Presented at the Stainless Steel World 2006 Conference
Houston, Texas - November 14, 2006.

Lean Substitution Options For 300 Series Alloys and Commercially Pure Titanium

Author: Cheryl A. Botti, ATI Allegheny Ludlum, an Allegheny Technologies company, USA.

Abstract

Today, many changing factors affect a customer's ability to procure the specified material for a project within budget. For austenitic stainless steels, the raw material surcharge component of the price, which fluctuates monthly, continues to be a major, volatile factor in alloy selection. For many applications where Types 301, 304, and 304L have been used, lower-nickel alloys can be successfully substituted. AL 201HP™ alloy (UNS S20100) is a high performance austenitic stainless steel formulated to have a lower and more stable cost due to the substitution of manganese for a portion of the nickel found in the 300 series alloys. AL 201LN™ alloy (UNS S20153) is similar to UNS S20100 in that a portion of the nickel is substituted with manganese and nitrogen, resulting in a composition that has higher strength than Type 304 and is suitable for a wide variety of temperature use, ranging from -320°F up to +800°F (-196°C up to +427°C) as specified by ASME.

Lean duplex alloy AL 2003™ alloy (UNS S32003) can be successfully substituted for Type 316L stainless steel in many applications. The raw material surcharge of UNS S32003 is lower and more stable than Type 316L due mostly to lower nickel and molybdenum contents. The composition of UNS S32003 allows for higher strength than Type 316L. Pitting resistance equivalency, or $PRE_{N,}$ is higher with UNS S32003 and corrosion resistance, even in the as-welded condition, meets or exceeds that of Type 316L.

Tight material availability, long lead-times, and high prices have continued to be factors in the choice of commercially pure titanium (CP) welded tubing for applications in the CPI and in seawater condensers. Super-ferritic AL 29-4C® alloy (UNS S44735) and SEA-CURE® alloy (UNS S44660), and super-austenitic AL-6XN® alloy (UNS N08367) are suitable alternatives that offer solutions to the technical design criteria requirements.

This paper will describe the properties of UNS S20100 alloy, UNS S20153 alloy, and UNS S32003 alloy, review actual and potential applications where these alloys may be used successfully in place of higher alloy 300 series metals. Comparison of CP titanium to UNS S44735, UNS S44600, and UNS N08367 in terms of technical aspects will be described.

™ trademark of and ® registered trademarks of ATI Properties, Inc.
SEA-CURE® is a registered trademark of Plymouth Tube Company.

Introduction

Today, many changing factors affect our ability to procure the specified material for a project within budget and delivery constraints. Material specifiers and engineers must respond effectively to these challenges. Lower cost substitute materials that offer lower and more stable prices and often improved strength and similar corrosion behaviors are commercially available. With the continued volatility of raw material prices these lower cost substitutes offer more attractive options.

Depending upon the material selected, different issues exist. For stainless steels and duplex stainless steels, the availability and long lead-times have loosened up. However, the portion of the invoice price known as raw material surcharge, which fluctuates monthly, continues to be a major component of the overall product cost. For commercially pure (CP) titanium, availability and lead-times are tight and extended, and prices remain high.

Austenitic Stainless Steel Substitutes

Austenitic stainless steel alloys UNS S20100 and S20153 are seeing a “switch” to increasing use in many markets where Type 304 or Type 301 stainless steels are often specified. ATI Allegheny Ludlum’s UNS S20100 alloy is a high performance austenitic stainless steel formulated to have a lower and more stable cost due to the substitution of manganese for a portion of the nickel found in the 300 series alloys. The resulting alloy has comparable properties and performance to the 300 series alloys and in many respects has the same look and feel of Type 304. [(1)] UNS S20153 alloy has a similar chemical composition with higher nitrogen and was originally designed for sub-zero temperature service. Both alloys have the potential for substitution in many areas where Type 304 and Type 301 have been used without corrosion or fabrication problems. Both alloys have been commercially available for over 50 years.

By definition, stainless steels are iron-based materials containing a minimum of 11% Chromium (Cr). The role of chromium in austenitic stainless steels is to combine with oxygen to form an invisible, adherent oxide or “passive” film which provides the corrosion resistance associated with this family of stainless steels. Nickel (Ni), the most commonly talked-about alloying element in stainless steels due to its impact on stainless steel price, stabilizes the austenitic phase as well as provides desirable mechanical properties which allow fabrication into many different shapes.

Chemical Composition

Type 304 is by far the most well known and most commonly used stainless steel of the austenitic family. Type 304 contains a minimum 8% nickel. There are other alloying elements in austenitic stainless steels that can be used to partially replace nickel and yet not negatively impact the corrosion resistance, since chromium is the alloying element that gives stainless steels most of their corrosion resistance. These alloying elements include manganese (Mn) which is also an austenite stabilizer. It can partially replace nickel, especially when accompanied by nitrogen (N) which can also provide strengthening. Copper (Cu) also is an austenite stabilizer. In ASTM specifications for Types 304, 301 and 201, copper is not specified. In UNS S20153 alloy, copper has a maximum limit of 1.0% by weight percent.

ATI Allegheny Ludlum's UNS S20153 alloy is a controlled composition version of UNS S20100 alloy with higher minimum nickel and nitrogen contents and is designed for sub-zero temperature service. The alloy has also been recently granted approval under Code Case 2504 of the ASME Boiler and Pressure Vessel Code for a maximum design temperature of 800°F (+427°C). ASME Code Case 2504 for was approved for use July 13, 2006. A corrected version, ASME Code Case 2504-1, was approved for use September 18, 2006. Although neither has been published yet, they can be used immediately. The use of the corrected version, 2504-1, is preferable. [(2)] The alloy is more commonly sold both as hot-rolled plate and cold-rolled annealed and tempered coil products.

Typical compositions for common austenitic alloys are listed in Table 1. These alloys are all covered under ASTM A 240 and ASTM A 666. [(3), (4)]

Table 1 – Typical Chemical Composition for Common Austenitic Alloys By Weight %

Alloy	UNS	Chromium	Nickel	Manganese	Nitrogen	Carbon
304	**S30400**	18.3	8.1	1.0	0.07	0.06
304L	**S30403**	18.2	8.1	1.3	0.07	0.02
301	**S30100**	17.3	6.7	1.8	0.04	0.10
201	**S20100**	16.3	4.5	7.1	0.07	0.08
201LN	**S20153**	16.4	4.1	6.7	0.15	0.02

Caution however, not all "201" alloys are alike. Other lower nickel austenitic alloys may be available from other producers; however, foreign producers may not manufacture to the ASTM standards. Such materials called "201" stainless have compositions containing lower chromium, lower nickel and higher copper. Such compositions are not the same and their resulting manufacturing and service performance are not the same as products produced to the ASTM standards.

Mechanical Properties

Table 2 – Typical Mechanical Properties for Annealed Cold-Rolled Sheet

Alloy	UNS	Tensile Strength MPa (ksi)	Yield Strength MPa (ksi)	Elongation (% in 2")	Hardness (RB)
304	**S30400**	655 (95)	310 (45)	53	85
304L	**S30403**	635 (92)	325 (47)	58	86
301	**S30100**	725 (105)	310 (45)	58	85
201	**S20100**	725 (105)	310 (45)	58	88
201LN	**S20153**	765 (111)	365 (53)	54	93

As shown above the annealed tensile strength of UNS S20100 alloy is about 10% higher than Type 304, which may allow the use of a thinner gauge and therefore less material. UNS S20153 alloy also has a higher annealed tensile strength than T304L, approximately 20% greater. The high uniform elongation of both alloys permit similar performance to Types 304 and 301 in bending, forming, and drawing.

Fabrication

Initial adjustments may be needed on existing equipment to compensate for the higher strength, but there should be no need for new equipment. Other manufacturing processes used to fabricate parts made of Type 304 and Type 304L are also suitable for UNS S20100 and UNS S20153 alloys.

Other fabrication processes used in the manufacturing of Type 304 and 304L can also be used with UNS S20100 and UNS S20153 alloys. They both can be welded using similar methods as Type 304 and 304L. If filler metals are required, there are commercially available weld wires suggested for use. Post weld heat treatment is not required.

Because UNS S20100 and UNS S20153 alloys fall in the same classification of austenitic alloy as Type 304 and 304L, their physical appearance will be virtually the same as Type 304 and 304L for both the as-shipped product from the mill producer and the final fabricated product. This visual similarity enables them to be used side-by-side without noting any physical differences. All of the finishes and flat-rolled product forms that are commercially available in Types 304 and 304L are also available in UNS S20100 and UNS S20153 alloys.

UNS S20100 and UNS S20153 alloys are also available as temper-rolled products in tempers up to full hard for thicknesses >0.015" as per ASTM A 666. Extra full hard tempers in excess of the 185 ksi min full hard temper specified in ASTM A 666 can also be achieved. [4]

Corrosion Resistance

Corrosion performance as ranked by a number of standard ASTM tests demonstrate very similar performance of UNS S20100 alloy compared with Type 304 in salt spray tests, crevice corrosion, and pitting corrosion tests. The similar chromium levels of UNS S20100 and S20153 alloys and Type 304 are responsible for this similar level of performance in service. Austenitic stainless steels obtain most of their corrosion resistance from the alloying element chromium. The 16.3% typical level of chromium in UNS S20100 alloy and 16.4% typical level of chromium in UNS S20153 alloy compared to the 18.3% in Type 304 is more than enough to protect the steel from corrosion in most environments. In most cases UNS S20100 alloy and UNS S20153 alloy will display comparable corrosion resistance to Type 304. The comparative results in the ASTM

G48A and G48B pitting and corrosion tests shown demonstrate similar performance. [5, 8] Another way to rank alloys with respect to their pitting and crevice corrosion resistance is a calculation known as the PRE_N value. UNS S20100 alloy has a PRE_N value of 18.4 compared to Type 304 PRE_N value of 20.4. ASTM B117 salt spray tests exposed for 100 hours yielded similar results for both UNS S20100 alloy and Type 304 with neither alloy exhibiting any rust. [6, 7]

Table 3 - Pitting and Crevice Corrosion Test Results [8]

		UNS S20100 and S20153	T304
ASTM G48A Pitting Test	**Weight Loss**	0.0228g/cm^2	0.0280g/cm^2
	Max Pit Depth	0.003”	0.003”
ASTM G48B Crevice Test	**Weight Loss**	0.0211g/cm^2	0.0205g/cm^2
PRE_N=%Cr+%3.3%Mo+16%N		18.4	20.4

Cost Savings and Availability

Not only do alloying elements provide specific roles to achieve desired corrosion resistance, formability, ability to fabricate, etc., but they also play a role in the overall product cost. Globally, mill producers generally use a mechanism known as a raw material surcharge to pass along producers’ cost of raw materials. A direct relationship exists between the price of nickel and chromium in these alloys, the weight percentage of each in each alloy, and the raw material surcharge. The price of nickel has risen to levels not seen since the late 1980’s. In these alloys nickel is the most significant raw material that affects the raw material surcharge. Generally, surcharges are applied on a monthly basis based on the prior two months’ final average trading price. The end result is volatility in the raw material surcharge price and hence in the final price of the stainless steel.

For shipments delivered in October 2006, the raw material surcharge component of the final price of the various stainless steel alloys are found in Table 4. [9]

Table 4 – Raw Material Surcharge Comparisons [9]

Alloy	UNS	Total Raw Material Surcharge*
304	**S30400**	$1.2519
301	**S30100**	$0.9602
201	**S20100**	$0.7350
201LN	**S20153**	$0.6912

*based on $13.945/lb average for nickel; $0.6510/lb average for chromium

UNS S20100 alloy is produced by ATI Allegheny Ludlum as cold-rolled sheet and strip in all the same finishes and sizes as produced in Type 304 and 301. UNS S20153 alloy is produced as both cold-rolled sheet and hot rolled plate in all the same finishes and sizes as Type 304L. Availability and lead-times are similar for these all of these alloys.

Applications

UNS S20100 alloy has been used in a variety of applications in commercial and residential food service. Hot food wells, garbage disposal flanges, toasters, ice and water dispensers are just a few of the many areas where UNS S20100 alloy has been specified. In addition the alloy has been successfully used in the manufacture of beverage dispensers and ice makers. Its clean appearance and resistance to corrosion have made UNS S20100 alloy a popular one in this industry (see Figure 1).

Figure 1: Icemakers made from UNS S20100 alloy

Exterior panels of both industrial and consumer appliances are often made from stainless steel. UNS S20100 alloy offers an economical alternative to T304 for many of these applications (see Figure 2).

Figure 2: UNS S20100 alloy can be used to provide appliances with long lasting stainless beauty

UNS S20100 alloy has been used to make cookware lids, and has also been used in the manufacture of pots and pans. Its combination of good formability and corrosion resistance make UNS S20100 alloy an excellent choice for many food and beverage storage and preparation applications. The protective chromium oxide film which forms naturally on the surface of UNS S20100 enhances the resistance of cookware and other food service applications to corrosion by foodstuffs and cleaning products, and prevents contamination of its contents.

Specialty hose clamps for a variety of applications are another market where UNS S20100 alloy has been used for many years. Often high strength tempers are specified. Such applications demonstrate the durability of the alloy in a wide range of demanding environments.

Figure 3: Clamps for various end uses made of UNS S20100 alloy

UNS S20153 alloy with its higher strength has been traditionally used in the structural components of truck trailers and railcars and cryogenic tanks. More recently the chemical process industry (CPI) and other process industries are interested in the alloy in areas where Types 304 and 304L have been used successfully. See examples of applications in Figures 4, 5 and 6.

Figure 4: Tank For The CPI

Figure 5: Cryogenic Vessels for liquidified gases of UNS S20153 alloy

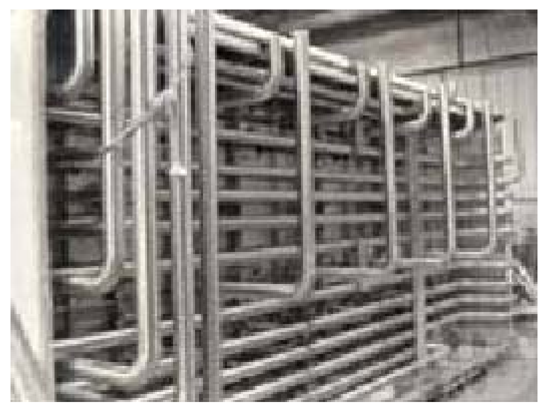

Figure 6: In-Plant Piping of UNS S20153 alloy

Duplex/Molybdenum-Containing Stainless Steel Substitutes

In environments where pitting resistance and chloride stress corrosion cracking are important a more highly alloyed stainless alloy like Type 316L or a duplex stainless steel like alloy 2205 may be required. A "switch" to a lean duplex like S32003 alloy offers economic value in terms of a reduced raw material surcharge as well as filling a gap between Types 316L and 2205 duplex in terms of corrosion resistance while possessing the higher mechanical properties characteristic of a duplex stainless steel. The microstructure of a duplex stainless steel, when properly heat treated, consists of a nearly equal mixture of the austenite and ferrite phases. Duplex alloys behave in a manner that is a combination of the characteristics of both phases. The nickel-free ferritic stainless steels are essentially immune to chloride stress corrosion cracking. This ferritic phase provides resistance to chloride stress corrosion cracking in these duplex alloys.

Chemical Composition

Table 5 shows the typical compositions of this group of alloys. The reduced levels of chromium (Cr) and molybdenum (Mo) contents of UNS S32003 alloy make it more resistant than 2205 alloy to the formation of detrimental phases such as sigma. The lower nickel and molybdenum contents of S32003 alloy compared to the other two alloys reduce the raw material surcharge component of the price while still producing a product having high corrosion resistance excellent mechanical properties.

Table 5 – Typical Chemistry for More Highly Alloyed Stainless Alloys By Weight %

Alloy	**UNS**	**Chromium**	**Nickel**	**Molybdenum**	**Nitrogen**	**PRE_N***
316L	**S31603**	16.2	10.2	2.2	0.06	24.4
AL 2003™	**S32003**	21.5	3.7	1.8	0.17	30.0
2205	**S31803**	22.5	5.8	3.3	0.16	36.0

*PRE_N=%Cr+%3.3%Mo+16%N

Mechanical Properties

The annealed higher tensile strength of S32003 alloy compared to Type 316L provides the opportunity for thickness reductions and improved wear resistance. Thickness reductions up to 1/3 have been reported where appropriate.

Table 6 - Typical Mechanical Properties for Annealed Cold-Rolled Sheet

Alloy	**UNS**	**Tensile Strength MPa(ksi)**	**Yield Strength MPa(ksi)**	**Elongation (% in 2")**	**Hardness**
316L	**S31603**	607 (88)	303 (44)	57	82 R_B
AL 2003™	**S32003**	724 (105)	517 (75)	40	20 R_C
2205	**S31803**	862 (125)	586 (85)	30	27 R_C

ASME Code Case 2503 for UNS S32003 alloy was approved by the ASME Board on Pressure Technology Codes and Standards on January 19, 2006. This code case allows the use of UNS S32003 alloy in ASME pressure vessel construction. [(10)] ATI Allegheny Ludlum has received accreditation as a qualified producer of UNS S32003 alloy along with UNS S31803 and UNS N08367 alloys in strip and plate products under NORSOK standard M-650. [(11)]

Fabrication

If switching from Type 316 to S32003 alloy, initial adjustments may be needed on existing equipment to compensate for the higher strength, but there should be no need for new equipment. If switching from alloy 2205 to S32003 alloy, few, if any, adjustments should be needed.

Other fabrication processes used in the manufacturing of 2205 alloy products can also be used with UNS S32003 alloy. They both can be welded using similar methods. If filler metals are required, use of the commercially available 2209 weld wire, developed for 2205 alloy, is suggested. Post weld heat treatment is not required when the 2209 filler metal is used. Autogenous welds should be given a full anneal heat treatment to restore weld ductility and corrosion resistance.

Corrosion Resistance

In tests conducted in a wide range of media (acids, salts, organic chemicals, etc.), UNS S32003 alloy has displayed corrosion resistance that exceeds that of Type 316L stainless steel and frequently exceeds that of T317L stainless steel. UNS S32003 alloy is a "leaner" alloy than type 2205 duplex stainless steel and cannot equal its corrosion resistance in all environments, especially high chloride environments. UNS S32003 alloy does exhibit similar corrosion resistance compared to 2205 alloy in a variety of lower-chloride environments. Thus, UNS S32003 alloy is suitable for use in place of Type 316L or Type 317L stainless steels where slightly greater corrosion resistance is desirable, or where resistance to stress corrosion cracking is required, and where the use of 2205 duplex stainless steel is not necessary.

A plot of the PRE_N vs. critical crevice corrosion temperature is a good indicator of the relative corrosion resistance to chloride pitting in aqueous environments. UNS S32003 alloy outperforms Type 316L and performs within a few degrees of 2205.

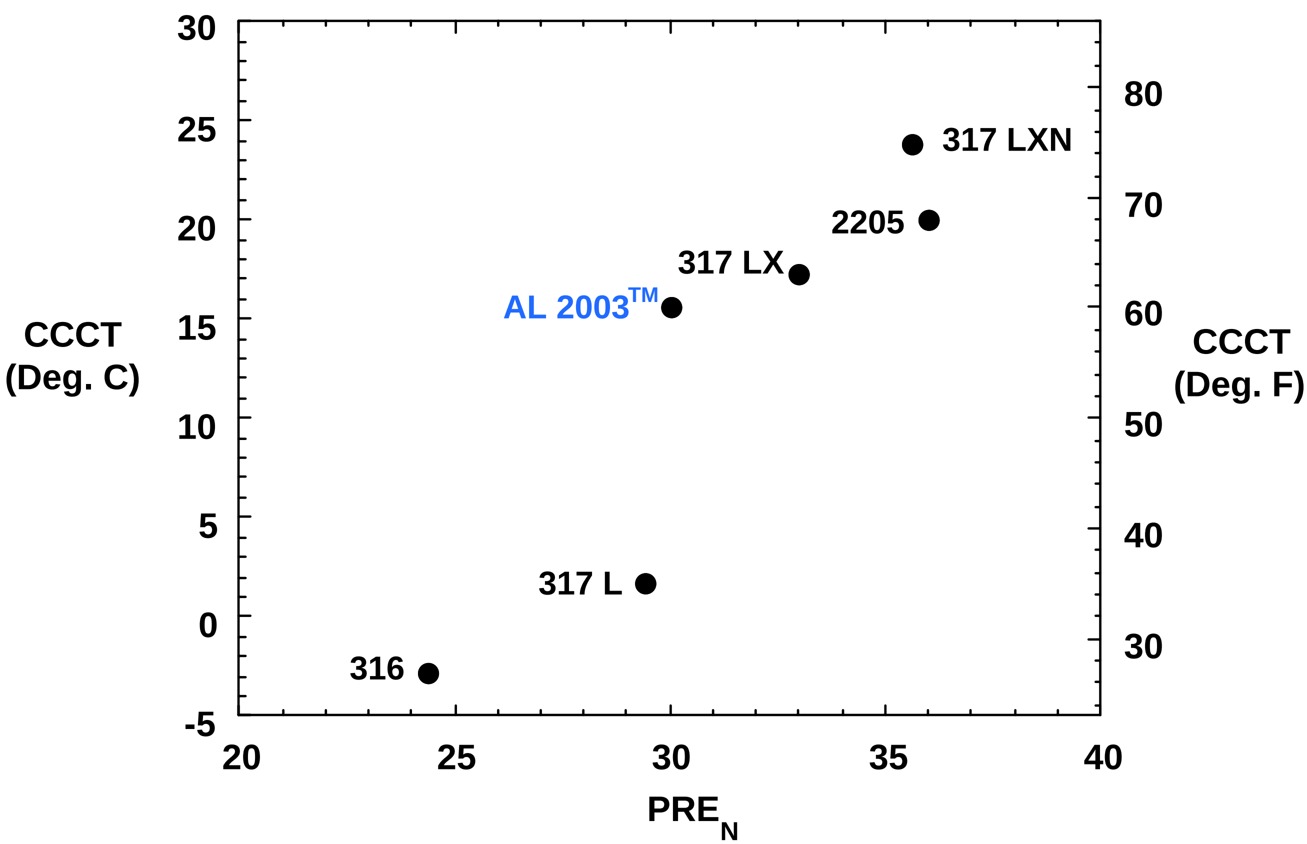

Figure 7: Critical Crevice Corrosion Temperature per ASTM G48C vs. PRE_N [5, 8]

The pitting corrosion comparisons as per ASTM G150's electrochemical critical pitting temperature test are listed in Table 7. (12)

Table 7 – Critical Pitting Test Results Per ASTM G150 (8)

Alloy	UNS	CPT, °C	CPT, °F
316L	**S31603**	17	63
AL 2003™	**S32003**	35	95
2205	**S31803**	49	120

Chloride stress corrosion cracking resistance was tested by U-bend immersion in boiling 26% NaCl solution to 1000 hours. Both duplex alloys passed at 1000 hours; T316L failed prior.

Table 8 – Stress Corrosion Cracking Performance (8)

Alloy	UNS	Result
316L	**S31603**	Failed, 530-940 hours
AL 2003™	**S32003**	Passed, 1000 hours
2205	**S31803**	Passed, 1000 hours

Cost Savings and Availability

The same raw material surcharge mechanism is in place for these alloys as with the austenitic stainless steels discussed earlier. Since molybdenum is an alloying element in all of these grades, it adds a component to the monthly raw material surcharge calculation. A direct relationship exists between the price of nickel, chromium and molybdenum in these alloys, the weight percentage of each in each alloy, and the raw material surcharge. The price of nickel has risen to levels not seen since the late 1980's. In these alloys both nickel and molybdenum are the most significant raw materials that affect the raw material surcharge. The surcharge is again applied on a monthly basis based on the prior two months' final average trading price of these alloying elements. The end result is volatility in the raw material surcharge price and hence in the final price of the stainless steel. UNS S32003 is priced competively with T316L.

For shipments delivered in October 2006, the raw material surcharge component of the final price of the various stainless steel alloys are found in Table 9. (9)

Table 9 – Raw Material Surcharge Comparisons (9)

Alloy	UNS	Total Raw Material Surcharge*
316L	**S31603**	$2.1025
AL 2003™	**S32003**	$0.9708
2205	**S31803**	$1.7280

*based on $13.945/lb average for nickel; $0.6510/lb average for chromium; $26.84/lb average for molybdenum

UNS S32003 alloy is produced by ATI Allegheny Ludlum as plate, sheet and strip. Welded pipe and tubes have been produced by several mills. Availability and lead-times for UNS S32003 are similar to Type 316L and 2205 alloys.

Applications

Some examples of industry end uses for UNS S32003 alloy are onshore and offshore equipment in the oil and gas industry, tubular heat exchangers for the power generation industry, desalination chambers, and wastewater reclamation. Piping systems and tanks for various processes including those in the CPI, pulp and paper, and pharmaceutical industries are also viable candidates for UNS S32003 alloy.

The higher strength of UNS S32003 alloy is an advantage for structural and architectural applications, especially when the design is based on strength. The alloy's resistance to pitting corrosion is a benefit for use where road salts and chemical cleaning products are present. Figure 8 is a structural example of one use for the alloy.

Figure 8:   UNS S32003 alloy used in piping for structure support. Canopy from the Medical Center Metro Station in Bethesda, MD.

Commercially Pure (CP) Welded Titanium Tubing For Condensers

Increased demand for titanium and titanium alloys in the commercial aerospace, chemical process and power industries has resulted in a tightened global supply which directly effects price, availability and lead-time. These market conditions have been present for well over a year and are expected to continue. Commercially pure (CP) welded titanium tubing is used in a variety of condenser applications where exposed to seawater and its challenging conditions are present. Municipal power plants, nuclear power plants, desalination plants and chemical processing plants are a few of the areas. Substitute materials have to meet or exceed the seawater alloy design criteria of a variety of forms of corrosion, erosion, vibration, and fouling in addition to possessing adequate weldability. Additionally, the commercial criteria of cost, availability and lead-times are also significant. A number of super stainless steels provide viable options for meeting or exceeding these technical and commercial requirements.

CP titanium is well known for its general corrosion resistance, crevice corrosion and localized pitting resistance and chloride-induced stress corrosion cracking. Two superferritic alloys can be offered as alternatives: AL 29-4C® alloy (UNS S44735) and SEA-CURE® alloy (UNS S44660). These fully ferritic alloys offer resistance to chloride-induced stress corrosion cracking, localized pitting and crevice corrosion. Use of super-austenitic AL-6XN® alloy (UNS N08367) is another alternative. This alloy also offers resistance to chloride pitting and crevice corrosion due to its high level of chromium, molybdenum and nitrogen. More than 30,000,000 feet [10,000,000 M] of UNS N08367 alloy in condenser tubing applications are currently in service, some for periods of more than 20 years. The high level of nickel at 24% provides resistance to chloride stress corrosion cracking. (13)

Chemical Composition

Typical chemical compositions of these stainless steels are shown in Table 10. The high chromium and molybdenum contents give these alloys high PRE values and are responsible for the improved corrosion properties of these materials compared those of other lower-alloyed grades.

Table 10 – Chemical Composition For Super Ferritic and Super Austenitic Stainless Steels By Weight %

Alloy	**UNS**	**Type**	**Cr**	**Mo**	**Ni**	**N**	**PRE_N**
AL 29-4C®	**S44735**	Super Ferritic	29	4.0	---	---	44
SEA-CURE®	**S44660**	Super Ferritic	27	3.7	2	---	39
AL-6XN®	**N08367**	Super Austenitic	20	6.0	24	0.20	45

*PRE_N=%Cr+%3.3%Mo+16%N

Corrosion

Stress-Corrosion Cracking

The ferritic structure provides high resistance to stress-corrosion cracking. In the austenitic alloys the resistance to stress-corrosion cracking is dependent upon the nickel content. The Copson's curve correlation (14) in demonstrates that the level of resistance increases as the nickel level increases above about 12%. Similarly as the level of molybdenum increases about the 3% level, the resistance to stress-corrosion cracking also improves. The typical nickel level of 24% and typical molybdenum level of 6% in UNS N08367 alloy allow it to have high resistance. Refer to Figure 9 which demonstrates a series of U-Bend tests superimposed on the Copson curve. (13) UNS N08367 alloy is compared to Types 304, 316 and Alloy 20 (UNS N08020).

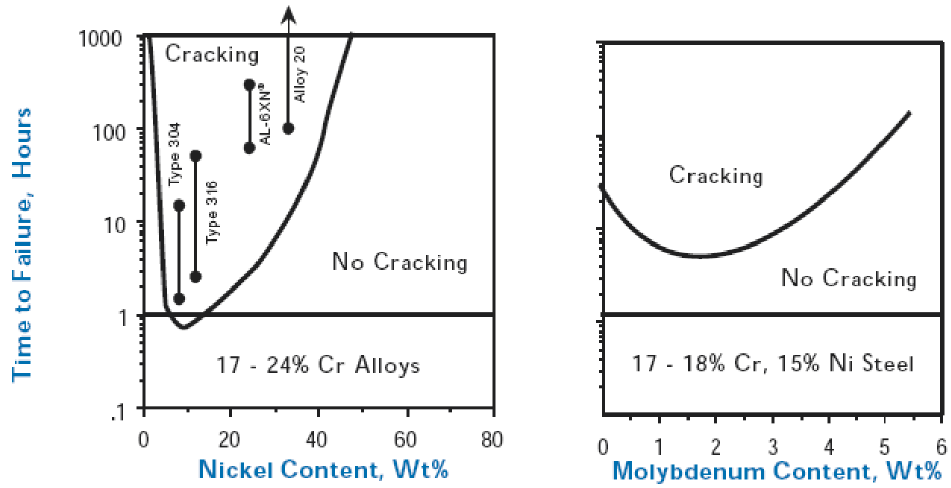

Figure 9: Effect of nickel (left) and molybdenum (right) on SCC resistance in boiling magnesium chloride solutions [13]

Pitting Corrosion

Figure 10 shows the experimentally determined Critical Pitting Temperatures (CPTs) for a variety of stainless materials plotted against their respective Pitting Resistance Equivalent (PRE) numbers. These data show that the superferritic stainless steels exhibit a higher CPT for a given PRE than do austenitic or duplex stainless steels.

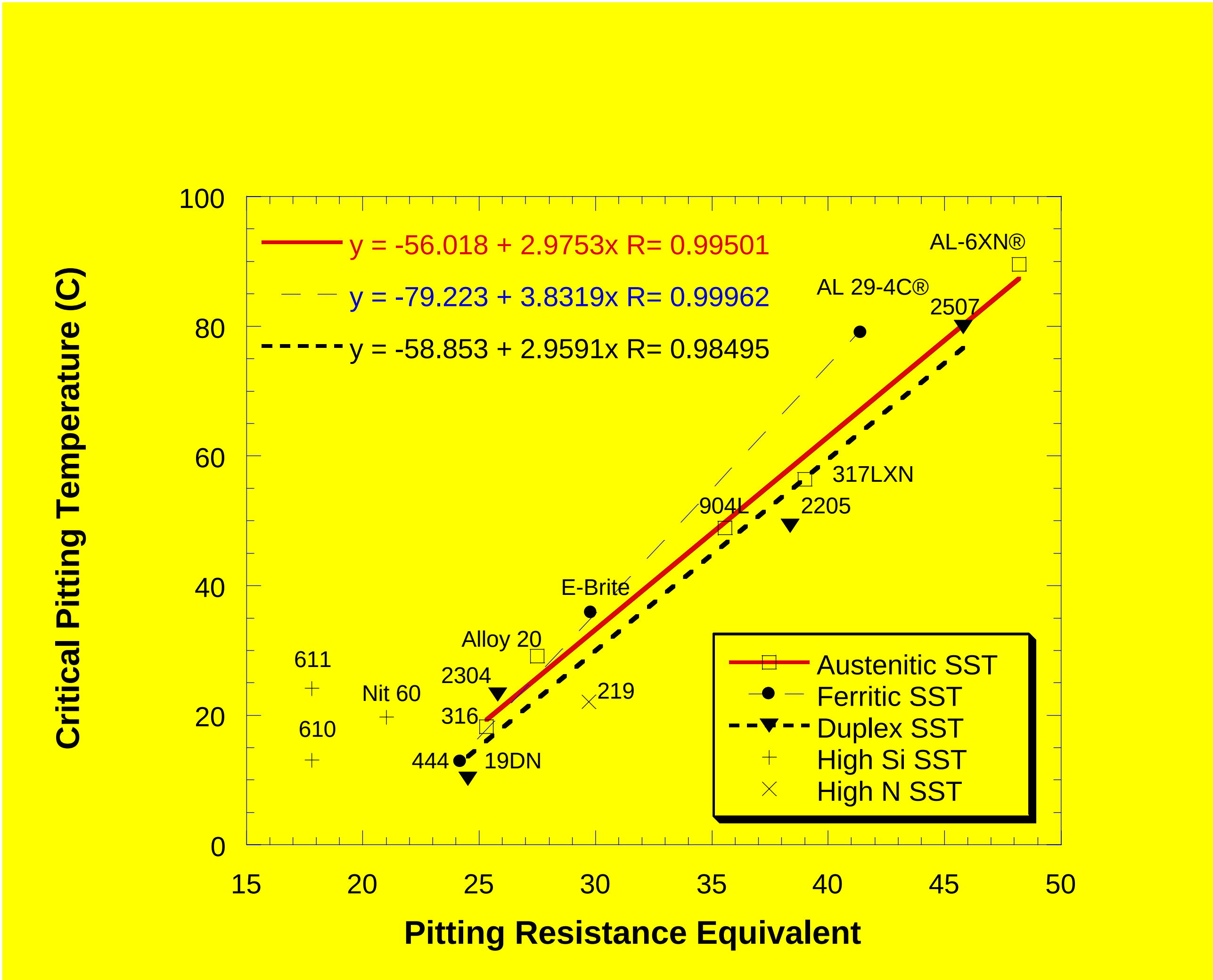

Figure 10: Critical Pitting Temperature as a function of Pitting Resistance Equivalent (PRE) number for austenitic, duplex, and ferritic stainless alloys. [15]

Crevice Corrosion

These super stainless steels exhibit high resistance to chloride crevice corrosion. Although they do not have as great a resistance to crevice corrosion as does CP titanium, they exhibit enough crevice corrosion resistance to resist this form of attack in a wide range of chloride environments, including natural seawater, at moderately elevated temperatures. In deaerated seawater or brines, they often can be used to near-boiling temperatures.

Table 11 – Temperatures of Onset of Crevice Corrosion Attack [8]

Alloy	**UNS**	**Temperature of Onset of Crevice Corrosion Attack, °C**
AL 29-4C®	**S44735**	45
SEA-CURE®	**S44660**	45
AL-6XN®	**N08367**	35
CP Titanium	**R50400**	NA

Mechanical Properties

Table 12 – Typical Mechanical Properties

Alloy	**UNS**	**Elastic Modulus, GPa (x10^6 PSI)**	**Yield Strength, MPa (KSI)**	**Tensile Strength, MPa (KSI)**	**Elongation, %**
AL 29-4C®	**S44735**	213 (31)	517 (75)	655 (95)	22
SEA-CURE®	**S44660**	210 (30)	517 (75)	655 (95)	22
AL-6XN®	**N08367**	190 (28)	379 (55)	758 (110)	45
CP Titanium	**R50400**	105 (15)	345 (50)	483 (71)	27

The higher modulus of elasticity in the alternative metals compared to CP will attribute to less tube vibration as well as other benefits. This reduces the need for additional tube support plates within the heat exchanger bundle.

The high strength of the stainless steels and the tenacity of their passive films gives them high resistance to flow induced erosion corrosion and also to water droplet impingement erosion. These stainless steels are actually slightly superior to titanium with regard to impingement erosion resistance, and some condenser manufacturers have used these stainless tubes in the first few rows near the steam inlet to protect the tubes in what is otherwise a titanium-tubed condenser.

Fabrication

These stainless steels are readily weldable. As with titanium, thorough cleaning before welding and stringent attention to inert gas shielding d back shielding are desirable. Other procedures and considerations for welding these materials are different than those for titanium, but they are not more difficult to weld. Under some circumstances, such as with on-site fabrication, they may be easier to weld properly.

Cost Savings and Availability

Table 13 – Comparison of Relative Tube Cost Per Meter

Alloy	**UNS**	**Relative Tube Cost Per Meter**
AL 29-4C®	**S44735**	1.5
SEA-CURE®	**S44660**	1.5
AL-6XN®	**N08367**	2
CP Titanium	**R50400**	3

As stated above, the possible use of a thinner-walled tube in the alternative metals can also contribute to reduced costs due to less weight involved. The actual material costs of the alternatives are also lower than CP titanium due to market conditions.

Extended lead-times for the starting mill product, flat-rolled skelp, have been and remain in the 26 to 52 week range for CP titanium. These superferritic and superaustenitic alloys have typical skelp lead-times half that of titanium. These super stainless alloys are more abundant than titanium hence the reduced lead-time and cost.

Conclusion

In summary, where price, availability and lead-time are affecting your ability to obtain material within budget and lead time, consider "switching" to an alternative. The substitute materials highlighted in this article demonstrate that there are viable options commercially available.

Resources:

1. D.S. Bergstrom and C.A. Botti, "A High-Performance, Lower-Nickel Alternative to 300 Series Alloys," Stainless Steel World 2005 Conference, Maastricht, The Netherlands, November 2005.

2. ASME Code Case 2504, American Society for Mechanical Engineers, Boiler and Pressure Vessel Code, New York, NY, 2006.

3. ASTM Standard A 240/A 240M – 05A, Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet and Strip for Pressure Vessels and for General Applications, ASTM International, West Conshohocken, PA, 2005.

4. ASTM Standard A 666 - 03, Standard Specification for Annealed or Cold Worked Austenitic Stainless Steel Sheet, Strip, Plate and Flat-Bar, ASTM International, West Conshohocken, PA, 2003.

5. ASTM Standard G48-03, Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution, ASTM International, West Conshohocken, PA, 2003.

6. ASTM Standard B117-03, Standard Practice for Operating Salt Spray (Fog) Apparatus, ASTM International, West Conshohocken, PA, 2003.

7. B. Ozturk, Salt Spray Testing of Type 201, 201LN, 301, 304, 430 and 439HP Samples, Internal ATI Allegheny Ludlum Report, June 27, 2005.

8. ATI Allegheny Ludlum, Internal Research.

9. ATI Allegheny Ludlum Surcharge Tables, www.alleghenyludlum.com, October 2006.

10. ASME Code Case 2503, American Society for Mechanical Engineers, Boiler and Pressure Vessel Code, New York, NY, 2006.

11. NORSOK Standard M-650, *Qualification of Manufacturers of Special Materials*, Standards Norway, Lysaker, Norway, 2004.

12. ASTM Standard G150-99, Standard Test Method for Electrochemical Critical Pitting Temperature Testing of Stainless Steels, ASTM International, West Conshohocken, PA, 2003.

13. AL-6XN® (UNS N08367) Alloy Blue Sheet

14. H. R. Copson, "Effect of Composition on Stress Corrosion Cracking of Some Alloys Containing Nickel," Physical Metallurgy of Stress Corrosion Fracture, Interscience Publishers, New York, 1959.

15. J. D. Fritz, B.W. Parks, J.F. Grubb, C.P. Stinner, "The Use of Electrochemical Critical Pitting Temperature Measurements for Evaluating Stainless Steels," Stainless Steel World 2001 Conference, November, 2001.