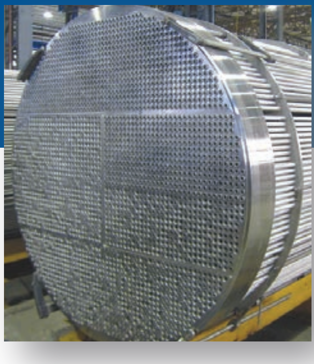
409 HIGH PERFORMANCE - 10™
409 ULTRA FORM®
STAINLESS STEEL



Exhaust Systems

Fuel Filers Pipes

Heat Exchangers

Tubular Manifolds

TYPE 409 STAINLESS STEEL is especially useful for applications requiring oxidation or corrosion protection beyond the capability of carbon steel and some coated steels. Current uses include automotive and truck exhaust systems, tubular manifolds, agricultural spreaders, gas turbine exhaust silencers, heat exchangers and fuel filters. This alloy provides good oxidation and corrosion resistance for automotive and non-automotive exhaust applications. Cleveland-Cliffs 409 ULTRA FORM® Stainless Steel was created to meet more severe forming requirements than typical Type 409 and is particularly suitable for parts requiring more complex shapes and improved weldability.

Product Description

Type 409 offers economical corrosion resistance and good formability. The nominal 11% chromium (Cr) content offers improved corrosion resistance over carbon steel. The composition of Type 409 is balanced with a titanium (Ti) addition and low-carbon levels to avoid austenite formation, making the alloy essentially non-hardenable when exposed to annealing temperatures and when welding. The titanium additions not only stabilize the steels to prevent hardening during welding, but also prevent the formation of chromium carbides. Welds and weld heat affected zones perform nearly as well as the base metal in corrosion resistance and forming.

Cleveland-Cliffs 409 ULTRA FORM Stainless Steel provides an outstanding combination of improved forming, ridging and roping. These benefits are achieved through precise control of chemistry and thermomechanical processing from melting to finishing.

Composition		(wt %)
Carbon	(C)	0.03 max.
Manganese	(Mn)	1.00 max.
Phosphorus	(P)	0.040 max.
Sulfur	(S)	0.02 max.
Silicon	(Si)	1.00 max.
Chromium	(Cr)	10.50 – 11.70
Nickel	(Ni)	0.5 max.
Nitrogen	(N)	0.03 max.
Titanium	(Ti)	8 (C+N) min. 0.15 – 0.50

AVAILABLE FORMS

Cleveland-Cliffs produces Type 409 in coils and cut lengths in thicknesses from 0.015 – 0.250 in. (0.381 – 6.350 mm) in widths up to and including 48 in. (1219 mm). For welded applications over 0.120 in. (3.048 mm) thick, Cleveland-Cliffs 409 Ni will provide improved toughness and weldability.

The surface finish of Type 409 stainless is obtained by annealing and pickling after rolling. The pickled surface is relatively matte and, like other titanium stabilized stainless steels, it may have some cosmetic titanium streaks. Therefore, where a uniform surface finish is required, these stainless steels may not be satisfactory. In cases where surface appearance is important, and titanium streaks are objectionable, Cleveland-Cliffs 400 should be considered.

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 MECHANICAL PROPERTIES ANNEALED CONDITION TRANSVERSE ORIENTATION

	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)	Rockwell Hardness, B
Acceptable Specifications ASTM A240 UNS S40920	55 (379) min.	25 (172) min.	20 min.	88 max.
Type 409	60 (414)	34 (234)	32	66
Cleveland-Cliffs 409 ULTRA FORM SS	62 (427)	35 (241)	35	67

TABLE 2 – EFFECT OF COLD WORK ON MECHANICAL PROPERTIES* 0.062 in. (1.545 mm)

Condition	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)	Rockwell Hardness, B
Annealed	60.6 (418)	32.6 (258)	36	70
Cold Worked 5%	63.0 (434)	51.5 (352)	32	70
Cold Worked 10%	71.1 (490)	70.5 (486)	17	85
Cold Worked 16.4%	79.0 (545)	78.5 (541)	10	89
Cold Worked 32.5%	95.4 (657)	94.5 (652)	4	94
Cold Worked 45.4%	105.9 (730)	104.5 (721)	4	85

**Average results of duplicate laboratory tests on randomly selected coils.*

TABLE 3 – EFFECT OF 885 °F (475 °C) EMBRITTLEMENT ON ROOM-TEMPERAURE PROPERTIES AND ROOM-TEMPERATURE PROPERTIES AFTER 30% COLD WORK

Unlike higher alloyed ferritic stainless steels, Type 409 stainless steel annealed and cold worked do not show any detrimental effect on ductility after exposure of up to 1000 hours within the 885 °F (475 °C) embrittlement range.

Condition	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)	Elongation % in 2 in. (50.8 mm)	Rockwell Hardness
Annealed	64.4 (444)	37.5 (258)	36	69
Annealed + 10 hrs @900 °F (492 °C)	64.0 (441)	38.4 (265)	35	70
Annealed + 100 hrs @900 °F (492 °C)	64.2 (443)	39.3 (271)	35	72
Annealed + 1000 hrs @900 °F (492 °C)	64.8 (447)	39.8 (275)	34	70
Cold Worked 30%	99.3 (685)	96.4 (631)	—	96
Cold Worked 30% + 100 hrs @900 °F (492 °C)	99.5 (687)	96.6 (632)	13	99

Mechanical Properties

TABLE 4 – TYPICAL SHORT-TIME ELEVATED TEMPERATURE PROPERTIES

(Average of duplicate tests on randomly selected coils)

Temperature, °F (°C)	UTS, ksi. (MPa)	0.2% YS, ksi. (MPa)
70 (21)	59.0 (4017)	33.9 (233)
400 (204)	52.0 (358)	25.0 (172)
700 (427)	48.0 (330)	23.0 (159)
1000 (538)	34.9 (241)	17.4 (120)
1200 (649)	22.8 (157)	12.5 (86)
1300 (704)	10.6 (73)	7.5 (52)
1400 (760)	6.1 (42)	4.4 (30)
1500 (816)	4.2 (29)	3.0 (21)
1600 (871)	3.0 (21)	2.4 (16)

TABLE 5 – ELEVATED TEMPERATURE FATIGUE STRENGTH (Tension/Tension R = 0.1)

Temperature, °F (°C)	Fatigue Strength to Surpass 10^7 Cycles, ksi. (MPa)
70 (21)	47.0
700 (371)	45.0
1100 (593)	17.0
1300 (704)	5.0
1600 (816)	1.5

TABLE 6 – STRESS RUPTURE PROPERTIES 0.045 – 0.060 in. (1.14 – 1.52 mm)

Temperature, °F (°C)	Maximum Stress to Failure, ksi. (MPa)	
	100 hrs.	1000 hrs.
1300 (704)	4.1 (27.5)	3.2 (22.0)
1500 (816)	1.5 (10.3)	0.9 (6.2)

FIGURE 1 – SPECIFIC HEAT

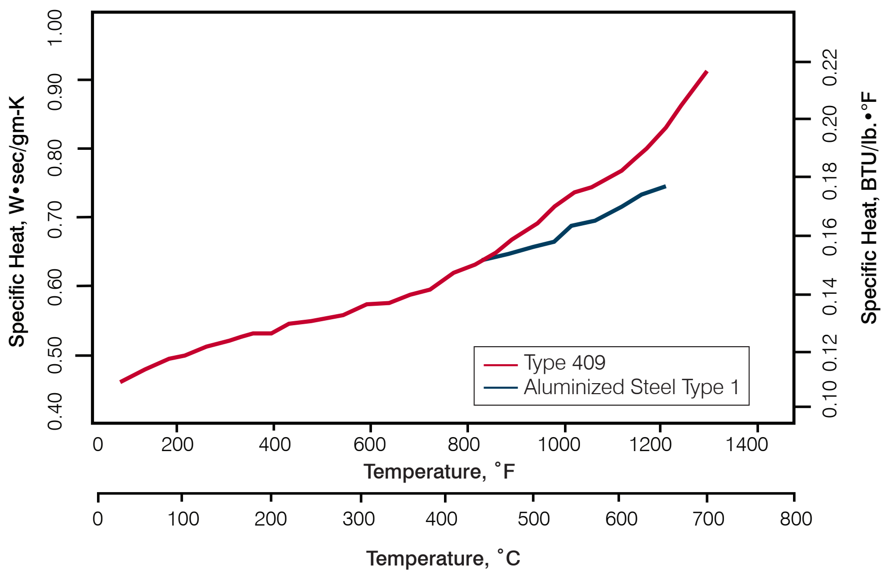


FIGURE 2 – ELEVATED TEMPERATURE THERMAL EXPANSION DATA

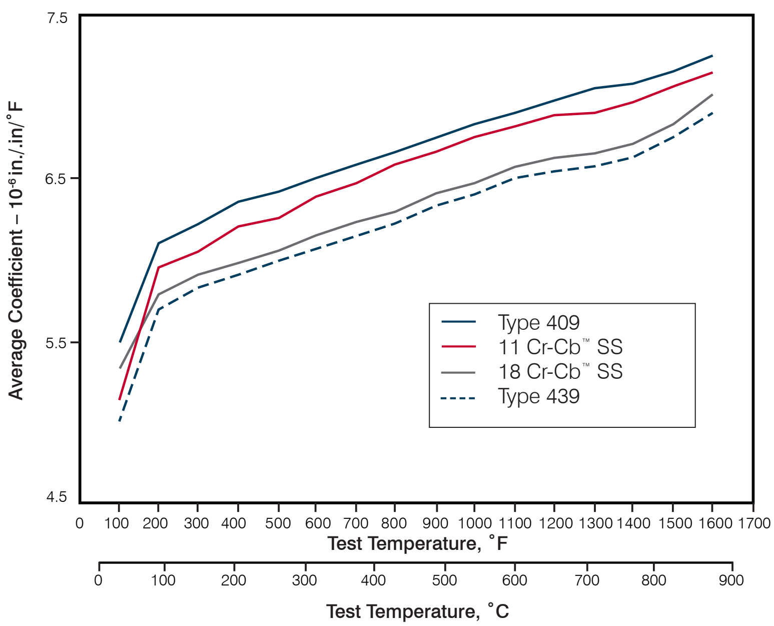


TABLE 7 – PHYSICAL PROPERTIES

Density, lbs/in.^{3} (g/cm^3)	0.280 (7.74)
Specific Electrical Resistance ($\mu\Omega$•cm)	60.0
Modulus of Elasticity in Tension at room temperature psi. (MPa)	30.2 x 10^6 (20.8 x 10^4)

Physical Properties

TABLE 8 – THERMAL CONDUCTIVITY, SPECIFIC HEAT AND DIFFUSIVITY

Temperature	Conductivity		Specific Heat		Diffusivity	
°F (°C)	W(m•K)	BTU (hr.•ft. •°F)	J/(Kg•K)	BTU/(lb.•°F)	mm²/sec.	ft.²/hr.
73 (23)	25.7	14.8	466	0.111	7.6	0.281
212 (100)	25.8	14.9	492	0.118	6.90	0.267
392 (200)	26.4	15.2	529	0.126	6.55	0.254
572 (300)	27.1	15.7	567	0.135	6.29	0.244
752 (400)	26.9	15.6	608	0.145	5.82	0.226
932 (500)	27.5	15.9	680	0.162	5.31	0.206
1112 (600)	26.9	15.5	767	0.183	4.61	0.179
1292 (700)	25.4	14.7	321	0.220	3.62	0.140
1472 (800)	30.7	17.7	882*	0.211	4.57	0.177
1598 (870)	32.3	18.7	846*	0.202	5.02	0.194

**Extrapolated values*

TABLE 9 – MODULUS OF ELASTICITY TEST DATA

E = average Young's modulus of elasticity at temperature, based on triplicate longitudinal sample tests

Temperature	Test E		ASME(1) E	
°F (°C)	psi. x 10^6	MPa x 10^4	psi. x 10^6	MPa x 10^4
70 (21)	30.2	20.8	29.2	20.1
200 (93)	29.4	20.3	28.5	19.6
300 (149)	—	—	27.9	19.2
400 (204)	28.9	19.9	27.3	18.8
500 (260)	—	—	26.7	18.4
600 (316)	27.9	19.2	26.1	18.0
700 (371)	—	—	25.6	17.6
800 (427)	26.1	18.0	24.7	17.0
900 (482)	—	—	23.2	16.0
1000 (649)	23.5	16.2	—	—
1200 (649)	16.6	11.4	—	—

Notes: (1) Data from 1989 ASME Boiler and Pressure Vessel Code, Section VIII, Division 2, Table AMG-2, Chromium steels 12 Cr – 17 Cr (Group F).
Note that Type 409 is nominally 11 Cr.

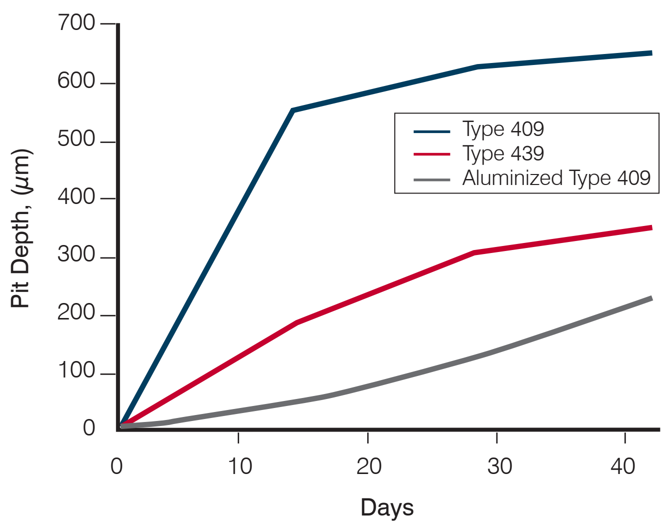
Corrosion Resistance

The general corrosion resistance of Type 409 is similar to Type 410, performing far superior to carbon steel products in most applications. Both Cleveland-Cliffs 409 ULTRA FORM Stainless Steel and regular Type 409 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 409 ULTRA FORM Stainless Steel to regular Type 409. Type 409 products contain a certain number of surface inclusions, which are the normal result of titanium additions. Occasional red rust may occur at these inclusion sites and lead to cosmetic corrosion. As a result, these steels are not suggested for applications where surface appearance is a factor.

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 measuring 1.5 – 1.8 mm (0.060 – 0.069 in.) are heat treated for 1 hr. at 427 °C (800 °F) once per week. They are then immersed in neutral sodium chloride solution for 15 min., followed by a 90 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 a week. Samples are removed from test every two weeks and cleaned. Pit depth measurements are collected.

FIGURE 3 – CLEVELAND-CLIFFS SALT CYCLE TESTING – TEST PROCEDURE



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

FIGURE 4

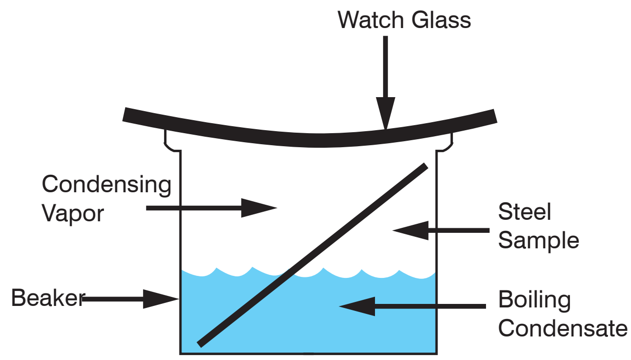
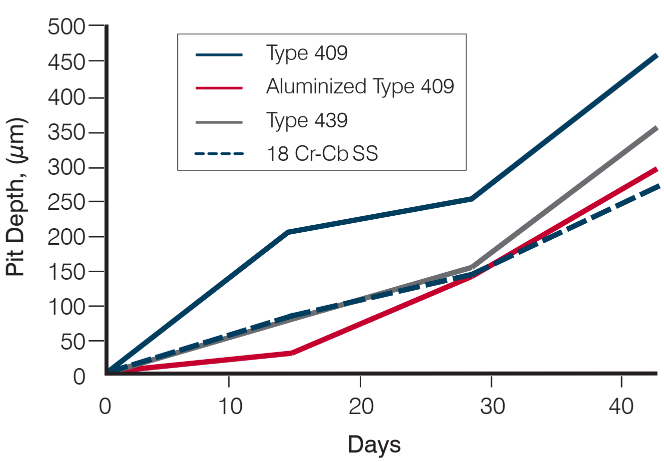


FIGURE 5 – CLEVELAND-CLIFFS MUFFLER CONDENSATE TEST



Corrosion Resistance

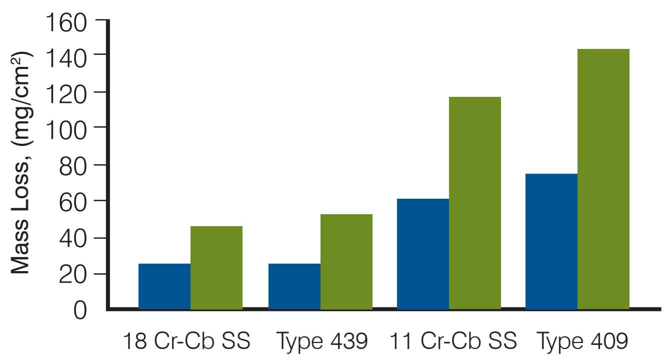
CLEVELAND-CLIFFS HOT SALT CYCLE

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.

TABLE 10 – HOT SALT TEST

Alloy	Mass Loss, (mg/cm²)	
	10 Cycles	20 Cycles
18 Cr-Cb SS	26	46
Type 439	26	54
11 Cr-Cb SS	62	117
Type 409	76	143

FIGURE 6 – HOT SALT TEST



TEST PROCEDURE

Four-inch-by-four-inch sheet specimens are exposed to a five- minute immersion to 5% sodium chloride solution, followed by a heat treatment exposure to 677 °C (1250 °F) for 90 mins. Upon completion of the 90-min. heat treatment, the test specimens are water quenched for 1 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. At 10 and 20 cycles, specimens are removed, bead blasted and measured for mass loss.

Oxidation Resistance

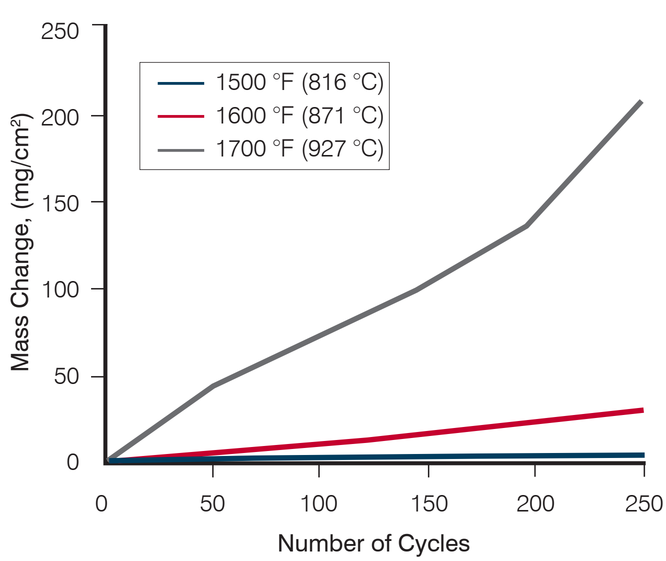
The temperature at which Type 409 starts to exhibit destructive scaling in air is 1450 °F (789 °C). This is considered the general maximum service temperature for continuous exposure in air. However, maximum service temperatures will vary appreciably, depending on the atmospheres involved.

TABLE 11 – CONTINUOUS SERVICE SCALING TESTS

Alloy	Weight Gain, mg/cm²* Temperature °F (°C)	
	1400 (760)	1550 (843)
Type 409	0.06	0.14
Type 430	0.04	0.14
Type 304	0.03	0.08

**Constant temperature for 100-hour exposure in air.*

FIGURE 7 – CYCLIC OXIDATION OF TYPE 409 AS A FUNCTION OF TEMPERATURE 1 CYCLE = 25 min. HEAT, 5 min. COOL



Properties

TABLE 12 – CYCLIC SCALING WITH TEMPERATURE VARIATIONS EXPRESSED IN WEIGHT CHANGE (mg/cm^2)

1500 °F (816 °C) cycles of 25 min. heat – 5 min. cool
1650 °F (899 °C) excursions cycles daily for 2 hrs.

Alloy	564 cycles, 1500 °F (816 °C)	564 cycles 1500 °F / 10 cycles, 1650 °F (899 °C)
Type 409	+1.50	+1.59
Type 439	+0.22	+0.45
11 Cr-Cb SS	+0.22	+0.37
Type 304	-21.8	-39.2

While 1450 °F (789 °C) is considered the practical upper temperature oxidation service limit, brief excursions above 1600 °F (871 °C) can be tolerated.

Note: The austenitic Type 304 alloy shows large negative weight changes indicating oxide spalling due to thermal expansion differences between the oxide and base metal.

FORMABILITY

A uniform grain structure, improved r_m value and improved ridging and roping resistance allow Cleveland-Cliffs 409 ULTRA FORM Stainless Steel to be formed into more complex shapes than is possible with standard Type 409.

Cleveland-Cliffs 409 ULTRA FORM Stainless Steel provides good fabricating characteristics and can be cut, blanked and formed without difficulty. Brake presses normally used on carbon steel can be used on this alloy.

Forming Limit Curves (Figure 9) provide guidelines to the forming capabilities of a specific material over a range of major-to-minor strain ratios. The Forming Limit Curves define the critical strain limit that a material can undergo prior to the onset of localized thinning. It is assumed that no previous deformation has taken place and that the strain path does not dramatically change during deformation.

Forming Limit Curves have proven very useful in diagnosing potential problems in sheet forming. Sheets are premarked with a known strain grid pattern and formed using either prototype or production tools. Strains near suspected trouble regions are measured and compared with the Forming Limit Curves. If the measured strains are near the experimental forming limit curve, some production failures are likely. Measured strains plotted on the forming limit diagram can also help to identify forming process changes needed that will take advantage of the material's ability to draw or stretch.

Standard forming tests show a typical Olsen Cup Height value of 0.400 in. (10.16 mm) and a Limiting Draw Ratio of 2.20 for Type 409.

At times, forming ability has been affected by temperature – in particular Ductile-to-Brittle Transition Temperatures (DBTT). Cleveland-Cliffs 409 Ni offers improved resistance to brittle impact fractures at lower temperatures.

The DBTT for hot-rolled 0.200 in. (5.08 mm) thick material is below -20 °F (-29 °C), while after cold rolling to 0.075 in. (1.9 mm) thick material and annealing, the DBTT is below -75 °F (-59 °C).

The plastic strain ratio, or r_m ($\bar{r}$) value, may be thought of as a material's resistance to thinning during drawing or tube bending operations. The higher the value, the greater the resistance to tearing or thinning. These stainless steels have a typical r_m ($\bar{r}$) value of 1.1 to 1.7 based on chemistry.

FIGURE 8 – TYPICAL FORMING LIMIT CURVES TYPE 439, 0.04 in. THICK, PRIMARY STRAIN TRANSVERSE TO SHEET ROLLING DIRECTION

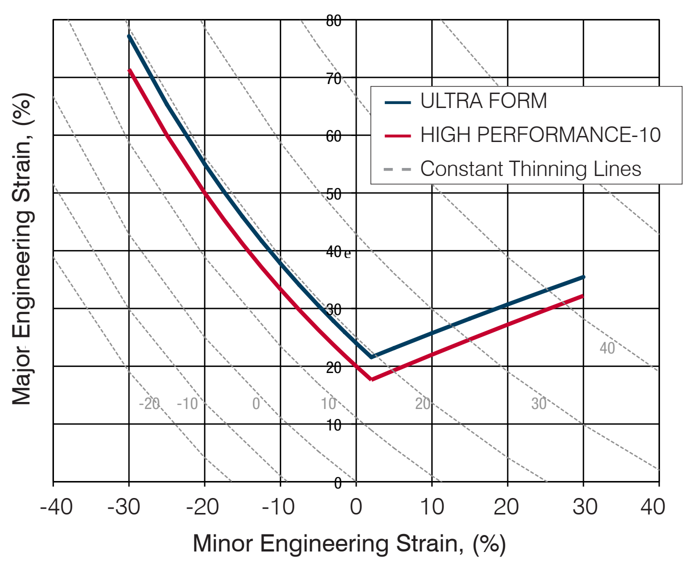
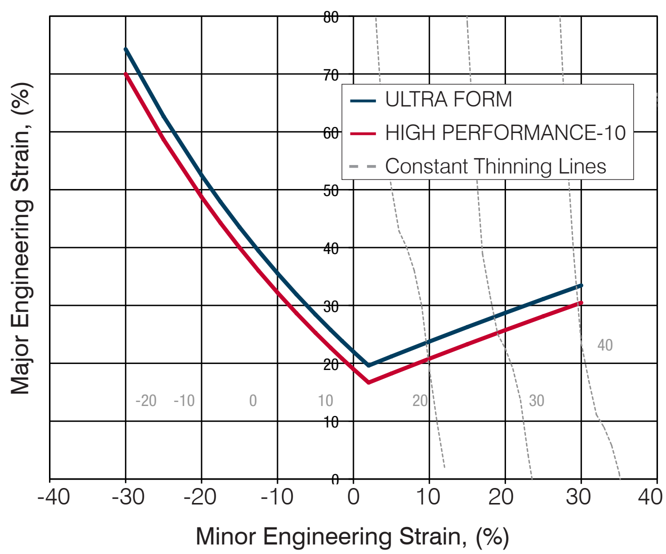


FIGURE 9 – TYPICAL FORMING LIMIT CURVES TYPE 409, 0.04 in. THICK, PRIMARY STRAIN TRANSVERSE TO SHEET ROLLING DIRECTION



WELDABILITY

Type 409 is readily welded by arc welding processes. When gauge thickness and weld joint geometry permit the use of gas shielded metal-arc welding, joints having good properties are easily obtained. The electrode wires most often suggested are AWS ER309 or ER308L austenitic stainless steel when the application does not include exposure to high temperatures. AWS ER309 or ER308L stainless wire may also be employed for joining these stainless steels to mild steel. Thin wall components for elevated-temperature service should be weld fabricated with a matching weld filler, such as Cleveland-Cliffs 409 Cb. AWS ER430 and W18 Cr-Cb filler wires are suitable alternatives.

Guidelines for the Shielded Metal-Arc (SMA) process and selection of electrodes are about the same as those employed for GMA and GTA welding, except that matching fillers for thermal application are not available in covered electrode form. Suitable substitutes are E410Ni Mo and E330.

Type 409 also is readily adaptable to resistance spot and seam welding.

TUBING PRODUCTION

Type 409 is readily produced on both high frequency and Gas Tungsten Arc Welding (GTAW) tubing mills. Such tubing generally has good formability. Even greater formability develops with a short-time post-weld anneal near 1600 – 1650 °F (871 – 899 °C).

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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