TECHNICAL SPECIFICATIONS

ALLOY APPLICATION AND DATA

HIGH CORROSION SEA-CURE® TUBE SOLUTION

PLYMOUTH TUBE CO USA®

TABLE OF CONTENTS

ABOUT SEA-CURE®

SEA-CURE is a high performance stainless steel tube solution designed for use in highly corrosive environments and seawater applications. With over 40 years of commercial history, SEA-CURE has an outstanding performance record, and over 145 million feet of SEA-CURE tubing has been shipped worldwide. It is one of the most cost-effective alloys used in power plant condensers, heat exchangers and desalination plants due to its excellent corrosion resistance, good thermal conductivity, and superior mechanical and physical properties. SEA-CURE is specially engineered to reduce life-cycle cost by preventing tube leaks, ensuring tube cleanliness, eliminating chemical treatment and reducing CO_2 costs. Since its inception, SEA-CURE condenser installations have saved the power generation industry hundreds of millions of dollars. Contact our team to find out how much it could save you.

ABOUT PLYMOUTH

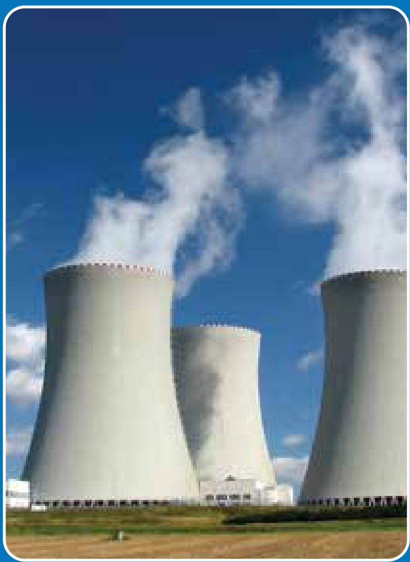
Plymouth Tube Company's facility in West Monroe, LA is home to SEA-CURE, a leader in super-ferritic stainless steel tubing for the power generation and heat transfer markets since 1978. A privately held, family-owned business founded in 1924, Plymouth was the first tube company to produce stainless steel feedwater heater tubes.

As an industry leader, Plymouth Tube is committed to its mission of providing products and services that meet or exceed our customers' expectations. Through the Plymouth Experience, we will deliver extraordinary service and value to our customers. We strive to achieve world class performance in our service package to customers as defined by excellence in on-time performance, responsiveness, 20% shorter lead times than competition, returns and allowances, and effective, solution-based, collaborative technical support. The Plymouth Experience is what differentiates us from the competition and makes us the benchmark in the industry.

ALLOY
APPLICATIONS & INDUSTRIES

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

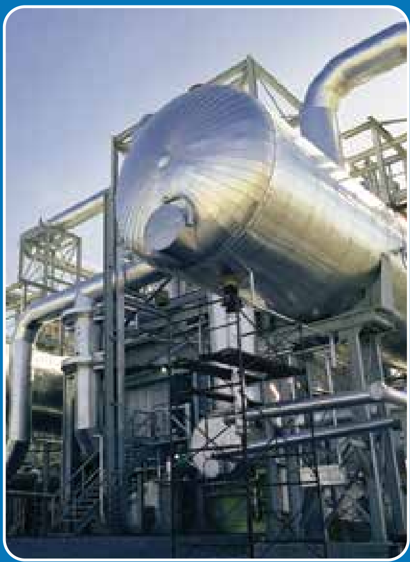
POWER PLANT CONDENSERS



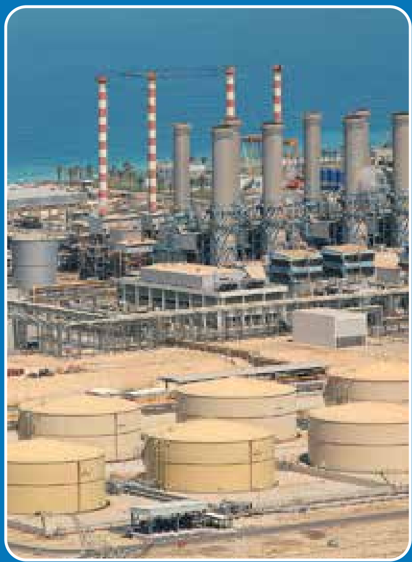
HEAT EXCHANGERS

PETROCHEMICAL

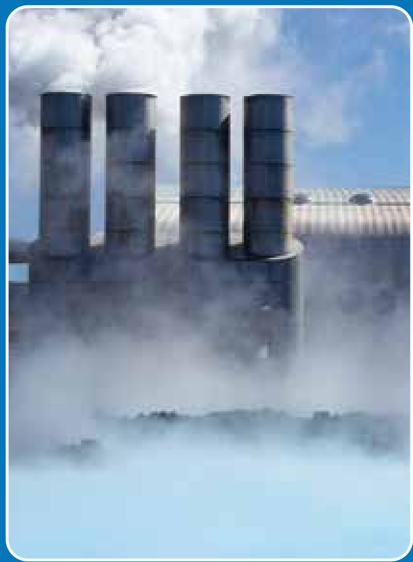
CHEMICAL PROCESSING



DESALINATION



GEOTHERMAL



DESCRIPTION
& COMPOSITION

METALLURGICAL 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.

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

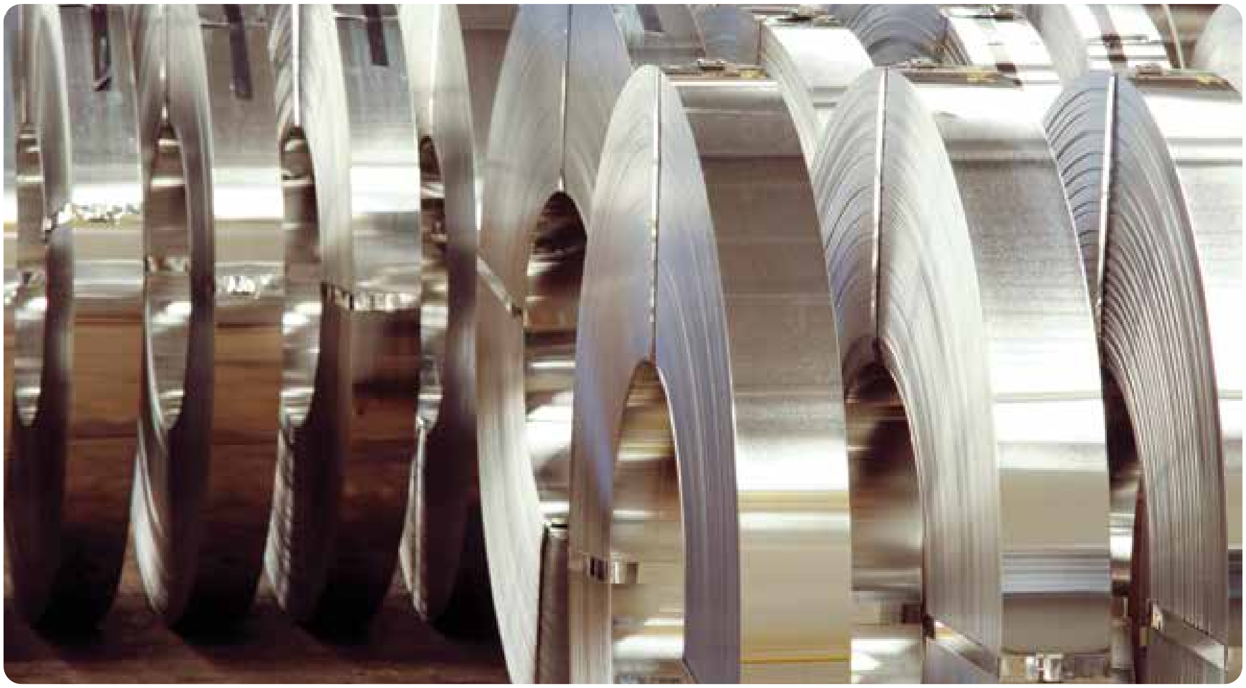
CRITICAL SPECIFICATION CRITERIA

SEA-CURE condenser tubing is only supplied by Plymouth Tube Company. When ordering SEA-CURE condenser tubes, refer to Plymouth Tube Specification OTS-053. The following should be cited for reliable condenser tubing:

- Ability to pass G-48 Method at 65° C for 72 hours in as-shipped condition
- Cold working of weld using both OD and ID tooling
- Air Under Water test at 150 psi
- Available with ASTM A803-S1 eddy current testing
- Available ultrasonic testing
- Water quenched to ensure absence of detrimental secondary phases
- U-bending available

FORMS AVAILABLE

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



FABRICATION PROCESS

1 WELDING

WELDING METHODS

While common methods used for welding stainless steels may be applicable to SEA-CURE stainless, more careful welding conditions are necessary to attain good weld corrosion resistance and toughness. For this reason, gas tungsten arc welding (GTA) with and without filler metal, is preferred to minimize heat input. Techniques used for titanium work well with SEA-CURE.

General procedures to follow include:

- Using low power input and small electrodes
- Using multiple passes as section size increases
- 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. The welded oxide should always be removed by pickling to retain the high corrosion resistance in the weld region.

FILLER METALS

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. For assistance in choosing the proper filler for your application, please contact Plymouth Tube.

2 ANNEALING

SEA-CURE, like all super-ferritics, requires very specialized heat treatments to achieve the expected corrosion rates. Therefore, Plymouth does not recommend re-annealing of SEA-CURE unless specialized equipment is available.

3 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.

4 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 or more. 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 1,200 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” (.712 mm).

CORROSION RESISTANCE

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

CORROSION RESISTANCE					
ACID SOLUTION	TEMPERATURE		TYPE 304	TYPE 316	SEA-CURE
	°F	°C	Corrosion Rate- MPY*		
0.1% Hydrochloric	212	100 B	17.40	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			>1000.00
93% Sulfuric	171	77		78.00	10.00
50% Phosphoric	228	109B	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	17.00		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		6.10	<0.10
50% NaOH	289	143		15.0	1.00

* *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*

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 and duplex stainless steels such as Types 304, 316, and 2205.

In natural seawater at ambient temperature, several tests have shown no attack in over 10 years. Today, numerous power plant condensers have over 30 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.

CORROSION RESISTANCE

EROSION-CORROSION RESISTANCE

SEA-CURE stainless steel is resistant to erosion-corrosion, also known as flow assisted corrosion (FAC). This failure mechanism occurs when the fluid velocity in a condenser or other heat exchanger is so high that it will actually "scrub" the protective film from the metal surface. The following table summarizes flow rates that are commonly assumed or tested maximum safe velocities for an alloy. Higher velocities are desired as they result in higher heat transfer and they keep surfaces clean, reducing the surface interface resistance. The maximum velocity of super-ferritic stainless steels such as SEA-CURE is more than three times that of typical austenitic stainless alloys such as 316. The higher allowable velocity gives the designer more flexibility in exchanger design and can be used to significantly improve thermal performance in an existing envelope.

MAXIMUM WATER FLOW RATES FOR EROSION-CORROSION

ALLOY	MAX VELOCITY
Admiralty	6 FPS
90/10 Cu/Ni	8 FPS
70/30 Cu/Ni	10 FPS
304/316 Stainless Steel	30+ FPS
Ti Grade 2	100 FPS
Super-ferritic Stainless Steel	100+ FPS

CHLORIDE STRESS-CORROSION CRACKING RESISTANCE

Like most other fully ferritic stainless steels, SEA-CURE 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% $CaCl_2$ solution, SEA-CURE 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.

As with other stainless steels, SEA-CURE is not resistant to stress corrosion in 40% magnesium chloride solution (boiling) at 284˚F (140˚C).

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 can resist most of these corrodents. *(As shown in the Corrosion Resistance table on page 7.)*

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 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 many alloys including 300 series stainless steel, admiralty brass, 90/10 copper nickel, and lean and intermediate duplex alloys. SEA-CURE is essentially immune to this reaction because of its very high resistance to pitting.

AMMONIA ATTACK

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

PHYSICAL & MECHANICAL
ATTRIBUTES

Plymouth SEA-CURE stainless steel has a number of attractive physical properties, including good thermal conductivity, low thermal expansion, and a high elastic modulus which provides high stiffness. The passive corrosion resistant film is extremely thin, which allows good heat transfer performance.

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**
Hardness (RB)	60	30	**95**
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 Limit (ksi)	Low	25	**35**

** Minimum ASTM Value* *** When anisotropy is not present*

EROSION RESISTANCE

SEA-CURE exhibits excellent resistance to all types of erosion. It is not affected by high water velocities (which may result from either mechanical design as previously discussed or tube blockage) nor by steam impingement erosion. The resistance of steam impingement erosion is a direct function of the hardness of the metal substrate below the protective oxide. In general, higher hardness provides higher erosion resistance. Using a water droplet impingement device developed by Avesta Sheffield, alloys can be ranked by time to failure as shown in the following table.

MECHANICAL STRENGTH

Due to its superior mechanical strength, SEA-CURE exhibits excellent resistance to mechanical damage. It is resistant to mechanical damage from both maintenance activities as well as impact from projectiles. SEA-CURE has the highest strength and hardness of commercially available alloys.

FOREIGN MATERIAL EXCLUSION (FME)

SEA-CURE's high strength and hardness make it less susceptible to wear damage from foreign materials. Materials such as bolts, nuts, stones, wooden sticks can lodge into condenser tubes, vibrate, and wear holes in the tubes. Materials with low strength and hardness such as titanium are much more susceptible to this type of damage.

RELATIVE EROSION RESISTANCE
BASED UPON EXTRAPOLATED DATA FROM WATER DROPLET IMPINGEMENT TESTS

ALLOY	HARDNESS HV	RELATIVE EROSION RESISTANCE
Admiralty	60 HV	0.4
70-30 Cu-Ni	135 HV	0.8
Ti Grade 2	145 HV	1.0
TP 304/TP 316	165 HV	2.0
Ti Grade 12	190 HV	3.6

ALLOY	HARDNESS HV	RELATIVE EROSION RESISTANCE
254 SMO/AL6XN®	200 HV	7.0
Ti Grade 9	215 HV	6.2
SEA-CURE	**240 HV**	**7.2**
Alloy 2507	290 HV	9.4

VIBRATION RESISTANCE

Because of its very high modulus of elasticity, SEA-CURE stainless steel condenser tubing 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	WALL
Admiralty	0.049"
90/10 Cu/Ni	0.043"
70/30 Cu/Ni	0.034"
TP 439	0.025"
TP 304/TP 316	0.026"
N08367	0.027"
SEA-CURE	0.023"
Ti Grade 2	0.053"

Data based on the Peake Method

THERMAL CONDUCTIVITY AND EXPANSION

The thermal conductivity is similar to titanium and higher than the austenitic stainless steels of high nickel alloys. The thermal expansion coefficients are similar to those of carbon steel and lower than those of the austenitic stainless steel or copper alloys.

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	$5.95x10^{-6}$	$10.71x10^{-6}$

MECHANICAL PROPERTIES

The ambient temperature strength of SEA-CURE stainless steel is retained over the temperature range encountered by most heat exchanger applications. 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.

ELEVATED TEMPERATURE MECHANICAL PROPERTIES

TEMP		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 DIV. 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

ANISOTROPY

As SEA-CURE has a cubic crystal structure, it does not have problems with anisotropy like that of titanium Grade 2 as referenced in ASME Section II, Part D, 2010 Edition, Appendix A-454. This section cautions that titanium properties may vary by as much as 45%.

PRECAUTIONS

GALVANIC CORROSION

Whenever the tubes and the tubesheet of a heat exchanger or condenser are of dissimilar materials and in contact with conductive water (usually more than 2,000 ppm dissolved solids), there is a possibility of galvanic corrosion to the material that is lower in the galvanic series (less noble). The chart to the right shows the sequence of common materials within the series.

SEA-CURE has a high electrode potential in seawater, making it very noble or cathodic. For instance, if SEA-CURE tubes are used with a Muntz metal tubesheet in seawater, the Muntz metal tubesheet can dissolve 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 -750 mv as measured against a standard calomel electrode to prevent generation of hydrogen, which can cause hydrogen embrittlement.

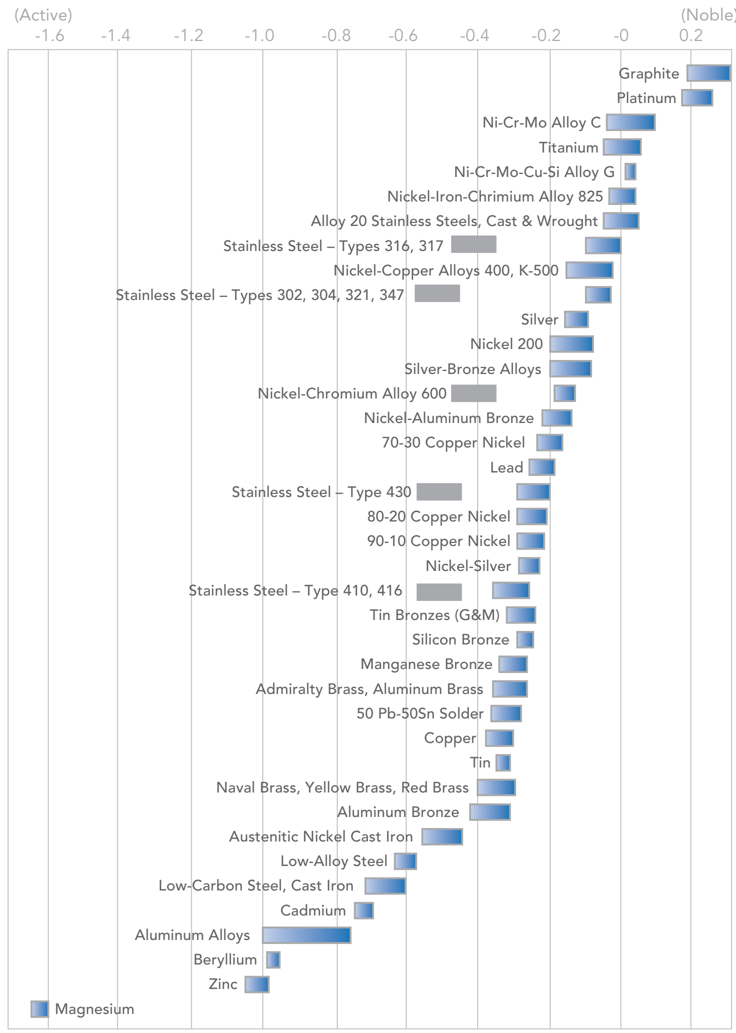
HYDROGEN EMBRITTLEMENT

Like titanium Grade 2, super-ferritic and super-duplex stainless steels are susceptible to embrittlement when nascent hydrogen is introduced to the surface of the tubing. The hydrogen is commonly generated on the tube surface when impressed current system voltages are allowed to drift negatively below -750 mv. Fortunately, SEA-CURE's embrittlement is reversible once the hydrogen source is removed. Titanium's embrittlement is permanent.

PREVENTION

If you are currently using magnesium sacrificial anodes, consider switching to zinc-based as an alternative. If you have an impressed current system, inspect the voltage and make sure that the voltage is no more negative than -750mv. It is also important to check all connections with reference electrodes. Additionally, you may want to consider using a cathodic protection expert to ensure the appropriate electrode spacing.

GALVANIC SERIES



CORRECTION

Fortunately, hydrogen embrittlement in SEA-CURE is reversible. Once the protection system is back in control, the ductility will likely be restored within a few days.

TEMPERATURE

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.

NOTES

CORPORATE HEADQUARTERS

29W150 Warrenville Rd.

Warrenville, IL 60555 U.S.A.

PHONE: (630) 393-3556
FAX: (630) 393-3177
E-MAIL: sales@plymouth.com

www.plymouth.com