CLIFFS

THERMAK® 17

STAINLESS STEEL

- **Manifolds**
- **Converters**
- **Maniverters**
- **Stamped Flanges**

THERMAK® 17 is a stainless steel with excellent high-temperature strength, thermal fatigue, and oxidation resistance. Its improved high strength will facilitate vehicle lightweighting.

It is designed for demanding, hot-end automotive exhaust applications where intermediate or high chromium grades may not be sufficient or where down gauging for lightweighting is desired.

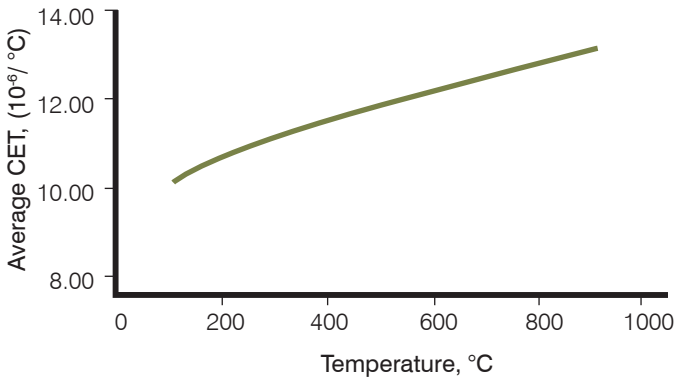
Product Description

PRODUCT FEATURES

THERMAK® 17 Stainless Steel is a ferritic stainless steel that is stabilized with both titanium and niobium. When given a high-temperature, final solution anneal, the alloy exhibits dramatic creep resistance. The dual stabilization prevents carbide sensitization exposure and makes the alloy thermally non-hardenable.

Composition		(wt %)
Carbon	(C)	0.02 max.
Manganese	(Mn)	1.2 max.
Phosphorus	(P)	0.05 max.
Sulfur	(S)	0.01 max.
Silicon	(Si)	1.0 – 1.5
Chromium	(Cr)	16.0 – 18.0
Nickel	(Ni)	0.5 max.
Nitrogen	(N)	0.02 max.
Copper	(Cu)	1.0 – 1.5
Titanium	(Ti)	0.5 max.
Niobium	(Nb)	0.5 max.

FIGURE 1 – COEFFICIENT OF THERMAL EXPANSION



AVAILABLE FORMS

Cleveland-Cliffs produces THERMAK 17 Stainless Steel in coils in thicknesses from 0.5 – 2.5 mm (0.02 – 0.10 in.) and widths up to and including 1175 mm (48 in.).

PHYSICAL PROPERTIES

Density, lbs/in³. (g/cm³)	7.69 (0.278)
Specific Heat, kJ/kg•K (BTU/lbs/°F) 32 – 212 °F (0 – 100 °C)	0.454 (0.108)

TABLE 1 – PHYSICAL PROPERTIES

	Type 444	18 Cr-Cb™	THERMAK 17
Yield Strength (MPa)	360	325	470
Tensile Strength (MPa)	515	500	590
Tensile Elongation (%)	30	30	30
Rockwell Hardness	B85	B80	B86

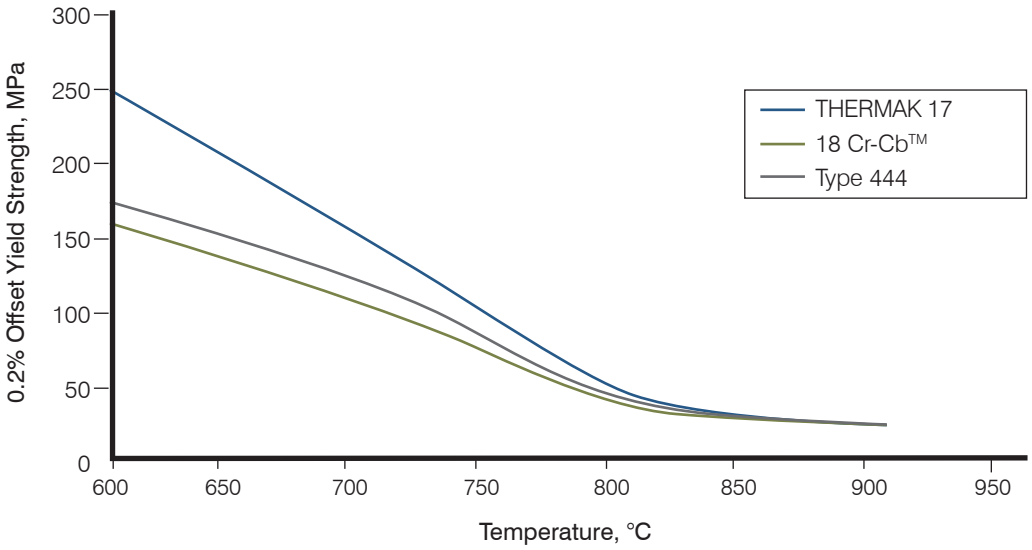
Mechanical Properties

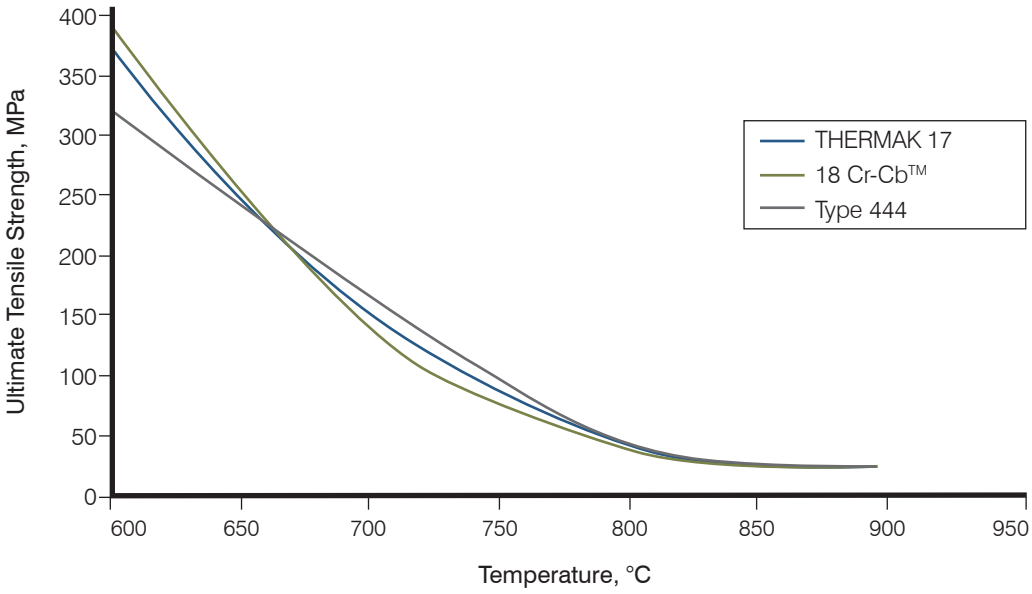
TABLE 2 – TYPICAL ROOM TEMPERATURE MECHANICAL PROPERTIES

0.2% YS, ksi. (MPa)	UTS MPa (ksi.)	Elongation % in 2 in. (50.8 mm)	Rockwell Hardness, B
469 (68)	586 (85)	30	86

Elevated Temperature Properties

FIGURE 2 – SHORT-TIME ELEVATED TEMPERATURE MECHANICAL PROPERTIES





Elevated Temperature Properties

HIGH TEMPERATURE CREEP RESISTANCE

Sag resistance testing is a simple, common measure of a material's resistance to creep. In testing, the sag resistance of THERMAK 17 Stainless Steel was found to be superior to Cleveland-Cliffs 18 Cr-Cb Stainless Steel and Type 444 in the temperature range of 700 – 930 °C. It was equivalent to Cleveland-Cliffs 15 Cr-Cb® Stainless Steel over the same temperature range.

TABLE 3 – DEFLECTION AFTER 144 HOUR TEST DURATION

Test Temperature (°C)	Condition*	THERMAK 17 (mm)	15 Cr-Cb (mm)	18 Cr-Cb (mm)	Type 444 (mm)
700	As-annealed	0.15	0.20	0.20	0.38
	704 °C/96 HR.	0.05	0.05	0.13	0.15
800	As-annealed	0.36	0.36	0.51	0.61
	704 °C/96 HR.	0.25	0.30	0.46	0.48
930	As-annealed	2.18	2.54	3.61	4.65
	704 °C/96 HR.	2.74	2.82	3.12	4.32

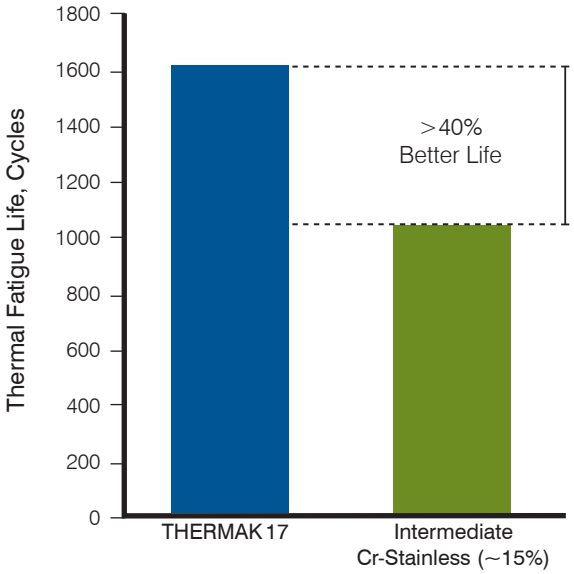
**As-annealed tested in duplicate, 704 °C aged single samples.*

THERMAL FATIGUE RESISTANCE

THERMAK 17 Stainless Steel has shown, in limited testing, to have 20 – 30% improved thermal fatigue resistance over intermediate chrome (Cr) products currently used in automotive hot end exhaust applications.

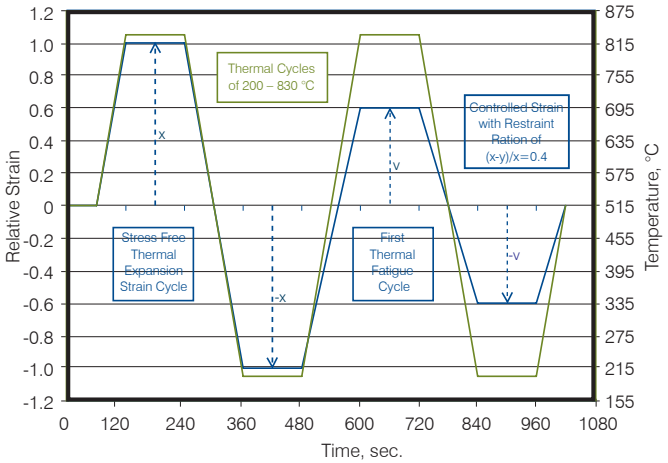
Thermal fatigue life was determined by the cycle number when the tensile stress at 200 °C reaches to 70% of the tensile stress at the first thermal fatigue cycle at 200 °C.

FIGURE 3 – THERMAL FATIGUE LIFE



Reduce gauge, save weight while maintaining the same durability

FIGURE 4 – THERMAL MECHANICAL FATIGUE CYCLE TESTING



Formability

THERMAK 17 Stainless Steel is readily drawn and formed. The ULTRA FORM® technology enhances formability and improves the consistency from one coil to another.

FIGURE 5 – FORMING LIMIT CURVE

THERMAK 17 STAINLESS STEEL COIL, 2 mm THICK

Determined using CamSys localized nodal strain measurement method 2.54 mm Square Grid Pattern

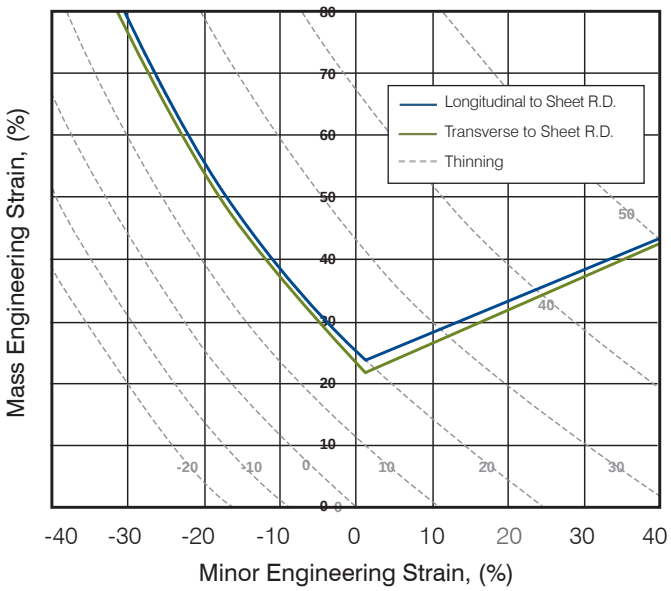


TABLE 5

Property	Orientation to Sheet R.D.		
	L	D	T
Tensile/Hardness Test (ASTM E8, E694, E18, A370)			
0.2%YS (MPa)	440	465	457
UTS (MPa)	563	584	545
% El. in 50.8 mm (man'l)	31	29	30
n-Value (10%-Ult.)	0.152	0.139	0.143
Strength Coeff. (MPa)	876	889	883
HRB (HRA)	90 (55.5)		
ASTM Grain Size	5.0		
Stretch r (plastic strain ratio) at 18% (ASTM E517)			
r-Value	1.01	0.92	1.49
r_m	1.09		
delta r	0.34		
delta r (Max – Min)	0.62		
Ridging No.	1.00		
Olsen Cup Height (mm)	11.40		
LDR	2.10		

Corrosion Resistance

THERMAK 17 Stainless Steel shows improved oxidation resistance and oxide adherence when compared to other 17% chromium ferritics. The high-silicon and manganese, copper-added alloy reduces spalling when exposed to cyclic high temperature salt conditions creating a barrier of oxide that provides protection to the steel substrate. The dual stabilized alloy resists intergranular corrosion when welded and provides comparable corrosion resistance to equivalent alloys in acidic, high sulfate and lower temperature, cyclic salt environments commonly found in automotive exhaust applications.

FIGURE 6 – SALT CYCLE TEST

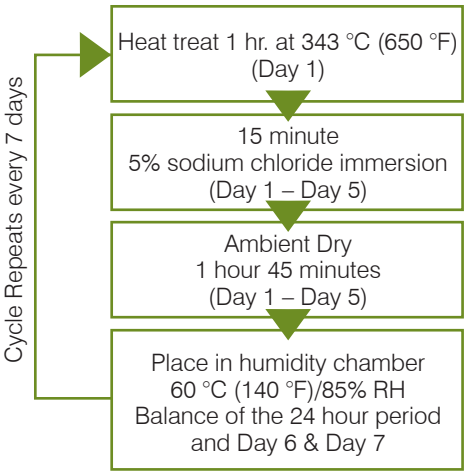


FIGURE 8 – SALT CYCLE

Solution Concentration: 5% Sodium Chloride
Heat Treatment: 343 °C (650 °F)

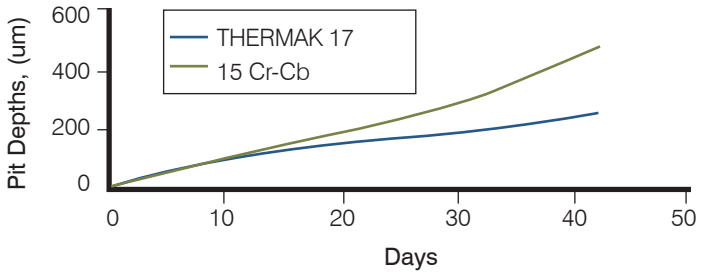


FIGURE 7 – MUFFLER CONDENSATE TEST

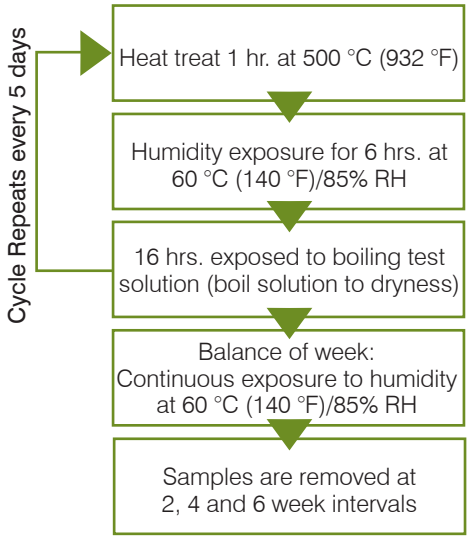
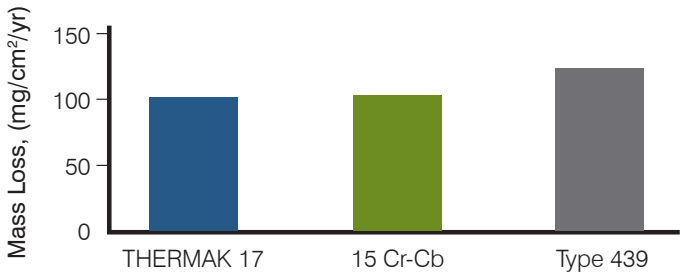


FIGURE 9 – MUFFLER CONDENSATE

Heat Treatment: 500 °C (932 °F)



TEST SOLUTION:

- 5000 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-} to the test solution

Corrosion Resistance

FIGURE 10 – HOT SALT TEST

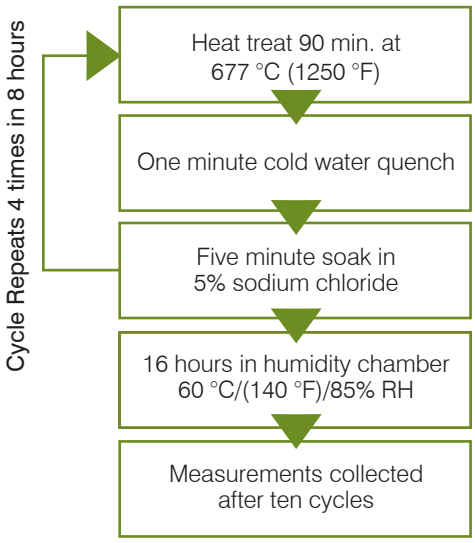


FIGURE 11 –SPALLING RESISTANCE – HOT SALT

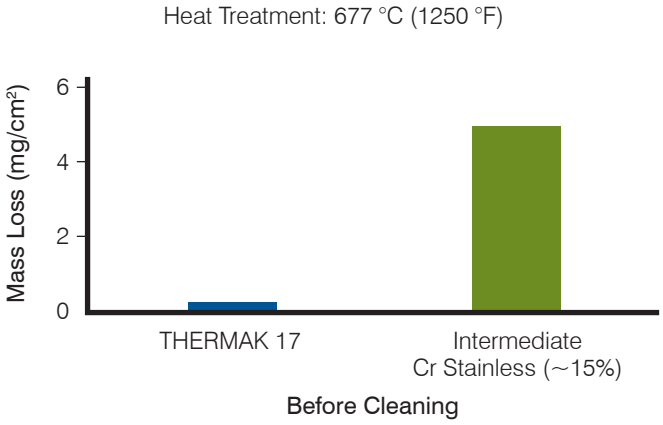
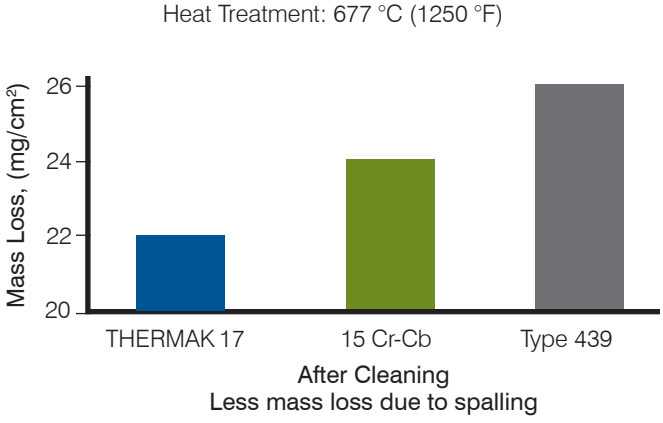


FIGURE 12 – TOTAL MASS LOSS – HOT SALT



OXIDATION RESISTANCE

THERMAK 17 stainless steel provides an improved oxidation resistance compared to other ferritic alloys such as Type 439. In addition to 17% chrome content, high-silicon and high-manganese contents improve high-temperature oxidation resistance in air and exhaust gas atmospheres.

In continuous service, 200 hours at 930 °C, THERMAK 17 Stainless Steel exhibited a uniform scale pattern and no spalling.

THERMAK® 17 STAINLESS STEEL

WELDABILITY

THERMAK 17 Stainless Steel is generally considered to be weldable by the common fusion and resistance welding processes. Grain growth in the weld heat affected zone, with reduced weld toughness, is a common occurrence in ferritic stainless steel weldments. Low weld heat input and elimination of weld discontinuities will provide maximum toughness in welded sections. Warming of welded parts prior to forming may also improve weld toughness. When a weld filler is required, Cleveland-Cliffs 18 Cr-Cb Stainless Steel is recommended for applications where high temperature thermal cycling is expected. Filler wires Type 308L or Type 309L will provide improved weld ductility for lower temperature applications. Additional information concerning the welding of ferritic stainless steels may be obtained from the following publications:

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, direct reduced iron, and ferrous scrap 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 supplier of steel to the automotive industry in North America. The Company is headquartered in Cleveland, Ohio with mining, steel and downstream manufacturing operations located across the United States and in Canada. For more information, visit www.clevelandcliffs.com.

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