

DESIGNER

HANDBOOK

S TAINLESS

STEEL IN

WATER

HANDLING

& DELIVERY

SYSTEMS



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INTRODUCTION

Stainless steel is not a single alloy, but rather the name applies to a group of iron based alloys containing a minimum 10.5% chromium. Other elements are added and the chromium content increased to improve the corrosion resistance, improve heat resisting properties, enhance mechanical properties, and/or to improve fabricating characteristics. There are over 50 stainless steel grades that were originally recognized by the American Iron and Steel Institute (AISI). Three general classifications are used to identify stainless steel. They are: 1. Metallurgical structure. 2. The AISI numbering system (200, 300 and 400 series numbers). 3. The Unified Numbering System, which was developed by the American Society for Testing Materials (ASTM) and the Society of Automotive Engineers (SAE) to apply to all commercial metals and alloys.

The various types of stainless steel are detailed in a designer handbook, "Design Guideline for the Selection and Use of Stainless Steel," available from the Specialty Steel Industry of North America (SSINA). Several other publications are also available, including: "Stainless Steel Fabrication," "Stainless Steel Fasteners," "Stainless Steel Finishes," "Stainless Steel Specifications," to mention a few. To order these free publications, or a list of all SSINA literature, call our toll-free number: 1-800-928-0355

Historically, stainless steels have established themselves as excellent corrosion resistant materials exhibiting superior performance in a variety of water-related applications in the food, drug, brewing and biotechnology industries.

Stainless steel has been extensively used for potable water service since the mid-1960s in domestic plumbing installations in the U.S., U.K., Germany and Japan; in desalination plants for handling product water; in potable water treatment plants for gravity filtration and piping; in Japan for small diameter household connectors; and in New York City for large diameter risers and other piping systems.

This handbook is intended to update the variety of water handling/delivery applications that are, or, should be utilizing stainless steel; particularly in view of the recent NSF International *acceptance of stainless steel in potable water applications*. Stainless steel is an accepted material as listed in Appendix "C" of ANSI/NSF Standard #61 "Drinking Water System Components - Health Effects." Copies of ANSI/NSF 61 are available from NSF International (1-800-NSF-MARK).

BACKGROUND

Stainless steel owes its stainless characteristics to an adherent, durable chromium oxide layer only a few angstroms thick. This passive film of chromium oxide forms almost instantly in air or water and is self replenishing when scratched or damaged. Stainless steels are easy to fabricate and join, employing compression, capillary or weld fittings, although the techniques are somewhat different than those employed for carbon steel or copper.

An extensive use of stainless steel piping for potable water has been for product water from desalination plants in the U.S., the Caribbean, and the Middle East. Types 304L and 316L are used for collection troughs in the plant and for piping in the blending plant where the high purity product water is blended with locally available groundwaters.

Subsequent to a decade of testing, the Tokyo Water Bureau has pioneered the use of stainless steel for the connector piping from the submain in the street to the meter at the dwelling, primarily to reduce leakage rates. By 1997, all dwellings in the city of Tokyo are scheduled to be served by stainless steel pipe connectors. Tokyo has also initiated the use of stainless steel piping on bridges as a means to circumvent troublesome pipelines originally installed under rivers where needed repairs are extremely difficult to complete.

Based upon a 15-year evaluation of candidate materials, New York City initiated substantial use of stainless steel (304L) in municipal water distribution systems for the large diameter risers in water tunnel 3, stage 1, which went into service in 1993. Even more extensive use of stainless steel piping is under way in stage 2. Stainless steel piping is being used selectively for sections that are difficult to replace and in which maximum durability is desired.

Stainless steel was introduced for use in the large central-control gravity filters in water treatment plants in 1965 and has since been used in more than 75 plants.

Stainless steel piping has been employed instead of ductile iron in more than 30 potable water treatment plants, largely because of cost savings achieved. As an example, the savings attributed to the use of stainless over ductile iron were estimated at \$50,000 for the Taunton, MA, potable water treatment plants.

Extensive testing over a 10-year period in Tokyo soils convinced Japanese utility personnel that T316L piping could be buried without external protection. This study confirmed earlier tests conducted in the U.S. by the National Bureau of Standards under auspices of the American Iron & Steel Institute. Other tests and experience indicate that stainless steels perform well in well-drained soils with clean backfill, but in poorly drained soils or backfill; the practices designed for carbon steel (wrap or cathodic protection) should be employed for buried stainless steel piping.

ALLOYS

The following grades of stainless steel are used in water handling applications:

Grade	UNS	C Max	Chromium	Nickel	Molybdenum	Y.S. (ksi)	T.S. (ksi)	E (%)
304	S30400	.08	18.0-20.0	8.0-11.0		30	75	35
304L	S30403	.03	18.0-20.0	8.0-13.0		25	70	35
316	S31600	.08	16.0-18.0	11.0-14.0	2.0-3.0	30	75	35
316L	S31603	.03	16.0-18.0	11.0-15.0	2.0-3.0	25	70	35
Cast								
CF3	J92500	.03	17.0-21.0	8.0-12.0		30	70	35
CF8	J92600	.08	18.0-21.0	8.0-11.0		30	70	35
CF3M	J92800	.03	17.0-21.0	9.0-13.0	2.0-3.0	30	70	30
CF8M	J92900	.08	18.5-21.0	9.0-12.0	2.0-3.0	30	70	30

All of the above exhibit an austenitic metallurgical structure and are non-magnetic. T304 is referred to as the basic "18-8" alloy and is the most readily available, often specified for all purpose applications, and exhibits excellent corrosion resistance with unusually good formability. T316 is basically a 304 grade enhanced by the addition of 2-3% molybdenum for greater corrosion resistance. It is selected for long term service in aggressive industrial, chemical and seacoast atmospheres. The low carbon version of these grades is designated with an "L" after the alloy number and is commonly referenced in conjunction with the standard grade. These are referred to as "dual certified" grade; i.e., (T304/304L) and are preferred where welding is the joining method. The lower carbon improves corrosion resistance at the weld site. Dual certification provides for meeting the .03% carbon maximum while meeting the higher mechanical properties of the standard grade.

CORROSION RESISTANCE

The thin chromium oxide film to which stainless steel owes its corrosion resistance forms almost instantly in air, water, or other media containing oxygen. Dissolved oxygen is the principal constituent of water that affects the corrosion behavior of stainless steel and the effect is highly beneficial. The agitation, turbulence, and high velocity of water that are so troublesome to carbon steel, cast and ductile iron, are highly beneficial to the durability and performance of stainless steel. There is no known limit to the durability of clean stainless in clean, aerated, low chloride waters.

Conversely, under crevice corrosion conditions the important factors are cleanliness and chloride concentration. Sediment-laden water and crevices can lead to localized pitting-type attack if chlorides are present in sufficient concentrations. Below 200 mg/l chlorides, crevice corrosion of T304 stainless steel is rare in natural waters, and crevice corrosion of T316 stainless is equally rare below 1000mg/l chlorides. None the less, crevice corrosion can and sometimes does occur in waters of lower chloride content if sediment, other deposits, or manmade crevices are able to occlude and concentrate chlorides from the water.

The 2-3% molybdenum addition in both the wrought and cast versions greatly improves their resistance to localized corrosion. When corrosion of stainless does occur, it consists of one or more small pits in a very localized region. In natural water, stainless steel does not suffer general metal loss as does carbon steels. The thin, but tough, durable chromium oxide film that protects stainless steel from corrosion occasionally contains defects, and may corrode when environmental conditions become aggressive enough to take advantage of weaknesses in the film. Except for the rusting of iron particles embedded in the surface during fabrication and handling, corrosion is rare in atmospheric exposures but does occasionally occur in water or soil exposure

under unusual conditions. The beneficial effect of molybdenum in enhancing the resistance to localized corrosion in those environments where localized corrosion of T304/304L occurs should be considered.

As discussed previously, corrosion, when it occurs, is usually localized in crevice areas. Crevices can be of two types: manmade, originating from design or construction; or natural, occurring at sites formed by sediments or deposits. Typical manmade crevices might occur as the result of incomplete fusion welds, flange faces, undergaskets, or any metal to metal junctions. Attention should be directed to eliminating manmade crevices through design and during construction. Naturally occurring crevices from sediment can be reduced by high flow rates or, when design or operating conditions are such that sediment deposits may occur, a practice of periodic flushing with a high pressure water stream should be employed and prior design should provide for the necessary flushing ports.

Another natural occurring crevice is the underdeposit crevice formed by black Fe-Mn deposits in some high Mn-Fe raw water lines when an oxidant such as chloride or potassium permanganate is employed. This deposit is normally benign to T304L stainless steel, but has resulted in serious underdeposit crevice corrosion near welds in the presence of free chloride and where heat tint oxide scale from welding has not been removed. The removal or prevention of heat tint scale will minimize this type of under deposit corrosion. Heat tint may be prevented by employing very tight fit-ups and using an internal inert gas purging equipment that excludes essentially all oxygen.

Stainless steel performs best in clean, flowing water, i.e., flow rates greater than 1.5 to 2 ft/s. The minimum design flow rate in raw water is 3ft/s to reduce sediment deposition.

WELDING

The low ("L" .03 max) carbon versions of T304 and T316 in both wrought and cast compositions are used for welded applications such as piping or anticipated repair/rebuild at some future time. Utilization of the low carbon grades ensures that the heat of welding will not sensitize the heat affected zone (HAZ) of the weld to intergranular corrosion. Sensitization is the term used to describe the reduction in corrosion resistance that occurs in the conventional (.08 max C) grade stainless steel in some environments because of the precipitation of carbides during welding in the HAZ adjacent to welds.

The precipitated carbides are combined with Chromium thereby depleting the adjacent areas of this vital element which provides for the durable, tough passive film. Sensitization is unlikely to lead to intergranular corrosion in most atmospheric and fresh water exposures, but it can lead to attack in aggressive (high sediment, high chloride) environments where the depleted regions act as point defects disrupting the continuous passive film.

If heat tint is not prevented from forming, it should be removed by pickling, grinding with an abrasive tool such as a rotating silicon carbide impregnated fiberbrush or electropolishing. Rather complex pipe sections of stainless steel piping are routinely cleaned in the field via grinding, pickling or electropolishing.

OTHER JOINING METHODS

The bulk of the aforementioned technical information presented has assumed welding to be employed for joining and therefore addressed potential problems associated with pipe greater than 2" NPS or section sizes exceeding .062".

When extending water handling and delivery systems further downstream at 2" NPS or less, additional joining systems become available, specifically compression and capillary fittings which employ non-metallic O-Rings and soldering respectively.

Standard O.D. pipe sizes through 2" at .049" wall are available with associated compression fittings. This system requires no flame as with welding or soldering; no cutting oils, chips or preparation times as with threading or flanging. The system simply consists of cutting pipe to a predetermined length, insertion into a coupling/fitting followed by pressing the coupling with a pneumatic tool as provided by the manufacturer.

Stainless steel tubing is also available in O.D.'s equivalent to copper water tube through 2" at wall thickness representing a 50% reduction in thickness when compared to type L copper water tube. Joining is accomplished via soldering by employing copper fittings, manufactured to ANSI standards, lead free solders such as "95-5" (Tin - Antimony) and fluxes bases upon phosphoric acid or water soluble chloride based fluxes which mandate internal flux removal by flushing subsequent to joint completion.

ADVANTAGES TO STAINLESS STEEL

Stainless steel does not require a corrosion allowance as is needed for ductile cast iron and carbon steel and thereby permits the selection of minimum thickness solely based on structural strength and pressure requirements. An added advantage is the reduction in weight of tube and pipe and their ability to be transported and installed manually in lieu of expensive machinery such as backhoes or cranes for trench site operations.

The ANSI/NSF standard confirms that stainless steels are highly resistant to leaching of any species that might contaminate potable water. The excellent performance offered by stainless steel depends on factors different from those that influence the performance of ductile cast iron, galvanized or coated steel, or copper alloys in potable waters. This guide has been developed to assist design engineers and operators in avoiding problems that have occurred with stainless steel so that the excellent performance of stainless steel can be realized.

SPECIFICATIONS

Pipe is usually specified to AWWA C220 which allows the use of either ASTM A312 or A778 or A269 (see Table 1). Fittings are usually specified to ASTM A403 or A774.

Table 1 SPECIFICATION REQUIREMENTS

Specifications

Pipe/Tube Form	A312 Welded & Seamless	A778 Welded	AWWA C220(1) T034L & T316L Welded & Seamless	A-269 304/304L Welded	A-778 A-269 Dimensions T304/304L Welded
Size	NPS 1/4"-30"	3-48" O.D.	4" & Greater	NPS 3/4", 1", 1-1/4", 1-1/2", 2"	5/8", 7/8", 1-1/8", 1-3/8", 1-5/8", 2-1/8"
Wall Thickness	Schedule 5S-80S	.062-0.5"	(1)	.049	.020", .0225", .025", .0275", .030", .035"
Solution Anneal	Required	As welded	(1)	Required	As welded
Mechanical Test	Tensile & Face Bend	Tensile & welded guided bend	(1)	Hardness Flange Reverse Flatten	Hardness Flange Reverse Flatten
Hydrostatic Test	Required	Optional	(1)	Required	Required
Filler Metal	Autogenous/ Matching	Matching	(1)	Autogenous	Autogenous
Scale Removal	Required	Optional	Must specify	Required	Optional
Associated Fitting Spec	ASTM A403	ASTM A774	ASTM A403 ASTM A774	Compression self-contained O-Ring grade "E" "Vic-Press"	Copper Capillary Fittings ANSI B 16.18 ANSI B 16.22

(1) AWWA C220: Allows use of either ASTM A312 or A778.

ANSI/NSF 61

As previously mentioned, stainless steel is listed as an accepted material to this standard (see Table 2). That means in all applications involving potable water stainless steel may be used without the need to obtain approval of the material from NSF.

AWWA C220

Pipe is usually specified to AWWA C220 which allows the use of either ASTM A312 or A778 (see Table 1). Fittings are usually specified to ASTM A403 or A774. Only T304L and T316L are permitted in pipes 4" and larger; surface scale and/or heat tint removal are required.

Table 2 MECHANICAL DEVICES

Acceptable Materials

Material	Specific Designation	Standard (Product) Reference	Surface Area-to-Volume Ratio	Composition
Gray Cast Iron	Class B	ASTM A 126	473 cm ² /L (73 in ² /L)	Percent Composition ¹ : Carbon (3.20-3.55), Silicon (1.60-2.20), Phosphorus (0.40 max.), Sulphur (0.15 max.), Manganese (0.40-0.80), Chrome (0.05-0.40), Aluminum (0.005 max.), Lead (0.005 max.), Tin (0.10 max.), Iron Balance
Stainless Steel	UNS S30400 (Type 304)	ASTM A 312 ASTM A 269	3,484 cm ² /L (540 in ² /L)	Percent Composition: Carbon (0.08 max.), Manganese (2.00 max.), Phosphorus (0.040 max.), Sulfur (0.030 max.), Silicon (0.75 max.), Nickel (8.00-11.0), Chromium (18.0-20.0)
Stainless Steel	UNS S30403 (Type 304L)	ASTM A 312 ASTM A 269	3,484 cm ² /L (540 in ² /L)	Percent Composition: Carbon (0.035 max.), Manganese (2.00 max.), Phosphorus (0.040 max.), Sulfur (0.030 max.), Silicon (0.75 max.), Nickel (8.00-13.0), Chromium (18.0-20.0)
Stainless Steel	UNS S31600 (Type 316)	ASTM A 312 ASTM A 269	3,484 cm ² /L (540 in ² /L)	Percent Composition: Carbon (0.08 max.), Manganese (2.00 max.), Phosphorus (0.040 max.), Sulfur (0.030 max.), Silicon (0.75 max.), Nickel (11.00-14.0), Chromium (16.0-18.0), Molybdenum (2.0-3.0)
Stainless Steel	UNS S31603 (Type 316L)	ASTM A 312 ASTM A 269	3,484 cm ² /L (540 in ² /L)	Percent Composition: Carbon (0.035 max.), Manganese (2.00 max.), Phosphorus (0.040 max.), Sulfur (0.030 max.), Silicon (0.75 max.), Nickel (10.0-15.0), Chromium (16.0-18.0), Molybdenum (2.0-3.0)

¹ Chemical content will vary from those shown, depending upon wall thickness and other characteristics of castings to be poured from melt, to ensure desired physical properties of the iron in the castings.

ASTM SPECIFICATIONS

The American Society for Testing Materials covers stainless steel in its specifications. The most common are listed below:

Pipes

ASTM A312

Standard specification for seamless and welded austenitic stainless steel pipes.

This specification covers seamless and straight-seam welded austenitic stainless steel pipe intended for high-temperature and general corrosive service.

Pipe Fittings

ASTM A403

Standard specification for wrought austenitic stainless steel pipe fittings.

This specification covers two general classes, WP and CR, of wrought austenitic stainless steel fittings of seamless and welded construction covered by the latest revision of ANSI B16.9, ANSI B16.11, ANSI B16.28, MSS Standard Practice SP-79, MSS Standard Practice SP-43 and MSS SP-95.

ASTM A774

Standard specification for as-welded wrought austenitic stainless steel fitting for general corrosion service at low or moderate temperature.

This specification covers five grades of as-welded wrought austenitic stainless steel fittings for low-pressure piping and intended for low and moderate temperatures and general corrosive service.

Tubular Products

ASTM A778

Standard specification for welded, unannealed austenitic stainless steel tubular products.

This specification covers straight seam and spiral butt seam welded unannealed austenitic stainless steel tubular products intended for low and moderate temperatures and corrosive service where heat treatment is not necessary for corrosion resistance.

ASTM A269

Standard specification for seamless and welded austenitic stainless steel tubing for general service.

This specification covers grades of nominal-wall-thickness, stainless steel tubing for general corrosion-resistance and low- or high-temperature service.

Joints and Fittings

Compression Fittings: Self-Contained O-Ring

Capillary Fittings: Copper Fittings; ANSI B 16.18 & B 16.22

Welding: ASME Section IX AWS B2.1

PRODUCTS

Pipe & Tube:

These products are enclosed sections used to transport or carry liquids and gases. Pipe was the first type of product made for these purposes and has looser dimensional tolerances. Outside diameter and wall thickness can vary more in pipe than in tube. Tubing is more refined with tighter tolerances on the diameter and wall thickness. Pipe is usually a pressure or mechanical type product. Tubing can be pressure, mechanical, structural, ornamental, etc.

Stainless steel pipe and tube are produced by several companies in various size ranges (see *Table 3*).

Pumps, Valves, Flanges, Castings:

The transfer or delivery of liquids, particularly water, requires equipment for moving and controlling, in addition to the use of pipes and tubes for transmission. There are many different types of these products and many of them are manufactured out of stainless steel. Once again, if stainless steel is used in conjunction with drinking water, the material in the specific component is already accepted by the ANSI/NSF 61 standard.

The American Water Works Association (AWWA - 6666 W. Quincy Ave., Denver, CO 80235 Tel: 303-794-7711) has a product directory that lists manufacturers and suppliers.

Applications

- Commercial Building Water Supply Systems
- Household Plumbing Systems
- Municipal Potable Water Treatment Plants
- Wastewater Treatment Plants
- Hydroelectric Plants
- Dams, Locks, Gates
- Pipes for River Crossings

SUGGESTIONS ON FABRICATION OF PIPING SYSTEMS

Quality work in the fabricating shop and during erection and particularly field welding is essential for a quality job. Whenever possible compression fitting or capillary fitting should be used. If welding is required, utilize reputable organizations with experience with stainless steel. Minimum fabrication requirements should include the following:

- Proof of acceptable welding procedure specifications for the work to be performed and verified welder performance qualifications. The engineer and/or customer should review and verify both. Suggested guides are ASME Section IX and AWS B2.1
- Require full penetration welds, free of cracks, overlaps and cold laps.
- Limit weld reinforcement and concave root (1/16 in. (1.6 mm) or as agreed).
- Limit on undercut 1/32 in. (0.8 mm) or 10% on base metal thickness, whichever is less.
- Require prevention or removal of heat tint on all water side surfaces.
- Provide for secure end closure after welding to remain in place until final assembly.

TESTING AND MAINTENANCE

- Provide for prompt and complete drainage of the piping system after hydrostatic testing.
- Establish a schedule to flush out sediment and debris on the horizontal runs of raw water piping.
- During downtimes, drain completely and dry or, alternatively, circulate water for one hour every two days.
- Check for manganese/iron deposits in raw water lines going to green sand filters and flush or hydroblast to clean as needed.
- Provide proper ventilation to avoid high chlorine vapor areas.

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(Note: NiDI has workshops and other technical publications on water and water handling applications)

Steel Service Center Institute

Key Center - Suite 2400
127 Public Square,
Cleveland, OH 44114-1216
216-694-3940

(Note: Steel service centers stock stainless steel pipe and tube products)

REFERENCES

ANSI/NSF 61

NSF International

3475 Plymouth Road
P.O. Box 130140
Ann Arbor, MI 48113-0140
800-NSF-MARK

ASTM Specifications Volume 01.01

American Society for Testing Materials

1916 Race Street
Philadelphia, PA 19103-1187

Table 3 **A LISTING OF STAINLESS STEEL PIPE AND TUBE MANUFACTURERS**
(not all inclusive)

Company	Location	Outside Diameter Wall Size Range
A.T. Wall Cos.	Warwick, RI	Up to 6" OD .003" - 1/2" Wall
Acme Tube Corp.	So. Bound Brook, NJ	1/4" - 8" OD .020" - 1/2" Wall
AI Tech Specialty Steel Corp.	Watervliet, NY	1.050" - 5.500" OD .065" - 1.250" Wall
Allegheny Ludlum	Claremore, OK	5/8" - 3" OD .025" - .109" Wall
Associated Tube	Markham, ONT, Canada	3/16" - 6 5/8" OD .010" - .265" Wall
Avesta Sheffield	Schaumburg, IL	1/2" -50" OD .049" - 2" Wall
Bristol Metals, Inc.	Bristol, TN	.840" - 96" OD .065" - .750" Wall
Carpenter Tech. Corp. <i>(Special Products Div.)</i>	El Cajon, CA	.060" - 15" OD 002" - .200" Wall
Consolidated Stainless, Inc.	Auburndale, FL	.840" -10.750" OD .065" - .237" Wall
Damascus-Bishop Tube Co.	Greenville, PA	1/4" - 8-5/8" OD .028" - .350" Wall
Davis Pipe & Metal Fabrication, Inc.	Bountville, TN	2" - 12" IPS 14" - 48" OD .078" - .375" Wall
DMV Stainless USA.	Houston, TX	1/2" - 4-1/2" OD 049" - .600" Wall