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May 21, 2007

Mr. Chuck Magnesio
Senior VP of Engineering & Technical Marketing
JVI Pittsfield, MA
30 Bishop Parkway
Pittsfield, MA 01201

Re: Stainless Steel Material Comparison

Dear Chuck:

Following is a comparative review of Type 304L and Type 201L stainless steel for potential substitution of Type 201L steel for the Type 304L grade currently used in your Vector connector and Mini V connector products. Of the various grades within the 200 series of stainless steel I agree that 201L is the best candidate to consider for substitution for 304L since welding is a requirement. A modified 201L grade, designated 201LN, is also available which is optimized for cryogenic applications but could also be used for structural applications under ambient temperature conditions.

In the comparison I have considered chemical composition, corrosion resistance, mechanical properties, weldability, and cold forming ability of the two grades.

Chemical Composition

Type 304L and 20lL grades are both austenitic stainless steels. The chemical composition requirements of the two grades are shown in Table 1 (Ref. 1). Both grades contain in excess of 12 % chromium for corrosion resistance and should therefore have similar atmospheric corrosion properties. The primary difference in chemical composition is the alloy additions used to achieve an austenitic condition at room temperature. Type 304L utilizes nickel in the range of 8-12% as an austenite stabilizer. Type 201L utilizes less nickel (3.5-5.5%) and substitutes increased manganese (5.5-7.5%), also an austenite stabilizer, to achieve this condition.

Table 1 Chemical Composition Requirements

Type	UNS Designation	Composition, wt%*							
		C	Mn	P	S	Si	Cr	Ni	Other
304L	S30403	0.03	2.0	0.045	0.03	0.75	18.0-20.0	8.0-12.0	N 0.10
201L	S20103	0.03	5.5-7.5	0.045	0.03	0.75	16.0-18.0	3.5-5.5	N 0.25
201LN	S20153	0.03	6.4-7.5	0.045	0.015	0.75	16.0-17.5	4.0-5.0	N 0.1-0.25 Cu 1.00

* Maximum unless otherwise indicated

Mechanical Properties

The tensile property requirements of the two steel grades specified in ASTM A666 (Ref.1) is shown in Table 2. In the annealed condition both grades have similar yield strength, tensile strength, and tensile ductility requirements with the 201L and 201LN grade having slightly higher yield and tensile strength. The 304L currently utilized for connectors is supplied in the annealed condition.

Table 2 Tensile Property Requirements

Type	UNS Designation	Yld. Strength, min (ksi)	TensileStrength, min (ksi)	Elong. (2"), min (%)
304L	S30403	25	70	40
201L	S20103	38	95	40
201LN	S20153	45	95	45

ASTM A666 also specifies yield and tensile strength requirements of both grades for cold worked material. The requirements of both grades for increasing amounts of cold deformation (ie. 1/16 hard, 1/8 hard, ¼ hard etc.) is comparable suggesting that the strain hardening behavior of both grades are similar. The bend requirements specified for the two grades in ASTM A666 are also identical. Since the connectors are cold formed by bending similar strain hardening and bending capacity would be desirable aspects in choosing a suitable alternative material.

Corrosion Resistance

Since the two grades are austenitic grades with comparable chromium content in excess of 12%, the corrosion resistance of the two grades would be expected to similar. Chromium content is the primary factor in corrosion resistance of stainless steels. Review of corrosion resistance performance of the two grades (Ref. 2,3,4) indicates that they possess similar corrosion resistance in mild atmospheric, industrial and marine environments. The low carbon "L" grade produced in both grades minimizes the potential for sensitization in the heat-affected zone in the welded condition. Hence, both grades would be expected to possess similar corrosion resistance when welded.

Weldability

Considering the chemical composition similarities of the two grades, the weldability of both grades would be expected to be similar. E308L filler metal, commonly used for welding Type 304L stainless steel, is also a suitable electrode for welding Type 201L and 201LN stainless steel (Ref.5,6). This would also be a good choice if dissimilar grade weld joints comprised of 304L and 201L or 201LN material were considered.

References

1. ASTM A666-00, "Standard Specification for Annealed or Cold Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar". ASTM, 2001.

2. *Design Guidelines for the Selection and Use of Stainless Steel*, Specialty Steel Industry of North America.
3. Technical Data Blue Sheet , *Stainless Steels Type 201 and 201L,* Allegheny Ludlum, 2005.
4. Technical Data Blue Sheet, *Stainless Steel Chromium-Nickel-Manganese Al 201LN* , Allegheny Ludlum, 1998.
5. AWS D1.6, *Structural Welding Code- Stainless Steel*, American Welding Society, 1999.
6. Welding Handbook, *Materials and Applications- Part 2*, Vol.4, Eighth Ed., American Welding Society, 1998.

Please advise if you have any questions or require additional information.

Sincerely yours,

Eric J. Kaufmann
Senior Research Engineer, ATLSS

The Switch is On™

The Case for AL 201LN™ Substitution

ATI Allegheny Ludlum
Allegheny Technologies

Why AL 201LN™ Alloy?

- ATI Allegheny Ludlum has been producing AL 201LN™ alloy for over 20 years.
- AL 201LN™ stainless steel has similar performance to higher-Ni alloys in many environments, at a lower and more stable cost.
- AL 201LN™ alloy can permanently replace T304L in many applications.
- AL 201LN™ alloy is available in sheet, strip, discrete plate and continuous mill plate product forms.
- AL 201LN™ alloy has low initial and life-cycle costs.

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The Technical Argument for AL 201LN™ Alloy

Lower cost raw materials such as manganese and nitrogen are added as partial substitutes for nickel, which has a higher and more volatile cost. These substitutions are made without major tradeoffs in performance.

Structural Strength	**Superior mechanical strength compared to Type 304L.**
Corrosion Resistance	**The composition of AL 201LN™ alloy provides excellent corrosion resistance, equivalent to Type 304L in most environments.**
Formability	**High uniform elongation permits bending and forming of AL 201LN similar to Type 304L.**
Impact Toughness	**AL 201LN™ alloy displays excellent cryogenic toughness in the welded condition.**
Weldability	**Similar to 300 series austenitic stainless.**
Code Coverage	**API & ASME pressure vessel approval as low as -320°F. ASME Code Case 2504-1 was approved on September 18, 2006 for use up to 800°F.**
Magnetic Permeability	**Low magnetic permeability that is comparable to Type 304L.**

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Raw Materials

Historical Nickel Prices (1980 through March 2007)

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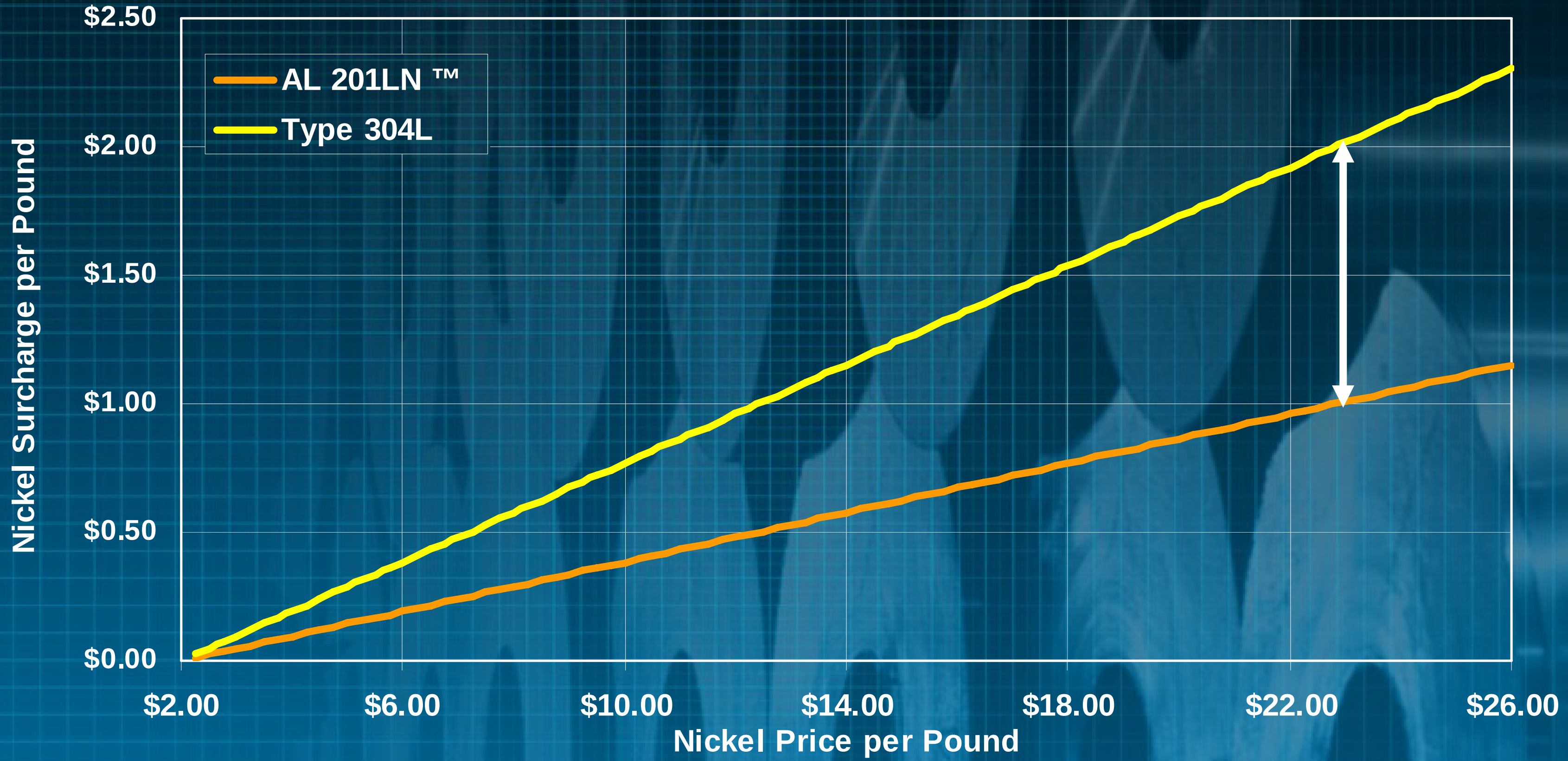
The Effect of Price on the Nickel Surcharge



AL 201LN™ Alloy

Technical Comparison

Allegheny Technologies

Low Nickel Austenitic Stainless Steels – "The Basics"

- The most important alloying element that makes stainless steels "stainless" is Chromium (Cr).
- When at least 11% Cr is present, a continuous layer of an invisible oxide film will form, which is what gives stainless steels their superior corrosion resistance.
- Nickel (Ni) is the most commonly talked about element in stainless steels, due to its effect on price. The main role of Ni in 200 and 300 series grades is to help create an austenitic structure, which provides favorable mechanical properties. T304, the most common grade of stainless, contains 8% minimum Ni. AL 201LN™ alloy contains 4% minimum Ni.

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Low Nickel Austenitic Stainless Steels – "The Basics"

- Manganese (Mn) is used as a replacement for Ni in AL 201LN™alloy. It is about half as effective at stabilizing the austenitic phase, so it replaces Ni in about a 2:1 ratio.
- Copper (Cu) is also an austenite stabilizer and may be used to replace Ni. It plays a role in reducing the work hardening rate.
- Nitrogen (N) enhances austenite stability and may be used to replace Ni. N also increases the strength of these alloys.

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Composition Comparison

per ASTM A240

UNS	C (max)	Mn	P (max)	S (max)	Si	Cr	Ni	N	Fe
S20153	0.03	6.4 / 7.5	0.045	0.015	0.75 max	16.0 / 17.5	4.0 / 5.0	0.10 / 0.25	Bal.
S30403	0.030	2.00 max	0.045	0.030	0.75 max	18.0 / 20.0	8.0 / 12.0	0.10 max	Bal.

Pitting and Crevice Corrosion Test Results

		AL 201LN™	Type 304
PRE_N=%Cr + 3.3% Mo + 16% N		18.4	20.4
ASTM G48 A Pitting Test	Weight Loss	0.0228 g/cm^2	0.0280 g/cm^2
	Max. Pit Depth	0.003”	0.003”
ASTM G48 B Crevice Test	Weight Loss	0.0211 g/cm^2	0.0205 g/cm^2

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Mechanical Property Comparison

per ASTM A240

Type	Tensile Strength (ksi, min)	Yield Strength (ksi, min)	Elongation (% in 2", min)	Hardness (RB, max)
AL 201LN	95	45	45	100
Type 304L	70	25	40	92

Typical Values – Cold-Rolled Sheet

Alloy	Tensile Strength (ksi)	Yield Strength (ksi)	Elongation (% in 2")	Hardness (RB)
AL 201LN	111	53	54	93
Type 304L	92	47	58	86

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Weldability

- AL 201LN™ alloy may be welded using the same methods and procedures as are used for T 304L.

- If filler metal is used, standard 308L wire may be used. Many other filler metals may also be used for specific applications, such as those requiring higher strength.

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Weldability

UNS (Type/Grade)	Filler	Alternative Fillers
Lower Strength S20100 (201-1)	308L (S30880)	209 (S20980) 219 (S21980) 2209 (S39209)
Higher Strength S20100 (201-2)	209 (S20980)	219 (S21980) 2209 (S39209) NiCrMo-4 (N10276) NiCrMo-10 (N06022)
S20153 (201LN)	209 (S20980)	219 (S21980) 2209 (S39209) NiCrMo-4 (N10276) NiCrMo-10 (N06022)

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Merits Of AL 201LN - Summary

Performance Characteristic	AL 201LN™	T 304L
Corrosion Resistance		
Crevice Corrosion	Good	Slightly Better
Pitting Resistance	Good	Slightly Better
Reducing Environment	Good	Good
Fabricability	Good	Good
Strength	Better	Good
Weldability	Good	Good

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AL 201LN™ Alloy Applications

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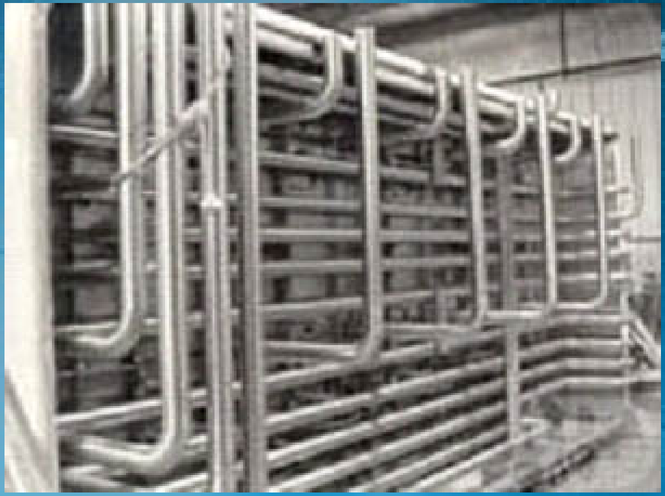
Applications for AL 201LN™ Alloy



Chemical Processing Tanks and Pipes

AL 201LN™ alloy has similar corrosion resistance and higher strength compared to T 304L. This makes it a natural substitute for most tank and pipe applications currently using T304L.

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Applications for AL 201LN™ Alloy

Cryogenic Vessels

AL 201LN™ alloy has excellent toughness at low temperatures, which makes it ideal for use in cryogenic tanks for LNG , liquid oxygen, and other liquefied gases.

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Applications for AL 201LN™ Alloy

Transportation

Railcars built by the Budd Manufacturing Company in 1955 using Type 201 are still in service and still gleaming after 50 years. Today, AL 201LN™ stainless steel is an alloy commonly chosen for railcar construction.

AL 201LN™ alloy has long been used in the frames of truck trailers. The high strength of AL 201LN allows for thinner sections to be used, thereby saving on material costs and improving fuel economy.

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Highlights & Value Proposition

Highlights & Value Proposition

•The cost of nickel has risen to record levels. It is currently trading at over $22.00/lb on the LME in April 2007.

•The price of nickel is expected to remain volatile.

•The surcharge cost component of austenitic grades increases proportionally to their nickel contents.

•AL 201LN™ alloy offers a lower cost (i.e. lower surcharge) and a more stable cost.

•AL 201LN™ alloy is available in the same product forms and finishes as Type 304L.

•AL 201LN™alloy has the same physical appearance as Type 304L.

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Highlights & Value Proposition

- If Type 304L is working satisfactorily in an application, the substitution of AL 201LN™ alloy should be considered.
- The higher strength of AL 201LN™ alloy may permit weight reduction through the use of thinner material.
- AL 201LN™ alloy has API & ASME coverage. Recently, the temperature range for permissible use under ASME Section VIII Divisions 1 & 2 was expanded to -320°F to +800°F and the range for Section XII use was expanded to -320°F to +650°F .
- AL 201LN ™alloy is available in sheet, strip, hot-rolled discrete plate, continuous plate, and cut plate shapes.

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Highlights & Value Proposition

•AL 201LN ™alloy has the same lead-time as T304/L.

•AL 201LN™ stainless steel is not a niche alloy with a few restricted applications.

•Current applications are in building & construction, transportation, household goods, chemical process industry (CPI), LNG, etc.

•Future markets are expected to include structural auto components and increased use in building & construction, especially in Asia.

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February 13, 2007 - ATI Allegheny Ludlum Announces Silicon Electrical Steel Raw Materials Surcharge ..more

January 24, 2007 - Allegheny Technologies Announces Strong Fourth Quarter and Full Year 2006 Results ..more

January 16, 2007 - ATI Allegheny Ludlum Announces Silicon Electrical Steel Raw Materials Surcharge ..more

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201LN™

AL 201LN™ Stainless Steel

An austenitic stainless steel developed by Allegheny Ludlum specifically for sub-zero temperature service as welded tanks and vessels. AL 201LN alloys is also suited for many ambient temperature structural applications, such as railroad freight cars, truck trailers, coal handling and other bulk transportation equipment where there is a need for a good combination of corrosion resistance, strength, toughness and ease of fabrication.

Technical Data Bluesheet

Surcharge

OSHA

Market Applications

Transportation, Cryogenic containment

Lower-Nickel Austenitic Stainless Steels for the Foodservice Industry – reprinted from FCSI's The Consultant magazine New!

Stainless Steel World 2006 Paper: Lean Substitutions Options for 300 Series Alloys and Commercially Pure Titanium. New!

Why Make The Switch To Type 201 Stainless Steel – reprinted from MAFSI's OutFront Magazine

Stainless Steel World Paper: AL 201HP™ (UNS S20100) Alloy: A High-Performance, Lower-Nickel Alternative To 300 Series Alloys

The Case for AL 201LN™ Substitution

The Case for AL 201LN™ vs 9% Ni Carbon Steel

Sheet	Plate	Strip

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Designation: A 666 – 00

Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar[1]

This standard is issued under the fixed designation A 666; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers austenitic stainless steels in the annealed and normally required cold-worked conditions for various structural, architectural, pressure vessel, magnetic, cryogenic, and heat-resisting applications. (This revision of Specification A 666 replaces prior Specifications A 412 and A 177.)

1.2 The application of this specification, or the use of material covered by this specification does not automatically allow usage in pressure vessel applications. Only annealed conditions of grades specifically approved by the ASME code are permitted for pressure vessel use.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 240/A 240M Specification for Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

A 480/A 480M Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip[2]

A 484/A 484M Specification for General Requirements for Stainless and Heat-Resisting Steel Bars, Billets, and Forgings[2]

3. Material Test Report and Certification

3.1 In addition to the requirements of Specification A 480/A 480M, the cold-worked condition (annealed, ¼H, ½H, and so forth) shall be noted.

4. Chemical Composition

4.1 The steel shall conform to the requirements as to chemical composition specified in Table 1, and shall conform to applicable requirements specified in the current edition of Specification A 480/A 480M.

5. Mechanical Properties

5.1 The material shall conform to the mechanical properties specified in Table 2 and Table 3, or Table 2 and Table 4.

6. General Requirements

6.1 The following requirements for orders for material furnished under this specification shall conform to the applicable requirements of the current edition of Specification A 480/A 480M or A484/A 484M:

6.1.1 Definitions,
6.1.2 General requirements for delivery,
6.1.3 Ordering information,
6.1.4 Process,
6.1.5 Special tests,
6.1.6 Heat treatment,
6.1.7 Dimensions and permissible variations,
6.1.8 Workmanship, finish and appearance,
6.1.9 Number of tests/test methods,
6.1.10 Specimen preparation,
6.1.11 Retreatment,
6.1.12 Inspection,
6.1.13 Rejection and rehearing,
6.1.14 Material test report,
6.1.15 Certification, and
6.1.16 Packaging, marking, and loading.

7. Sampling

7.1 Tension and bend-test specimens of sheet, strip, and plate products shall be selected from finished material and shall be selected in the transverse direction, except in the case of strip under 9 in. (229 mm) in width, in which case tension test specimens shall be selected in the longitudinal direction.

7.2 Flat bar tension and bend-test specimens shall be selected from the finished material and shall be in the longitudinal direction.

7.3 Corrosion samples, if required, shall be taken from material after final annealing and descaling and prior to cold working.

8. Number of Tests

8.1 For cold-worked product produced in coil form, one

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.17 on Flat Stainless Steel Products.

Current edition approved March 10, 2000. Published May 2000. Originally published as A 666 – 72. Last previous edition A 666 – 99.

[2] *Annual Book of ASTM Standards*, Vol 01.03.

tension test shall be made from each end of each coil. One bend test shall be made from one end of each coil.

8.2 For cold-worked flat bar and plate products, two tension test and one bend test shall be made on each size of flat bar and each thickness of plate from each heat in a lot annealed in a single charge or under the same conditions in a continuous furnace.

8.3 Annealed material produced to Table 2 requirements shall be tested in accordance with Specification A 480/A 480M.

9. Test Methods

9.1 *Tension Test*:

9.1.1 The yield strength shall be determined by the offset method as described in Test Methods and Definitions A 370. An alternative method of determining field strength may be used based on the following total extension under load:

Yield Strength, min. psi	Total Extension under Load in 2 in. Gage Length, incl.
45 000	0.0071
75 000	0.0098
110 000	0.0125
135 000	0.0144
140 000	0.0148

9.1.2 The requirement of this specification for yield strength will be considered as having been fulfilled if the extension under load for the specified yield strength does not exceed the specified values. The values obtained in this manner should not, however, be taken as the actual yield strength for 0.2 %. In case of dispute, the offset method of determining yield strength shall be used.

9.2 *Bend Test*:

9.2.1 Bend-test specimens shall withstand cold bending without cracking when subjected to either the free-bend method or the controlled-bend (V-block) method at the condition specified by Table 3 or Table 4, respectively. Specimens shall be bent around a diameter equal to the product of the bend factor times the specified thickness of the test specimen. The choice of test method for materials in conditions other than annealed shall be at the option of the seller.

9.2.2 Free-bend test specimens shall be bent cold, either by pressure or by blows. However, in the case of dispute, tests shall be made by pressure.

9.2.3 Controlled-bend (V-block) test specimens shall be bent cold by means of V-blocks or a mating punch and die having an included angle of 45° and with proper curvature of surface at the bend areas to impart the desired shape and diameter of bend to the specimen.

TABLE 1 Chemical Composition Requirements[A]

Type	UNS Designation	Composition, %[B]							
		Carbon	Manganese	Phosphorus	Sulfur	Silicon	Chromium	Nickel	Other Elements
201	S20100	0.15	5.5–7.5	0.060	0.030	0.75	16.0–18.0	3.5–5.5	N 0.25
201L	S20103	0.03	5.5–7.5	0.045	0.030	0.75	16.0–18.0	3.5–5.5	N 0.25
201LN	S20153	0.03	6.4–7.5	0.045	0.015	0.75	16.0–17.5	4.0–5.0	N 0.10–0.25 Cu 1.00
202	S20200	0.15	7.5–10.0	0.060	0.030	0.75	17.0–19.0	4.0–6.0	N 0.25
. . .	S20400	0.030	7.0–9.0	0.040	0.030	1.00	15.0–17.0	1.50–3.00	N 0.15–0.30
205	S20500	0.12–0.25	14.0–15.0	0.060	0.030	0.75	16.5–18.0	1.00–1.75	N 0.32–0.40
301	S30100	0.15	2.00	0.045	0.030	1.00	16.0–18.0	6.0–8.0	N 0.10
301L	S30103	0.03	2.00	0.045	0.030	1.00	16.0–18.0	6.0–8.0	N 0.20
301LN	S30153	0.03	2.00	0.045	0.030	1.00	16.0–18.0	6.0–8.0	N 0.07–0.20
302	S30200	0.15	2.00	0.045	0.030	0.75	17.0–19.0	8.0–10.0	
304	S30400	0.08	2.00	0.045	0.030	0.75	18.0–20.0	8.0–10.5	N 0.10
304L	S30403	0.030	2.00	0.045	0.030	0.75	18.0–20.0	8.0–12.0	N 0.10
304N	S30451	0.08	2.00	0.045	0.030	0.75	18.0–20.0	8.0–10.5	N 0.10–0.16
304LN	S30453	0.030	2.00	0.045	0.030	0.75	18.0–20.0	8.0–12.0	N 0.10–0.16
316	S31600	0.08	2.00	0.045	0.030	0.75	16.0–18.0	10.0–14.0	Mo 2.00–3.00
316L	S31603	0.030	2.00	0.045	0.030	0.75	16.0–18.0	10.0–14.0	Mo 2.00–3.00
316N	S31651	0.08	2.00	0.045	0.030	0.75	16.0–18.0	10.0–14.0	Mo 2.00–3.00 N 0.10–0.16
XM–11	S21904	0.04	8.0–10.0	0.060	0.030	0.75	19.0–21.5	5.5–7.5	N 0.15–0.40
XM–14	S21460	0.12	14.0–16.0	0.060	0.030	0.75	17.0–19.0	5.0–6.0	N 0.35–0.50

[A] Types XM–10 and XM–19, which appeared in Specification A 412, do not appear as XM–10 is no longer produced and XM–19 is covered in Specification A 240/A 240M.

[B] Maximum unless otherwise indicated.

TABLE 2 Tensile Property Requirements[A]

Annealed

Type	UNS Designation	Tensile Strength, min psi	Tensile Strength, min MPa	Yield Strength, min psi	Yield Strength, min MPa	Elongation in 2 in. or 50 mm, min, %	Hardness, max Brinell	Hardness, max Rockwell B
201–1[B]	S20100 Class 1	95 000	655	38 000	260	40	217	95
201–2	S20100 Class 2	95 000	655	45 000	310	40	241	100
201L	S20103	95 000	655	38 000	260	40	217	95
201LN	S20153	95 000	655	45 000	310	45	241	100
202	S20200	90 000	620	38 000	260	40	241	. . .
. . .	S20400	95 000	655	48 000	330	35	241	100
205	S20500	115 000	790	65 000	450	40	255	100
301	S30100	75 000	515	30 000	205	40	217	95
301L	S30103	80 000	550	32 000	220	45	241	100
301LN	S30153	80 000	550	35 000	240	45	241	100
302	S30200	75 000	515	30 000	205	40	201	92
304	S30400	75 000	515	30 000	205	40	201	92
304L	S30403	70 000	485	25 000	170	40	201	92
304N	S30451	80 000	550	35 000	240	30	217	95
304LN	S30453	75 000	515	30 000	205	40	217	95
316	S31600	75 000	515	30 000	205	40	217	95
316L	S31603	70 000	485	25 000	170	40	217	95
316N	S31651	80 000	550	35 000	240	35	217	95
XM–11	S21904							
	Sheet, Strip	100 000	690	60 000	415	40	. . .	. . .
	Plate	90 000	620	50 000	345	45	. . .	. . .
XM–14	S21460	105 000	725	55 000	380	40	. . .	. . .

1⁄16 Hard[C]

Type	UNS Designation	Tensile Strength, min psi	Tensile Strength, min MPa	Yield Strength, min psi	Yield Strength, min MPa	Elongation in 2 in. or 50 mm, min, % <0.015 in.	≥0.015 to ≤0.030 in.	>0.030 in.
201	S20100 PSS[D]	95 000	655	45 000	310	40	40	40
	FB[E]	75 000	515	40 000	275	. . .	. . .	40
201L	S20103	100 000	690	50 000	345	40	40	40
201LN	S20153	100 000	690	50 000	345	40	40	40
205	S20500	115 000	790	65 000	450	40	40	40
301	S30100	90 000	620	45 000	310	40	40	40
301L	S30103	100 000	690	50 000	345	40	40	40
301LN	S30153	100 000	690	50 000	345	40	40	40
302	S30200 PSS	85 000	585	45 000	310	40	40	40
	FB	90 000	620	45 000	310	. . .	. . .	40
304	S30400 PSS	80 000	550	45 000	310	35	35	35
	FB	90 000	620	45 000	310	. . .	. . .	40
304L	S30403	80 000	550	45 000	310	40	40	40
304N	S30451	90 000	620	45 000	310	40	40	40
304LN	S30453	90 000	620	45 000	310	40	40	40
316	S31600 PSS	85 000	585	45 000	310	35	35	35
	FB	90 000	620	45 000	310	. . .	. . .	40
316L	S31603	85 000	585	45 000	310	35	35	35
316N	S31651	90 000	620	45 000	310	35	35	35

1⁄8 Hard[C]

Type	UNS Designation	Tensile Strength, min psi	Tensile Strength, min MPa	Yield Strength, min psi	Yield Strength, min MPa	Elongation in 2 in. or 50 mm, min, % <0.015 in.	≥0.015 to ≤0.030 in.	>0.030 in.
201	S20100	100 000	690	55 000	380	45	45	45
201L	S20103	105 000	725	55 000	380	35	35	35
201LN	S20153	110 000	760	60 000	415	35	35	35
205	S20500	115 000	790	65 000	450	40	40	40
301	S30100	100 000	690	55 000	380	40	40	40
301L	S30103	110 000	760	60 000	415	35	35	35
301LN	S30153	110 000	760	60 000	415	35	35	35
302	S30200	100 000	690	55 000	380	35	35	35
304	S30400	100 000	690	55 000	380	35	35	35
304L	S30403	100 000	690	55 000	380	30	30	30
304N	S30451	100 000	690	55 000	380	37	37	37

TABLE 2 *Continued*

304LN	S30453	100 000	690	55 000	380	33	33	33
316	S31600	100 000	690	55 000	380	30	30	30
316L	S31603	100 000	690	55 000	380	25	25	25
316N	S31651	100 000	690	55 000	380	32	32	32

¼ Hard

Type	UNS Designation	Tensile Strength, min		Yield Strength, min		Elongation in 2 in. or 50 mm, min, %		
		psi	MPa	psi	MPa	<0.015 in.	≥0.015 to ≤0.030 in.	>0.030 in.
201	S20100	125 000	860	75 000	515	25	25	25
201L	S20103	120 000	825	75 000	515	25	25	25
201LN	S20153	120 000	825	75 000	515	25	25	25
202	S20200	125 000	860	75 000	515	12	12	. . .
. . .	S20400	140 000	965	100 000	960	20	20	20
205	S20500	125 000	860	75 000	515	45	45	45
301	S30100	125 000	860	75 000	515	25	25	25
301L	S30103	120 000	825	75 000	515	25	25	25
301LN	S30153	120 000	825	75 000	515	25	25	25
302	S30200	125 000	860	75 000	515	10	10	12
304	S30400	125 000	860	75 000	515	10	10	12
304L	S30403	125 000	860	75 000	515	8	8	10
304N	S30451	125 000	860	75 000	515	12	12	12
304LN	S30453	125 000	860	75 000	515	10	10	12
316	S31600	125 000	860	75 000	515	10	10	10
316L	S31603	125 000	860	75 000	515	8	8	8
316N	S31651	125 000	860	75 000	515	12	12	12
XM-11	S21904	130 000	895	115 000	795	15	15	. . .

½ Hard

Type	UNS Designation	Tensile Strength, min		Yield Strength, min		Elongation in 2 in. or 50 mm, min, %		
		psi	MPa	psi	Mpa	<0.015 in.	≥0.015 to ≤0.030 in.	>0.030 in.
201	S20100	150 000	1035	110 000	760	15	18	18
201L	S20103	135 000	930	100 000	690	22	22	20
201LN	S20153	135 000	930	100 000	690	22	22	20
205	S20500	150 000	1035	110 000	760	15	18	18
301	S30100	150 000	1035	110 000	760	15	18	18
301L	S30103	135 000	930	100 000	690	20	20	20
301LN	S30153	135 000	930	100 000	690	20	20	20
302	S30200	150 000	1035	110 000	760	9	10	10
304	S30400	150 000	1035	110 000	760	6	7	7
304L	S30403	150 000	1035	110 000	760	5	6	6
304N	S30451	150 000	1035	110 000	760	6	8	8
304LN	S30453	150 000	1035	110 000	760	6	7	7
316	S31600	150 000	1035	110 000	760	6	7	7
316L	S31603	150 000	1035	110 000	760	5	6	6
316N	S31651	150 000	1035	110 000	760	6	8	8

¾ Hard

Type	UNS Designation	Tensile Strength, min		Yield Strength, min		Elongation in 2 in. or 50 mm, min, %		
		psi	MPa	psi	MPa	<0.015 in.	≥0.015 to ≤0.030 in.	>0.030 in.
201	S20100	175 000	1205	135 000	930	10	12	12
205	S20500	175 000	1205	135 000	930	15	15	15
301	S30100	175 000	1205	135 000	930	10	12	12
302	S30200	175 000	1205	135 000	930	5	6	6

Full Hard

Type	UNS Designation	Tensile Strength, min		Yield Strength, min		Elongation in 2 in. or 50 mm, min, %		
		psi	MPa	psi	MPa	<0.015 in.	≥0.015 to ≤0.030 in.	>0.030 in.
201	S20100	185 000	1275	140 000	965	8	9	9
205	S20500	185 000	1275	140 000	965	10	10	10
301	S30100	185 000	1275	140 000	965	8	9	9
302	S30200	185 000	1275	140 000	965	3	4	4

[A] This specification defines minimum properties only and does not imply a range. Depending on the work hardening characteristics of the particular grade, either the yield or the tensile strength can be the controlling factor in meeting the properties. The noncontrolling factor normally will exceed considerably the specified minimum.

[B] Type 201 is generally produced with a chemical composition balanced for rich side (Type 201-1) or lean side (Type 201-2) austenite stability depending on the properties required for specific applications.

[C] Annealed material that naturally meets mechanical properties may be applied.

[D] PSS means plate, strip, sheet.

[E] FB means flat bar.

TABLE 3 Free Bend Requirements

Type	UNS Designation	Thickness ≤0.050 in.		Thickness >0.050 to ≤0.1874 in.	
		Included Bend Angle,°	Bend Factor	Included Bend Angle,°	Bend Factor
Annealed and 1⁄16 and 1⁄8 Hard					
201	S20100	180	1	180	1
201L	S20103	180	1	180	1
201LN	S20153	180	1	180	1
202	S20200	180	1	180	1
. . .	S20400	180	1	180	1
205	S20500	180	1	180	1
301	S30100	180	1	180	1
301L	S30103	180	1	180	1
301LN	S30133	180	1	180	1
302	S30200	180	1	180	1
304	S30400	180	1	180	1
304L	S30403	180	1	180	2
304N	S30451	180	1	180	1
304LN	S30453	180	1	180	2
316	S31600	180	1	180	2
316L	S31603	180	1	180	2
316N	S31651	180	1	180	1
XM-11	S21904	180	1	180	1
XM-14	S21460	180	1	180	2
1⁄4 Hard					
Type	UNS Designation	Thickness ≤0.050 in.		Thickness >0.050 to ≤0.1874 in.	
		Included Bend Angle,°	Bend Factor	Included Bend Angle,°	Bend Factor
201	S20100	180	1	90	2
201L	S20103	180	1.5	135	1.5
201LN	S20153	180	1.5	135	1.5
202	S20200	180	2	90	2
. . .	S20400	180	1	90	2
205	S20500	180	1	90	2
301	S30100	180	1	90	2
301L	S30103	180	1.5	90	1.5
301LN	S30153	180	1.5	90	1.5
302	S30200	180	1	90	2
304	S30400	180	1	90	2
304L	S30403	180	2	90	3
304N	S30451	180	1	90	2
304LN	S30453	180	2	90	3
316	S31600	180	2	90	2
316L	S31603	180	2	90	3
316N	S31651	180	1	90	2
XM-11	S21904	90	2	90	2
1⁄2 Hard					
Type	UNS Designation	Thickness ≤0.050 in.		Thickness >0.050 to ≤0.1874 in.	
		Included Bend Angle,°	Bend Factor	Included Bend Angle,°	Bend Factor
201	S20100	180	2	90	2
201L	S20103	180	2	135	2
201LN	S20153	180	2	135	2
205	S20500	180	2	90	2
301	S30100	180	2	90	2
301L	S30103	180	2	90	2
301LN	S30153	180	2	90	2
302	S30200	180	2	90	2
304	S30400	180	2	90	2
304L	S30403	180	3	90	3
304N	S30451	180	2	90	2
304LN	S30453	180	3	90	3
316	S31600	180	3	90	3
316L	S31603	180	3	90	3
316N	S31651	180	2	90	2

TABLE 3 *Continued*

Type	UNS Designation	Thickness ≤0.050 in.		Thickness >0.050 to ≤0.1874 in.	
		Included Bend Angle,°	Bend Factor	Included Bend Angle,°	Bend Factor
¾ Hard					
201	S20100	180	3	90	3
205	S20500	180	3	90	3
301	S30100	180	3	90	3
302	S30200	180	4	90	5
Full Hard					
201	S20100	180	4	90	5
205	S20500	180	4	90	5
301	S30100	180	4	90	5
302	S30200	180	6	90	8

TABLE 4 V-Block Bend Requirements

Type	UNS Designation	Thickness ≤0.050 in.		Thickness >0.050 to ≤0.1874 in.	
		Included Bend Angle,°	Bend Factor	Included Bend Angle,°	Bend Factor
Annealed and ⅛ Hard					
201	S20100	135	2	135	3
201L	S20103	135	2	135	3
201LN	S20153	135	2	135	3
202	S20200	135	4	135	4
205	S20500	135	2	135	3
301	S30100	135	2	135	3
301L	S30103	135	2	135	3
301LN	S30153	135	2	135	3
302	S30200	135	2	135	3
304	S30400	135	2	135	3
304L	S30403	135	5	135	6
304N	S30451	135	3	135	4
304LN	S30453	135	4	135	5
316	S31600	135	5	135	6
316L	S31603	135	6	135	7
316N	S31651	135	5	135	6
¼ Hard					
201	S20100	135	2	135	3
201L	S20103	135	2	135	3
201LN	S20153	135	2	135	3
205	S20500	135	2	135	3
301	S30100	135	2	135	3
301L	S30103	135	2	135	3
301LN	S30153	135	2	135	3
302	S30200	135	2	135	3
304	S30400	135	2	135	3
304L	S30403	135	5	135	6
304N	S30451	135	3	135	4
304LN	S30453	135	4	135	5
316	S31600	135	5	135	6
316L	S31603	135	6	135	7
316N	S31651	135	5	135	6

TABLE 4 *Continued*

½ Hard					
Type	UNS Designation	Thickness ≤0.050 in.		Thickness >0.050 to ≤0.1874 in.	
		Included Bend Angle,°	Bend Factor	Included Bend Angle,°	Bend Factor
201	S20100	135	4	135	4
201L	S20103	135	4	135	4
201LN	S20153	135	4	135	4
205	S20500	135	4	135	4
301	S30100	135	4	135	4
301L	S30103	135	4	135	4
301LN	S30153	135	4	135	4
302	S30200	135	4	135	4
304	S30400	135	4	135	4
304L	S30403	135	7	135	8
304N	S30451	135	5	135	6
304LN	S30453	135	6	135	7
316	S31600	135	7	135	8
316L	S31603	135	8	135	9
316N	S31651	135	7	135	8
¾ Hard					
Type	UNS Designation	Thickness ≤0.050 in.		Thickness >0.050 to ≤0.1874 in.	
		Included Bend Angle,°	Bend Factor	Included Bend Angle,°	Bend Factor
201	S20100	135	6	135	7
205	S20500	135	6	135	7
301	S30100	135	6	135	7
302	S30200	135	8	135	9
Full Hard					
Type	UNS Designation	Thickness ≤0.050 in.		Thickness >0.050 to ≤0.1874 in.	
		Included Bend Angle,°	Bend Factor	Included Bend Angle,°	Bend Factor
201	S20100	135	6	135	8
205	S20500	135	6	135	8
301	S30100	135	6	135	8
302	S30200	135	8	135	10

A DESIGNERS' HANDBOOK SERIES

N^{O} 9 002

WELDING OF STAINLESS STEELS AND OTHER JOINING METHODS

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Produced by
AMERICAN
IRON AND STEEL
INSTITUTE

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The information presented in this section was originally produced by the Committee of Stainless Steel Producers, American Iron and Steel Institute. The original Handbook also contained data from ASM International publication *Joining of Stainless Steels*. The Committee of Stainless Steel Producers no longer exists. The Nickel Development Institute (www.nidi.org) has reprints of this handbook titled "Welding of Stainless Steels and Other Joining Methods" (A designer handbooks series No. 9 002).

It should be noted that the data are typical or average values. Materials specifically suggested for applications described herein are made solely for the purpose of illustration to enable the reader to make his own evaluation.

The Nickel Development Institute reprinted it for distribution in August 1988.

Material presented in the hand-book has been prepared for the general information of the reader and should not be used or relied on for specific applications without first securing competent advice.

Introduction

Stainless steels are iron-base alloys containing 10.5% or more chromium. They have been used for many industrial, architectural, chemical, and consumer applications for over a half century.

Reference is often made to stainless steel in the singular sense as if it were one material. Actually there are well over 100 stainless steel alloys. Three general classifications are used to identify stainless steels. They are: 1. Metallurgical Structure; 2. The AISI numbering system: namely 200, 300, and 400 Series numbers; 3. The Unified Numbering System, which was developed by American Society for Testing Materials (ASTM) and Society of Automotive Engineers (SAE) to apply to all commercial metals and alloys.

Stainless steels are engineering materials capable of meeting a broad range of design criteria. They exhibit excellent corrosion resistance, strength at elevated temperature, toughness at cryogenic temperature, and fabrication characteristics and they are selected for a broad range of consumer, commercial, and industrial applications. They are used for the demanding requirements of chemical processing to the delicate handling of food and pharmaceuticals. They are preferred over many other materials because of their performance in even the most aggressive environments, and they are fabricated by methods common to most manufacturers.

In the fabrication of stainless steel products, components, or equipment, manufacturers employ welding as the principal joining method. Stainless steels are welded materials, and a welded joint can provide optimum corrosion resistance, strength, and fabrication economy. However, designers should recognize that any metal, including stainless steels, may undergo certain changes during welding. It is necessary, therefore, to exercise a reasonable degree of care during welding to minimize or prevent any deleterious effects that may occur, and to preserve the same degree of corrosion resistance and strength in the weld zone that is an inherent part of the base metal.

The purpose of this booklet is to help designers and manufacturing engineers achieve a better understanding of the welding characteristics of stainless steels, so they may exercise better control over the finished products with respect to welding. In addition to welding, other ancillary joining methods are discussed, including soldering and brazing.

Stainless Steel Welding Characteristics

During the welding of stainless steels, the temperatures of the base metal adjacent to the weld reach levels at which microstructural transformations occur. The degree to which these changes occur, and their effect on the finished weldment — in terms of resistance to corrosion and mechanical properties — depends upon alloy content, thickness, filler metal, joint design, weld method, and welder skill. Regardless of the changes that take place, the principal objective in welding stainless steels is to provide a sound joint with qualities equal to or better than those of the base metal, allowing for any metallurgical changes that take place in the base metal adjacent to the weld and any differences in the weld filler metal.

For purposes of discussion, in welding there are three zones of principal concern: 1) The solidified weld metal, composed of either base metal or base metal and filler metal; 2) the heat-affected zone (HAZ) in which the base metal is heated to high temperatures but less than the melting temperature; and 3) the base metal which is only moderately warmed or not warmed at all. The three zones are illustrated by the drawing in Figure 1.

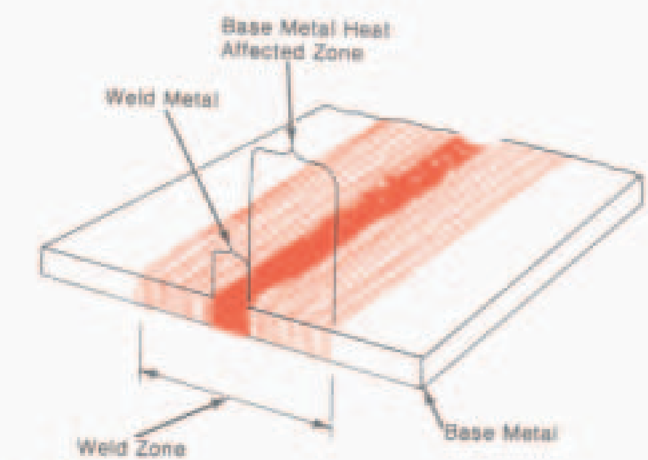


Figure 1
Thermal Affected Area of Metal Due to Welding

Although risking over-simplification, the following discussion will be helpful in understanding the metallurgical characteristics of stainless steels and how their microstructures can change during welding.

AUSTENITIC STAINLESS STEELS

Austenitic stainless steels (Table 1) containing chromium and nickel as the principal alloying elements (in addition to iron) are identified as 300 Series (UNS designated S3xxxx). Those containing chromium, nickel, and manganese (in addition to iron) are identified as 200 Series (UNS designated S2xxxx).

The stainless steels in the austenitic group have different compositions and properties but many common characteristics. They can be hardened by cold working, but not by heat treatment. In the annealed condition, all are nonmagnetic, although some may become slightly magnetic by cold working. At room temperature the 300 and 200 Series stainless steels retain an austenitic microstructure.

While resistance to corrosion is their principal attribute, they are also selected for their excellent strength properties at high or extremely low temperatures. They are considered to be the most weldable of the high-alloy steels and can be welded by all fusion and resistance welding processes. Comparatively little trouble is experienced in making satisfactory welded joints if their inherent physical characteristics and mechanical properties are given proper consideration.

In comparison with mild steel, for example, the austenitic stainless steels have several characteristics that require some revision of welding procedures that are considered standard for mild steel. As illustrated in Table 2, the melting point of the austenitic grades is lower, so less heat is required to produce fusion. Their electrical resistance is higher than that of mild steel so less electrical current (lower heat settings) is required for welding. These stainless steels also have a lower coefficient of thermal conductivity, which causes a tendency for heat to concentrate in a small zone adjacent to the weld. The austenitic stainless steels also have coefficients of thermal expansion approximately 50% greater than mild steel, which calls for more attention to the control of warpage and distortion.

Table 2
Comparison of Welding Characteristics of 304 Stainless Steel with Carbon Steel

	Carbon Steel	304	Remarks
Melting Point °F Approx.	2800	2550-2650	304 requires less heat to produce fusion, which means faster welding for the same heat or less heat input for the same speed.
Electrical Resistance (Annealed) (Michrohm-cm, approx.) At 68 F At 1625 F	12.5 125	72.0 126	This is of importance in electric fusion methods. The higher electrical resistance of 304 results in the generation of more heat for the same current or the same heat with lower current, as compared with carbon steel. This, together with its low rate of heat conductivity, accounts for the effectiveness of resistance welding methods on 304.
Rate of Heat Conductivity (Compared in Percent) At 212 F Over 1200 F	100% 100% Note: 304 at 212 F has a rate of 9.4 and at 932 F a rate of 12.4 Btu/ft²/hr/F/ft.	28% 66%	304 conducts heat much more slowly than carbon steel thus promoting sharper heat gradients. This accelerates warping, especially in combination with higher expansion rates. Slower diffusion of heat through the base metal means that weld zones remain hot longer, one result of which may be longer dwell in the carbide precipitation range unless excess heat is artificially removed by chill bars, etc.
Coefficient of expansion per °F Over range indicated	.0000065 (68-1162 F)	.0000098 (68-932 F)	304 expands and contracts at a faster rate than carbon steel, which means that increased expansion and contraction must be allowed for in order to control warping and the development of thermal stresses upon cooling.

An important part of successful welding of the austenitic grades, therefore, requires proper selection of alloy (for both the base metal and filler rod), and correct welding procedures. For the stainless steels more complex in composition, heavier in sections or the end-use conditions more demanding (which narrows the choice of a base metal), a greater knowledge of stainless steel metallurgy is desirable.

Two important objectives in making weld joints in austenitic stainless steels are: (1) preservation of corrosion resistance, and (2) prevention or cracking.

Table 1 Austenitic Stainless Steels

	Chemical Analysis % (Max. unless noted otherwise)									Nominal Mechanical Properties (Annealed sheet unless noted otherwise)						
										Tensile Strength		Yield Strength (0.2% offset)		Elongation in 2" (50.80 mm)	Hardness (Rockwell)	Product Form
(UNS)	C	Mn	P	S	Si	Cr	Ni	Mo	Other	ksi	MPa	ksi	MPa	%		
201 (S20100)	0.15	5.50/7.50	0.060	0.030	1.00	16.00/18.00	3.50/5.50		0.25N	95	655	45	310	40	B90	
202 (S20200)	0.15	7.50/10.00	0.060	0.030	1.00	17.00/19.00	4.00/6.00		0.25N	90	612	45	310	40	B90	
205 (S20500)	0.12/0.25	14.00/15.50	0.030	0.030	0.50	16.50/18.00	1.00/1.75		0.32/0.40N	120.5	831	69	476	58	B98	(Plate)
301 (S30100)	0.15	2.00	0.045	0.030	1.00	16.00/18.00	6.00/8.00			110	758	40	276	60	B85	
302 (S30200)	0.15	2.00	0.045	0.030	1.00	17.00/19.00	8.00/10.00			90	612	40	276	50	B85	
302B (S30215)	0.15	2.00	0.045	0.030	2.00/3.00	17.00/19.00	8.00/10.00			95	655	40	276	55	B85	
303 (S30300)	0.15	2.00	0.20	0.15 (min)	1.00	17.00/19.00	8.00/10.00	0.60*		90	621	35	241	50		(Bar)
303Se (S30323)	0.15	2.00	0.20	0.060	1.00	17.00/19.00	8.00/10.00		0.15Se (min)	90	621	35	241	50		(Bar)
304 (S30400)	0.08	2.00	0.045	0.030	1.00	18.00/20.00	8.00/10.50			84	579	42	290	55	B80	
304L (S30403)	0.030	2.00	0.045	0.030	1.00	18.00/20.00	8.00/12.00			81	558	39	269	55	B79	
S30430	0.08	2.00	0.045	0.030	1.00	17.00/19.00	8.00/10.00		3.00/4.00Cu	73	503	31	214	70	B70	(Wire)
304N (S30451)	0.08	2.00	0.045	0.030	1.00	18.00/20.00	8.00/10.50		0.10/0.16N	90	621	48	331	50	B85	
305 (S30500)	0.12	2.00	0.045	0.030	1.00	17.00/19.00	10.50/13.00			85	586	38	262	50	B80	
308 (S30800)	0.08	2.00	0.045	0.030	1.00	19.00/21.00	10.00/12.00			115	793	80	552	40		(Wire)
309 (S30900)	0.20	2.00	0.045	0.030	1.00	22.00/24.00	12.00/15.00			90	621	45	310	45	B85	
309S (S30908)	0.08	2.00	0.045	0.030	1.00	22.00/24.00	12.00/15.00			90	621	45	310	45	B85	
310 (S31000)	0.25	2.00	0.045	0.030	1.50	24.00/26.00	19.00/22.00			95	655	45	310	45	B85	
310S (S31008)	0.08	2.00	0.045	0.030	1.50	24.00/26.00	19.00/22.00			95	655	45	310	45	B85	
314 (S31400)	0.25	2.00	0.045	0.030	1.50/3.00	23.00/26.00	19.00/22.00			100	689	50	345	40	B85	
316 (S31600)	0.08	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00		84	579	42	290	50	B79	
316F (S31620)	0.08	2.00	0.20	0.10 (min)	1.00	16.00/18.00	10.00/14.00	1.75/2.50		85	586	38	262	60	B85	
316L (S31603)	0.030	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00		81	558	42	290	50	B79	
316N (S31651)	0.08	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00	0.10/0.16N	90	621	48	331	48	B85	
317 (S31700)	0.08	2.00	0.045	0.030	1.00	18.00/20.00	11.00/15.00	3.00/4.00		90	621	40	276	45	B85	
317L (S31703)	0.030	2.00	0.045	0.030	1.00	18.00/20.00	11.00/15.00	3.00/4.00		86	593	38	262	55	B85	
321 (S32100)	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/12.00		5xC Ti (min)	90	621	35	241	45	B80	
329** (S32900)	0.10	2.00	0.040	0.030	1.00	25.00/30.00	3.00/6.00	1.00/2.00		105	724	80	552	25	230 (Brinell)	(Strip)
330 (N08330)	0.08	2.00	0.040	0.030	0.75/1.50	17.00/20.00	34.00/37.00		0.10Ta 0.20Cb	80	552	38	262	40	B80	
347 (S34700)	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/13.00		10xC Cb+Ta (min)	95	655	40	276	45	B85	
348 (S34800)	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/13.00		10xC Cb+Ta (min) (Ta 0.10 - 0.20 Co max)	95	655	40	276	45	B85	
384 (S38400)	0.08	2.00	0.045	0.030	1.00	15.00/17.00	17.00/19.00			75	517	35	241	55	B70	(Wire)

*May be added at manufacturer's option.
**Duplex alloy–austenite + ferrite.

PRESERVATION OF CORROSION RESISTANCE

The principal criteria for selecting a stainless steel usually is resistance to corrosion, and while most consideration is given to the corrosion resistance of the base metal, additional consideration should be given to the weld metal and to the base metal immediately adjacent to the weld zone. Welding naturally produces a temperature gradient in the metal being welded, ranging from the melting temperature of the fused weld metal to ambient temperature at some distance from the weld. The following discussion will be devoted to preserving corrosion resistance in the base metal heat affected zone.

Carbide Precipitation — A characteristic of an annealed austenitic stainless steels such as 304, is its susceptibility to an important microstructural change if it is exposed to temperatures within an approximate range of 800-1650F. Within this range, chromium and carbon form chromium carbides, and these precipitate out of the solid solution at the boundaries between the grains. The rapidity of carbide development depends on a number of factors. The actual metal temperature between the range of 800-1650F is one factor. Chromium carbides form most rapidly at about 1200F, and the formation falls off to nil at the upper and lower limits. Another factor is the amount of carbon originally present in the material — the higher the carbon content the more pronounced the action. Time at temperature is a third factor.

The effect of carbide precipitation on corrosion resistance is to reduce the chromium available to provide corrosion resistance. Because low-carbon content reduces the extent to which carbide precipitation occurs, the low-carbon austenitic grades may be preferred for weldments to be used in highly corrosive service. 304 with a maximum carbon content of 0.08% is widely used. Also available are low-carbon 304L, 316L, and 317L with 0.03% carbon.

321 and 347 contain titanium and columbium-tantalum, respectively, alloying elements which have a greater affinity for carbon than does chromium, thus reducing the possibility of chromium carbide precipitation. These stabilized types are intended for long-time service at elevated temperatures in a corrosive environment or when the low-carbon grades are not adequate.

The removal of precipitated carbides from 304 in order to restore maximum corrosion resistance can be accomplished by annealing (at 1800 to 2150F) (above the sensitizing range) followed by rapid cooling. Stress relieving a weldment at 1500-1700F will not restore corrosion resistance, and, in fact, may foster carbide precipitation in stainless steels that do not have a low-carbon content or are not stabilized.

Stress-Corrosion Cracking — The chance of stress-corrosion cracking is another reason for post-weld heat treatment. In the as-welded condition, areas close to the weld contain residual stresses approaching the yield point of the material. It is difficult to predict when an environment will produce stress-corrosion cracking and to decide how much reduction must be made in the magnitude of residual stress to avoid its occurrence. To ensure against this stress-corrosion cracking in welded austenitic stainless steels is to anneal the types which contain regular carbon content, and to stress relieve the stabilized and extra-low-carbon types.

WELDING PREHEATING

The question often arises whether an austenitic stainless steel should be preheated for welding. In general, preheating is not helpful because no structural changes, such as martensite formation, occur in the weld or the heat-affected zones. In some cases, preheating could be harmful in causing increased carbide precipitation, or greater warpage.

MARTENSITIC STAINLESS STEELS

Martensitic stainless steels, which are identified by 400 Series numbers (UNS desiignated S4xxxx) (Table 3), contain chromium as the principal alloying element. In the annealed condition these stainless steels have basically a ferritic microstructure and are magnetic. On heating beyond the critical temperature, the ferrite transforms into austenite. If then rapidly cooled to below the critical temperature, the austenite transforms into martensite. In many respects, the martensitic stainless steels are similar to the quenched and tempered carbon or alloy steels whose mechanical properties can be varied through heat treatment. Whether or not the transformations take place depends upon alloy content, especially the chromium and carbon contents. Other alloying additions may also affect transformation.

Table 3 Martensitic Stainless Steels

	Chemical Analysis % (Max. unless noted otherwise)									Nominal Mechanical Properties (Annealed sheet unless noted otherwise)						
										Tensile Strength		Yield Strength (0.2% offset)		Elongation in 2″ (50.80 mm)	Hardness (Rockwell)	Product Form
(UNS)	C	Mn	P	S	Si	Cr	Ni	Mo	Other	ksi	MPa	ksi	MPa	%		
403 (S40300)	0.15	1.00	0.040	0.030	0.50	11.50/13.00				70	483	45	310	25	B80	
410 (S41000)	0.15	1.00	0.040	0.030	1.00	11.50/13.50				70	483	45	310	25	B80	
414 (S41400)	0.15	1.00	0.040	0.030	1.00	11.50/13.50	1.25/2.50			120	827	105	724	15	B98	
416 (S41600)	0.15	1.25	0.060	0.15 (min)	1.00	12.00/14.00		0.60*		75	517	40	276	30	B82	(Bar)
416 Se (S41623)	0.15	1.25	0.060	0.060	1.00	12.00/14.00			0.15 Se (min)	75	517	40	276	30	B82	(Bar)
420 (S42000)	0.15 (min)	1.00	0.040	0.030	1.00	12.00/14.00				95	655	50	345	25	B92	(Bar)
420 F (S42020)	0.15 (min)	1.25	0.060	0.15 (min)	1.00	12.00/14.00		0.60*		95	655	55	379	22	220 (Brinell)	(Bar)
422** (S42200)	0.20/0.25	1.00	0.025	0.025	0.75	11.00/13.00	0.50/1.00	0.75/1.25	0.15/0.30 V 0.75/1.25 W	145	1000	125	862	18	320 (Brinell)	(Bar)
431 (S43100)	0.20	1.00	0.040	0.030	1.00	15.00/17.00	1.25/2.50			125	862	95	655	20	C24	(Bar)
440 A (S44002)	0.60/0.75	1.00	0.040	0.030	1.00	16.00/18.00		0.75		105	724	60	414	20	B95	(Bar)
440 B (S44003)	0.75/0.95	1.00	0.040	0.030	1.00	16.00/18.00		0.75		107	738	62	427	18	B96	(Bar)
440 C (S44004)	0.95/1.20	1.00	0.040	0.030	1.00	16.00/18.00		0.75		110	758	65	448	14	B97	(Bar)

*May be added at manufacturer's option. **Hardened and Tempered

As a group, the martensitic stainless steels (hardenable by heat treatment) have certain characteristics in common which influence their behavior when subjected to the temperatures encountered in welding. These characteristics are as follows:

1) Their melting points are approximately 2700F, which compares with 2800F for mild steel. This means that they require less heat for their melting or that they melt faster than mild steel for the same rate of heat input.
2) Their coefficients of expansion and contraction are about the same as or slightly less than the corresponding value for carbon steel. This is in contrast to the chromium-nickel grades whose coefficients are about 45-50% higher than that of mild steel.
3) The heat conductivity ratings are less than half that of mild steel depending upon temperature. In this respect, they are similar to the chromium-nickel grades.
4) Their resistance to the flow of electrical current is higher than that of mild steel. For that reason, less amperage is required for their welding.

In the soft annealed condition, a martensitic stainless steel such as 410 (the general-purpose grade) exhibits maximum ductility. On heating to temperatures above about 1500F, the metallurgical structure begins to change to austenite; at approximately 1850F the structure is completely austenititic. Cooling from these temperatures results in the transformation of austenite to martensite, a hard, strong, nonductile structure. Rapid cooling from 1850F results in maximum martensite content. Cooling from temperatures between 1500-1850F results in less martensite. These characteristic reactions to heating and cooling determine the welding behavior of the martensitic stainless steels.

Martensitic stainless steels can be welded in any one of several conditions: annealed, semihardened, hardened, stress relieved, or tempered. Regardless of prior condition, welding will produce a hardened martensitic zone adjacent to the weld (where the temperature reaches 1500-1850F). The hardness of the zone will be dependent primarily upon the carbon content and can be controlled to a degree by the welding procedure. It should be recognized that the sharp temperature gradients, which are accentuated by the low rate of heat conductivity, cause intense stresses to be developed due both to thermal expansion and to volumetric changes caused by the changes in the crystal structure. Their severity may be sufficient to produce fractures.

WELDING PREHEATING

Preheating and interpass temperature control are the best means of avoiding cracking in the welding of martensitic stainless steels. The preheating temperatures employed are usually in the order of 400 to 600F. Carbon content is the most important factor in establishing whether preheating will be necessary.

The following guide can be useful to coordinate welding procedures with carbon content and to accommodate the welding characteristics of the martensitic grades:

Below 0.10%C — Generally no preheating or heat treating after welding required.
0.10 to 0.20%C — Preheat to 500F, weld, and cool slowly.
0.20 to 0.50%C — Preheat to 500F, weld, and heat treat after welding.
Over 0.50%C — Preheat to 500F, weld with high heat input, and heat treat after welding.

Post-heating, which should always be regarded as an integral part of a welding operation on the martensitic types, may be accomplished by either of two methods:

1) Anneal at 1500F or higher followed by controlled cooling to 1100F at a rate of 50 degrees per hour and then air cooling.
2) Heat to 1350-1400F and follow with the same cooling cycle as described in (1).

If hardening and tempering immediately follow welding, the post-anneal may be eliminated. Otherwise, anneal promptly after welding without allowing the part to cool to room temperature.

Where permissible, the use of austenitic stainless steel filler metal will help in preventing brittle welds. A ductile weld bead is deposited, but, of course, the hardening of the metal in the HAZ will not be eliminated.

Table 4 Ferritic Stainless Steels

	Chemical Analysis % (Max. unless noted otherwise)									Nominal Mechanical Properties (Annealed sheet unless noted otherwise)						
										Tensile Strength		Yield Strength (0.2% offset)		Elongation in 2″ (50.80 mm)	Hardness (Rockwell)	Product Form
(UNS)	C	Mn	P	S	Si	Cr	Ni	Mo	Other	ksi	MPa	ksi	MPa	%		
405 (S40500)	0.08	1.00	0.040	0.030	1.00	11.50/14.50			0.10/0.30 Al	65	448	40	276	25	B75	
409 (S40900)	0.08	1.00	0.045	0.045	1.00	10.50/11.75			6xC/0.75 Ti	65	448	35	241	25	B75	
429 (S42900)	0.12	1.00	0.040	0.030	1.00	14.00/16.00				70	483	40	276	30	B80	(Plate)
430 (S43000)	0.12	1.00	0.040	0.030	1.00	16.00/18.00				75	517	50	345	25	B85	
430F (S43020)	0.12	1.25	0.060	0.15 (min)	1.00	16.00/18.00		0.60*		95	655	85	586	10	B92	(Wire)
430F Se (S43023)	0.12	1.25	0.060	0.060	1.00	16.00/18.00			0.15 Se (min)	95	655	85	586	10	B92	(Wire)
434 (S43400)	0.12	1.00	0.040	0.030	1.00	16.00/18.00		0.75/1.25		77	531	53	365	23	B83	
436 (S43600)	0.12	1.00	0.040	0.030	1.00	16.00/18.00		0.75/1.25	5xC/0.70 Cb + Ta	77	531	53	365	23	B83	
442 (S44200)	0.20	1.00	0.040	0.030	1.00	18.00/23.00				80	552	45	310	20	B90	(Bar)
446 (S44600)	0.20	1.50	0.040	0.030	1.00	23.00/27.00			0.25N	80	552	50	345	20	B83	

*May be added at manufacturer's option.

FERRITIC STAINLESS STEELS

Ferritic stainless steels are also straight chromium alloys in the 400 Series with a microstructure, in the annealed condition, consisting of ferrite and carbides (Table 4). They are also magnetic. On heating most ferritic types above a critical temperature, the structure becomes austenitic which on cooling may partially transform into martensite (but not sufficiently to impart high strength). Consequently, ferritic stainless steels are considered not to be hardenable by heat treatment. Also, there will be a tendency for the ferrite grains to increase in size.

These two structural features, (a) martensite formation and (b) grain growth, result in a reduction of ductility and toughness. Also, rapid cooling from temperatures above 700F may cause intergranular precipitation (similar to carbide precipitation in austenitic stainless steels) that results in reduced resistance to corrosion. Consequently, the ferritic stainless steels are not considered attractive from the standpoint of weldability.

In the last few years several new ferritic stainless steels have been introduced. These steels are characterized by levels of carbon and nitrogen substantially below those typically produced in 430. In most cases these steels are stabilized by additions of either titanium or columbium, or the combination of the two. These steels are ferritic at all temperatures below the melting point showing no transformations to austenite or martensite. As is typical of ferritic grades they are susceptible to grain growth, but at the lowered carbon levels the toughness of these grades is significantly higher than the standard grades.

PRESERVATION OF CORROSION RESISTANCE

Although fabricators would much prefer to avoid post-weld heat treatment, this operation may be vital under some circumstances to assure adequate corrosion resistance or mechanical properties. The customary annealing temperature is 1450F. The time at temperature depends upon the mass involved and may vary from only a few minutes for thin-gauge sheet to several hours for heavy plate.

Cooling ferritic stainless steels from the annealing temperature can be done by air or water quenching. Often the parts are allowed to furnace cool to about 1100F, followed by rapid cooling. Slow cooling through a temperature range of 1050F down to 750F should be avoided since it induces room-temperature brittleness. Heavy sections usually require at least a spray quench to bring them through this range of embrittlement.

Also, modifications to the steel in the form of titanium or columbium additions help to reduce the amount of intergranular precipitation.

WELDING PREHEATING

Although little danger exists from excessive hardening in the HAZ during welding of ferritic stainless steels, there is a consideration to use preheating. Heavier sections (about 1/4 inch thick and heavier) are in greater danger of cracking during welding. However, the design of the weldment, the restraint afforded by clamping or jigging, the type of joint, the ambient temperature, the weld process to be used, and sequence of welding may have almost as much influence as the material thickness. In actual practice, a preheat temperature range of 300-450F is used for heavier sections. This point should be explored in the prudent development of any welding procedure.

For the low carbon or stabilized ferritic grades, the use of preheat is usually undesirable for lighter sections, less than 1/4 inch thick.

PRECIPITATION HARDENING STAINLESS STEELS

In general, the precipitation hardening stainless steels (Table 5) can be readily welded and good mechanical properties can be developed in weldments. However, differences in welding properties can be expected. Those grades containing only additions of copper or molybdenum produce a molten pool similar to the austenitic stainless steels, while those grades containing aluminum or unusually high titanium content may appear noticeably different and possibly will require a greater degree of protection from the atmosphere during welding.

Changes in structure can occur in the precipitation hardening grades when they are subjected to the localized heat of welding. It will be important to note the condition of the base metal prior to welding; that is, whether it is annealed, solution treated, or hardened. The heat of welding will invariably produce a solution treated or annealed base metal zone, and the post-weld heat treatments required to harden this zone may involve either single or double treatments.

Because of the many combinations of welding and heat treatment that can be used with the precipitation hardening stainless steels, more-detailed information should be obtained from producers.

WELD ROD SELECTION

Proper weld or filler rod selection is important to achieve a weld metal with the desired corrosion-resistant and strength characteristics. A well designed product, for example, can fail in the weld zone if the weld rod selected results in the weld zone having a lower alloy content than that of the parent metal.

Table 5 Precipitation Hardening Stainless Steels

Chemical Analysis % (Max. unless noted otherwise)										Nominal Mechanical Properties (Solution Treated Bar)						
										Tensile Strength		Yield Strength (0.2% offset)		Elongation in 2″ (50.80 mm)	Hardness (Rockwell)	Product Form
(UNS)	C	Mn	P	S	Si	Cr	Ni	Mo	Other	ksi	MPa	ksi	MPa	%		
S13800	0.05	0.10	0.010	0.008	0.10	12.25/13.25	7.50/8.50	2.00/2.50	0.90/1.35 Al 0.010 N	160	1103	120	827	17	C33	
S15500	0.07	1.00	0.04	0.03	1.00	14.00/15.50	3.50/5.50		2.50/4.50 Cu 0.15/0.45 Cb+Ta	160	1103	145	1000	15	C35	
S17400	0.07	1.00	0.040	0.030	1.00	15.50/17.50	3.00/5.00		3.00/5.00 Cu 0.15/0.45 Cb+Ta	160	1103	145	1000	15	C35	
S17700	0.09	1.00	0.040	0.040	0.040	16.00/18.00	6.50/7.75		0.75/1.50 Al	130	896	40	276	10	B90	

The characteristics of the weld metal are primarily dependent on the alloy content of the filler rod and to a lesser extent on the degree to which the molten weld metal is protected from the environment. This protection is provided by the shielding gases used in certain welding processes or by the action of chemical fluxes applied to welding rods.

The first criteria for weld rod selection is alloy content, and Table 6 lists the filler metals suggested for stainless steels. The following discussion will further help in the understanding of what filler material to use.

AUSTENITIC STAINLESS STEELS

The long list of stainless steel filler metals frequently causes concern as to how to select the filler metal appropriate for a given application. The general rule most often followed is to use the alloy most similar to the base metal being welded. The greater amount of chromium and nickel in certain alloys, 308 for example, is useful for welding 302 and 304 base metals and hence is standard for all the lower chromium-nickel base metals. While the same principle applies to 316, in that the minimum chromium is higher in the weld metal than the base metal, the designation of the filler metal is the same.

Certain standards of weld metal invariably have a fully austenitic structure, for example, 310, 310Cb, 310Mo, and 330. In these, the ratio of ferrite-formers to austenite-formers cannot be raised high enough within permissible limits to produce any free ferrite in the austenite. Consequently, these weld metals must be used carefully in highly restrained joints and on base metals containing additions of alloying elements like phosphorus, sulfur, selenium or silicon — such as base metal 302B, 303, and 314.

In selecting welding materials, there is a misconception that the higher the AISI number, the higher the alloy content. This is not always true, as in the case of 347, which is a stabilized grade for preventing carbide precipitation in high-temperature service. 347 should not be used as a “general-purpose” filler metal for welding other alloys, because 347 can be crack sensitive.

The one principal exception in the list of austenitic stainless steels is 329, which is a duplex (dual-phase) alloy. If welding of 329 is expected, it is suggested that a stainless steel producer be contacted for assistance.

MARTENSITIC STAINLESS STEELS

The only standard martensitic stainless steels available as either covered electrodes or bare welding wire are 410 and 420. This sometimes presents a problem in procurement when attempting to secure similar properties in the weld metal as in the base metal. Except for 410 NiMo, martensitic stainless steel weld metals in the as-deposited condition are low in toughness and are seldom placed in service without being heat treated.

Austenitic stainless steel weld deposits are often used to weld the martensitic grades. These electrodes provide an as-welded deposit of somewhat lower strength, but of great toughness. For as-welded applications in which thermal compatibility is desired, the 410 NiMo filler metal is a good choice.

FERRITIC STAINLESS STEELS

The weld metal of ferritic stainless steels usually is lower in toughness, ductility, and corrosion resistance than the HAZ of the base metal. For this reason, it has been the custom to heat treat after welding to improve toughness. However, a goodly amount of welded ferritic stainless steel is placed in service, as-welded where the toughness is adequate for the service.

As shown in Table 7, an austenitic stainless steel filler metal is used frequently to join ferritic base metal to secure a ductile weld. For example, 430 is frequently welded with 308 filler metal. Of course, the use of austenitic filler metals does not prevent grain growth or martensite formation in the HAZ.

For the low carbon or stabilized ferritic grades, the use of austenitic filler metal can provide a weld of good mechanical properties. The austenitic weld metal should also be selected as a low carbon grade, e.g., 316L weld wire. The filler metal should always be selected so that the chromium and molybdenum content of the filler metal will be at least equal to that of the base metal. This insures the weld will have adequate corrosion resistance in severe environments. It is generally unnecessary to post-anneal the weld of a low carbon or stabilized ferritic grade when the low carbon austenitic wire is used.

However, the use of austenitic filler metal for ferritic stainless steels should not be supplied indiscriminately, because applications may arise where the difference in color, physical characteristics — such as thermal expansion — or mechanical properties may cause difficulty. Also, if the welded part is annealed after welding, the post-anneal is liable to cause carbide precipitation that may result in intergranular corrosion of the weld.

PRECIPITATION HARDENING STAINLESS STEELS

The selection of a filler metal to weld precipitation hardening stainless steels will depend upon the properties required of the weld. If high strength is not needed at the weld joint, the filler metal may be a tough austenitic stainless steel. When mechanical properties comparable to those of the hardened base metal are desired in the weld, the weld metal must also be a precipitation hardening composition. The weld analysis may be the same as the base metal, or it may be modified slightly to gain optimum weld metal properties.

A great deal of information on weld rod selection is available from the American Welding Society (AWS), weld rod manufacturers, and stainless steel producers. Designers are encouraged to consult with these sources for help in specifying weld materials, particularly for corrosive applications or when difficult weld problems are encountered.

Table 6 Filler Metals Suggested for Welding Stainless Steels			
	Condition (In which weldment will be placed in service)	Electrode or Filler Rod	Remarks
Austenitic Stainless Steels			
201 202	As-welded or fully annealed	308	308 weld metal is also referred to as 18-8 and 19-9 composition. Actual weld analysis requirements are 0.08% max C, 19.0% min Cr and 9.0 min Ni. 310 weld metal may be used, but the pickup of silicon from the base metal may result in weld hot cracking.
301 302 304 305 308	As-welded or fully annealed	308	
302B	As-welded	309	
304L	As-welded or stress-relieved	347 308L	
303 303Se	As-welded or fully annealed	312	Free-machining base metal will increase the tendency for hot cracks to form in weld metal. 312 weld metal contains a large amount of ferrite to overcome this cracking tenndency.
309 309S	As-welded	309	
310 310S	As-welded	309 310 316	
316	As-welded or fully annealed	310	Welds made with 316, 316L, 317, 317-Cbb and 318 electrodes may occasionally display poor corrosion resistance in the "as-welded" condition. In such cases, corrosion resistance of the weld metal may be restored by the following heat treatments: (1) For 316 and 317 base metal, full anneal at 1950-2050F. (2) For 316 and (317L) base metal, 1600F stress-relief. (3) For 316-Cb base metal, 1600-1650F stabilizing treatment. Where postweld heat treatment is not possible, other filler metals may be specially selected to meet the requirements of the application for corrosion resistance.
316L	As welded or stress-relieved	316-Cb 316L	
(316-Cb)	As-welded or after stabilizing and stress-relieving heat treatment	316-Cb	
317	As-welded or fully annealed	317	
317L	As-welded or stress-relieved	317-Cb	
321	As-welded or after stablizing and stress-relieving heat treatment	321 347	321 covered electrodes are not regularly manufactured because titanium is not readily recovered during deposition.
347	As welded or after stabilizing and stress-relieving heat treatment	347	Caution needed in welding thick sections because of cracking problems in base metal heat-affected zones.
348	As-welded or after stabilizing and stress-relieving heat treatment	347	Ta restricted to 0.10 max, and Co restricted to 0.20 max for nuclear service.
Ferritic Stainless Steels			
405	Annealed	405-Cb 430	Annealing improves ductility of base metal heat-affected zones and weld metal. 405 weld metal contains columbium rather than aluminum to reduce hardening.
	As-welded	309 310 410-NiMo	These austenitic weld metals are soft and ductile. However, base metal heat-affected zone has limited ductility.
430	Annealed	430	Annealing employed to improve weld joint ductility.
	As-welded	308 309 310	Weld metal is soft and ductile, but base metal heat-affected zones have limited ductility.
430F	Annealed	430	Remarks on 430 base metal apply.
430F Se	As-welded	308 309 312	Remarks on 430 base metal apply.
446	Annealed	446	
	As-welded	308 309 310	308 weld metal can be used, but will not display scaling resistance equal to the base metal. Consideration must be given to difference in coefficient of expansions of base and weld metal.
Martensitic Stainless Steels			
403 410	Annealed or hardened and stress-relieved	410	Annealing softens and imparts ductility to heat-affected zones and weld. Weld metal responds to heat treatment in a manner similar to the base metal.
	As-welded	309 310 410-NiMo	These austenitic weld metals are soft and ductile in as-welded condition. However, base metal heat-affected zone will have limited ductility.
416 416 Se	Annealed or hardened and stress-relieved	410	Remarks on 410 base metal apply.
	As-welded	308 309 312	Remarks on 410 base metal apply.
420	Annealed or hardened and stress-relieved	420	Requires careful preheating and postweld heat treatment to avoid cracking.
431	Annealed or hardened and stress-relieved	410	Requires careful preheating and postweld heat treatment to avoid cracking.
	As-welded	308 309 310	Requires careful preheating. Service in as-welded condition requires consideration of hardened weld heat-affected zones.

Welding Processes For Stainless Steels

The two basic methods for welding stainless steels are fusion welding and resistance welding. In fusion welding, heat is provided by an electric arc struck between a carbon or metal electrode (connected to one terminal of a power supply) and the metal to be welded (which is connected to the other terminal). In resistance welding, bonding is the result of heat and pressure. Heat is produced by the resistance to the flow of electric current through the parts to be welded, and pressure is applied by the electrodes. Austenitic stainless steels can be readily welded using any of the arc welding processes TIG, MIG, MMA and SA. Ferritic stainless steels can be readily fusion welded. Martensitic stainless steels can be welded by the TIG or MIG method, but precautions should be taken to avoid cracking in the HAZ. Please contact the American Welding Society (www.aws.org) for codes and procedures.

Welding Dissimilar Metals

AUSTENITIC STAINLESS STEELS TO LOW CARBON STEELS

In joining austenitic stainless steels to carbon steels or low-alloy steels for low and moderate temperatures (not over approximately 700F) it is customary to use a stainless steel welding rod that is sufficiently high in total alloy content to prevent martensite formation when diluted with carbon steel while at the same time preserving residual amounts of ferrite, which counteract the tendencies for hot cracking (at the time of welding) even under conditions of severe restraint.

309 is probably used more than any other electrode for joining carbon steel to stainless steel (including overlay welding). 312 also enjoys some usage in joining carbon steel to stainless. 309 normally contains about 5 to 10% ferrite, while 312 is strongly ferritic.

The use of ENiCrFe-2 covered electrodes or ERNiCrFe-6 bare filler metal will also produce satisfactory welds when joining the austenitic stainless steels to low-alloy steel, especially for elevated-temperature service.

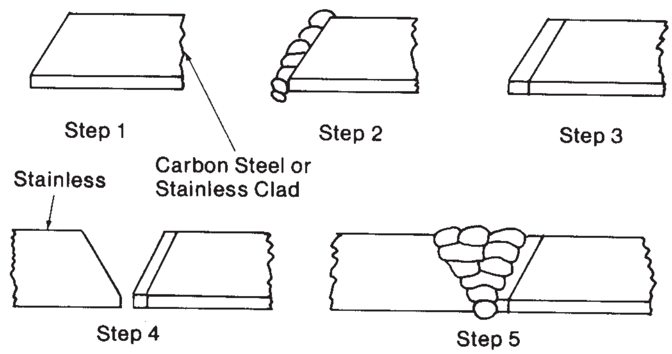
When making a transition joint between austenitic stainless steel and carbon steel, it is good practice to "butter" the carbon steel surface with a layer of 309 or other suitable stainless steel weld metal prior to actually joining it to the stainless steel. In this manner, the portion of the joint where difficulties are most likely to occur is buttered while there is little restraint on the weld metal. Following the deposition and inspection of the buttered layer or layers, the joint between the stainless steel member and the buttered layer will be a conventional stainless steel to stainless steel joint. The welding rod in this case can be the type normally used to weld the stainless steel member of the joint (i.e., 308 if the stainless steel member is 304).

The deposition of carbon steel or low-alloy steel weld metal on stainless steel can result in hard, brittle weld deposits which frequently crack when deposited and which would be likely to fail in service. *Avoid depositing carbon steel or low-alloy steel weld metal on stainless steel.* When this must be done because of service requirements, use the short-circuiting method of metal transfer.

PROCEDURES FOR WELDING TRANSITION JOINTS

Figure 2 illustrates a method of joining stainless steel components to carbon steel or stainless-clad carbon steel and it is especially useful when stress relief of the carbon steel is needed. This method has been widely used in the welding of stainless steel pipe to stainless steel lined carbon steel or low-alloy steel.

Figure 2
Clad Metal Joint Design



Design for joining stainless steel to carbon steel or stainless clad carbon steel. Commonly used for welding stainless steel pipe to stainless steel lined carbon or low-alloy steel.
Step 1. Bevel edge of carbon steel or stainless clad carbon steel plate for welding.
Step 2. Apply overlay or "buttered" layer of stainless steel weld metal of suitable alloy content to avoid problems from dilution by carbon steel. Use welding procedure that results in minimum penetration of weld metal into carbon steel.
Step 3. Machine or grind to restore required dimensions. Stress relieving, if required, may follow this step.
Step 4. Fit-up for welding.
Step 5. Deposit stainless steel weld by any suitable process, using the filler metal which is normally employed for welding the stainless steel member, or the same filler metal that was employed to apply the overlay or "buttered" layer on the carbon steel member.

The overlay or buttered layer that is applied to the carbon steel surface should be of sufficient thickness that the subsequent welding operation will not adversely affect the carbon steel base metal. If the righthand member of the joint shown in Figure 2 is solid carbon steel or if the cladding is 304 stainless steel, 309 should be used for the overlay operation. Great care must be taken in depositing the overlay to keep carbon steel dilution of the stainless steel weld metal to a minimum. Excessive dilution can cause cracking of the stainless steel weld metal. Stress relieving, when required, should be performed after deposition of the stainless steel overlay.

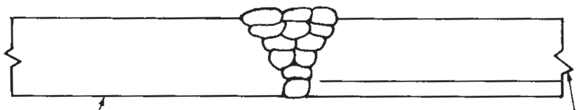
The final weld between the solid stainless steel and the buttered surface on the carbon steel can be made with the filler metal composition that is normally employed for welding the solid stainless steel member or the composition used to apply the overlay on the carbon steel member.

Another method employs a short stainless steel member that is welded to the carbon steel or stainless clad carbon steel member prior to the stress relieving operation. This method insures that the final weld will have no effect on the carbon steel base metal. Stress relieving is performed while there is little restraint on the joint.

The final weld is a simple stainless to stainless joint. Figure 3 shows the least desirable of the three methods. In this method the stainless steel and the stainless-clad carbon steel or carbon steel member are beveled and fit up for welding, leaving a suitable root gap. The two are then joined, using an electrode sufficiently high in alloy content that cracking of the stainless steel weld will not occur with normal dilution from the carbon steel.

The welding procedure used should hold penetration into the carbon steel to a minimum. One disadvantage with this method is that the most critical portion of the weld is deposited while the weld is under restraint. Another is that local stress relief of the weld must also be performed on a restrained joint. (A point to remember is that stress-relief temperatures can result in carbide precipitation.)

Figure 3
Clad Metal Joint Design



Design for stainless steel to carbon steel transition joints.
Step 1. Bevel both members and fit up leaving a root gap.
Step 2. Deposit the weld using stainless steel filler metal of sufficiently high alloy content to avoid problems from carbon steel dilution.
Step 3. Welding procedure employed should hold penetration into the carbon steel to the minimum value possible.

FERRITIC AND MARTENSITIC STAINLESS STEELS TO CARBON OR LOW-ALLOY STEELS

When welding ferritic or martensitic stainless steels to carbon or low-alloy steels for general purposes (not high-temperature service), austenitic stainless steel or modified ErNiCrFe-6 filler metal will produce welds of suitable quality provided that the correct welding procedures are followed. For the low carbon or ferritic grades, the low carbon austenitic filler metals will produce welds of good mechanical quality while maintaining corrosion resistance.

There are two methods of making such a joint. The first would involve overlaying each member of the joint, utilizing suitable preheat and postheat treatments as required, and then making a weld without preheat or postheat between the overlayed surfaces. Austenitic stainless steel electrodes such as 309, which are sufficiently high in alloy content to minimize the problems from dilution by the carbon steel or straight chromium stainless steels, are widely used for this application. The welding procedure used should hold penetration into the base metal to a minimum. The second method would involve depositing the weld directly between the two members of the joint. In this case, dilution of the weld metal by both of the base metals must be kept under control while depositing the restrained weld.

Use of Chill Bars

Successful welding of stainless steel by various welding methods depends to a large extent on the type of back-up bar or plate used. Experience has indicated that pure copper is the most satisfactory material for backing up a weld.

The high heat conductivity of such a back-up bar or plate will prevent its sticking to the weld metal, while its chill-mold effect will assure a clean smooth weld metal surface. Copper back-up bars can be made by cutting pieces from copper plate or sheet. Chill bars serve the best purpose by controlling distortion on light gauge material, and also help to prevent excessive burn-through or melting of the base metal.

Joint Design

Probably the most frequently used joint in stainless steel is the butt joint. On thin sheet metal, a square butt joint may be used, as shown in Figures 4 and 5. If the members being joined are thicker than about 1/8 or 3/16 inch, it is necessary to bevel the edges in order to assure full penetration welds, Figure 6. If the base metal is thicker than about 1/2 inch, the V-joint requires a large volume of weld metal, so U-groove (Figure 7) double V- and double U- grooves (Figure 8) are used, although they are more costly to prepare.

Normally, full penetration welds are essential and therefore conventional backing rings are not used. However, consumable backing rings or inserts (Figure 9), which are melted during the first weld pass and become an integral part of the weld, are used successfully.

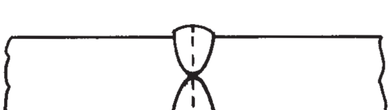
PREPARATION

Stainless steels cannot be cut with the ordinary oxy-acetylene torch. Powder cutting, in which iron powder is injected into the cutting stream of an oxy-acetylene torch, is used as are arc processes such as plasma arc. Stainless steels can be severed by using cutting electrodes or even mild steel coated electrodes, although these produce a great deal of spatter and rough cuts.

The edges of a thermally cut weld joint should be cleaned by machining or grinding to remove surface contamination, particularly iron. Parts to be joined must also be free of oil, grease, paint, dirt, and other contaminants.

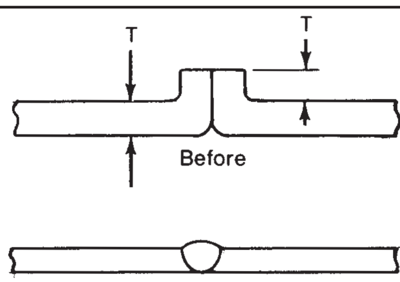
Because of the relatively high coefficient of thermal expansion of the austenitic grades, adequate clamping or jigging devices should be employed to align the work. If it is

Single bead for 14 gage and lighter.



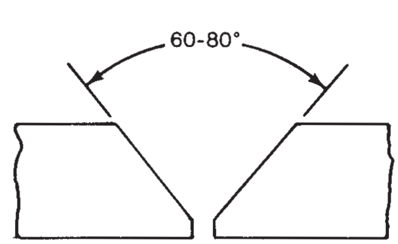
Double bead for 12 gage to 3/16 inch.

Figure 4



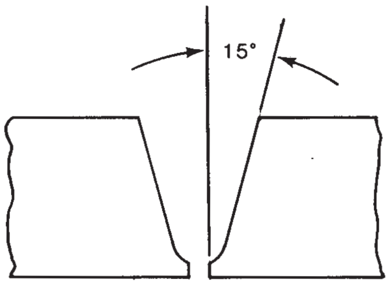
This standing edge or flange joint may be used for light gages. Little or no filler metal need be added.

Figure 5



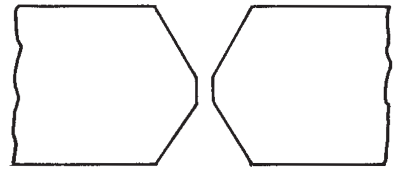
Single "V" joint. For 1/4 to 1/2 inch thick material. Number of beads required is determined by thickness of material.

Figure 6

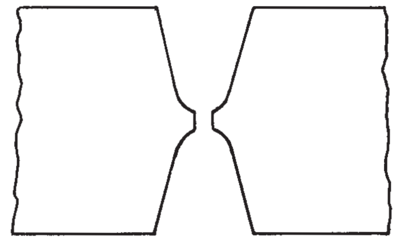


Single "U" joint. For material over about 1/2 inch thick.

Figure 7

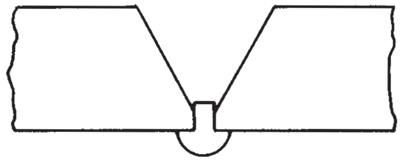


Double "V" joint. For material over about 1/2 inch thick.

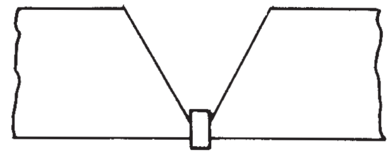


Double "U" joint. For material over about 1 inch thick.

Figure 8



"EB" Insert



Rectangular Insert

Typical Consumable Inserts

Figure 9

not feasible to construct accurate jigs and fixtures, tack welds may suffice to hold the parts in proper alignment during welding. With light gauge sheet metal, small tack welds every inch or two are used. In heavier plate, the tack welds need not be spaced closely together, but each tack should be substantial.

Post/Weld Cleaning and Finishing

Welds and the surrounding area should be thoroughly cleaned to avoid impairment of corrosion resistance. Weld spatter, flux, or scale may become focal points for corrosive attack if not properly removed, especially in aggressive environments. Also, the residue from welding should be removed before heat treatment for stress relief or annealing. The discoloration by heat, or heat tint, is not necessarily harmful, but should be removed if the weldment is to serve a decorative purpose. This can be accomplished mechanically by using a mild abrasive cleaner, chemically with a phosphoric acid base cleaner, or electrochemically with commercially-available weld-cleaning kits.

WELD SPATTER

When welds are made using stick electrodes, some spatter is normal. However, it is easily removed by light grinding (aluminum oxide) or wire brushing. Spatter-resisting compounds applied before welding reduces this annoyance. Tightly adhering slag or scale is easily removed by light grinding or sandblasting. Cleaning time is reduced or eliminated when welding is done using the inert gas processes. DO NOT USE IRON OR STEEL WIRE BRISTLES. USE STAINLESS STEEL WIRE BRUSHES.

FLUX REMOVAL

Most welding flux or slag can be chipped off, but it is better to grind the flux off using *clean* grinding wheels. Sandblasting with clean silica sand is also an effective and economical way to remove slag. Where extreme corrosion resistance is required, sand blasting should be followed by brief immersion in a chemical cleaner, such as a solution of nitric acid. A most important aspect of cleaning stainless steel welds is to use stainless steel brushes and clean grinding wheels (wheels not contaminated with carbon steel particles). Contamination can cause rust staining and increased corrosion.

FINISHING WELDS

Stainless steels, in particular, 304 and similar analysis materials, are widely used in food, dairy, drug and processing equipment. To prevent bacterial growth, all fractures, cracks and crevices in the weld should be removed, and exposed surfaces be ground and polished to match the parent metal. If welds are made in prefinished stainless steel, the weld beads should be held to a minimum size to avoid excessive and expensive finishing costs. The chrome-nickel grades are more difficult to grind than the straight chromium grades, so weld metal deposits should be as flat as possible. Heat from grinding should be held to a minimum also to avoid distortion of thin gauge materials. If the grinding wheels or belts were used previously on carbon steel, chemical cleaning should follow to remove any iron particles that might have become imbedded in the stainless steel surface.

A technique of butt-welding polished sheets from the reverse or unpolished side has been successful. Sheets are first sheared from the back side so that any "shear drag" is on the polished side. Full penetration of the joint is achieved with a minimum of welding alloy penetrating the polished side. Relatively light grinding can then be used to prepare the weld on the polished side for final polishing and blending with the surrounding area.

The gas-tungsten-arc welding method allows a good welder to produce smooth uniform beads that are easy to grind, polish or finish. (Welds on surfaces that have mill-rolled finishes cannot be blended to match the surrounding base metal. Ground or polished finishes, however, can be matched by using the same grit and polishing techniques.)

Soft Soldering

Sheet metal soldering today is practically a lost art and has been largely replaced by welding shops; the reason being, soldered joints have relatively low strength. However, soldering still does have some very important practical and economic applications, such as in architecture, food processing, and plumbing. Several applications are suggested in Figure 10.

Soft soldering is an easy method of joining two sections, or pieces, of metal at a low temperature. In the case of stainless steel, or a dissimilar metal to stainless steel, such joints are used for sealing where strength is not a requirement but a water tight joint or good appearance is desirable.

Stainless steels generally have good solderability; however, some surface finishes and types of stainless are more difficult to flux or wet (tin) than others. Since all metals have a surface oxide as they come from the mill, good joining principles require its removal.

The most common annealed and pickled finishes (#1 or #2) or the polished surfaces (#3 or #4) are easier to flux and solder than the highly polished surfaces such as #7 or #8. Surface finishes that have been temper rolled after conventional annealing and pickling (#2 or #2B) will bond almost as easy as the pickled finishes.

Bright annealed finishes are difficult to solder.

The 300 Series stainless steels solder with relative ease, while the 400 Series, especially those with high carbon content, are somewhat more difficult.

Also, the molybdenum-bearing stainless steels, such as 316, or those containing titanium, may be somewhat difficult.

PROPER CLEANING A MUST

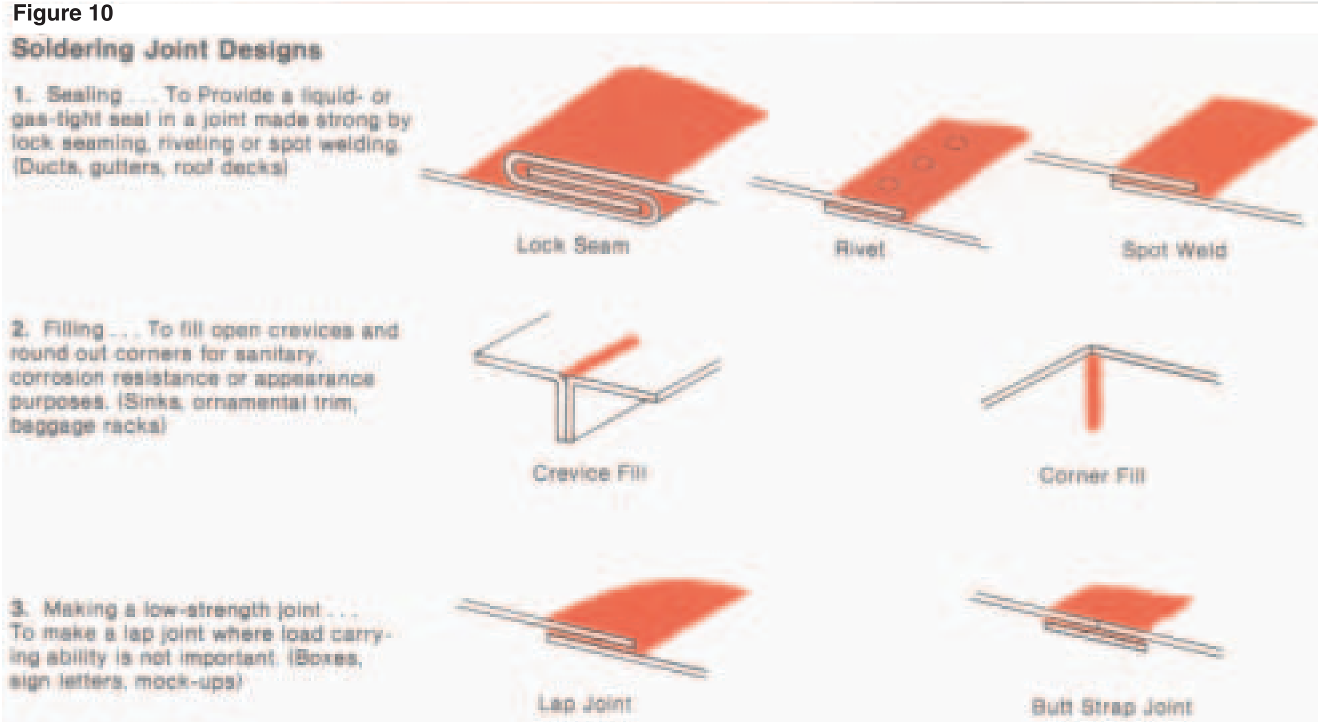
Cleaning any metal before any form of joining or fabrication is a must. Dirt, dust, grease, scale, finger prints, etc., should always be removed by either mechanical or chemical means. Stainless steel nearly always comes from the mill with a surface film. This film must be removed before fluxing or soldering. Oil or grease can be removed by commercial solvents or alcohol. Before fluxing, the area should be wiped with a cloth soaked with the cleaning agent, then wiped with a clean cloth. (Follow manufacturer's instructions and provide adequate ventilation.)

Where possible, tin. Tinning is the act of coating the metal with tin or solder. It is really spreading out a thin layer of fluxed metal so the following layer will provide a strong bond. After tinning, the solders flow easier and are more controllable. Tinning is accomplished by applying a coat of solder and quickly "wiping" the surface with a cloth or brushing it with a stainless steel wire brush. Tinning will help when using a soldering iron or a torch, because it reduces the amount of time needed to complete the job and it enhances strength and corrosion resistance.

SELECTION OF THE PROPER FLUX

The tenacious oxide film on the surface of stainless steel must be removed before soldering. This is done with an active flux. Commercial acid-type fluxes containing chlorides, such as hydrochloric acid or ammonium chloride, can be used, but with extreme care — and they should not be used if immediate and thorough neutralizing and flushing after soldering is not practical. Residual chloride-containing fluxes can and most often will cause pitting of stainless steel.

Figure 10



The preferred fluxes are those with a phosphoric acid base because the phosphoric acid is active only at soldering temperatures. To enhance the fluxing action, the surfaces to be tinned or soldered should be prepared by sanding with a fine emery cloth.

SELECTION OF THE PROPER SOLDER

Most solders have a melting point under 800F; however, this varies several hundred degrees when different combinations of alloys are used. For instance, a 50% tin, 50% lead combination will melt at 361F and flow at 421F; while a 62% tin, 38% lead will melt at 358F; and a 30% tin, 30% lead, 40% bismuth mixture will melt at 198F. However, stainless steel requires, in most cases, at least 50-50 and some prefer a 60-40 alloy, while others prefer 70-30 mix. If better color match is required, the higher the tin mix, the better the match. Table 7 suggests soft solders for stainless steel industrial sheet metal work.

As for soldering technique, what applies to other metals also applies to stainless steel, except consideration for the low heat conductivity of stainless steels. This requires a slightly shorter period of heat application to bring the metal up to the temperature at which the solder will flow properly.

CLEANING AFTER SOLDERING

All corrosive flux, vapor and flux residue left on stainless after it is soldered must be removed to preserve its corrosion resistance.

Strong acid-chloride type fluxes may attack and pit stainless steels if left on the work, as well as mar the stainless finish. Remove spilled fluxes immediately by flushing with water.

Vapors from the flux also are corrosive and may settle on cold surfaces some distance from the joint. Thus, any areas exposed to flux vapors should be cleaned thoroughly after soldering. There are several ways of removing traces of corrosive flux and flux residue.

A. *Cleaning Method #1. (Use of Neutralizer)*

For field jobs or for shop work where every part cannot be inspected, this method is the safest to insure a corrosion-free joint.

First, wet the work with water, then scrub with a soft bristle brush. Be sure to scrub first with plain water and not with neutralizing solution. If the neutralizing solution is used first, the flux residue may become insoluble in water and much harder to remove

To neutralize any remaining harmful flux residue, wash the work in a 5% neutralizing solution, rinse with running water and wipe dry. The neutralizing solution can be made up by adding about 3/4 cup (6 ounces) of sodium carbonate (washing soda) or sodium bicarbonate (baking soda) to 1 gallon of water. Also, aqua ammonia can be used.

B. *Cleaning Method #2. (Use of Water Only)*

This method can be used if visual inspection is possible. First wet the work down with fresh water, and scrub hard with a soft bristle brush. Then use plenty of clean water to remove all traces of the flux residue, and dry with a clean cloth.

C. *Cleaning Method #3. (Use of Weak Acid Cleaning Solution)*

This method is used for shop production work, or for production tinning, but it must be carefully followed to insure complete flux residue removal.

First, the tinned or soldered parts are placed in a solution of hot water and 5% phosphoric acid to make the flux residue soluble in water. After standing for five minutes in this solution, which is agitated, the parts should be thoroughly rinsed in water and wiped dry.

The cleaning solution can be made up by adding about 1/2 cup (4 fluid ounces) of commercial 85% phosphoric acid to one gallon of water. Brand-name cleaning solutions can also be used.

A 2% hydrochloric acid solution is sometimes used for cleaning soldered work, but is not recommended for stainless steel. Hydrochloric acid is strongly corrosive, and if the solution is not removed completely and immediately, it may attack stainless steel.

Brazing

Brazing is a method of joining stainless steels to themselves or to dissimilar metals using a non-ferrous filler wire, powder or thin-shim form of alloy that has a melting point above 800F, but below the melting point of the base metal. Silver-brazing alloys are available in many different analyses but, in the case of stainless steel, most contain at least 40% silver. Usually a 45% silver gives good results since it has excellent capillary flow and adheres to most stainless steels easily. The alloys range in melting point from 1145F to 1300F and are extremely fluid. Nickel-base brazing alloys are also used with melting points up to 2100-2125F. These permit the use of brazed stainless steel components at considerably higher temperatures than with the lower-temperature silver-brazing alloys.

Table 7
Soft Solders for Stainless Steel Industrial Sheet Metal Work

Common Name	Nominal Composition (Percent): Tin (Sn)	Lead (Pb)	Antimony (Sb)	Silver (Ag)	Short-Time Bulk Solder Strength: Tensile (psi)	Shear (psi)	Density (lb/cu in)	Melting Range: Melts (°F)	Flows (°F)	Max. Service Temp. (°F)	Color Match To Stainless Steel	Use	Comments
Fifty-Fifty	50	50	—	—	6,000	5,200	0.321	361	421	200	Poor	Duct work, roofing, etc. where appearance or special joint properties are not important.	Satisfactory general purpose solder. Not for color matching.
Sixty-Forty	60	40	—	—	7,600	5,600	0.308	361	374	200	Fair	Signs, ornamental trim, flashing, etc. where appearance is more important. Used for tinning.	Best all-around tin-lead solder. May discolor with time. Has better wetting and flowing properties than 50-50 solder.
Pure Tin	100	—	—	—	1,700	1,800	0.263	450	450	200	Good	Distilled water equipment or special chemical use where lead cannot be tolerated.	Low joint strength. Good corrosion resistance. Nontoxic. Good color match.
Tin-Antimony	95	—	5	—	5,900	6,000	0.260	452	464	350	Good	Food handling equipment where lead must be avoided. Refrigeration equipment to minus 160° F.	Wide service temperature range. Good food contact solder. Nontoxic. Good non-staining properties. Good joint strength. Higher cost.
Tin-Silver	96	—	—	4	(Note 1)	(Note 1)	0.266	430	430	350	Very Good	Food handling equipment, fine ornamental work, high strength and other uses requiring special joint properties.	Best color-match and blending properties. Very good joint strength. Nontoxic. Good corrosion resistance. Highest cost.

(NOTE 1) The short-time bulk solder strength of tin-silver solder is similar to tin-antimony solder. Soldered joints made with either tin-antimony or tin-silver solder have a much higher long-time tensile-shear strength than joints made with tin-lead or pure tin solder.

ALLEGHENY LUDLUM
An Allegheny Teledyne Company

Technical Data BLUE SHEET

Allegheny Ludlum Corporation ◆ Pittsburgh, PA

Stainless Steel Chromium-Nickel-Manganese AL 201LN™

(UNS Designation S20153)

GENERAL DESCRIPTION

Materials for use at sub-zero temperatures should be ductile, tough and strong at the use temperature. Only a limited number of materials, among them most of the austenitic stainless steels, satisfy all of these requirements. The austenitic stainless steels not only maintain their toughness and ductility, but they also increase in yield and tensile strengths as temperatures decrease. By choosing the right austenitic stainless steel, many cryogenic temperature applications can be satisfied.

The familiar type 300 series austenitic stainless steels have been used satisfactorily for many years as materials of construction for liquid oxygen tanks and accessories as well as liquid hydrogen handling equipment. Other applications include components containing liquid carbon dioxide, acetylene, methane, argon and nitrogen. Hence, service temperatures ranging from -80°F to -320°F are typical based on the boiling points of these liquids.

Type 201 austenitic stainless steel has been available for over 40 years and has gained acceptance in a number of applications. Compared to the 300 series alloys, the lower-nickel 200 series alloys offer an economical way to obtain superior mechanical properties. Allegheny Ludlum has created a special composition of type 201 specifically for sub-zero temperature service as welded tanks and vessels. This alloy, designated AL 201LN, also identified by the Unified Numbering System Designation S20153, has replaced the familiar 300 series stainlesses such as type 301 or type 304 in many applications based upon technical equivalency and economic considerations. Consequently, AL 201LN alloy is a natural choice for use at temperatures down to -320°F.

AL 201LN alloy is also suited for many ambient temperature structural applications, such as railroad freight cars, truck trailers, coal handling and other bulk transport equipment where there is a need for a good combination of corrosion resistance, strength, toughness and ease of fabrication.

COMPOSITION

Ferritic alloys such as carbon steels or 400 series stainless steels experience a ductile-to-brittle transition (DBT) as the temperature is reduced. This DBT is a major barrier to the use of most ferritic steels at sub-ambient temperatures. Even some of the austenitic stainless steels can be embrittled at low temperatures. This embrittlement has been attributed to a transformation from austenitic to martensitic structure at low temperature. Most austenitic stainless steels resist transformation to martensite even at very low temperatures and maintain their toughness and ductility. However, the stability of austenite varies with chemical composition. The type 301 stainless steel, which exhibits a relatively high work hardening rate even at room temperature, is an example of relatively unstable austenite. Type 304 has a much lower work hardening rate, indicating a more stable austenite. However, even the relatively unstable type 301 is often satisfactory for low temperature service.

Composition									
Specification	**ASTM Range - Weight Percent**								
Composition Balanced AL 201LN™ (UNS S20153)	**C*** 0.03	**Mn** 6.40/7.50	**P*** 0.045	**S*** 0.015	**Si*** 0.75	**Cr** 16.00/17.50	**Ni** 4.00/5.00	**N** 0.10/0.25	**Cu*** 1.00
Type 201 Alloy to ASME SA-240, ASTM A666, and ASTM A240 (UNS S20100)	0.15	5.50/7.50	0.060	0.030	1.00	16.00/18.00	3.50/5.50	0.25*	--

* means maximum value.

Allegheny Ludlum's AL 201LN alloy has been designed specifically to provide sufficient austenite stability for low temperature service. As part of the composition design, carbon has been restricted to 0.03 percent maximum to minimize sensitization during welding since welding is typically required in the construction of low temperature equipment.

AL 201LN alloy can be used for various pressure vessel, cryogenic, structural, architectural, magnetic and heat resisting applications. AL 201LN (UNS S20153) alloy is a carefully balanced composition of type 201 which satisfies the requirements of ASME Boiler and Pressure Vessel Specification SA-240 and ASTM A 240 (Standard Specification for Heat Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels).

ASME Code Case 2123-3 permits AL 201LN alloy which meets the ASTM A 240-96 requirements to be used for the manufacture of Section VIII, Divisions 1 and 2 welded pressure vessels for low temperature service. The minimum and maximum design temperatures are -320°F (196°C) and 100°F (40°C), respectively. The maximum allowable stress values are 23,800 psi (164 MPa) for Division 1 and the maximum allowable design stress intensity value S_m in tension is 30,000 psi (207 MPa) for Division 2. These limiting stresses (based upon room temperature properties) are employed when designing to cryogenic temperatures even though the strength of austenitic stainless steels increases as temperature decreases below room temperature. The 23,800 psi (164 MPa) maximum allowable stress for AL 201LN alloy is substantially higher than the maximum allowable stress for type 304 alloy, 18,750 psi (129 MPa), allowing the use of thinner sections for AL 201LN alloy, or allowing an additional safety factor with a gage equivalent to that for type 304 alloy.

TYPICAL APPLICATIONS

Liquefied Gas Storage Vessels
Portable Gas Storage Tanks

In summary, the austenitic stainless steels have been proven to be excellent materials for use at sub-zero temperatures to at least -320°F. Allegheny Ludlum AL 201LN alloy represents the marriage of high room temperature strength, and excellent mechanical properties at sub-zero temperatures and fabricated corrosion resistance of low carbon type 300 series stainless steels.

DENSITY

0.284 lbs/in^3
7.857 gm/cm^3

MECHANICAL PROPERTIES

The austenitic stainless steels are generally utilized in the annealed condition. The mechanical properties which are of primary importance in fabrication and use, and consequently receive the most attention are the yield strength, tensile strength, elongation, and impact properties. Since toughness and resistance to impact loading are important at low temperatures these properties are given below for a number of heats to demonstrate the excellent impact resistance of Allegheny Ludlum's AL 201LN alloy.

Impact Loading

It is known that austenitic stainless steels (e.g., type 304), in general, retain their excellent impact properties at low temperatures. AL 201LN alloy, as illustrated on page 4, retains excellent impact properties down to -320°F (-196°C).

AL 201LN™ Alloy -- Room Temperature Data

Data for Tests at +70°F (21°C)						
Heat	**Direction**	**0.2% Yield Strength (ksi)**	**Tensile Strength (ksi)**	**Elongation (% in 2")**	**Impact Energy (ft-lbs.)**	**Lateral Expansion (in.)**
M-6	T	46.4	99.3	56.0	208	0.085
M-7	T T	 46.6	 97.6	 59.0	184 162	0.088 0.092
M-8	T T T	 49.8 	 97.1 	 56.5 	154 186 172	0.087 0.084 0.087

AL 201LN™ Alloy -- Low Temperature Data

Data for Tests at -100°F (-73°C)						
Heat	**Direction**	**0.2% Yield Strength (ksi)**	**Tensile Strength (ksi)**	**Elongation (% in 2")**	**Impact Energy (ft-lbs.)**	**Lateral Expansion (in.)**
M-6	T T	63.4 61.8	179.2 176.0	42.5 45.0	150 150	0.084 0.081
M-7	T T	68.7 71.7	177.3 176.9	47.0 46.0	134 130	0.080 0.072
M-8	T T	72.8 70.7	179.2 177.7	47.5 50.0	142 138	0.070 0.078

Data for Tests at -320°F (-196°C)						
Heat	**Direction**	**0.2% Yield Strength (ksi)**	**Tensile Strength (ksi)**	**Elongation (% in 2")**	**Impact Energy (ft-lbs.)**	**Lateral Expansion (in.)**
M-1	T T T	83.2 	231.5 	27.0 	68 59 68	0.045 0.048 0.046
M-2	L L L	83.9 	203.0 	25.0 	82 86 106	0.048 0.050 0.054
M-6	T T T L L L	75.6 77.8 82.5 75.2 	233.9 210.0 190.5 242.6 	31.0 23.0 22.0 37.0 	61 58 80 95 84 59	0.038 0.038 0.044 0.056 0.053 0.038
M-7	T T T L L L	84.8 87.6 87.6 87.4 	200.5 244.2 234.0 249.7 	22.5 36.0 27.5 34.0 	56 68 47 54 52 56	0.034 0.041 0.028 0.038 0.032 0.035

L - Designates impact sample length lies in longitudinal or rolling direction and notch running through thickness.

T - Designates impact sample length lies in transverse or width direction and notch running through thickness.

Impact Energy and Lateral Expansion are determined according to the American Society for Testing and Materials (ASTM) Procedure E-23 (Notched Bar Impact Testing of Metallic Materials).

Yield and Tensile Strengths

The yield and tensile strengths of austenitic stainless steels actually increase as temperature is decreased below zero degrees Fahrenheit. The tensile strength tends to increase more rapidly than does the yield strength. The effects of sub-zero temperatures on the AL 201LN alloy are graphically illustrated in Figure 1.

AL 201LN alloy maintains high elongations and continues to increase in tensile strength as temperature decreases. Austenite stability has been controlled in the AL 201LN alloy. In addition to the effect of austenite stability, variables associated with welding can also influence low temperature properties.

EFFECT OF SENSITIZATION

Since welding is an important method of fabrication, the potential effect of sensitization on mechanical properties must be considered. Sensitization of annealed austenitic stainless steels normally causes a small loss of toughness at low temperatures. The degree of change is related to the amount of carbide precipitation which occurs. This, in turn, is dependent on the carbon content of the material. In AL 201LN alloy, the carbon content has been reduced to the level of 0.03 percent maximum, minimizing the amount of carbide precipitation, and maintaining low temperature impact properties in welded sections. In addition to the loss of toughness induced by the presence of carbides, the depletion of carbon from solid solution can destabilize austenite. This can lead to martensite formation and further loss of toughness.

An additional effect of welding, that of an increased grain size in and adjacent to the welds, can have an effect on sub-zero properties. However the data below on AL 201LN alloy, including data for grain size deliberately grown to ASTM # 1 (a very large grain size), shows that large grain size does not detrimentally affect properties at -320°F (-196°C).

Effect of Grain Size on AL 201LN™ Alloy (Properties for Heat M-6)

Heat Treatment	ASTM Grain Size	Test Temp °F (°C)	0.2% Yield Strength (ksi)	Tensile Strength ksi (MPa)	Elongation (% in 2")	Impact Energy ft-lbs. (Joules)	Lateral Expansion (in.)
Mill Anneal	6	70 (21)	46.4 (320)	99.3 (685)	51	184-202 (250-274)	0.085-0.088
Mill Anneal	6	-320 (-196)	75.6-77.8 (521-536)	210.0-234.0 (1448-1613)	23-31	58-61 (74-83)	0.038-0.039
Mill Anneal + 100 Min. @ 2050°F	2.5-3	-320 (-196)	81.7 (563)	191.4 (1320)	21	107-108 (145-146)	0.055-0.057
Mill Anneal + 300 Min. @ 2050°F	0.5-1.5	-320 (-196)	71.6 (525)	213.3 (1471)	23.5	124-134 (168-182)	0.057-0.067

Impact Energy and Lateral Expansion data are range of three samples tested.

RESISTANCE TO CORROSION

Allegheny Ludlum AL 201LN alloy is resistant to a wide variety of mild to moderately corrosive media. Generally speaking, AL 201LN alloy has proven entirely adequate for applications where type 301 has been satisfactory and has been successfully substituted for type 304 in a variety of mild environments.

AVAILABLE PRODUCT FORMS

Allegheny Ludlum AL 201LN stainless steel is available in plate, sheet, and strip product forms and is listed in ASTM A240.

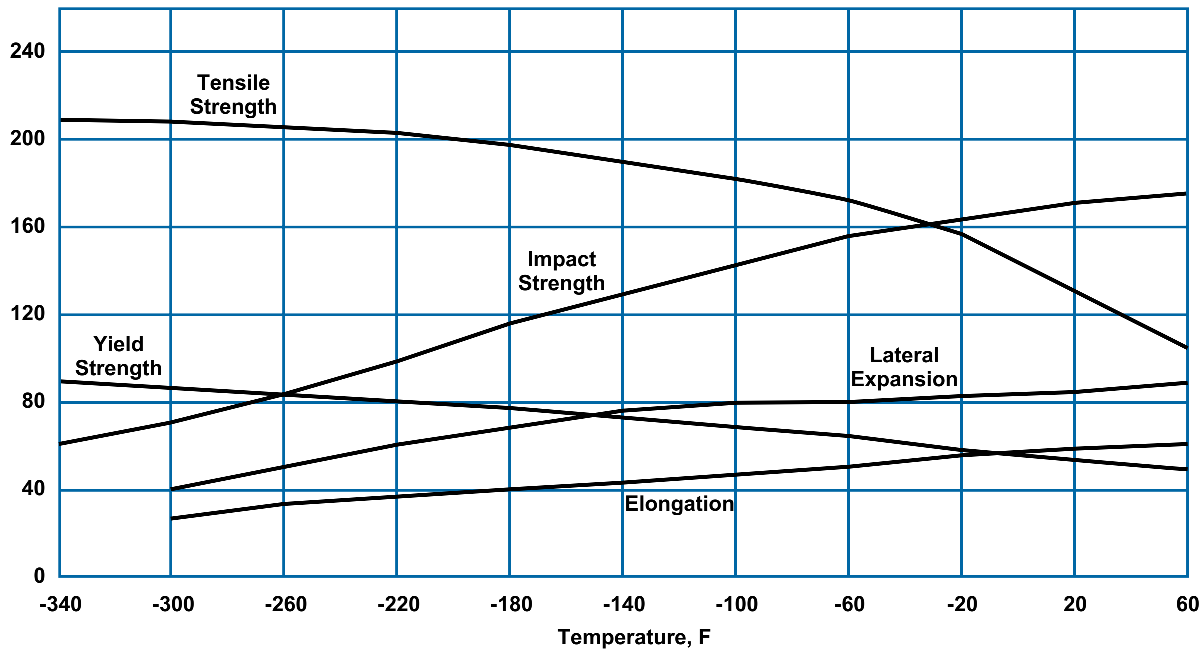


Figure 1 - AL 201LN™ alloy mechanical properties from room temperature to -320°F

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Referenced 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 above.

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

Lean Substitution Options For 300 Series Alloys and Commercially Pure Titanium

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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.

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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

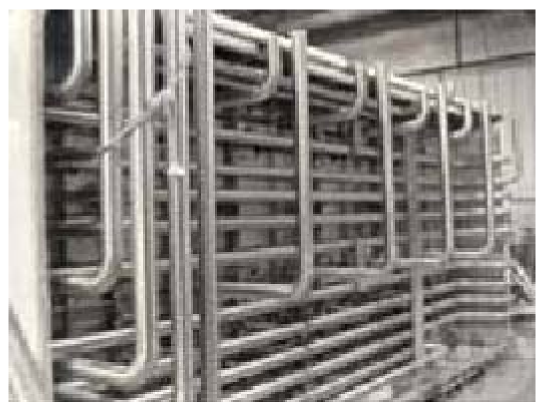

Figure 6: In-Plant Piping of UNS S20153 alloy

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.

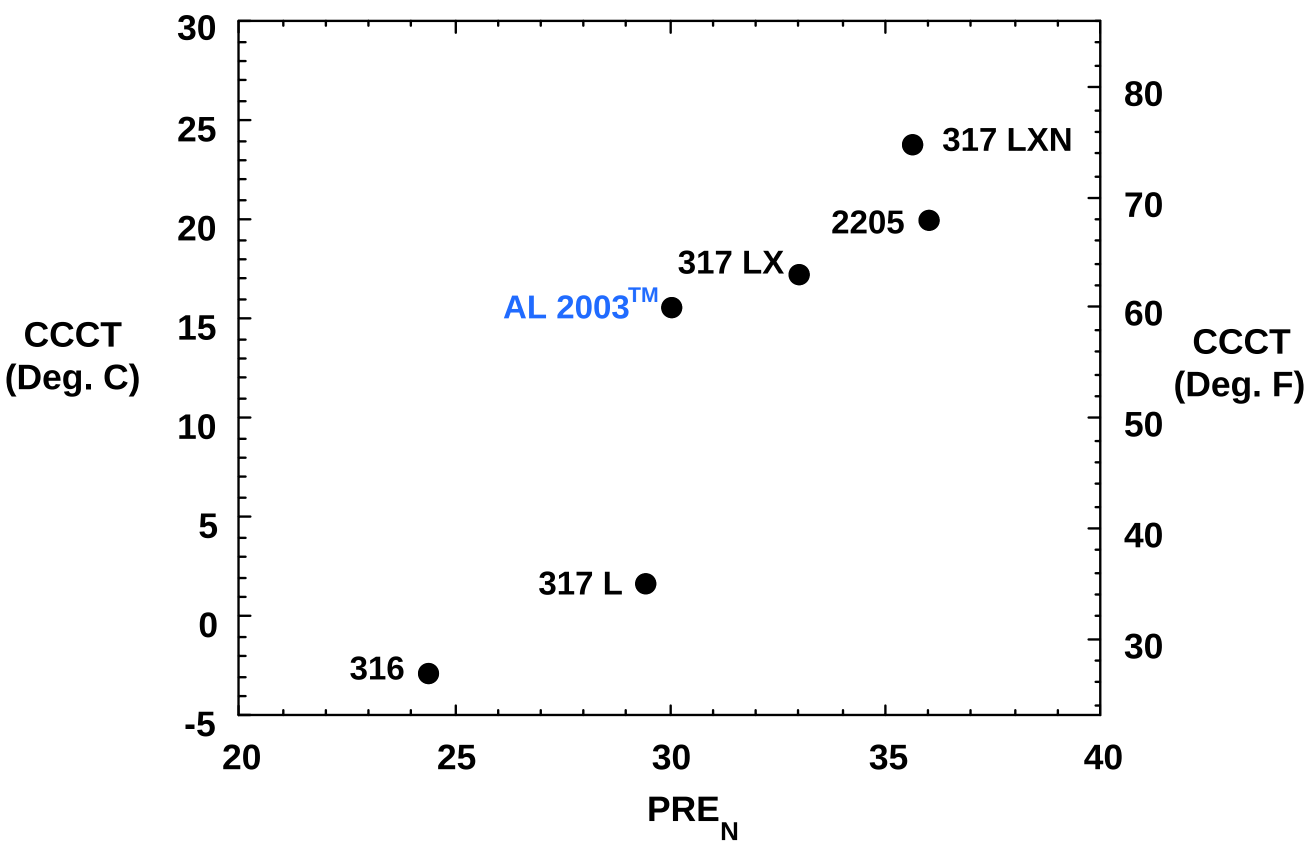

Figure 7: Critical Crevice Corrosion Temperature per ASTM G48C vs. PRE_N [5, 8]

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).

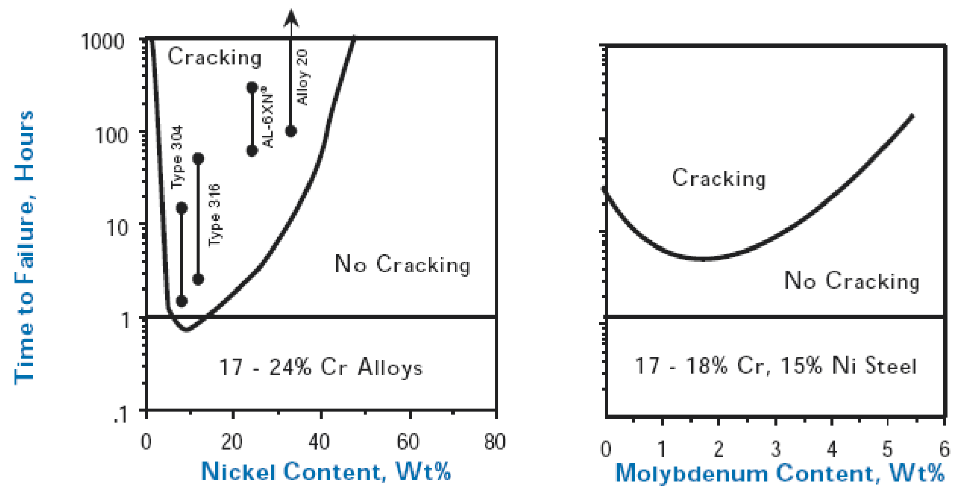

Figure 9: Effect of nickel (left) and molybdenum (right) on SCC resistance in boiling magnesium chloride solutions [13]

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.

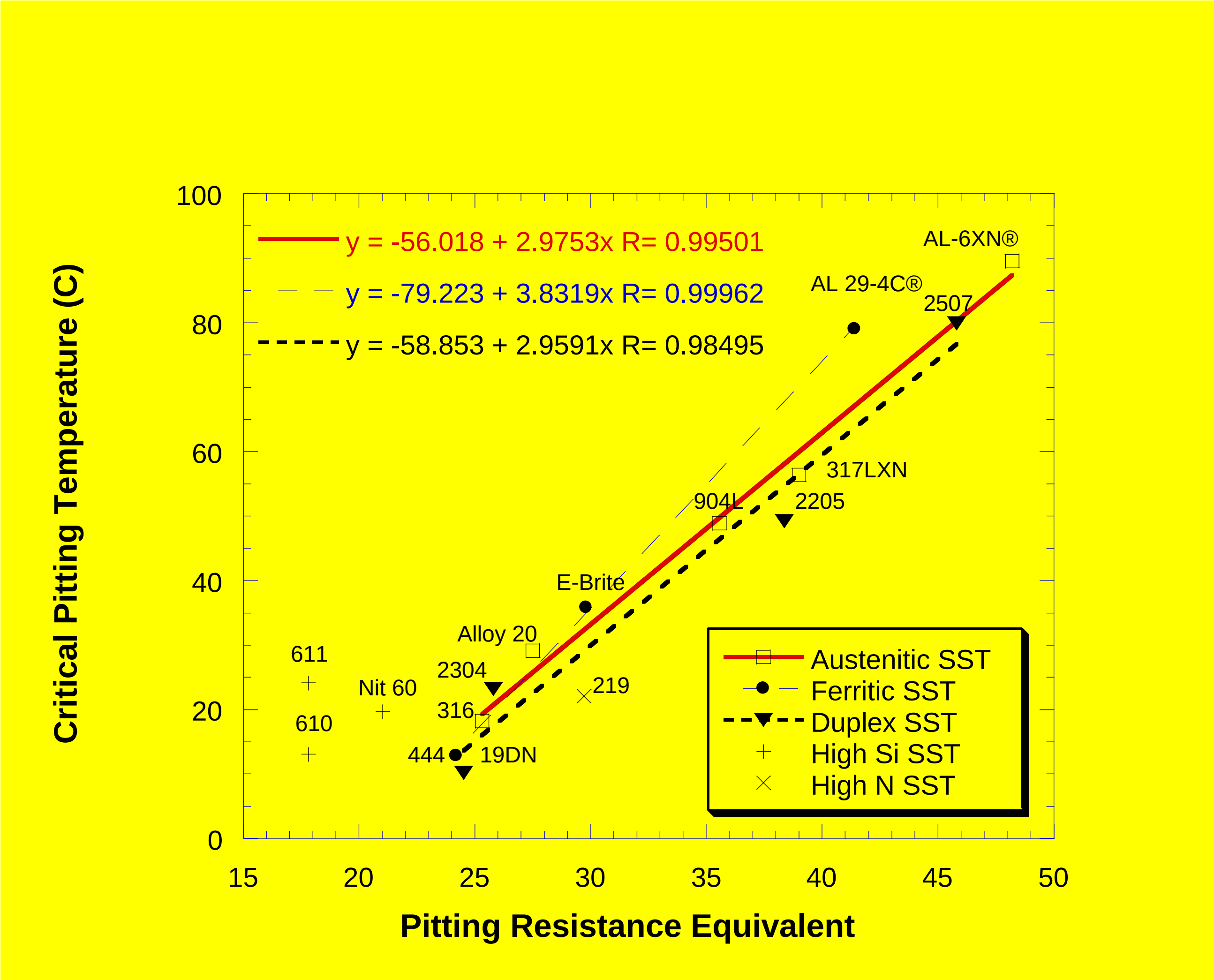

Figure 10: Critical Pitting Temperature as a function of Pitting Resistance Equivalent (PRE) number for austenitic, duplex, and ferritic stainless alloys. [15]

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:

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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.

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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.

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