

Condition	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)	Rockwell Hardness
Annealed	70.0 (483)	44.0 (303)	35	B77
Annealed + 10 hrs. @900° F (482° C)	72.7 (501)	48.8 (337)	33.5	B81
Annealed + 100 hrs. @900° F (482° C)	90.0 (621)	74.2 (511)	25.2	B93
Annealed + 100 hrs. @900° F (482° C) + 1 hr. @ 1100°F (593° C)	71.1 (491)	45.8 (316)	32	B79
Annealed + 1000 hrs. @900° F (482° C)	114.4 (768)	98.2 (677)	21.5	C20
Cold-worked 30%	105.9 (730)	103.7 (715)	4	B97
Cold-worked 30% + 100 hrs. @ 900° F (482° C)	123.2 (849)	115.2 (794)	13.2	C25
Cold-worked 30% + 100 hrs. @ 900° F (492° C)+ 1 hr. @ 900° F (492° C)	105.2 (725)	96.4 (665)	12	B99

**All values are average of duplicate except * denotes a single text.*

TABLE 5 – SHORT-TIME ELEVATED TEMPERATURE STRENGTH

Temperature, °F (°C)	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)
1000 (538)	37.3 (257)	21.2 (146)
1200 (650)	17.7 (122)	12.0 (83)
1300 (705)	9.4 (65)	7.0 (48)
1400 (761)	5.8 (40)	4.6 (32)
1500 (817)	4.2 (29)	3.3 (23)
1584 (862)	2.9 (20)	2.6 (18)

TABLE 6 – 439 FATIGUE STRENGTH

Temperature, °F (°C)	Fatigue Strength (r=0.1) to Surpass 10^7 Cycles – ksi. (MPa)
1300 (704)	5.5 (38)
1500 (816)	2.0 (14)

Mechanical Properties

TABLE 7 – STRESS RUPTURE PROPERTIES

Temperature, 1300° F (704° C)		Temperature, 1500° F (815° C)	
Stress, ksi. (Mpa) 100 hrs.	Stress, ksi. (MPa) 1000 hrs.	Stress, ksi. (MPa) 100 hrs.	Stress, ksi. (MPa) 1000 hrs.
4.0 (27.5)	3.0 (20.7)	1.6 (11.0)	1.0 (6.9)

TABLE 8 – STRESS RUPTURE PROPERTIES OF STAINLESS STEEL AUTOMOTIVE EXHAUST ALLOYS

Alloy	Exposure Temperature			
	Temperature, 1300° F (704° C)		Temperature, 1500° F (815° C)	
	Stress, ksi. (MPa), for rupture in:			
	100 hrs.	1000 hrs.	100 hrs.	1000 hrs.
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)
Cleveland-Cliffs 11 Cr-Cb™ SS	5.1 (34.7)	3.7 (25.9)	1.8 (12.6)	1.4 (9.8)
Cleveland-Cliffs 18 Cr-Cb™ SS	5.8 (39.6)	4.4 (30.8)	2.4 (16.8)	1.8 (12.6)
Cleveland-Cliffs 17 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)

**All values are average of duplicate except * denotes a single text.*

IMPACT PROPERTIES

Ductile to brittle transition (DTBT) curves were obtained from the charpy V-notch test. Longitudinal and transverse transition curves are shown in Figures 1 and 2. Material tested was 0.058 in. (1.47 mm) thick. The transition temperature is the point on the graph where the material changes sharply from displaying ductile behavior to displaying brittle behavior. The transition temperature shown by the graph for the longitudinal samples tested is -130 °F (-90 °C) and for the transverse samples, -160 °F (-107 °C).

FIGURE 1 – LONGITUDINAL IMPACT 439 ULTRA FORM STAINLESS STEEL

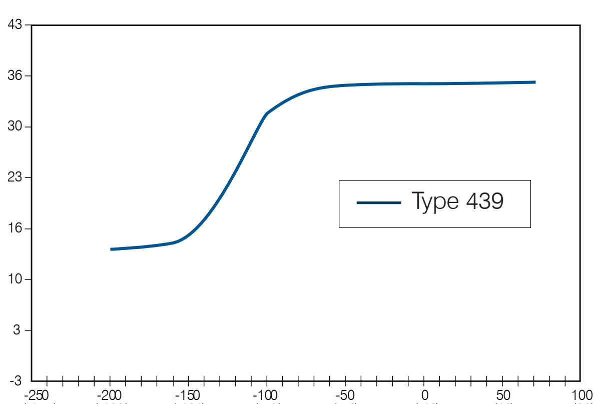
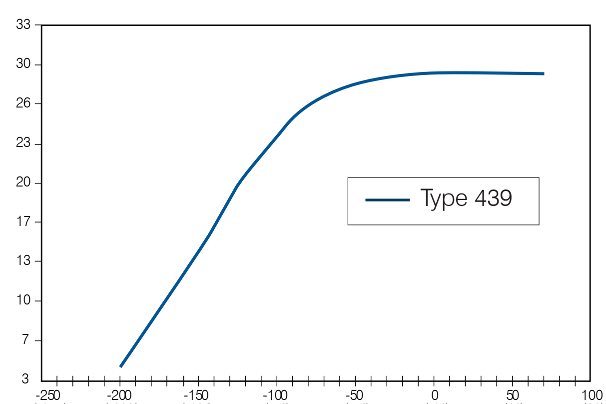


FIGURE 2 – TRANSVERSE IMPACT 439 ULTRA FORM STAINLESS STEEL



Physical Properties

TABLE 9 – PHYSICAL PROPERTIES

Density, lbs/in.^{3} (g/cm^3)	0.28 (7.8)
Electrical Resistivity (μΩ•in.)	24.80

TABLE 10 – YOUNG'S MODULUS VERSUS TEMPERATURE

Young's Modulus Versus Temperature, psi. (MPa)	
Temperature °F (°C)	Young's Modulus
70 (21)	28.4 x 10^6 (193 x 10^3)
300 (148)	27.4 x 10^6 (190 x 10^3)
500 (260)	26.6 x 10^6 (183 x 10^3)
700 (427)	26.2 x 10^6 (181 x 10^3)
900 (482)	24.5 x 10^6 (169 x 10^3)
1100 (593)	22.3 x 10^6 (154 x 10^3)
1300 (704)	20.1 x 10^6 (139 x 10^3)

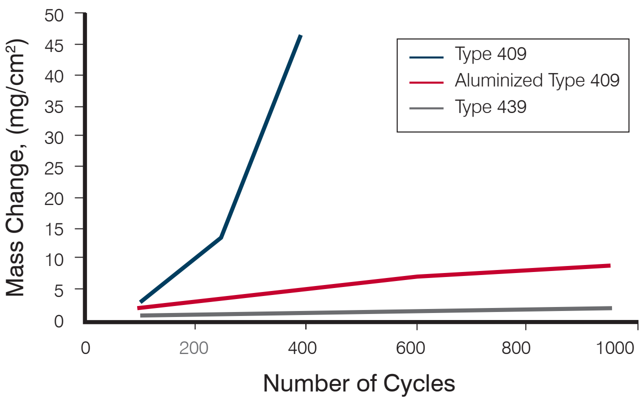
TABLE 11 – AVERAGE COEFFICIENT OF THERMAL EXPANSION

Temperature °F (°C)	10^{-6} in./in.•°F
200 (93)	5.71 (10.3)
400 (204)	5.90 (10.6)
600 (316)	6.08 (10.9)
800 (427)	6.26 (11.2)
1100 (593)	6.49 (11.7)
1300 (704)	6.54 (11.8)
1500 (816)	6.77 (12.1)
1600 (871)	6.90 (12.4)

Oxidation Resistance

Results of cyclic oxidation tests of Aluminized Steel Type 1 and Type 409, Type 439 and Type 304 Stainless Steels are shown in Tables 8 and 9. Type 439 exhibits considerably better oxidation resistance than Type 409 at the 1700 °F (927 °C) temperature.

FIGURE 3 – CYCLIC OXIDATION AT 1650° F (900° C)1 CYCLE = 25 min. HEAT/5 mins. COOL



Figures 4, 5 and 6 provide results from 1500 °F (816 °C), 1600 °F (871 °C) and 1700 °F (926 °C) cyclic oxidation tests. Cleveland-Cliffs 439 ULTRA FORM Stainless Steel samples were tested until they gained sufficient weight to reach the point of breakaway oxidation and catastrophic failure. In the 1500 °F (816 °C) test, the samples gained less than 2 mg/in² after 1100 cycles, showing no sign of failure.

Samples in the 1600 °F (871 °C) test gained approximately 10 mg/in², still showing no sign of failure. The Cleveland-Cliffs 439 ULTRA FORM Stainless Steel samples at 1700 °F (926 °C) gained 320 mg/in² after 1000 cycles, but were not determined as catastrophic failures. Cleveland-Cliffs 11 Cr-Cb™ Stainless Steel and Aluminized Type 409 data are shown for comparison.

FIGURE 4 – CYCLIC OXIDATION 439 ULTRA FORM STAINLESS STEEL 1500° F (816° C)1 CYCLE = 25 min. HEAT/5 min. COOL

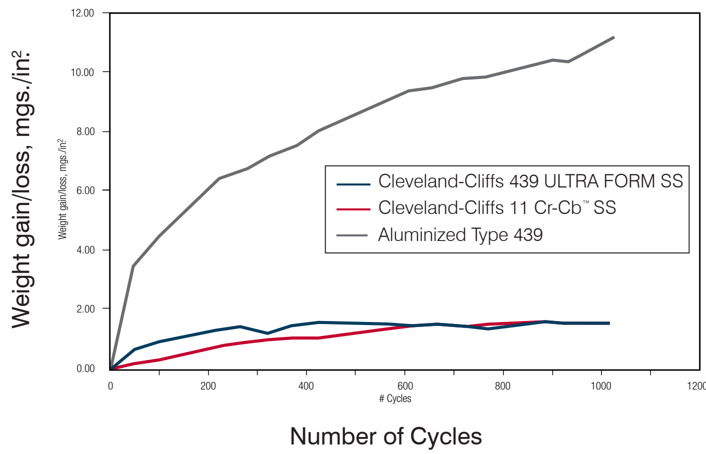


FIGURE 5 – CYCLIC OXIDATION 439 ULTRA FORM STAINLESS STEEL 1600° F (871° C)1 CYCLE = 25 min. HEAT/5 min. COOL

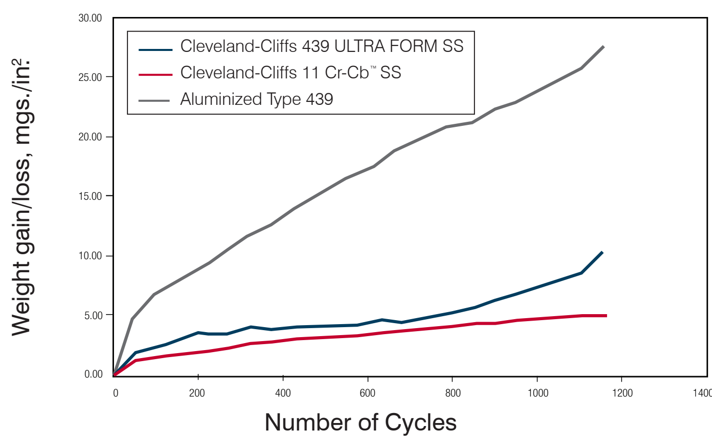
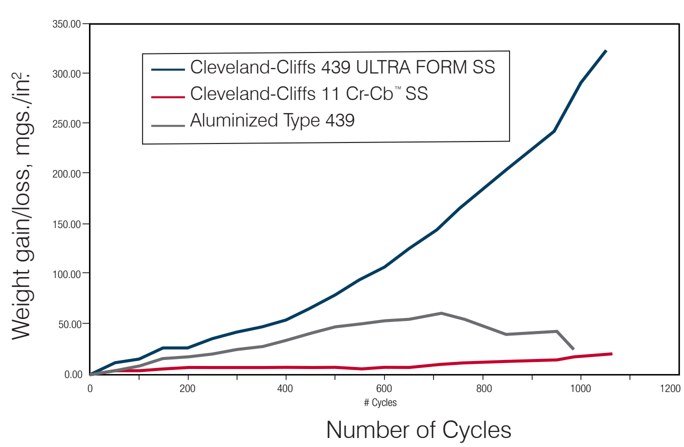


FIGURE 5 – CYCLIC OXIDATION 439 ULTRA FORM STAINLESS STEEL 1700° F (926° C)1 CYCLE = 25 min. HEAT/5 min. COOL



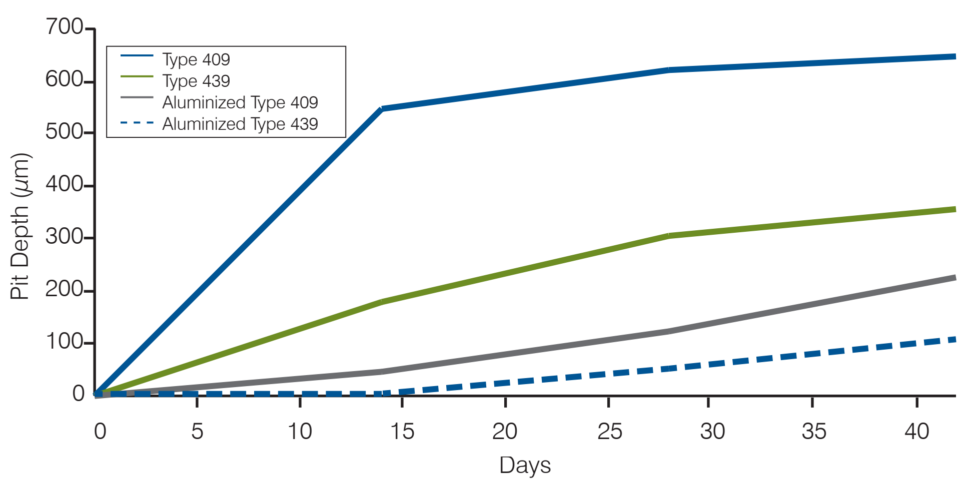
Corrosion Resistance

The general corrosion resistance of Type 439 is superior to Type 409 in most environments due to the added 17% chromium. Both Cleveland-Cliffs 439 ULTRA FORM Stainless Steel and regular Type 439 exhibit good wet corrosion resistance to chlorides, sulfates, and many organic acids and have proven to be acceptable for many automotive exhaust applications. Very little difference in corrosion behavior has been observed when comparing Cleveland-Cliffs 439 ULTRA FORM Stainless Steel to regular Type 439.

CLEVELAND-CLIFFS SALT CYCLE TESTING

When comparing the pitting resistance of various alloys used for automotive exhaust applications, a cyclic 5% sodium chloride exposure is used to mimic road salt exposure experienced during service. Flat sheet samples 0.060 – 0.069 in. (1.5 – 1.8 mm) are heat treated for 1 hr. at 427 °C (800 °F) once per week and then immersed in neutral, sodium chloride solution for 15 minutes followed by a 1 hr. 30 min. ambient air dry. The balance of the 24-hour period is held in a fixed temperature/humidity chamber set at 60 °C (140 °F)/85% RH. This process is repeated five days/week. Samples are removed from test every two weeks, cleaned and pit depth measurements are collected.

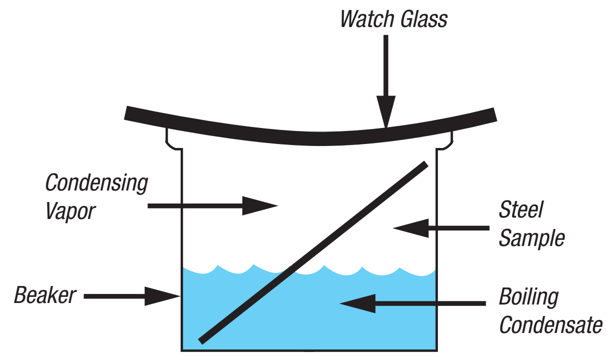
FIGURE 7 – SALT CYCLE TESTING



Corrosion Resistance

ACIDIC MUFFLER CONDENSATE TEST

Corrosion caused by internal exhaust condensate is a common occurrence in the field. This test is used as a materials screening to evaluate the corrosion resistance of various alloys under very aggressive cyclic acid condensate exposure similar to what is experienced during service in some locations.



TEST SETUP:

Partial immersion of 2 x 4 in. (7.6 x 10.2 cm) coupon in synthetic condensate

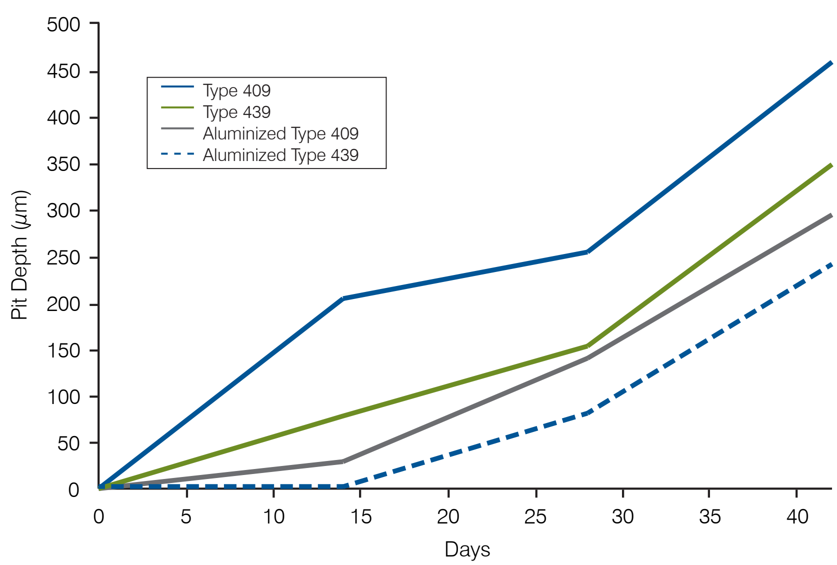
Test Solution:

- 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 hour at 500 °C (932 °F)
- Humidity exposure for 6 hours at 60 °C (140 °F)/85% RH
- 16 hours exposed to boiling test solution (boil to dryness)

FIGURE 8 – ACIDIC MUFFLER TEST



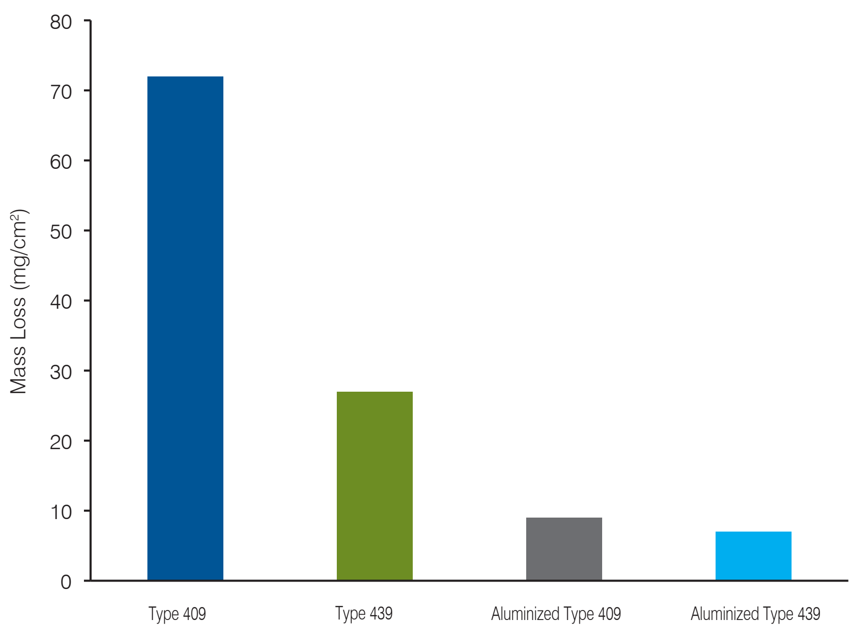
Corrosion Resistance

HOT SALT CYCLE

The following accelerated lab test was designed to simulate hot end operating conditions. This test is used to evaluate the effect of residual salt attack on exhaust components at high temperatures.

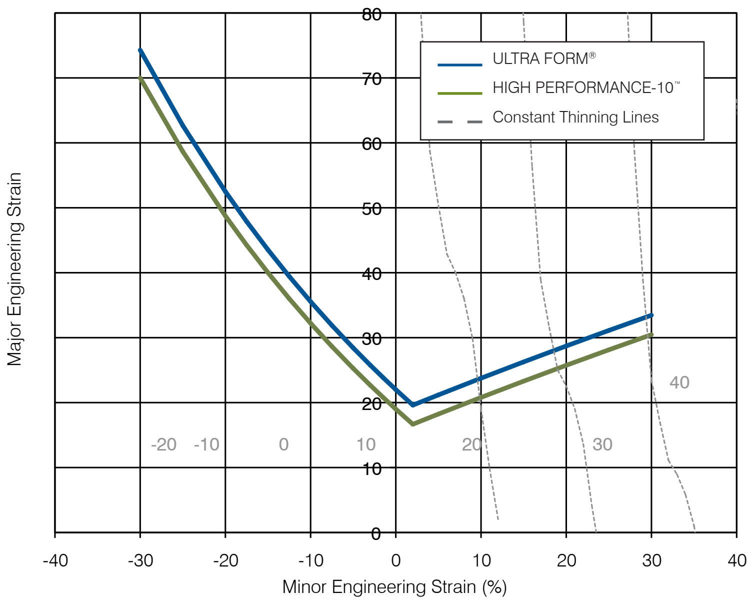
Four-inch by four-inch sheet specimens are exposed to a 5 minute immersion to 5% sodium chloride solution followed by a heat treatment exposure to 677 °C (1250 °F) for 90 minutes. Upon completion of the 90 minute heat treatment the test specimens are water quenched for one minute. This salt dip-heat treatment cycle is repeated four times per day with the balance of the day exposed to 60 °C (140 °F)/85% RH. This is equal to four cycles within a 24 hour period. Specimens are removed at 20 cycles, bead blasted and measured for mass loss.

FIGURE 9 – HOT SALT TEST



Formability

FIGURE 10 – FORMING LIMIT CURVES TYPE 439, 0.04 in. THICK PRIMARY STRAIN TRANSVERSE TO SHEET ROLLING DIRECTION DEVELOPED IN ACCORDANCE WITH ASTM E 2208



Type 439 provides good formability. The limiting draw ratio (LDR) for this alloy is 2.13.

A uniform grain structure, improved rm value, and improved ridging and roping resistance allow Cleveand-Cliffs 439 ULTRA FORM Stainless Steel to be formed into more complex shapes than is possible with standard Type 439. The material provides good fabricating characteristics and can be blanked and formed without difficulty.

Results from the Olsen Cup and stretch-r_m formability tests are shown in Table 12. For the Olsen Cup test, duplicate sets were run for each coil tested and the data listed is the average of all tested coils.

TABLE 12 – FORMABILITY CLEVELAND-CLIFFS 439 ULTRA FORM STAINLESS STEEL

Material Thickness, in. (mm)	Dome Height, in. (mm)	r_m – value
0.022 – 0.028 (0.56 – 0.71)	0.330 (8.38)	1.96
0.030 (0.76)	0.342 (8.69)	2.03
0.056 – 0.059 (1.42 – 1.50)	0.408 (10.36)	1.62
0.035 (0.89)	0.371 (9.42)	1.78

439 HIGH PERFORMANCE-10™ | 439 ULTRA FORM® STAINLESS STEEL

TYPE 439/439 ULTRA FORM WELDABILITY

Cleveland-Cliffs 439 HIGH PERFORMANCE-10 Stainless Steel and Cleveland-Cliffs 439 ULTRA FORM Stainless Steel can be joined by the common fusion and resistance welding processes, including laser and high-frequency induction tube welding. Low welding heat input will minimize grain growth and improve toughness in the weld heat-affected zone. Stabilization with titanium virtually eliminates weld zone sensitization. Cleveland-Cliffs 439 ULTRA FORM Stainless Steel offers slightly improved weldability when compared to the standard Cleveland-Cliffs 439 HIGH PERFORMANCE-10 Stainless Steel. AWS classification filler wires ER439, EC439, and EC439Nb are often used when a filler is needed for light gauge high temperature service (>1000 °F) where thermal cycling is expected. Austenitic filler wires ER308L or EC308L may be used for lower temperature applications. Additional 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)

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.

CLEVELAND-CLIFFS INC.
200 Public Square
Suite 3300
Cleveland, OH 44114-2315
844.STEEL99 | 844.783.3599
clevelandcliffs.com

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