TECHNICAL DATA
BLUE SHEET

Stainless Steel
E-BRITE®

Alloy for Solid Oxide Fuel Cells
(UNS 44627, ASTM Type XM-27)

Allegheny Ludlum's E-BRITE alloy is a high purity ferritic stainless steel which combines excellent resistance to corrosion and oxidation with good fabrication characteristics. Vacuum melting techniques control chemical composition to tight tolerances resulting in optimum corrosion resistance and ductility. Careful processing and quality assurance maintain the chemical and physical integrity of E-BRITE alloy from ingot to finished mill product forms.

PLANAR SOLID OXIDE FUEL CELLS

Fuel cells are an emerging power generation technology which produce electricity directly from the chemical reaction of a fuel gas with an oxidizer. Fuel cells can be made small and efficient, which makes them attractive from a distributed power generation standpoint. Planar solid oxide fuel cells (PSOFC's) are fabricated primarily from ceramic components. Recent designs incorporate a metallic interconnect as a way to reduce cost. The interconnect collects the electrical output of the cell and also serves as a gas tight seal with adjacent ceramic components to separate the fuel and oxidizer gas streams.

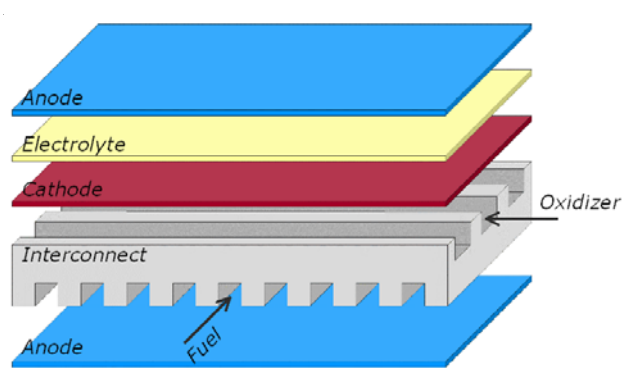


Figure 1 -

The interconnect must expand and contract with changes in temperature at the same rate as the ceramic components to avoid damage during thermal cycling. It also must form an oxide scale which is compact and electrically conductive at elevated temperatures. Ferritic stainless steels offer optimum properties at relatively low cost.

CHEMICAL COMPOSITION

Chromium, molybdenum and small additions of columbium (niobium) are the major alloying constituents which lead to E-BRITE alloy's resistance to corrosion and oxidation. Ultralow carbon and nitrogen content leads to superior ductility and formability when compared to conventional ferritic stainless steels.

		ASTM XM-27	
Element	**Typical**	**Min**	**Max**
C	0.002		0.010
Mn	0.05		0.40
P	0.01		0.020
S	0.01		0.020
Si	0.20		0.40
Cr	26.0	25.0	27.5
Ni	0.15		0.50
Mo	1.0	0.75	1.50
N	0.010		0.015
Cu	0.02		0.20
Cb	0.10	0.05	0.20
Ni+Cu	0.17		0.50
Fe	Remainder		

Table 1 - Chemical Composition for E-BRITE®.

Data are typical and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown herein.

PHYSICAL PROPERTIES

E-BRITE alloy is a ferritic (body centered cubic structure) ferromagnetic stainless steel which exhibits a lower thermal expansion coefficient and higher thermal conductivity than common austenitic stainless steels and nickel–base alloys.

	10^{-6}/C°	10^{-6}/°F
E-BRITE® alloy	9.9	5.5
Type 316	16.0	8.9
AL 600® alloy	11.5	6.4
AL 825 ® alloy	13.0	7.2
Nickel	13.3	7.4
Type 446	10.4	5.8
AISI 1020 Carbon Steel	11.7	6.5

Table 2 - Mean coefficient of thermal expansion (α) for E-BRITE® alloy and others in the range 21–100°C(70–212°F).

The coefficient of thermal expansion varies with temperature and is tabulated below for the entire range of temperatures where planar solid oxide fuel cells typically operate.

Temperature (°C)	Temperature (°F)	10^{-6}/C°	10^{-6}/F°
40	104	9.2	5.1
100	212	9.5	5.3
200	392	10.0	5.5
300	572	10.3	5.7
400	752	10.6	5.9
500	932	10.9	6.1
600	1112	11.1	6.2
700	1292	11.5	6.4
800	1472	11.9	6.6
900	1652	12.5	7.0
1000	1832	13.1	7.3

Table 3 - Mean coefficient of thermal expansion for E-BRITE® alloy at elevated temperatures.

The mean coefficient of thermal expansion increases in a relatively linear fashion until about 1184ºF (640ºC) where the slope increases abruptly. This is related to the Curie transition temperature, where E–BRITE alloy becomes non–magnetic.

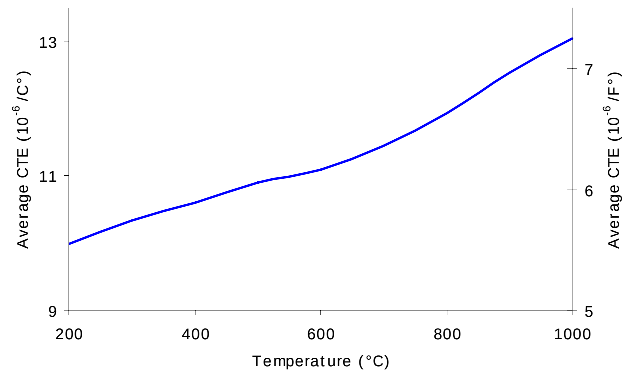


Figure 2 - Mean coefficient of thermal expansion for E-BRITE alloy at elevated temperatures.

The management of heat inside a solid oxide fuel cell is an important consideration. The thermal conductivity of E-BRITE alloy compares favorably with other common engineering alloys.

	W/m•K	Btu/ft^2•hr•F°/in
E-BRITE® alloy	16.7 (25°C) 20.3 (260°C)	116 (77°F) 141 (500°F)
Type 316	14.4 (25°C) 17.3 (260°C)	100 (77°F) 120 (500°F)
AL 600 alloy	14.8 (25°C) 18.3 (260°C)	103 (77°F) 127 (500°F)
AL 825 alloy	11.1 (25°C) 14.8 (260°C)	77 (77°F) 103 (500°F)
Nickel	74.9 (25°C) 56.9 (260°C)	520 (77°F) 395 (500°F)

Table 4 - Thermal Conductivity Values for E-BRITE® alloy and others.

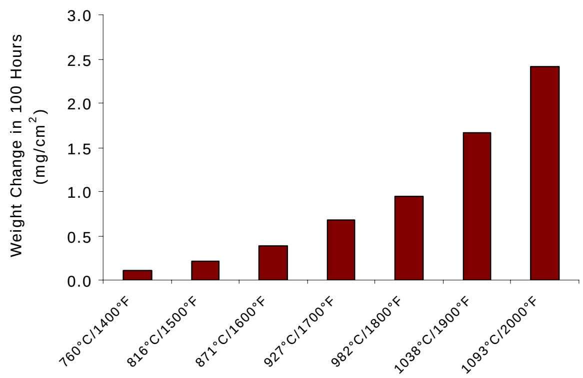
Other physical properties of interest are tabulated below.

Density	7,660 kg/m^3	0.28 lb_m/in^3
Specific Heat	427 J/kg•K	0.102 Btu/lb_m•F°
Resistivity	52-57 $\mu\Omega$•cm	
Curie Temperature	640°C	1185°F
Saturation Flux Density	1.4 T	14,000 gauss
Elastic Modulus in Tension (E)	200 GPa	29 x 10^6 psi

Table 5 - Physical Properties of E-BRITE® Alloy at room temperature.

HIGH TEMPERATURE OXIDATION RESISTANCE

E-BRITE alloy exhibits excellent resistance to scaling at elevated temperatures due to its high chromium content, required for the formation and maintenance of a protective oxide scale layer, and the relatively low coefficient of thermal expansion, which helps to prevent the spallation of the protective oxide during thermal cycling. Basic oxidation data is presented below in the form of specific weight change after one hundred hours over a wide range of temperatures.



Some fuel cell designs are built around the use of light gauge metallic foils. Metallic alloys in foil form are particularly susceptible to failure through a phenomenon known as breakaway oxidation. This is caused by the depletion of the element responsible for the formation of the protective oxide film, in this case chromium. A thin foil contains a limited supply of chromium. Once it is used up, other elements, in this case iron, are oxidized and the sample rapidly converts to oxide. The high chromium content of E-BRITE alloy results in good oxidation resistance and lower susceptibility to breakaway oxidation, as can be seen from long time testing at elevated temperatures for foils as thin as 50 microns (0.002") thick.

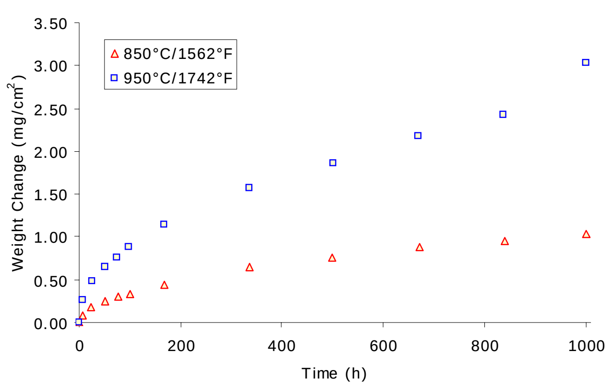


Figure 4 - Oxidation weight change over long times for 50 micron (0.002") thick foils.

MECHANICAL PROPERTIES

The room temperature mechanical properties of E-BRITE alloy are presented below.

	Yield Strength (0.2% offset)		Tensile Strength	
	MPa	**ksi**	**MPa**	**ksi**
Typical	345	50	485	70
ASTM A240 minimum	275	40	450	65

	% Elongation in 2" gauge length	Hardness (Rb)
Typical	30	83
ASTM A240 minimum	22	90

Table 6 - Room temperature mechanical properties of annealed E-BRITE® alloy.

E-BRITE alloy is a single phase, fully ferritic alloy at all temperatures. It cannot be hardened by heat treatment. Ferritic alloys exhibit some degree of work hardening when deformed at room temperature. The result is an increase in strength and a decrease in ductility.

% Cold Reduction	Yield Strength (0.2% offset)		Tensile Strength	
	MPa	**ksi**	**MPa**	**ksi**
0	345	50	485	70
20	605	88	655	95
40	750	108	760	110
60	800	116	850	124
80	860	125	905	131

% Cold Reduction	% Elongation in 2" gauge length	Hardness (Rb)
0	35	83
20	8	97
40	6	101
60	4	104
80	2.5	104

Table 7 - Room temperature mechanical properties of annealed E-BRITE® alloy.

The influence of temperature on tensile properties of E–BRITE alloy is shown below. For short time tensile testing, strength decreases with increasing temperature, the effect becoming pronounced above 538ºC (1000ºF). Elongation shows little variation until about 538ºC, where it begins to increase rapidly with temperature.

The anomalous strength behavior observed in the 427–538ºC (800–1000ºF) range below is due to hardening which accompanies the so called 475ºC (*885ºF) embrittlement* phenomenon observed in high chromium stainless steels. Extended exposure of E–BRITE alloy to temperatures in the range of 371–538ºC (700–1000ºF) can adversely affect room temperature tensile properties, with the effect occurring most rapidly at 475ºC (885ºF). This is shown in the table below, which demonstrates the effect of 10,000 hour exposures on the tensile properties of E-BRITE alloy.

Hold Temperature		Yield Strength (0.2% offset)		Tensile Strength	
°F	°C	MPa	ksi	MPa	ksi
—		360	52.0	480	69.5
650	343	390	57	530	77
700	371	415	60.6	550	79.9
750	399	600	86.8	620	89.5

Hold Temperature		% Elongation in 2" gauge length	Hardness (Rb)
°F	°C		
—		35	160
650	343	32	176
700	371	28	181
750	399	3	251

Table 8 - Effect of 10,000 hour holds at intermediate temperatures on mechanical properties of E-BRITE® alloy strip.

The loss of mechanical properties caused by 475ºC (885ºF) embrittlement can be reversed by heating to elevated temperatures.

IMPACT PROPERTIES

Like other ferritic materials, E–BRITE alloy exhibits a transition in failure mode from ductile to brittle as temperature decreases or strain rate increases. Above the ductile to brittle transition temperature (DBTT), failure is ductile in nature. Ductile crack propagation absorbs large amounts of energy and the surrounding metal exhibits significant plastic deformation. Below the DBTT, the fracture is brittle in nature. In the brittle temperature range, the material fails with little warning, absorbing little energy in the process. The DBTT is thickness dependant, with thick material having a higher DBTT than thin material. At a constant thickness, material with coarse grain size will generally exhibit a higher DBTT than material with fine grain size.

Slow cooling of E-BRITE alloy from temperatures above 650ºC (1200ºF), particularly for thicker sections, can adversely affect impact properties. Resititution of impact ductility can be achieved by annealing at 760ºC (1400ºF) or higher, followed by a rapid cool.

The forming of heavier sections of E–BRITE alloy may be aided by pre–heating the workpiece to several hundred degrees above ambient temperature to avoid brittle fracture.

ELEVATED TEMPERATURE CREEP PROPERTIES

The strength of E–BRITE alloy falls off rapidly at temperatures over 540ºC (1000ºF). This can lead to creep of loaded parts. Time to 1% creep strain and to failure (creep rupture) are presented below. More detailed creep data is available upon request.

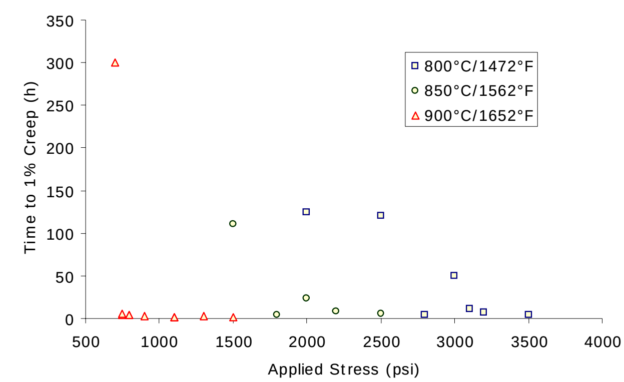


Figure 5 - Time to 1% creep strain at varying temperatures.

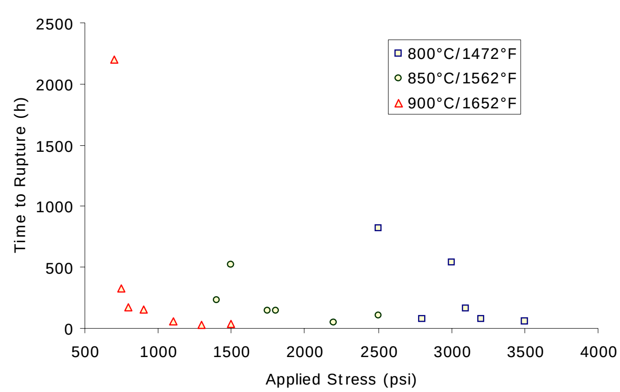


Figure 6 - Time to rupture at varying temperatures.

Hold Temperature		Yield Strength (0.2% offset)		Tensile Strength	
°F	°C	MPa	ksi	MPa	ksi
—		360	52.0	480	69.5
650	343	390	57	530	77
700	371	415	60.6	550	79.9
750	399	600	86.8	620	89.5

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