PLYMOUTH TUBE CO USA®

SUPER FERRITIC STAINLESS STEEL (UNS #S44660)

ALLOY APPLICATION & DATA

SEA-CURE® Stainless Steel meets or exceeds ASTM A-268 and ASME-SA268 requirements.

CHEMICAL COMPOSITION

ELEMENT	PERCENT
Chromium	25.0 -28.0
Molybdenum	3.0-4.0
Nickel	1.0-3.5
Manganese	1.00 max
Silicon	1.00 max
Carbon	0.030 max
Nitrogen	0.040 max
Phosphorous	0.040 max
Sulfur	0.030 max
Titanium + Niobium	0.020-1.00
Iron	Balance

DESCRIPTION

The ferritic structure of SEA-CURE® stainless steel provides a high strength/low work hardening material with good ductility. These properties allow high design stress limits with good fabrication characteristics. Because of the nickel addition, SEA-CURE® has a lower ductile-to-brittle transition temperature than similar ferritic steels without nickel additions.

APPLICATIONS

This alloy is specifically designed for applications where chloride induced pitting, crevice, and stress corrosion cracking may be encountered.

Plymouth SEA-CURE® stainless steel is used in electric power plant condensers and BOP exchangers, various heat exchangers in chemical, petrochemical, and refining applications, desalination heat exchangers and flue gas handling systems such as the secondary heat exchangers in high efficiency furnaces. The American Gas Association has approved SEA-CURE® for flue gas condensate applications. SEA-CURE® stainless steel has better resistance to general corrosion over a broader range of conditions than the austenitic stainless steels.

CORROSION RESISTANCE

Resistance to a number of strong acids was evaluated using the Materials Technology Institute of the Chemical Process Industries procedures. Representative data are given below.

Acid Solution	Temperature ˚F	˚C	Type 304	Type 316	SEA-CURE®
			Corrosion Rate—MPY*		
0.1% Hydrochloric	212	100 B	17.4	2.08	0.23
1.0% Hydrochloric	210	99 B			0.68
1.0% Hydrochloric + 3% FeCl3	167	75			2.27**
10% Sulfuric	215	102 B			1.05
60% Sulfuric	244	118 B			>1000
93% Sulfuric	171	77		78.0	10.0
50% Phosphoric	228	109 B	2.46	3.87	1.78
10% Nitric	219	104 B	0.37	0.96	0.46
65% Nitric	241	116 B	3.34	3.95	1.20***
60% Nitric + 2% HCL	235	113 B			4.18***
80% Acetic	217	103 B	17.0		0.02
100% Acetic	243	117 B	0.39	0.54	0.44
50% Acetic + 50% Anhyd	164	73	0.40		1.60
50% Formic	221	105 B			0.89
10% Oxalic	216	102 B			1.31
55% NaOH + 8% NaC +3% NaClO3	210	99		6.1	<0.1
50% NaOH	289	143		15.0	1.0

* Corrosion rate in mils per year— evaluated over a 96 hour test period.

** Pitting.

*** Welded SEA-CURE® showed good performance in the nitric tests. However, caution should be exercised in using any titanium stabilized alloy in highly oxidizing environments.

B — Boiling

ACID CONDENSATE RESISTANCE

Heat recovery systems are particularly susceptible to severe corrosion caused by acid condensates in the environment. The process of condensation and evaporation concentrates acids and chlorides, increasing the corrosive attack at the condensate dew point or water boiling point. SEA-CURE® stainless steel has the capability to resist most of these corrodents.

SEAWATER CORROSION RESISTANCE

SEA-CURE® stainless steel was developed specifically to resist localized pitting and crevice corrosion in aggressive chloride solutions, such as seawater. In comparative accelerated laboratory and crevice corrosion testing, SEA-CURE® ranks far superior to the common austenitic stainless steels such as Types 304 & 316.

TESTING RESULTS

In natural seawater at ambient temperature, several tests have shown no attack in over 10 years. Today, numerous power plant condensers have over 25 years of exposure. Under the same conditions, Type 316 experienced a .039 inch crevice corrosion attack.

In areas where organic pollution is present (which can decay to produce hydrogen sulfide), SEA-CURE® stainless steel resulted in significantly higher corrosion resistance than the copper alloys, such as copper-nickel.

CHLORIDE STRESS-CORROSION CRACKING RESISTANCE

Like most other fully ferritic stainless steels, SEA-CURE® stainless steel has excellent resistance to chloride-induced stress-corrosion cracking. When stressed to 90% of its yield strength and placed in a 212˚F (100˚C) 40% CaC12 solution, SEA-CURE® stainless did not crack even after a 5000 hour exposure. Type 316L stainless cracks within 400 hours under the same conditions. SEA-CURE® U-Bend specimens exposed to 1500 ppm sodium chloride at 212˚ F (100˚C) also did not crack. Like other stainless steels, SEA-CURE® is not resistant to stress corrosion in 40% magnesium chloride solution (boiling) at 284˚F (140˚C).

EROSION-CORROSION RESISTANCE

SEA-CURE® exhibits excellent resistance to all types of erosion. It is not affected by high water velocities, which may result from either tube blockage or mechanical design, nor by steam or impingement erosion. In a wear-erosion test using silica sand and water impinging on various stainless steels, it shows only 25% of the weight loss of Type 316.

GALVANIC CORROSION

Whenever the tubes and the tubesheet of a heat exchanger or condenser are of dissimilar materials and in contact with a conductive water (usually more than 1000ppm dissolved solids), there is a possibility of galvanic corrosion of the other alloy. SEA-CURE® has a high electrode potential in seawater, making it very noble or cathodic. It is slightly below titanium, gold and platinum, and is more noble than the copper alloys, copper-nickel or carbon steel in the galvanic series. Therefore, there is a possibility of galvanic attack to the material that is lower in the galvanic series. Thus, if SEA-CURE® tubes are used with a Muntz metal tubesheet in seawater, the Muntz metal tubesheet can pit in the ligament section between the tubes. Covering the tubesheet with an epoxy-type coating or using an impressed voltage cathodic protection system usually protects the tubesheet. If a cathodic protection system is used, the voltage should be maintained more positive than -0.800 volts as measured against a standard calomel electrode to prevent generation of hydrogen, which can cause hydrogen embrittlement.

MARINE FOULING

All metals foul in seawater over time. Because most stainless steels do not contain copper, which dissolves and forms copper ions that are poisonous to marine growth, fouling may occur earlier. The tendency for marine fouling of all materials can be minimized by chlorination, mechanical cleaning or high water velocity. SEA-CURE® stainless, by virtue of its erosion resistance, is ideally suited to either mechanical cleaning or high water velocity. In softer copper alloys, these methods can cause severe wear.

SULFIDE PITTING ATTACK

Pitting corrosion in the presence of sulfur compounds and certain bacteria in polluted seawater may occur with copper-nickel, aluminum-brass and other alloys high in copper. SEA-CURE® is not attacked by these sulfur compounds and the associated bacteria.

MANGANESE BACTERIA ATTACK

Manganese can be extracted from certain waters by certain types of bacteria and deposited on heat exchanger surfaces as hydrated manganous oxide. In the presence of chlorine, this compound can be oxidized to the permanganate and the chlorine reduced to the chlorine ion. This reaction can cause pitting in the 300 Series stainless steels and Admirality brass. SEA-CURE® is essentially immune to this reaction because of its very high resistance to pitting.

AMMONIA ATTACK

Copper-base alloys are very susceptible to ammonia attack resulting in accelerated general corrosion, pitting attack, or ammonia-induced stress corrosion crack. SEA-CURE® like other stainless steels, is essentially immune to ammonia attack.

FABRICATION

WELDING

Gas tungsten arc welding (GTA) without and with filler metal, gas metal arc (GMA), and shield metal arc (SMA) processes are common methods used for welding stainless steels that may be applicable to SEA-CURE® stainless. More careful welding conditions than used with austenitic stainless steels are necessary to attain good weld corrosion resistance and toughness. Thus, the GTA process is preferred to minimize heat input. Techniques used for titanium work well with SEA-CURE®.

General procedures to follow include the use of low power input and small electrodes, using multiple passes as section size increases, and cooling to room temperature between passes. It is absolutely important to minimize contamination by oxygen, nitrogen and carbon, and to avoid the loss of stabilization elements from the weld metal. This can be achieved by thorough cleaning of the joint surfaces prior to welding, the use of dry electrodes, and the use of rigorous gas shielding techniques.

Sound weld joints can be made with a variety of filler metals. The choice of filler metal, however, requires a careful study of corrosion and mechanical property requirements of the application. Austenitic iron base alloys such as Incoloy 825®, Incoloy 135®, and Type 310 Mo produce welds with good toughness and a duplex microstructure. Fillers that produce a ferritic structure such as Ferralium Alloy 255® have the best potential for optimum corrosion resistance, but limited toughness. Highly alloyed nickel based filler metals such as Incoloy 625® are attractive for corrosion resistance and ease of welding, however, weld toughness properties are somewhat less than the austenitic iron based alloys. The welded oxide always should be removed by pickling or grinding to retain the high corrosion resistance in the weld region.

ANNEALING

SEA-CURE®, like all superferritics, require very specialized heat treatments to achieve the expected corrosion rates. Therefore, Plymouth does not recommend reannealing of SEA-CURE® unless specialized equipment is available. If necessary, contact Plymouth Tube before proceeding.

FORMING

SEA-CURE® stainless has good formability. Due to its high strength, more force may be needed during the initial stage of forming; however, the lower strain hardening makes the material easier to form a second time without an intermediate anneal. It is less suitable for stretch forming operations than austenitic grades.

ROLLED TUBESHEET JOINTS

The combined properties of high elastic modulus, strength and ductility are advantageous in achieving strong leak-tight joints. The nickel addition produces a tough crack-resistant base metal and weld that can be reduced to over 15% wall reduction. Because of the differences in tube to tubesheet hardnesses, and the difficulty of accurately measuring wall thinning, we suggest that the rolling be controlled by torque. When doing a combination for the first time, developing the proper torque using a mockup tubesheet of the same materials is best. Push out loads should exceed 1200 lbs (550 kg).

For maximum installation efficiency, five-roll expanders should be used. Lubrication is suggested and the tool should be adjusted so as not to produce a feather edge on the tube end. End flaring is not necessary for inlet erosion, but may be employed to improve flow or to match a tubesheet previously designed for end flaring. SEA-CURE® will produce a higher joint strength than other heat exchanger tube alloys for a given set of tube/tubesheet conditions. This is a result of the high elastic modulus and yield strength which make it particularly attractive for use with high strength tubesheet materials. When high strength tubesheet materials such as duplex stainless steels have been utilized, push out loads exceeding 4000 lbs (1800 kg) are common on walls as thin as .028".

THERMAL CONDUCTIVITY FROM 70-600˚F

Temperature		Conductivity	
˚F	˚C	Btu/hr./ft./˚F	W/m-˚C
70	20	9.2	15.9
100	40	9.3	16.1
200	95	10.5	18.1
300	150	11.3	19.5
400	200	11.9	20.6
500	260	12.5	21.6
600	315	13.8	23.8

THERMAL EXPANSION OVER THE RANGE OF 70-700˚F

Temperature		Coefficient of Thermal Expansivity	
˚F	˚C	in./in.˚F	mm/mm/˚C
70-200	20-100	$5.38x10^{-6}$	$9.68x10^{-6}$
70-300	20-150	$5.43x10^{-6}$	$9.77x10^{-6}$
70-500	20-250	$5.81x10^{-6}$	$10.46x10^{-6}$
70-700	20-375	$5.95x10^{-6}$	$10.71x10^{-6}$

COMPARATIVE PROPERTIES OF VARIOUS ALLOYS

	Ti Grade 2	90-10 Cu/Ni	SEA-CURE®
Yield Strength* (ksi)	40	15	65
Tensile Strength* (ksi)	50	40	85
Elongation* (%)	20	25	20
Elastic Modulus (PSI x 10^6)	15.5**	18.0	31.5
Density (lb/in^3)	0.16	0.32	0.278
Expansion Coefficient (in/in-˚Fx10^6)	4.7	9.5	5.38
Thermal Conductivity (Btu/hr-ft^2-˚F/ft)	12.6	26.0	10.1
Specific Heat (Btu/lb-˚F)	0.124	0.092	0.12
Fatigue Endurance (ksi)	16	25	35

* Minimum ASTM Value
** Maximum ASTM Value

PHYSICAL PROPERTIES

Plymouth SEA-CURE® stainless steel has a number of attractive physical properties, including low thermal expansion, good thermal conductivity, and a high elastic modulus which provides high stiffness. High stiffness allows less vibration than with other engineering materials. The thermal expansion coefficients are similar to those of carbon steel and lower than those of the austenitic stainless steel or copper alloys.

The thermal conductivity is similar to titanium and higher than the austenitic stainless steels of high nickel alloys. The passive corrosion resistant film is extremely thin, which allows good heat transfer performance.

VIBRATION RESISTANCE

Because of its very high modulus of elasticity, Plymouth SEA-CURE® stainless steel is very resistant to vibrational fatigue damage. For the purpose of comparison, the following minimum tube wall would be required to prevent vibration damage under the same conditions of turbine exhaust steam velocity, steam density, tube support spacing, and tube diameter:

ALLOY	MINIMUM WALL THICKNESS	
	inches	mm
SEA-CURE® Stainless	0.019	0.48
Types 304/316	0.022	0.56
90-10-Cu-Ni	0.034	0.86
Titanium	0.038	0.97
Admirality Brass	0.041	1.04
Zirconium	0.046	1.17

MECHANICAL PROPERTIES

The ambient temperature strength of SEA-CURE® stainless steel is retained over the temperature range encountered by most heat exchanger applications. Plymouth SEA-CURE® is approved for ASME Boiler and Pressure Vessel Code construction Section VIII, Division I. The allowable stresses for both sheet and tube are substantially higher than those of lower alloy ferritic and austenitic stainless steels. This factor can produce substantial savings through reduced section thickness or higher operating pressures. An upper temperature limit of 500˚F is imposed to avoid danger from 885˚F embrittlement which is a characteristic of all ferritic steels that contain more than 12% chromium.

ELEVATED TEMPERATURE MECHANICAL PROPERTIES

Temperature		0.2% Yield Strength		Tensile Strength		Elongation in 2 inches
˚F	˚C	ksi	MPa	ksi	MPa	
74	23	75	517	90	620	25
200	93	66	455	83	572	24
300	149	57	392	78	538	23
400	204	53	365	75	517	21
500	260	50	345	75	517	21

ASME SECTION VIII DIVISION 1 ALLOWABLE STRESSES

Temperature		Allowable Stress	
˚F	˚C	ksi	MPa
100	38	18.0	124.1
200	93	18.0	124.1
300	149	18.0	124.1
400	204	17.8	122.7
500	260	17.7	122.0

FORMS AVAILABLE

- Welded Tubular Products
- Cold Rolled Annealed Strip/Sheet
  (Max. Thickness: 0.083" Avg. [2.1mm])

HIGH CORROSION SEA-CURE® TUBE SOLUTION
OVER 70 MILLION FEET IN SERVICE WORLDWIDE

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