

# **Guide for Welding Austenitic Stainless Steel Piping and Tubing**



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**An American National Standard**

**Approved by the**  
**American National Standards Institute**  
**March 24, 2023**

# **Guide for Welding Austenitic Stainless Steel Piping and Tubing**

**5th Edition**

**Revises AWS D10.4-86**

Prepared by the  
American Welding Society (AWS) D10 Committee on Piping and Tubing

Under the Direction of the  
AWS Technical Activities Committee

Approved by the  
AWS Board of Directors

## **Abstract**

This document presents a detailed discussion of the metallurgical characteristics and weldability of many grades of austenitic stainless steel used in piping and tubing. The delta ferrite content as expressed by Ferrite Number (FN) is explained, and its importance in minimizing hot cracking is discussed.

Several figures and tables illustrate recommended joint designs and procedures. Annex A presents information on the welding of high-carbon stainless steel cast pipe and fittings.



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# Foreword

This foreword is not part of this standard but is included for informational purposes only.

This guide is intended to provide information that may be used to avoid, or at least minimize, difficulties in welding austenitic stainless steel piping and tubing. The term pipe used in the text also includes tube. Cast chromium-nickel stainless steel pipe with carbon content above 0.20 percent requires practices different from the austenitic stainless steels, therefore they are covered in Annex A.

The first document on this subject was approved by the AWS Board of Directors in August 1955 under the title, *The Welding of Austenitic Chromium-Nickel Steel Piping and Tubing, A Committee Report* and published as AWS D10.4-55T. This version was revised in 1966.

In 1979, a major updating of the document was completed and published as AWS D10.4-79, *Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing*. This version presented a detailed discussion of the role of delta ferrite in austenitic chromium-nickel steel welds.

In 1986, the document further expanded and refined this information. In addition, an annex was added that gives recommendations for welding high-carbon stainless steel castings.

This edition provides updated information based on current industry standards, material selections, and welding practices.

The evolution of AWS D10.4M/D10.4, *Guide for Welding Austenitic Stainless Steel Piping and Tubing*, is shown below:

|                       |                                                                                                       |
|-----------------------|-------------------------------------------------------------------------------------------------------|
| D10.4-55T             | <i>The Welding of Austenitic Chromium-Nickel Steel Piping and Tubing</i>                              |
| AWS D10.4-66          | <i>Welding of Austenitic Chromium-Nickel Steel Piping and Tubing</i>                                  |
| AWS D10.4-79          | <i>Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing</i> |
| ANSI/AWS D10.4-86     | <i>Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing</i> |
| ANSI/AWS D10.4-86R    | <i>Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing</i> |
| AWS D10.4M/D10.4:2023 | <i>Guide for Welding Austenitic Stainless Steel Piping and Tubing</i>                                 |

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D10 Committee on Piping and Tubing, American Welding Society, 8669 NW 36 St., # 130, Miami, FL 33166. A formal reply will be issued after it has been reviewed by the appropriate personnel following established procedures.

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# Guide for Welding Austenitic Stainless Steel Piping and Tubing

## 1. General Requirements

**1.1 Scope.** This guide for welding austenitic stainless steel pipe is primarily for the welding of piping systems used for the distribution of fluids and gases, where smooth continuous flow of product is the desired result. It is written for welders, engineers, and management to provide the essential knowledge for successful welding of these materials using manual, semiautomatic, automated, mechanized, and orbital welding techniques and processes.

Austenitic, superaustenitic, and high carbon stainless steels are readily weldable when the proper procedures and techniques are followed. They can be joined by most of the fusion welding processes, and good pipe welders can adapt very quickly from carbon steel or low-alloy steel to stainless steel. Orbital pipe welding is also adaptable to these materials and is commonly used for high quality repeatable welds in critical applications.

This guide can be used by any competent pipe welder in any good shop or field site. Reasonable care is required, as in any pipe welding operation; however, careful adherence to the welding procedure requirements will usually produce excellent welds in stainless steel piping and tubing.

Although this guide is not written with mandatory requirements, mandatory language, such as the use of “shall,” will be found in those portions of the document where failure to follow the instructions or procedures could produce inferior, misleading, or unsafe results.

**1.2 Units of Measurement.** This standard makes use of both the International System of Units and U.S. Customary Units. The latter are shown within brackets ([ ]) or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

To identify nominal pipe sizes in both SI and U.S. Customary Units, the following designations are used:

- (1) DN (Diameter Nominal) is the SI designation, and
- (2) NPS (Nominal Pipe Size) is the U.S. Customary designation.

**1.3 Safety.** Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety

and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

## 2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments or revisions of the publications may not apply since the relevant requirements may have changed.

American Welding Society standard:

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*

American National Standards Institute (ANSI) standard:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

## 3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document.

**discoloration.** Any change in surface color from that of the base metal, usually associated with oxidation. Discoloration may occur on the weld, heat-affected zone, or base metal of the weld joint such as a result of heating the metal during welding. Discoloration begins with a pale yellow color. As the oxide thickness increases, the yellow darkens, turning successively orange, brown-red, blue, purple, brown, then grey until ultimately forming into an opaque grey/brown film.

**heat tint.** A nonstandard term for **discoloration**.

## 4. Material Compositions and Specifications

**4.1 Compositions.** Chemical composition ranges and type numbers for those stainless steels generally available in wrought piping and tubing are listed in Table 4.1. These are American Iron and Steel Institute (AISI) standard compositions. Chemical composition ranges and designations for stainless steels generally available as cast pipe are shown in Table 4.2. These are included because cast valves and fittings are considered part of a piping system.

The weldability of castings may be somewhat less than that of a wrought stainless steel of the same type. This is because fully austenitic castings have much larger grains than similar wrought material. Consequently, there is less grain boundary area along which to disperse the impurities. As a result, there may be a tendency toward hot cracking when welding some castings. Hot cracking can be minimized by controlling the composition of the casting to a minimum 4 Ferrite Number (FN) when possible (see 7.2 for detailed discussion of FN).

**4.2 Specifications.** Typical American Society for Testing and Materials (ASTM) specifications covering piping and tubing in both cast and wrought form (seamless or welded) are summarized in Table 4.3. For a more complete listing of references, see Annex B. ASTM employs the AISI type numbers for designating the austenitic types. However, the ASTM chemical composition requirements differ slightly from the AISI requirements and will vary slightly in different ASTM specifications. The composition ranges specified for cast tubular products are identical with those of the American Castings Institute (ACI). Specifications for covered welding electrodes and welding rods and electrodes are provided in 6.2.

**Table 4.1**  
**Common Types of Chromium-Nickel Stainless Steel Available in Piping and Tubing**

| Type                 | Nominal Chemical Composition, % <sup>a</sup> |      |      |           |                 |       |      | Other Elements                          |
|----------------------|----------------------------------------------|------|------|-----------|-----------------|-------|------|-----------------------------------------|
|                      | C                                            | Mn   | Si   | Cr        | Ni <sup>b</sup> | P     | S    |                                         |
| 304                  | 0.08                                         | 2.00 | 1.00 | 18.0–20.0 | 8.0–10.5        | 0.045 | 0.03 | —                                       |
| 304H                 | 0.04–0.10                                    | 2.00 | 1.00 | 18.0–20.0 | 8.0–10.5        | 0.045 | 0.03 | —                                       |
| 304L                 | 0.03                                         | 2.00 | 1.00 | 18.0–20.0 | 8.0–12.0        | 0.045 | 0.03 | —                                       |
| 304LN                | 0.035                                        | 2.00 | 1.00 | 18.0–20.0 | 8.0–10.5        | 0.045 | 0.03 | N 0.10–0.15                             |
| 304N                 | 0.08                                         | 2.00 | 1.00 | 18.0–20.0 | 8.0–10.5        | 0.045 | 0.03 | N 0.10–0.16                             |
| 305                  | 0.12                                         | 2.00 | 1.00 | 17.0–19.0 | 10.5–13.0       | 0.045 | 0.03 | —                                       |
| 308                  | 0.08                                         | 2.00 | 1.00 | 19.0–21.0 | 10.0–12.0       | 0.045 | 0.03 | —                                       |
| 309                  | 0.20                                         | 2.00 | 1.00 | 22.0–24.0 | 12.0–15.0       | 0.045 | 0.03 | —                                       |
| 309S                 | 0.08                                         | 2.00 | 1.00 | 22.0–24.0 | 12.0–15.0       | 0.045 | 0.03 | —                                       |
| 310                  | 0.15                                         | 2.00 | 1.00 | 24.0–26.0 | 19.0–22.0       | 0.045 | 0.03 | —                                       |
| 310S                 | 0.08                                         | 2.00 | 1.00 | 24.0–26.0 | 19.0–22.0       | 0.045 | 0.03 | —                                       |
| 316                  | 0.08                                         | 2.00 | 1.00 | 16.0–18.0 | 10.0–14.0       | 0.045 | 0.03 | Mo 2.0–3.0                              |
| 316H                 | 0.04–0.10                                    | 2.00 | 1.00 | 16.0–18.0 | 10.0–14.0       | 0.045 | 0.03 | Mo 2.0–3.0                              |
| 316L                 | 0.03                                         | 2.00 | 1.00 | 16.0–18.0 | 10.0–14.0       | 0.045 | 0.03 | Mo 2.0–3.0                              |
| 316LN                | 0.03                                         | 2.00 | 1.00 | 16.0–18.0 | 10.0–14.0       | 0.045 | 0.03 | Mo 2.0–3.0<br>N 0.10–0.3                |
| 316N                 | 0.08                                         | 2.00 | 1.00 | 16.0–18.0 | 10.0–14.0       | 0.045 | 0.03 | Mo 2.0–3.0<br>N 0.10–0.16               |
| 317                  | 0.08                                         | 2.00 | 1.00 | 18.0–20.0 | 11.0–15.0       | 0.045 | 0.03 | Mo 3.0–4.0                              |
| 317L                 | 0.035                                        | 2.00 | 1.00 | 18.0–20.0 | 11.0–15.0       | 0.045 | 0.03 | Mo 3.0–4.0                              |
| 321                  | 0.08                                         | 2.00 | 1.00 | 17.0–19.0 | 9.0–12.0        | 0.045 | 0.03 | Ti 5 × % C min.;<br>0.70 max.           |
| 321H                 | 0.04–0.10                                    | 2.00 | 1.00 | 17.0–19.0 | 9.0–12.0        | 0.045 | 0.03 | Ti 4 × % C min.;<br>0.70 max.           |
| 347                  | 0.08                                         | 2.00 | 1.00 | 17.0–19.0 | 9.0–13.0        | 0.045 | 0.03 | Nb 10 × C min.                          |
| 347H                 | 0.04–0.10                                    | 2.00 | 1.00 | 17.0–20.0 | 9.0–13.0        | 0.045 | 0.03 | Nb 8 × C min. –1.0                      |
| 348                  | 0.08                                         | 2.00 | 1.00 | 17.0–19.0 | 9.0–13.0        | 0.045 | 0.03 | Nb 10 × C min.<br>Co 0.2<br>Ta 0.10     |
| 348H                 | 0.04–0.10                                    | 2.00 | 1.00 | 17.0–20.0 | 9.0–13.0        | 0.045 | 0.03 | Nb 8 × C min. –1.0<br>Co 0.2<br>Ta 0.10 |
| 904L                 | 0.02                                         | 2.0  | 1.0  | 19.0–23.0 | 23.0–28.0       | 0.03  | 0.01 | Cu 1.0–2.0<br>Mo 4.0–5.0                |
| AL-6XN <sup>c</sup>  | 0.03                                         | 2.0  | 1.0  | 20.0–22.0 | 23.5–25.5       | 0.03  | 0.01 | Mo 6.0–7.0<br>N 0.18–0.25               |
| 254 SMO <sup>d</sup> | 0.02                                         | 1.0  | 0.8  | 19.5–20.5 | 17.5–18.5       | 0.01  | 0.01 | Cu 0.5–1.0<br>Mo 6.0–6.5<br>N 0.18–0.22 |

Note: Additional materials are described in AWS G2.3M/G2.3, *Guide for the Joining of Solid Solution Austenitic Stainless Steels*.

<sup>a</sup> Single values are maximums.

<sup>b</sup> For some tube making processes, the nickel content of certain austenitic types must be slightly higher than shown.

<sup>c</sup> AL-6XN<sup>®</sup> (UNS Number N08367) is a registered trademark of Allegheny Technologies (ATI).

<sup>d</sup> 254 SMO (UNS Number S31254) is a registered trademark of Outokumpu.

**Table 4.2**  
**Types of Chromium-Nickel Stainless Steel Castings**

| ASTM <sup>b</sup><br>Designation | Nominal<br>Composition | Chemical Composition, % <sup>a</sup> |     |       |       |      |           |           | Other Elements |
|----------------------------------|------------------------|--------------------------------------|-----|-------|-------|------|-----------|-----------|----------------|
|                                  |                        | C                                    | Mn  | P     | S     | Si   | Cr        | Ni        |                |
| CF3                              | 19-9                   | 0.03                                 | 1.5 | 0.04  | 0.04  | 2.00 | 17.0-21.0 | 8.0-12.0  | —              |
| CF8                              | 19-9                   | 0.08                                 | 1.5 | 0.04  | 0.04  | 2.00 | 18.0-21.0 | 8.0-11.0  | —              |
| CF8M                             | 19-10-2Mo              | 0.08                                 | 1.5 | 0.04  | 0.04  | 2.00 | 18.0-21.0 | 9.0-12.0  | 2.0-3.0 Mo     |
| CF3M                             | 19-10-2Mo              | 0.03                                 | 1.5 | 0.04  | 0.04  | 1.50 | 17.0-21.0 | 9.0-13.0  | 2.0-3.0 Mo     |
| CH8                              | 25-12                  | 0.08                                 | 1.5 | 0.040 | 0.040 | 1.50 | 22.0-26.0 | 12.0-15.0 | —              |
| CPK20                            | 25-19                  | 0.20                                 | 1.5 | 0.040 | 0.040 | 1.00 | 23.0-27.0 | 19.0-22.0 | —              |
| CPH20 or<br>CPH10                | 25-12                  | 0.20                                 | 1.5 | 0.040 | 0.040 | 2.00 | 22.0-26.0 | 12.0-15.0 | —              |

<sup>a</sup> Single values are maximums.

<sup>b</sup> American Society for Testing and Materials.

Note: Chromium-nickel stainless steel castings with carbon content above 0.20% are covered in Annex A.

**Table 4.3**  
**ASTM Specifications Applicable to Austenitic Stainless Steel  
Piping and Tubing Components**

| Specification Designation | Product                                                                                                                        |
|---------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| A213/A213M                | Seamless ferritic and austenitic alloy steel boiler, superheater, and heat-exchanger tubes                                     |
| A249/A249M                | Welded austenitic steel boiler, superheater, heat-exchanger, and condenser tubes                                               |
| A269/A269M                | Seamless and welded austenitic stainless steel tubing for general service                                                      |
| A270/A270M                | Seamless and welded austenitic stainless steel sanitary tubing                                                                 |
| A312/A312M                | Seamless and welded austenitic stainless steel pipe                                                                            |
| A351/A351M                | Austenitic steel castings for valves, flanges, fittings, and other pressure-containing parts                                   |
| A358/A358M                | Electric fusion welded austenitic chromium-nickel alloy steel pipe for high-temperature service                                |
| A376/A376M                | Seamless austenitic steel pipe for high temperature central-station service                                                    |
| A403/A403M                | Wrought pipe fittings                                                                                                          |
| A409/A409M                | Welded large outside diameter light-wall austenitic chromium-nickel alloy steel pipe for corrosive or high-temperature service |
| A451/A451M                | Centrifugal cast austenitic steel pipe for high-temperature service                                                            |
| A688/A688M                | Welded tubes                                                                                                                   |

## 5. Base Metals

**5.1 Primary Types (304, 309, and 310).** These materials have many applications and are widely used for their corrosion and oxidation resistance, high-temperature strength, and low-temperature properties. However, there are several welding-related characteristics that may affect all of these, as noted below.

These materials may become sensitized by welding, depending on carbon content and the manner in which it is welded, such as with high heat input processes. Sensitization occurs when unstabilized or high carbon stainless steels are held in a temperature range between 425 °C and 815 °C [800 °F and 1500 °F], as occurs during welding. Within this exposure time, chromium carbides may be precipitated in the grain boundaries, leaving adjacent areas deficient in chromium. These grain boundaries are subject to accelerated corrosion under specific conditions, resulting in intergranular attack. As this is a time and temperature dependent phenomenon, minimizing heat input and reduced interpass temperatures are often recommended to reduce sensitization during welding. The application of a solution annealing heat treatment will restore resistance to intergranular attack (see 12.2 for detailed discussion of this form of corrosive attack). However, these steels often are used in the as-welded condition when intergranular attack is not a concern. Low carbon grades may be used to minimize sensitization.

**5.2 Chromium-Nickel-Molybdenum Types (316 and 317).** The addition of molybdenum is used to improve the pitting and crevice corrosion resistance of the chromium-nickel alloys and does not alter their welding characteristics in any significant way. However, the welds themselves may display slightly greater susceptibility to intergranular corrosion in sensitized heat-affected zones than Type 304 in nitric acid service. Molybdenum reduces the resistance of stainless steel to corrosion by nitric acid.

**5.3 Stabilized Types (321, 347, and 348).** Titanium, niobium, and tantalum are carbide stabilizing elements. During the steel making process, they combine with carbon before chromium does. Thus, in subsequent welding, the formation of chromium carbides is minimized reducing the potential for sensitization. As a result, these alloys are often considered resistant to stress corrosion cracking or other corrosion mechanisms that are exacerbated by sensitization.

However, during welding, a very narrow zone immediately adjacent to the fusion line, in the heat-affected zone (HAZ) of the weld, is heated to a temperature high enough to dissolve almost all of the titanium, niobium, and tantalum carbides. If the welded joint is subsequently heated to a temperature of approximately 650 °C [1200 °F], chromium carbides will precipitate at the grain boundaries. Thus, the conditions are set up for what is known as “knife line attack” in a corrosive environment.

Knife line attack can be prevented by reheating the welded joint to a temperature of 870 °C [1600 °F]. At this temperature, titanium, niobium, and tantalum carbides precipitate in preference to chromium carbides as their solubility temperature is lower than that of chromium carbide. This is called a “stabilizing heat-treatment” since it does not impair the corrosion resistance of the steel.

Type 321 is stabilized with titanium while 347 and 348 are stabilized with niobium and tantalum. Type 321 displays a greater susceptibility to knife line attack than 347 and 348 because of the lowered solution temperature of titanium carbide compared with niobium carbide and tantalum carbide.

**5.3.1 Stress Relaxation Cracking (SRC).** SRC is a cracking mechanism that can occur in short periods of time in a susceptible material, such as stabilized stainless steels (Types 321 and 347) and was first used to describe cracks that form after postweld heat treatment (PWHT), where the component has never been in service.<sup>1</sup> The stress relief and stabilization temperatures for stainless steel, usually performed at 900 °C [1650 °F], can cause precipitation of niobium carbides which can result in strain-age embrittlement in areas of high stress due to precipitation of carbides on the slip plane dislocations, causing grain boundary tearing on cooling.

These cracks can likewise occur in service after fabrication, when the operating temperatures are typically above 500 °C [932 °F],<sup>2</sup> often within a few thousand hours of service.

Figure 5.1 shows a typical SRC in AISI 347 stainless steel after being in service at 600 °C to 650 °C [1112 °F to 1202 °F].

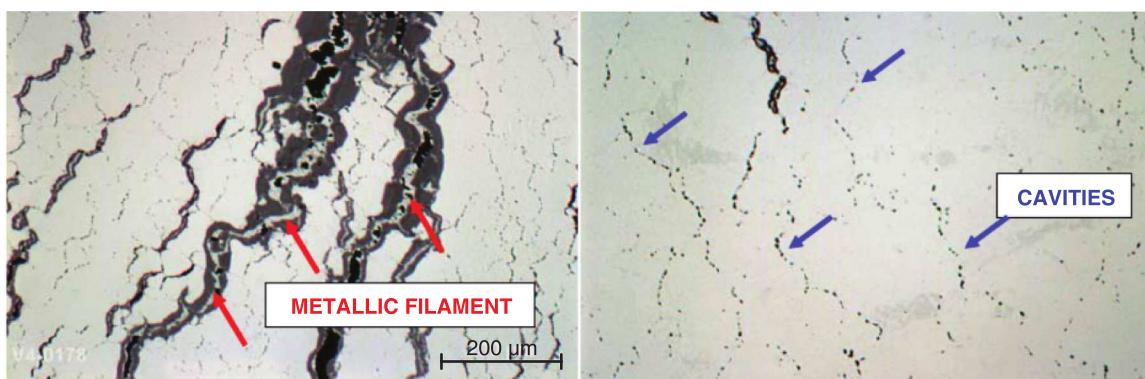


**Figure 5.1—SRC on AISI 347 Stainless Steel after Being in Service at 600 °C to 650 °C [1112 °F to 1202 °F]<sup>3</sup>**

<sup>1</sup> Fahiron E., Birke A. “Technical Basis for Improved Reliability of 347H Stainless Steel Heavy Wall Piping in Hydrogen Service,” Paper 03647, NACE (2003).

<sup>2</sup> Christian E. “Stress Relaxation Cracking of Welded Joints in Thick Sections of a TP347 Stabilized Grade of Stainless Steel,” Paper 08454, NACE (2008).

<sup>3</sup> Hans van Wortel. “Control of Relaxation Cracking in Austenitic High Temperature Components,” Paper 07423, NACE (2007).

**5.3.2 Identification of Stress Relaxation Cracking.** The following criteria identify stress relaxation cracking:

- (1) Austenitic stainless steels stabilized with niobium or titanium (321, 347, or 348) are susceptible.
- (2) Thick wall thickness (>25 mm [>1 in]) of 347 or 321 stainless steel.
- (3) Grains that are coarser than ASTM No 3.5 are more susceptible.<sup>4</sup>
- (4) Susceptibility increases with heat cycles (welding + PWHT/Stabilization HT + repairs).
- (5) Cracks are normally located at the heat-affected zone (HAZ).
- (6) A layer of chromium (Cr) and presence of iron (Fe) within the crack is always present.
- (7) Voids are always present on the tip of the crack.
- (8) It normally appears at stress intensification areas, like undercuts, weld cap reinforcement, etc.

These cracks often propagate from the nonprocess side of the equipment where stress fields are highest and it has been proven that the cracks are purely mechanical.<sup>5</sup>

**5.4 Low Carbon Types (304L and 316L).** These types are low-carbon modifications of the corresponding or primary grades. In Types 304L and 316L, an extra low carbon content (0.030% maximum) minimizes the precipitation of chromium carbide both during welding and any postweld heat treatment. This in turn preserves the corrosion resistance of the weldment.

**5.5 “H” Types (304H, 316H, 321H, 347H and 348H).** Carbon contributes to the high-temperature strength of austenitic stainless steel. Austenitic Cr-Ni steels having an extra low carbon content are not typically used in high temperature service where strength is an issue. Steels are identified with the “H” suffix for use at high temperature. In these steels, the carbon content must be held within a specified range (i.e., 0.04% to 0.10%), rather than being held at or below a maximum carbon level.

**5.6 Stainless Steels for Nuclear Service.** In most nuclear applications, the most common types of stainless steels have been 304, 304L, 316, and 316L; with the L-grades being the most common. However, problems resulting from the use of these types in certain systems of boiling water reactors resulted in the development of special nuclear grades with very low carbon, of no more than 0.020%, with the addition of nitrogen to improve strength and offset the reduction in carbon. These nuclear grade stainless steels provided an additional margin of resistance to intergranular stress corrosion cracking (IGSCC) in the boiling water reactor (BWR) environment. Specialized fabrication techniques have now been developed to minimize IGSCC with conventional materials, such as heat-sink welding and mechanical stress improvement which reduces high tensile residual stresses on the pipe inside surface reducing the potential for stress corrosion cracking. As a result of these developments, the nuclear grade materials are rarely required for most nuclear fabrication activities.

**5.7 Cast Stainless Steel.** Two casting methods are typically used for stainless steel piping components. These include centrifugal castings commonly used for tubular components and some pipe fittings, and static castings employed for most fittings and internal furnace support structures such as tube sheets. While these cast alloys retain important metallurgical properties, including high creep strength at elevated temperatures, they present several serious welding problems as outlined below:

- (1) Original as-cast and the reconditioned material has low ductility. The typical elongation of 10 percent is much lower than the 25 percent values usually found in wrought steels.
- (2) Short time exposure to 650 °C to 1000 °C [1200 °F to 1850 °F] during welding and service conditions further reduces the ductility; the average elongation decreases to about three percent and values as low as one and one-half percent have been observed.
- (3) Exposure to certain process gases at elevated temperature may carburize the steel, making it unsuitable for welding.
- (4) The radiographic acceptance standards for castings are much lower than those for wrought materials. Even the highest quality, commercially available castings contain flaws beyond the standard acceptance limit for weldments.

<sup>4</sup> See reference 2.

<sup>5</sup> See reference 1.

These cause porosity, and a form of cracking known as internal shrinkage, and occur most frequently in static castings. In most cases, it is possible to compensate for the limitations of these alloys through thorough planning, welder training, supervision, and inspection to produce serviceable joints.

**5.8 High-Carbon Cast Types (HK, HT, HU, and HP).** In many applications requiring resistance to oxidation, cast Cr-Ni austenitic heat-resisting steels are used. These castings are modifications of wrought types 304, 309, 310, 312, and 330 with carbon content increased up to as much as 0.75%.

The other types involve higher carbon content and some changes in the chromium, nickel, or chromium-nickel composition. These cast alloys are designed for higher temperature service than the primary types.

The welding of high carbon (over 0.20%) stainless steel castings requires special high-carbon electrodes to match the high-temperature strength and creep properties. In addition, special welding techniques and procedures are required for these materials to compensate for the low elongation and the aging characteristics associated with these alloys after being in high-temperature service.

Weldability of these alloys, including welding techniques, filler metal selection, and special treatments are discussed in further detail in Annex A.

**5.9 Low-Carbon Cast Types (CF3, CF8, CF8M, CF3M, CK20, and CH20).** Table 4.2 lists the most widely used types of chromium-nickel stainless steel castings with carbon contents under 0.20%. These castings, although their compositions are not identical, may be welded in the same way as their wrought equivalents.

**5.10 Superaustenitic (6% Mo; e.g., UNS Nos. N08367, N08926, and S31254).** Applications requiring high degrees of pitting and stress corrosion cracking resistance in chloride environments use the family of alloys known as superaustenitic. These alloys utilize high chromium levels to provide resistance to general corrosion and oxidizing environments while the combination of chromium, molybdenum, and nickel are used to increase pitting resistance. Nitrogen is also often added and carefully controlled to increase strength and corrosion resistance of this alloy family. Although not superaustenitic, the 4% molybdenum stainless steels [N08904 (904L), S31725 (317LM), and S31726 (317LMN)] offer similar benefits with a lower alloy content.

## 6. Filler Metal

**6.1 Selection of Filler Metal.** Filler metals that yield weld metal of the same general composition as the base metals are available. However, the selection of a suitable filler metal to join a particular type of base metal is not always accomplished by matching the type numbers or even actual chemical compositions. The performance of present-day welding electrodes and rods has been improved through modifications in composition to control weld structure, which in turn determines the properties of the weld metal. In some instances, new designations are applied to the filler metals because of extensive modifications in composition. The types of stainless steels used in piping and the filler metals commonly used for joining them are shown in Table 6.1.

All stainless steel and nickel alloy covered electrodes used for these applications are susceptible to moisture absorption. This can lead to porosity during production welding. After opening the containers, the electrodes should be stored at temperatures ranging from 120 °C to 175 °C [250 °F to 350 °F]. If moisture absorption or improper storage is suspected, the electrodes should be baked at 315 °C [600 °F] for 1 h or 260 °C [500 °F] for 2 h prior to hot box storage. (**Caution:** Electrodes should be removed from plastic or other combustible or low melting containers prior to heating.) The bare filler materials for gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) should be stored in a clean, dry, controlled environment, preferably in original containers sealed in plastic bags.

The superaustenitic stainless steels are typically welded with NiCrMo-3 type alloys (i.e., alloy 625). Variations also include the use of NiCrMo-4 (C276) or NiCrMo-10 (C22) welding alloys.

Annex A addresses welding of high carbon stainless steels to meet high temperature applications.

**6.2 Welding Electrodes.** Chemical composition requirements of weld metal from welding electrodes and rods are given in Tables 6.2, 6.3, and 6.4 and the latest editions of AWS A5.4/A5.4M, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding*, AWS A5.9/A5.9M, *Welding Consumables—Wire Electrodes, Strip Electrodes, Wires, and Rods for Arc Welding of Stainless and Heat Resisting Steels—Classification*, and AWS A5.22/A5.22M *Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods*.

**Table 6.1**  
**Electrodes and Welding Rods used in Welding Specific Cast and Wrought Austenitic Stainless Steels**

| Type of Stainless Steel |                   | Nominal Composition | Covered Electrodes, Specification AWS A5.4, Shielded Metal Arc Welding <sup>b</sup> | Bare Welding Rods or Electrodes, Specification AWS A5.9, Gas Tungsten Arc, Gas Metal Arc, and Submerged Arc Welding <sup>b</sup> |
|-------------------------|-------------------|---------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Wrought                 | Cast <sup>a</sup> |                     |                                                                                     |                                                                                                                                  |
| 304                     | CF-8              | 18-8                | E308                                                                                | ER308                                                                                                                            |
| 304H                    | —                 | 18-8                | E308H                                                                               | ER308H                                                                                                                           |
| 304L                    | CF-3              | 18-8LC              | E308L<br>E347                                                                       | ER308L<br>ER347                                                                                                                  |
| 309                     | CH20              | 25-12               | E309                                                                                | ER309                                                                                                                            |
| 309S                    | CH8               | 25-12LC             | E309<br>E309Nb                                                                      | ER309                                                                                                                            |
| 310                     | CPK-20            | 25-20               | E310                                                                                | ER310                                                                                                                            |
| 310S                    | —                 | 25-20LC             | E310<br>E310Nb                                                                      | ER310                                                                                                                            |
| 316                     | CF-8M             | 18-12Mo             | E316                                                                                | ER316                                                                                                                            |
| 316H                    | CF-12M            | 18-12Mo             | E16-8-2<br>E316                                                                     | ER16-8-2<br>ER316                                                                                                                |
| 316L                    | CF-3M             | 18-12MoLC           | E316L<br>E318                                                                       | ER316L                                                                                                                           |
| 317                     | —                 | 19-14Mo             | E317                                                                                | ER316                                                                                                                            |
| 317L                    | —                 | 19-14MoLC           | E317L                                                                               | ER317L                                                                                                                           |
| 321                     | —                 | 18-10Ti             | E347 <sup>c</sup>                                                                   | ER321                                                                                                                            |
| 321H                    | —                 | 18-10Ti             | E347<br>E16-8-2                                                                     | ER347<br>ER16-8-2                                                                                                                |
| 347                     | —                 | 18-10Nb             | E347                                                                                | ER347                                                                                                                            |
| 347H                    | —                 | 18-10Nb             | E347<br>E16-8-2                                                                     | ER347<br>ER16-8-2                                                                                                                |
| 348                     | —                 | 18-10Nb             | E347                                                                                | ER347                                                                                                                            |
| 348H                    | —                 | 18-10Nb             | E347                                                                                | ER347                                                                                                                            |
| —                       | CF-8C             | 18-10Nb             | E347                                                                                | ER347                                                                                                                            |
| 904L                    | —                 | 20-25Mo             | E385                                                                                | ER385                                                                                                                            |

<sup>a</sup> Castings higher in carbon but otherwise of generally corresponding compositions are available in the heat-resisting grades. These castings carry the “H” designation (HF, HH, and HK, for instance). Electrodes best suited for welding these high carbon versions are the standard electrodes recommended for the corresponding but lower carbon corrosion-resistant castings shown above (see Annex A).

<sup>b</sup> Joints containing 316, 316L, 317, and 318 weld metal may occasionally display poor corrosion resistance in the “as-welded” condition, particularly where hot oxidizing acids are involved. Corrosion resistance of the weldment, for all grades of Cr-Ni (versus Cr-Ni-Mo) base metal may be restored by solution annealing.

<sup>c</sup> Type 321 covered electrodes are not manufactured because titanium is not readily transferred across an electric arc.

**6.2.1 Covered Electrodes.** There are three kinds of coverings commonly used on stainless steel electrodes, “lime,” “titania,” and “silica-titania.” The lime covering is designated by the suffix -15, titania (or rutile) by -16, and silica-titania by -17. The -15 is for use with direct current electrode positive (DCEP) and has a lighter slag than the other two types and is used for all position welding, with some electrodes of this type used primarily for vertical down welding. The -16 is used with alternating current (AC) or DCEP. Electrode sizes of 4.0 mm [5/32 in] and smaller are often used for all welding positions. The -16 electrode has a less penetrating arc and produces flatter, smoother welds in the horizontal and flat positions, with easier slag removal than -15. Some -16 coverings operate satisfactorily with direct current electrode negative (DCEN) and may be used in special cases where shallower penetration is desired. There is also a -26 classification,