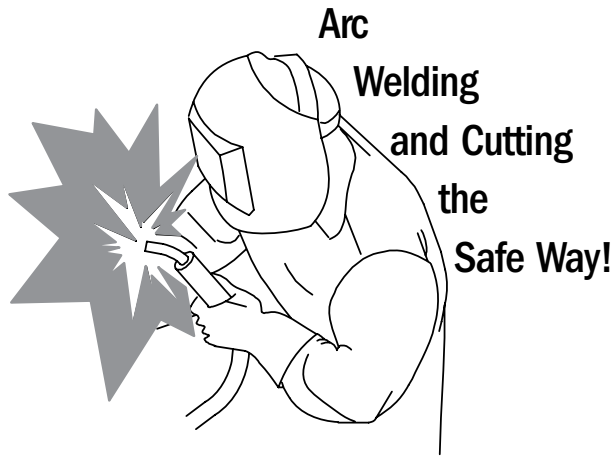




# Stainless Steel

Technical Welding Guide



As in all occupations, safety is paramount. Because there are numerous safety codes and regulations in place, we recommend that you always read all labels and the Owner's Manual carefully before installing, operating or servicing the unit. Read the safety information at the beginning of the manual and in each section. Also read and follow all applicable safety standards, especially ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes.

ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes is available as a free download from the American Welding Society at: <http://www.aws.org>

Here is a list of additional safety standards and where to get them:

*Safe Practices for the Preparation of Containers and Piping for Welding and Cutting*, American Welding Society Standard AWS F4.1, from Global Engineering Documents (Phone: 1-877-413-5184, website: [www.global.ihs.com](http://www.global.ihs.com))

*National Electrical Code*, NFPA Standard 70, from National Fire Protection Association, Quincy, MA 02269 (Phone: 1-800-344-3555, website: [www.nfpa.org](http://www.nfpa.org) and [www.sparky.org](http://www.sparky.org))

*Safe Handling of Compressed Gases in Cylinders*, CGA Pamphlet P-1, from Compressed Gas Association, 4221 Walney Road, 5th Floor, Chantilly, VA 20151 (Phone: 703-788-2700, website: [www.cganet.com](http://www.cganet.com))

*Safety in Welding, Cutting, and Allied Processes*, CSA Standard W117.2, from Canadian Standards Association, Standards Sales, 5060 Spectrum Way, Suite 100, Ontario, Canada L4W 5N5 (Phone: 800-463-6727, website: [www.csa-international.org](http://www.csa-international.org))

*Safe Practice for Occupational and Educational Eye And Face Protection*, ANSI Standard Z87.1, from American National Standards Institute, 25 West 43rd Street, New York, NY 10036 (Phone: 212-642-4900, website: [www.ansi.org](http://www.ansi.org))

*Standard for Fire Prevention During Welding, Cutting, and Other Hot Work*, NFPA Standard 51B, from National Fire Protection Association, Quincy, MA 02269 (Phone: 1-800-344-3555, website: [www.nfpa.org](http://www.nfpa.org))

*OSHA, Occupational Safety and Health Standards for General Industry*, Title 29, Code of Federal Regulations (CFR), Part 1910, Subpart Q, and Part 1926, Subpart J, from U.S. Government Printing Office, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954 (Phone: 1-866-512-1800) (There are 10 OSHA Regional Offices—phone for Region 5, Chicago, is 312-353-2220, website: [www.osha.gov](http://www.osha.gov))

*Booklet, TLVs, Threshold Limit Values*, from American Conference of Governmental Industrial Hygienists (ACGIH), 1330 Kemper Meadow Drive, Cincinnati, OH 45240 (Phone: 513-742-3355, website: [www.acgih.org](http://www.acgih.org))

*Towing a Trailer – Being Equipped for Safety*, Publication from U.S. Department of Transportation, National Highway Traffic Safety Administration, 400 Seventh Street, SW, Washington, D.C. 20590

*U.S. Consumer Product Safety Commission (CPSC)*, 4330 East West Highway, Bethesda, MD 20814 (Phone: 301-504-7923, website: [www.cpsc.gov](http://www.cpsc.gov))

*Applications Manual for the Revised NIOSH Lifting Equation*, The National Institute for Occupational Safety and Health (NIOSH), 1600 Clifton Rd, Atlanta, GA 30333 (Phone: 1-800-232-4636, website: [www.cdc.gov/NIOSH](http://www.cdc.gov/NIOSH))

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Prepared by Hobart Brothers Co.

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## WARNING

This document contains general information about the topics discussed herein. This document is not an application manual and does not contain a complete statement of all factors pertaining to those topics.

The installation, operation and maintenance of arc welding equipment and the employment of procedures described in this document should be conducted only by qualified persons in accordance with applicable codes, safe practices and manufacturer's instructions.

Always be certain that work areas are clean and safe and that proper ventilation is used. Misuse of equipment and failure to observe applicable codes and safe practices can result in serious personal injury and property damage.

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# Welding Stainless Steels with Hobart Electrodes and Wires

## Introduction

This publication is not intended to be a welding engineering or technique manual. Its purposes are as follows:

- Review the basics of stainless steel metallurgy
- Discuss the industry's most popular stainless steel alloys
- Provide reference material for guidance
- Provide detailed information on Hobart stainless steel electrodes and wires, including suggested parameters for customer applications

Hobart Brothers Co. is proud of its excellent reputation in the stainless steel market. Products are well established in the marketplace, well accepted by end users and, when properly used, result in consistently high-quality weldments and customer satisfaction.

THE RESPONSIBILITY OF THE WELDING PRODUCTS MANUFACTURER IS TO SUGGEST FILLER METAL COMPOSITIONS FOR WELDING STAINLESS STEEL BASE METALS ALREADY SPECIFIED BY DESIGN AND/OR CORROSION CONSULTANTS. STAINLESS STEEL ELECTRODE AND WIRE GRADES MAY BE SUGGESTED FOR CUSTOMER USE BASED ON THE INFORMATION RECEIVED, BUT THE RESPONSIBILITY FOR RESULTS AND WELDMENT PERFORMANCE IN SERVICE RESTS WITH THE FABRICATOR.

After you invest the time necessary to study this publication, keep it in a prominent place for continued reference. Your inquiries for additional technical information or availability of Hobart® standard or special products will be sincerely appreciated.

NOTE: The following is in reference to the typical properties listed in this publication for Hobart. The information contained herein is based on data and information developed in the laboratories of Hobart ("Seller"), but is presented without guarantee or warranty. The Seller makes no recommendation for and disclaims any liability incurred from any use thereof, including without limitation, any use in a commercial process not controlled by the Seller and any use in violation of any existing patent, foreign or domestic, or of applicable laws and regulations.

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## Hobart

Hobart has a rich and diverse history. The company was incorporated in 1917 by Charles Clarence (C.C.) Hobart, along with his wife, Lou Ella, and their three sons, Edward, Charles and William.

The company began its manufacturing endeavors with a variety of products, including generators (Dynamos), metal office furniture and air compressors. In 1925, it produced its first welder, which started Hobart on the path to becoming a preeminent company in the welding industry. It also became a prominent supporter of welding education with the establishment of the Hobart Institute of Welding Technology in 1930. The school became a separate non-profit entity in 1940 and has since trained more than 90,000 welders.

In 1937, Hobart turned its attention to the production of stick electrodes and shortly thereafter, began serving an active role in manufacturing during the turbulent years of World War II. It produced more than 100,000 welders and approximately 45,000 generators to support the war effort, and received the Army/Navy E Award for excellence for its contribution.

In the mid-1940s, Hobart launched what is now known as Hobart® Ground Power after being approached by American Airlines to design a generator specifically to start large aircraft engines.

By 1958, Hobart began manufacturing solid wires, which led to the development and production of tubular wires in the mid-1960s – both under the Hobart® brand.

Hobart purchased Tri-Mark® and Corex® in 1986, adding metal-cored wire development to its capabilities.

The acquisition of McKay® in 1993 added hard surfacing and stainless steel filler metal options to its growing capability list; the addition of MAXAL in 2011 allowed the company to offer aluminum filler metals.

Hobart was family-owned and operated until its acquisition by Illinois Tool Works (ITW) in 1996. ITW is a multinational manufacturer of a diversified range of value-adding and short lead time industrial products and equipment, and is also the parent company of Miller Electric Mfg. Co., Bernard, Tregaskiss and Jetline.

In May 2013, the company consolidated all of its brands under a single Hobart® brand in order to simplify its filler metal offering and provide a full product line to distributors and end users. The Hobart® brand signifies collaboration, innovation and expertise, and is a recognized leader in the industry.

Today, Hobart continues to develop and manufacture Hobart tubular wires (metal-cored and flux-cored), solid wires and stick electrodes for distribution to a diverse customer base around the globe. Each of its products has been carefully formulated to offer the highest-quality results, improve productivity for end users and help reduce operation costs.



# Definition and Origin of Stainless Steels

## Definition

Stainless steels are defined as iron base alloys containing relatively low carbon and a minimum of about 11 percent chromium (some put the minimum at 10 percent and others at 12 percent). Most commercial grades are higher than 11 percent chromium and contain up to about 0.08 percent carbon. Some may go to 0.2 percent carbon or even to 1 percent carbon. For increased corrosion resistance or for manufacturing requirements in specific applications, chromium may be increased and other elements such as nickel or molybdenum may be added as required. The effects of alloying elements and impurities in stainless steels and high-strength, heat-resisting alloys are shown in the section “Effects of Alloying Elements and Impurities in Stainless Steels and High Strength Heat-Resisting Alloys” on page 32. Stainless steels are sometimes called stain-resisting steels, since the term stainless may suggest non-staining. However, stainless is a correct designation; it does not mean non-staining in all environments, but less staining or less resistant to corrosive attack when compared with steels containing under about 11 percent chromium. When the total alloy content exceeds about 50 percent, the designation “heat-resisting” is more applicable than “stainless.”

## Origin

There is an old story about stainless steel being discovered shortly after World War I by a European scrap dealer. After noticing one shiny cannon barrel in a pile of rusty scrap cannon barrels, he had it analyzed and found its chromium level to be quite high. While that event may have occurred, the claim to original “discovery” is considered fictional. Somebody must have known something to produce a superior artillery piece.

Another legend has it that stainless steels were discovered by Harry Brearley, an English metallurgist. In the early 1900s he made a series of experimental steels with 6–16 percent chromium for gun barrels. In a discarded heap he observed that some barrels had not rusted like the rest of the heap.

During the century preceding World War I, extensive research with chromium alloy steels was conducted in Europe, England and the U.S. Unfortunately, many of the early metallurgists studied alloys of unfavorable composition, e.g., chromium too low or too high and carbon too high (likely due to difficulty in obtaining low carbon-level alloys.) To make matters worse, early experiments were limited to exposure in

sulfuric acid, completely overlooking the significance of resistance to attack by nitric acid.

“Discovery” of stainless steels having compositions within the ranges of the three major classes recognized today (martensitic, ferritic and austenitic) occurred progressively during the productive period of about 1905–1915 in three distinct directions: constitution, corrosion resistance and industrial applications. In 1905–1906, Leon Alexandre Guillet (France) was the first to produce and explore stainless steels metallurgically and mechanically in compositions falling within the three major classes. However, he did not discover the phenomenon of passivity, the remarkable resistance of stainless steels to most corrosive chemical solutions, which would readily attack ordinary steels. Passivity is a relative term, since a stainless steel may be passive, e.g., inert (corrode at very low rates) in one medium, and active (corrode at high rates) in another.

From 1908–1910, the research of Phillip Monnartz (Germany) disclosed the ‘stainlessness’ of stainless steel as a function of passivity. If any one person can be given the credit for discovery of the stainless phenomenon of the steels described as stainless, it should be Monnartz. He noted the significance of the minimum level of about 11 percent chromium, the need for low carbon, the fact that carbon could be stabilized, and the contribution of molybdenum in enhancing corrosion resistance.

As it pertains to industrial usefulness or commercial applications, history records that Benno Strauss and Eduard Maurer promoted austenitic grades in Germany in the 1909–1912 time frame. In the U.S. (1911–1914), Frederick Becket and Christian Dantsizen were conducting work with ferritic grades. In addition, Harry Brearley introduced cutlery steels (Type 420, martensitic) in England (1913–1916).

In summary, we can say that the discovery of stainless steels followed the cumulative efforts of many investigators during the century preceding 1915, with full revelation occurring in the productive decade of discovery between 1905 and 1915. Within another 10–15 years, stainless steels were well recognized and widely in use in a large variety of applications.

Since the 1905–1915 glory years of discovery, many new grades of stainless steel have been developed. The American Iron and Steel Institute (AISI) now lists 60 standard types. Many proprietary grades are also in use commercially. In recent years, the precipitation hardening (PH) stainless steels have emerged as the fourth class. More recently, duplex stainless steels, containing approximately 50 percent ferrite and 50 percent austenite, are being promoted for aggressive environments where resistance to stress corrosion cracking is of paramount importance.

# How Stainless Steels Work

Chromium (the key element in stainless steels) in excess of about 11 percent forms a tenacious, refractory oxide, protective film on any exposed layer, e.g., a corrosion barrier. This relatively impervious film is considered to be self-healing or self-restoring. It will, if broken, repair itself spontaneously upon re-exposure to an oxidizing agent such as air or nitric acid. Passivity, the resistance to corrosive attack under specific conditions, is enhanced by progressively increasing chromium more than 11 percent and/or by the addition of other elements such as nickel, molybdenum and copper. The degree of imperviousness of the oxide film in certain environments depends not only on the alloy composition but also on the specific medium and its concentration and temperature. While some may dispute that passivity actually results from the presence of a chromium oxide film (herein called the CROX theory), the concept does offer an exceptionally convenient working hypothesis and has been the commonly accepted explanation for more than 50 years.

Note that the term “passivation” is often used to describe a cleaning operation with nitric acid especially to dissolve iron contamination from the surface of stainless steels. References:

ASTM Standards 1985 Section I Volume 01.03. Steel – Plate, Sheet and Wire. ASTM A380 Page 196.

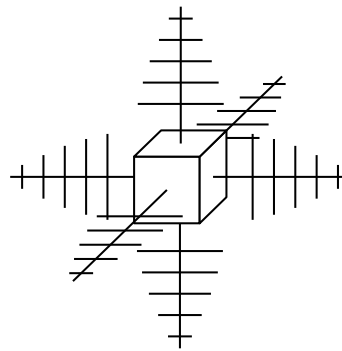
Carpenter Stainless Steels Working Data, Page 184 – Cleaning and Passivation of Stainless Steels – Carpenter Technology Corp., Reading, PA 19603.

Bradford Derustit Corp. – Curtis Industrial Park, Rte. 67, Ballston Spa, NY 12020. Offers liquid and paste forms of Derustit SS-3 chemical cleaner for stationary or immersible applications.

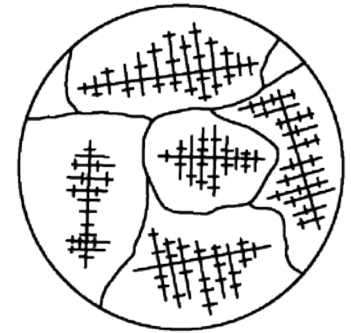
Cleaning and Descaling Stainless Steels – Nickel Development Institute, 15 Toronto St., Suite 402, Toronto Ontario, Canada M5C2E3.

## Grains and Grain Boundaries?

Before discussing the major classes of stainless steels and appropriate welding filler metals it would be prudent to review the mechanism of solidification and subsequent formation of grains and grain boundaries. When a liquid steel cools through the solidification temperature range peculiar to that particular grade of steel, the process of crystallization commences. Although individual atoms have great freedom (mobility) in the liquid state, once freezing starts they begin to orient themselves in a specific type of crystal lattice or arrangement.



**Figure 1 –  
Dendritic Growth  
of Cubic Crystal.**



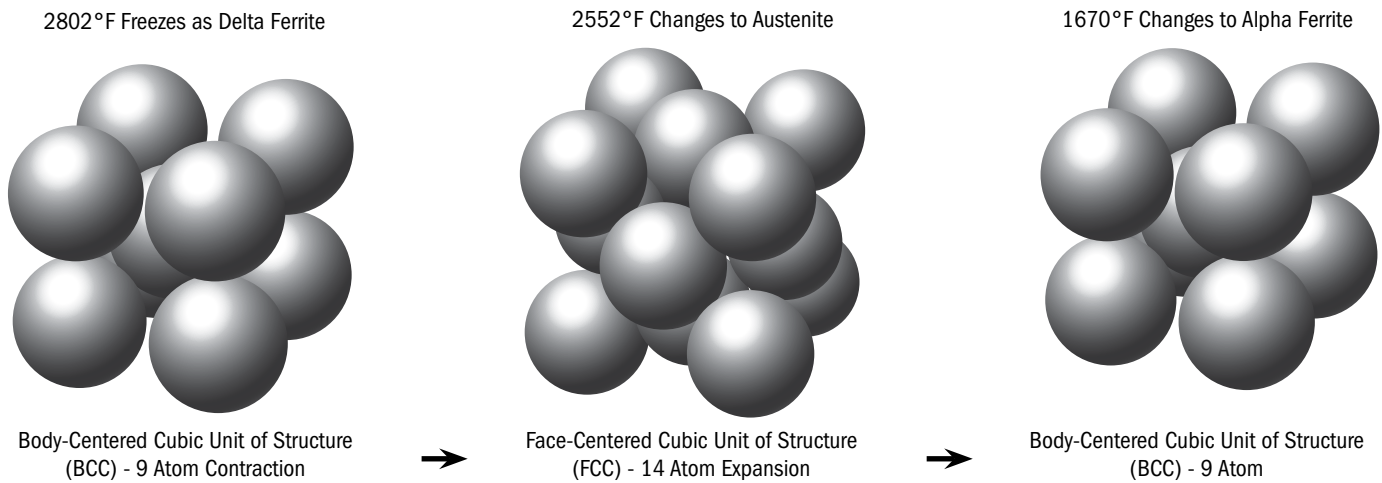
**Figure 2 – Grain Size and Shape  
Are Determined by the Manner  
in Which the Branches From  
Dendrites Meet.**

Nucleation of crystals occurs simultaneously in various locations. The pattern in each location repeats itself. Crystal growth resembles pine tree formations and is described as dendritic (branching). See Figure 1 and Figure 2. During the process of solidification the separate crystals, growing at varying rates in different locations (each in their own orientation or plane of atoms), converge to form boundaries. The individual areas of uniform crystal structure are called grains and the boundary areas, grain boundaries. Grain size and shape are determined by the manner in which the branches from dendrites meet. See Figure 2.

Grain boundaries represent junctions of differently oriented crystals or regions of disarray in the atomic arrangement. The atomic structure in converging grains at random orientation cannot match perfectly at their interfaces. Therefore, between any two grains there exists a transition layer where the atoms are not in their proper places with respect to either grain. Exposure to a chemical etching solution results in preferential attack in these vulnerable grain boundary locations. Thus, the metallurgist can prepare and etch a metallographic specimen from stainless steel base metal or a weld deposit. His “crystal” ball for determining the intricacies of grain size, shape, structure etc., is called a microscope.

Subsequent to solidification, say after cooling to room temperature, grain growth – where larger grains grow at the expense of smaller ones – may occur during heating and cooling cycles. Explanation of this phenomenon lies in the realm of thermodynamics involving so-called free energy at grain interfaces. Grain growth occurs above the recrystallization temperature because grains have a tendency to decrease their surface energy. Large grains have smaller grain boundary area per unit volume, hence smaller surface energy. Because larger grains grow at the expense of smaller ones, energy is conserved.

# Ferrite, Austenite, Martensite and Solid Solutions



**Figure 3 – Pure Iron Has Two Structurally Distinct Forms. Note Changes as Temperature Decreases.**

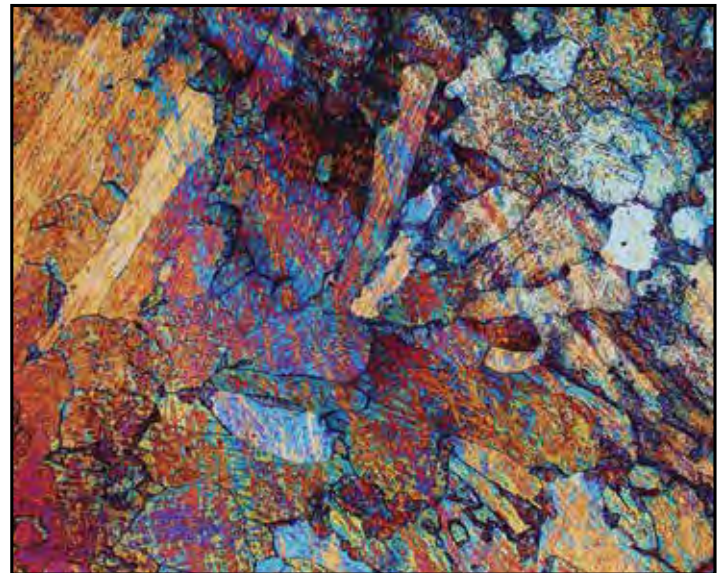
## What Are They?

Since the three main classes of stainless steels are named in accordance with their predominant metallurgical phases, e.g. ferritic, austenitic and martensitic, it seems advisable to explain these phases before discussing each stainless steel class in further detail. An elementary knowledge of solid solutions in metals will also lead to a better understanding of stainless steels.

## Ferrite And Austenite

Pure iron freezes at 2802°F in a crystal form called ferrite. It has a body-centered cubic (BCC) structure with the basic cell containing one atom at each of eight corners and one atom in the middle. See Figure 3. Upon cooling to 2552°F the ferrite structure transforms into a modification called austenite, the unit cell of which is face-centered cubic (FCC) containing one atom at each of eight corners and one atom on each face (none in the middle). At 1670°F the austenite phase reverts to ferrite, the form stable at room temperature.

Although structurally identical, the ferrite forming at the higher temperature is designated delta ferrite while the ferrite forming at the lower temperature is called alpha ferrite. Austenite is often designated as the gamma phase. Note the gaps between the eight corner atoms are larger in austenite than in ferrite.



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400  $\mu$ m

**Figure 4 – An As-Welded Weld Deposit on UNS S40900 Type 409 Stainless Steel Magnified 100 Times Showing Large, Columnar Ferrite Grains With Martensite at the Grain Boundaries. The Image Was Produced Using an Optical Light Microscope With Bright-Field (Bf) Illumination and the Etchant Was 3 G Potassium Disulfite, 10 G Sodium Thiosulfate, 2 MI Hydrochloric Acid and 100 MI Water.**

## Martensite

In commercial steels, the addition of carbon and alloying elements, such as chromium will modify the structure at room temperature in accordance with composition and thermal history. Plain carbon steels, even when cooled rapidly from the austenitizing temperature, develop ferrite and pearlite. Under the microscope at high magnification, pearlite can be identified as alternate platelets of ferrite and iron carbide. The latter is sometimes described as  $\text{Fe}_3\text{C}$  or cementite.

The FCC structure of austenite is more compact than the BCC structure of ferrite. During the austenite to ferrite transformation an expansion occurs. Shifting of the atom layers and groups can cause “foreign” atoms to trap and jam, leading to great distortion. When alloy steels containing sufficient carbon and alloy content are cooled rapidly enough from the austenitizing temperature, the distorted structure called martensite is formed – producing high strength and hardness.

Martensite can be described as a distorted arrangement of atoms having a body-centered tetragonal (BCT) unit structure. During fast cooling, the normal transformation from austenite to ferrite that would be expected in a low carbon steel is hindered by the presence of higher carbon and alloying elements and the lack of time to reach a condition of greater equilibrium. Since martensitic structures as-formed are hard and brittle, subsequent heat treatment (tempering) is necessary to reduce their hardness and strength, and increase their ductility to the level required for most industrial applications.

## Solid Solutions

We’re all familiar with liquid solutions such as salt in water. If you add salt (the solute) to a cup of hot water (the solvent) the salt dissolves and forms a liquid solution. But if you then put the cup in the refrigerator and examine it several hours later you see a precipitate in the bottom, e.g. some of the salt has come out of the solution. You can say that the solubility of salt in water decreases with decreasing temperature.

The same type of thing occurs in steels. We call them solid solutions. For example, an alloy of iron with about 13% chromium consists of a random mixture of iron (solvent) and chromium (solute) atoms. Iron (Fe) and chromium (Cr) atoms are approximately the same size and about one in seven atoms will be Cr. This distribution of atoms in a crystal (grain) in which the atoms of the second element are evenly distributed in the parent crystal structure is known as a solid solution. Where the Cr atoms are to be found in the same sites as the Fe atoms, the solid solution is known as substitutional.

When you add carbon (C) to the alloy, the C atoms – being smaller than the Fe or Cr atoms – distribute themselves in the gaps (interstices) between the other atoms, assuming the C is under about 0.1%. The carbon then has formed an interstitial solid solution. With C above about 0.1%, the C atoms in excess of the solubility limit may combine with Cr atoms to form chromium carbides.

Certain interstices within the FCC Structure of austenite are considerably more accommodating to C than those of the BCC structure of ferrite. Since the gaps between the atoms are larger in austenite than in ferrite, the solubility of C is greater in austenite but decreases abruptly when, with decreasing temperature, the austenite phase changes to ferrite or martensite.

“Steels” are alloys of iron and carbon with modest quantities of manganese and silicon plus residuals, some of which may be undesirable. Alloying elements such as chromium, nickel, molybdenum, etc. may be added for specific properties. Austenite in stainless steels is considered to be a solid solution of one or more elements in FCC iron.



# Standard Classes of Stainless Steels

Stainless steels are capable of meeting a wide range of final needs – corrosion resistance, strength at elevated temperatures, toughness at cryogenic temperatures etc., and are selected for a broad range of applications. Designers need to be familiar with properties of the various types available and should consider the advice of corrosion and welding consultants when specifying stainless steel grades for commercial service.

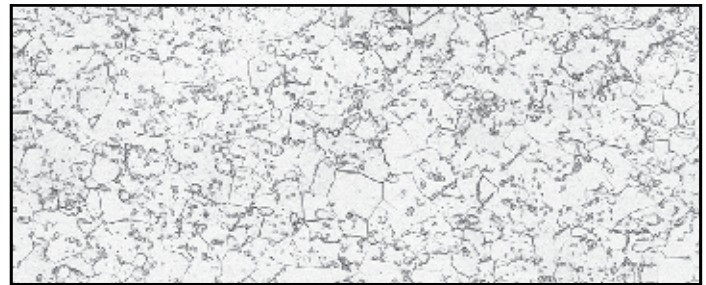
The three major classes of stainless steels that have been widely used in industrial applications for over 50 years are designated martensitic (e.g. AISI 410), ferritic (e.g. AISI 430) and austenitic (e.g. AISI 304) – names derived from the predominant crystal structure or phase normally found at room temperature. A fourth class, the PH or precipitation hardening types (e.g. 17/4 PH), has also come into prominence within the last 25 years. More recently there is great interest in the Duplex or ferritic-austenitic class (e.g. 2205 alloy). Hobart suggested for welding the above stainless steels are listed in Figure 66 on page 55 and Figure 67 on page 56. Since the austenitic class is the major stainless steel class specified for welded structures, more attention will be devoted to this esteemed and hallowed group of chromium-nickel alloys than to the other classes of stainless steel.

## Class I – Martensitic Stainless Steels

The martensitic class of stainless steels shown in Figure 7 depend primarily on Cr from 11.5 to 18% as the major alloying element. This class and the ferritic stainless steel class share the AISI 400 numbering series. They are sometimes referred to as straight chromium grades. In contrast, the austenitic stainless steels are essentially chromium-nickel alloys; they are covered by the AISI 300 series for most standard compositions of wrought products. AISI 410, the principal alloy of the martensitic class, ranges 11.5 to 13.5% Cr. However, the relatively new 13Cr / 4.5Ni / .5Mo low carbon casting grade CA-6NM, provides higher strength, increased toughness, better weldability and greater corrosion resistance than the CA-15 (Type 410) casting grade.

Martensitic stainless steels exhibit magnetic properties similar to those of plain carbon steels and, therefore, are also subject to arc blow in welding. Unlike mild steels, they are air-hardening when allowed to cool rapidly from the austenitizing temperature range (1600-1850°F) where the austenite phase is predominant.

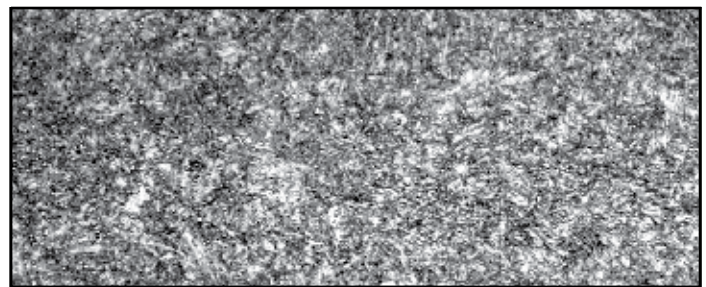
Austenitizing temperatures are reached in the heat-affected zones of weldments and subsequent cooling occurs at rates sufficient to produce martensite. In the annealed condition martensitic stainless steels have basically a ferritic microstructure with dispersed chromium carbides (See Figure 5 and Figure 6).



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100 μm

**Figure 5 – Annealed 410 Martensitic Stainless Steel Uns Number S41000 0.15% C Max; 12.5% Cr. The Image Contains Equiaxed Ferrite Grains and Round Particles of Chromium Carbide. The Image Was Created Using 250X Magnification and a Marble Reagent to Etch the Surface.**



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50 μm

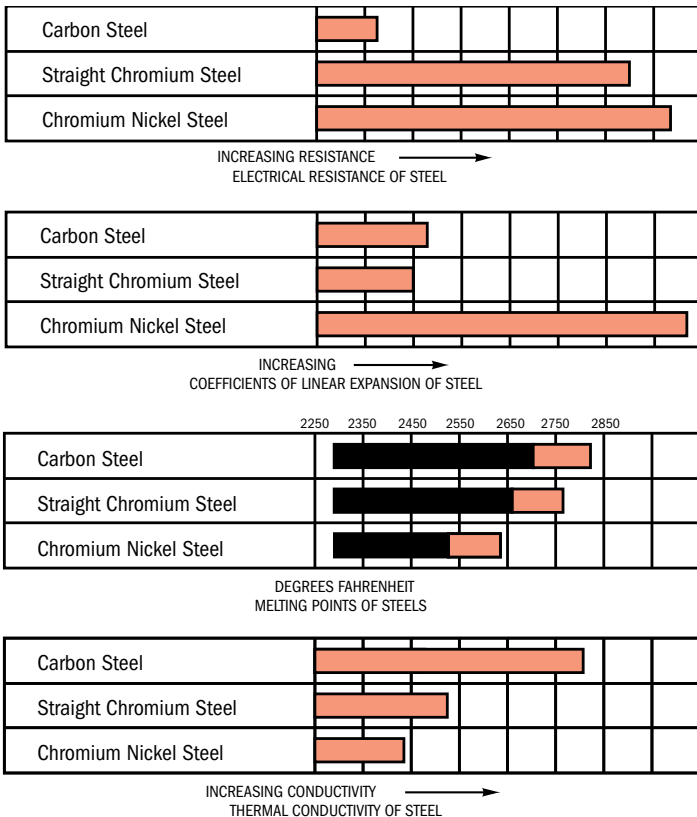
**Figure 6 – Quenched and Tempered 410 Martensitic Stainless Steel Uns Number S41000 0.15% C Max; 12.5% Cr. The Image Contains Fine A Martensite Matrix With White Chrome Carbides. The Image Was Created Using 500X Magnification and a Marble Reagent to Etch the Surface.**

Carbon and chromium in the martensitic stainless steels act in concert to prevent transformation of austenite to ferrite during rapid cooling. The result is the distorted BCT structure called martensite (body-centered tetragonal – like BCC but elongated in one direction). The heat-affected zone on either side of a weldment will develop the hard, brittle martensite phase and, unless local preheating is practiced, may develop cracks due to shrinkage stresses and hydrogen. The hardness of the heat-affected zone depends primarily on the carbon content of the base metal. Increased hardness results in decreased toughness and more susceptibility to cracking. Although the most suitable preheat and interpass temperature will depend on carbon content, the mass of the joint, degree of restraint and the filler metal composition, temperatures of 400-600°F are commonly specified.

Martensitic Stainless Steels									
Chemical Analysis Percent (Maximum unless noted otherwise)									
AISI Type (UNS)*	C	Mn	P	S	Si	Cr	Ni	Mo	Other
403 (S40300)	0.15	1.00	0.040	0.030	0.50	11.50/13.00			
410 (S41000)	0.15	1.00	0.040	0.030	1.00	11.50/13.50			
414 (S41400)	0.15	1.00	0.040	0.030	1.00	11.50/13.50			
416 (S41600)	0.15	1.25	0.060	0.15 (min)	1.00	12.00/14.00		0.60*	
416Se (S41623)	0.15	1.25	0.060	0.060	1.00	12.00/14.00			0.15 Se (min)
420 (S42000)	0.15 (min)	1.0	0.040	0.030	1.00	12.00/14.00			
420F (S42020)	0.15 (min)	1.25	0.060	0.15 (min)	1.00	12.00/14.00		0.60*	
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	0.15/0.30V 0.75/1.25W
431 (S43100)	0.25	1.00	0.040	0.030	1.00	15.00/17.00	1.25/2.50		
440A (S44002)	0.60/0.75	1.00	0.040	0.030	1.00	16.00/18.00		0.75	
440B (S44003)	0.75/0.95	1.00	0.040	0.030	1.00	16.00/18.00		0.75	
440C (44004)	0.95/1.20	1.00	0.040	0.030	1.00	16.00/18.00		0.75	

\*ASTM-SAE unified numbering system

**Figure 7 – Martensitic Stainless Steels Chemical Analysis Percent (Max. Unless Noted Otherwise).**

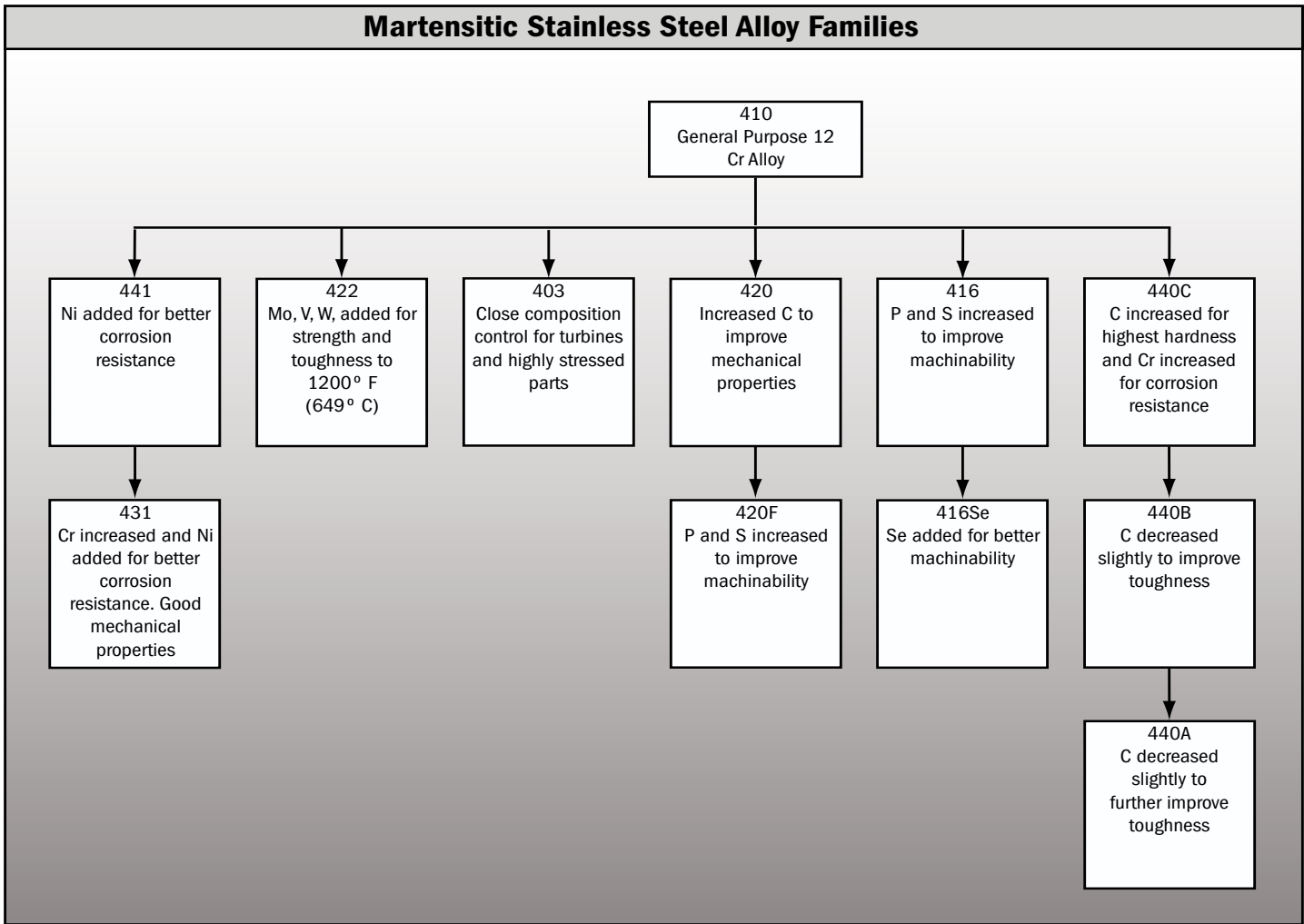


**Figure 8 – The Four Tables Above Compare Characteristics of Carbon Steels, Straight Chromium Stainless Steels (400 Series) and Chromium-Nickel Stainless Steels (300 Series).**

Compared with plain carbon steels, martensitic stainless steels have higher electrical resistance, lower thermal conductivity (see Figure 8) and, when rapidly cooled, brittle structure. Preheating the base metal retards the rate of cooling, permitting the weld metal and heat-affected zones to cool at a slower and more uniform rate, thereby reducing shrinkage stresses. The slower cooling also allows more of the hydrogen to escape.

Postweld heating at 1300-1400°F, followed by controlled cooling at a rate of 50°F per hour to 1100°F before air cooling, is also desirable to temper the martensitic structure in the weldment (reducing hardness and increasing ductility and corrosion resistance). Where possible, postweld heating should be done before the weldment cools down. For optimum results the weldment should not be allowed to cool below the preheating temperature between weld passes or prior to postweld heating. Where 410NiMo filler metals (somewhat less hardenable than 410) or austenitic filler metals such as 309 or 312 are used, preheating and postheating procedures may be less demanding than with 410 filler metals.

Austenitic grades are sometimes specified where the differences in composition and physical properties (such as coefficient of expansion) are acceptable for the application. If preheating or postweld heating cannot be done or is impractical, austenitic filler metals such as 309 or 312 can be specified to give more assurance that cracking will be averted.



**Figure 9 – Martensitic Stainless Steels Family Tree.**

The AISI 500 series (e.g. 502 with 5 Cr, ½ Mo and 505 with 9 Cr, 1 Mo) heat-resisting steels, although not classed as stainless due to Cr being under the 11% minimum, are nevertheless martensitic and require essentially the same tender-loving care as martensitic stainless steels like 410.

Martensitic stainless steels, being lower in alloy content, are lower in cost than austenitic stainless steels. When suitably heat treated they have adequate corrosion resistance in many environments and also offer high strength and good fatigue properties together with excellent wear, oxidation resistance and erosion resistance. They are adaptable for moderately high-temperature service because of good tensile and creep strength at moderately elevated temperature. Creep strength is the slow deformation of a metal held for long periods of time at elevated temperatures under stresses which are less than the yield point.

Typical applications include Type 403 for turbine blades (high velocity fluid flow), Type 410 for valve seat facing and Types 420 and 431 for cutlery grades, razor blades and surgical instruments.

## Class II – Ferritic Stainless Steels

Some of the common ferritic stainless steels are shown in Figure 10. Note that the AISI 400 series covers the ferritic as well as the martensitic stainless steels. As Cr content is increased beyond the 11.5-18% range of the martensitic class, the predominant metallurgical structure is ferrite, even at elevated temperatures. See Figure 11. In some grades, there is enough C and nitrogen (N) to result in some austenite at high temperatures and hence, partial hardening on rapid cooling. However, generally speaking, the ferritic stainless steels are relatively non-hardening.

Ferritic Stainless Steels									
Chemical Analysis Percent (Maximum Unless Noted Otherwise)									
AISI Type (UNS)**	C	Mn	P	S	Si	Cr	Ni	Mo	Other
405 (S40500)	0.08	1.00	0.040	0.030	1.00	11.50/14.00			0.10/0.30 Al
409 (S40900)	0.08	1.00	0.045	0.045	1.00	10.50/11.75			6xC/0.75 Ti
429 (S442900)	0.12	1.00	0.040	0.030	1.00	14.00/16.00			
430 (S43000)	0.02	1.00	0.040	0.030	1.00	16.00/18.00			
430F (S43020)	0.12	1.25	0.060	1.15 (min)	1.00	16.00/18.00		0.60*	
430FSe (S42000)	0.12	1.25	0.060	0.060	1.00	16.00/18.00			0.15 SE (min)
434 (S43400)	0.12	1.25	0.040	0.030	1.00	16.00/18.00		0.75/1.25	
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
442 (S44200)	0.20	1.00	0.040	0.030	1.00	18.00/23.00			
446 (S44600)	0.20	1.50	0.040	0.030	1.00	23.00/27.00		0.25 N	

\* May be added at manufacturer's option.

\*\* ASTM-SAE unified numbering system.

Figure 10 – Ferritic Stainless Steels Chemical Analysis Percent (Max. Unless Noted Otherwise).

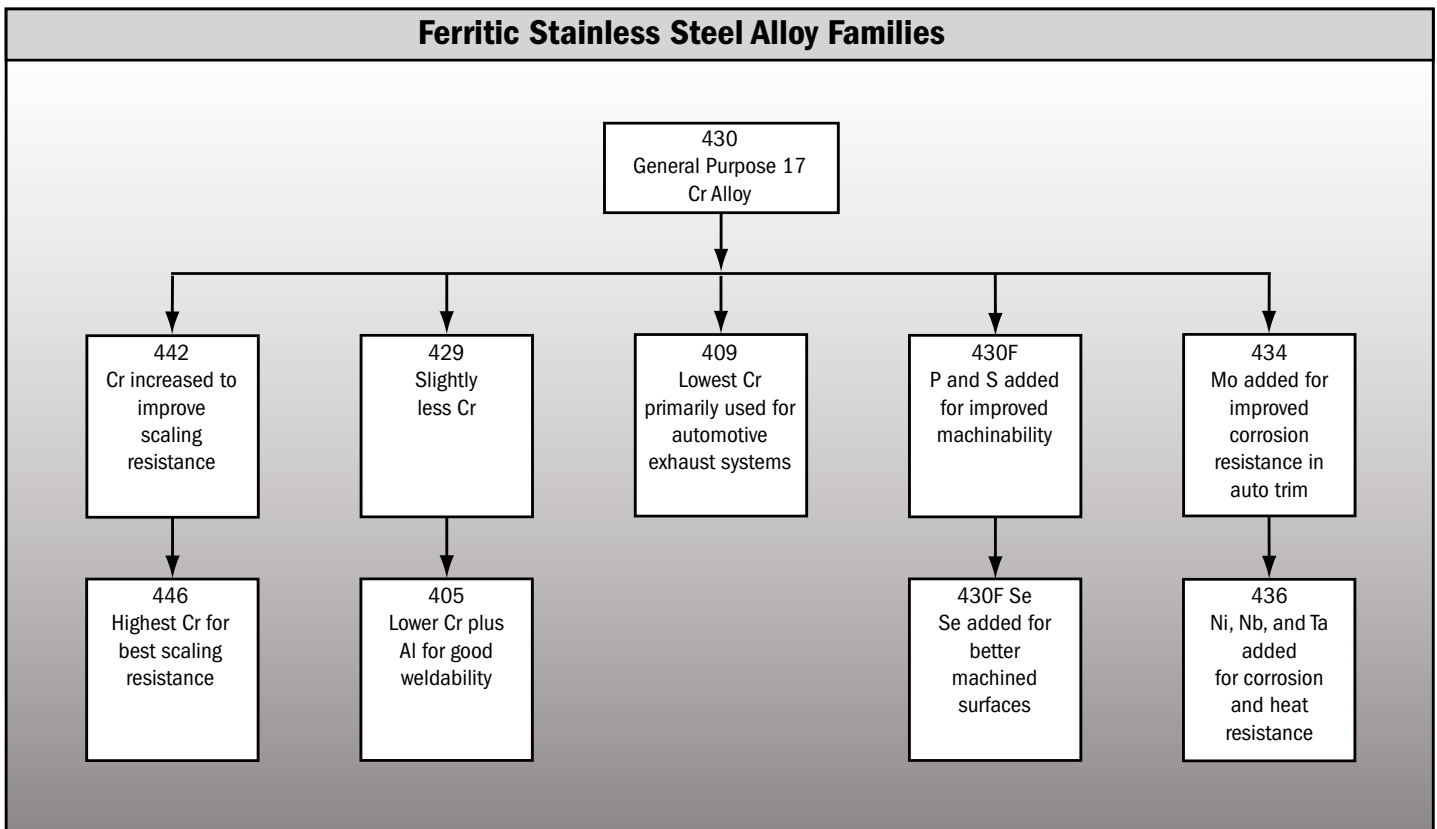
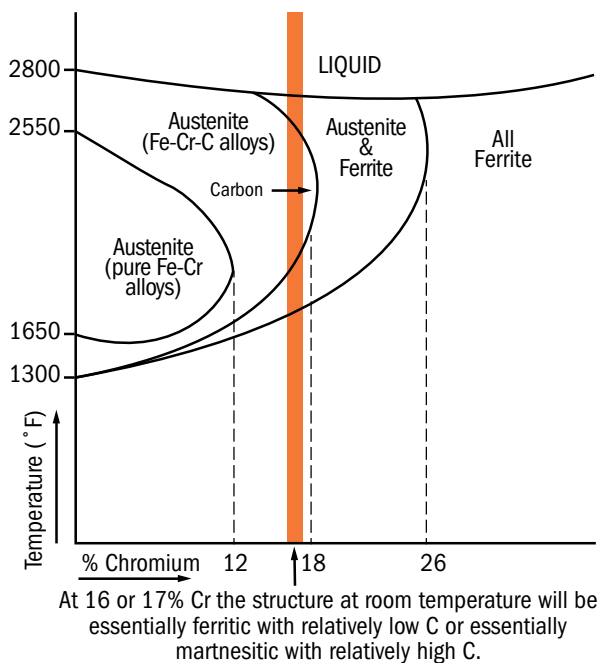


Figure 11 – Ferritic Stainless Steel Alloy Families.





**Figure 12 – Effect of Chromium and Carbon on the Austenite ‘Gamma Loop’ Increasing Carbon up to About 0.60% Expands the Austenite “Gamma Loop” up to About 18% Chromium. Above 0.60% Carbon, Carbides Are Produced. Above 18% Chromium, Ferrite Is Produced. Above 26% Chromium the Structure Is Essentially All Ferritic.**

At a Cr level of 16% or 17%, the structure at room temperature could be essentially ferritic with relatively low C (e.g. 430 with 0.12C max.) or essentially martensitic with relatively high C (e.g. 431 with 0.20C max.). Indeed, even with Cr as low as 10.5% and C less than 0.08% together, with the addition of about 0.50-0.75% Ti, the structure is still predominantly ferritic. Some of the new so-called super ferritic grades produced by AOD (argon-oxygen decarburization) and vacuum melting techniques with quite low C&N contents (about 0.02%C and 0.02%N) offer outstanding resistance to stress-corrosion cracking in chloride solutions.

Ferritic stainless steels, like carbon and martensitic stainless steels, are quite magnetic and thus subject to arc blow in welding. In some of the standard ferritic grades, residual carbon and nitrogen can combine with chromium to form carbides and nitrides at grain boundaries. This causes chromium depletion and, in some cases, intergranular corrosion, although not to the extent experienced with austenitic stainless steels. Carbide precipitation is discussed in greater detail in the section on austenitic stainless steels.

Ferritic stainless steel products are usually annealed (See Figure 13) at the mill to make sure that any martensite present may be transformed

to the softer structure of ferrite and dispersed chromium carbides. However, subsequent welding may produce small amounts of austenite in the heat-affected zones which, on cooling, could transform to martensite and reduce ductility, toughness and corrosion resistance. The only redeeming feature of the martensite thus formed is that it tends to inhibit ferrite grain coarsening.

Grain coarsening is a fact of life with ferritic stainless steels. Heating above approximately 1700°F causes enlargement of ferrite grains with consequent embrittlement due to loss of ductility and toughness. Since there is no phase change (ferrite doesn't change into austenite) there is no chance of grain refinement. Embrittlement can also occur when ferritic stainless steels are held within the temperature range of 750-1050°F (most crucially at 885°F). The effect increases with increased Cr content. However, heating to about 1100°F for a short time followed by a rapid cooling through the 1050-750°F range will reverse the condition. A third contributor to embrittlement is sigma phase, an intermetallic compound of Fe & Cr which originates in the grain boundaries. Given enough time in the damaging temperature range of 1000-1700°F, particularly around 1200°F, sigma phase can extend completely through entire grains. Chi phase, another embrittling intermetallic compound, can occur along with sigma phase when molybdenum is present.



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25 μm

**Figure 13 – Type 430 Stainless Steel Uns Number: S43000 That Was Annealed at 1550°F and Cooled in Air. The Microstructure Consists of Equiaxed Grains of Ferrite and Randomly Dispersed Particles of Chromium Carbide (500X Magnification) Using Vilella’s Regent to Etch the Surface.**

## Class III – Austenitic Stainless Steels

### General Comments

From the foregoing, it is obvious that prolonged heating of ferritic stainless steels within the 700-1700°F range should be avoided. Welding heat input should be minimized and slow cooling from welding avoided. Despite this, preheating of 300-450°F is recommended for welding when thickness exceeds about 1/4", since ductility of the base metal is improved in that temperature range – particularly in the heat-affected zone which may contain some martensite.

Postweld heating of the low chromium ferritic stainless steels at 1450 to 1550°F will assure a wholly ferritic structure and partially restore mechanical properties and corrosion resistance that may have been adversely affected by the welding temperatures. However, exposure within this temperature range will quickly produce embrittling sigma phase in the higher chromium alloys such as 444 or 26-1. To minimize distortion, cooling may be done in the furnace down to no lower than 1100°F but prolonged exposure in the 1050-750°F range should be avoided due to 885°F brittleness.

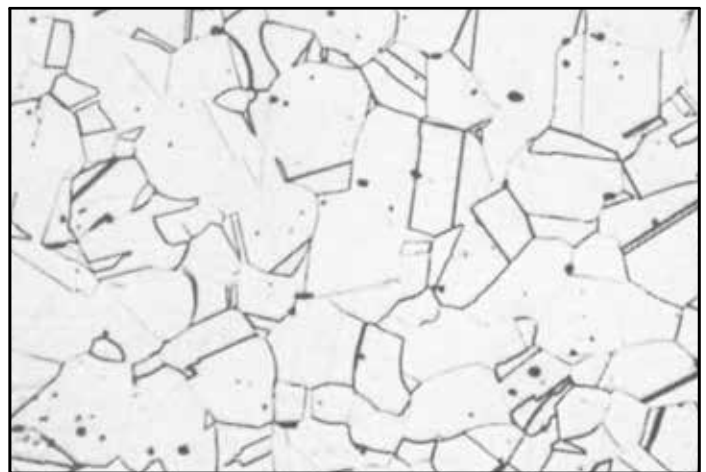
Because of embrittlement problems, the ferritic stainless steels are not considered readily weldable and are used primarily for nonstructural applications. They are recommended for resistance to chloride stress-corrosion cracking, corrosion in aqueous media, oxidation at high temperature and pitting and crevice corrosion in chloride media. Applications include automobile exhaust equipment, radiator tanks, catalytic reactors, culverts, dry fertilizer tanks and animal containment housings. Type 430 is used for decorative trim, nitric acid tanks and annealing baskets. Type 442 is used for components requiring protection from scaling at high temperatures such as furnace parts, nozzles and combustion chambers.

Matching metals for most ferritic stainless steels are not readily available. The 409 and 439 are available from some manufacturers as a tubular metal cored product. They are primarily used in automotive exhaust welding applications. Austenitic filler metals such as 309, 310 and 312 are often used where the application can reconcile the different corrosion-resistant characteristics and the greater coefficients of linear expansion of the austenitic grades. Where postweld annealing at 1450°F is specified, the austenitic filler metal should be either a stabilized or low carbon grade to avoid carbide precipitation. See page 14 for discussion on carbide precipitation.

Solid wires for GMAW or GTAW are available in 410 and 430 compositions.

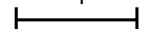
The Austenitic stainless steel 300-series filler metals (with Cr content ranging from about 15-32% and Ni content about 8-37%) are used in over 90% of stainless steel welding applications for the simple reason that austenitic stainless steels are much more weldable than martensitic, ferritic or precipitation-hardening stainless steels. They have good corrosion resistance and excellent strength at both low and high temperatures. Welded joints in 300 series steels are characterized by a high degree of toughness even in the as-welded condition. Standard AISI grades are shown in Figure 15 and Figure 16.

In contrast with the "straight chromium" martensitic and ferritic classes, the austenitic class contains nickel as a second major alloying element e.g. Type 304 with 19% Cr, 9% Ni, 1.5% Mn. See Figure 14. In the AISI 200 series, manganese is increased to replace some of the nickel on the basis of about 2 Mn for 1 Ni and nitrogen (N) is added up to about 0.25%. The effect of Ni at the levels used in austenitic stainless steels (in many common grades 10-20% Ni along with about 20-25% Cr and carbon levels normally less than 0.25%) is to suppress the transformation of austenite – it makes it so sluggish that the austenite phase is stable even at room temperature and below. See Figure 17.



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50 µm

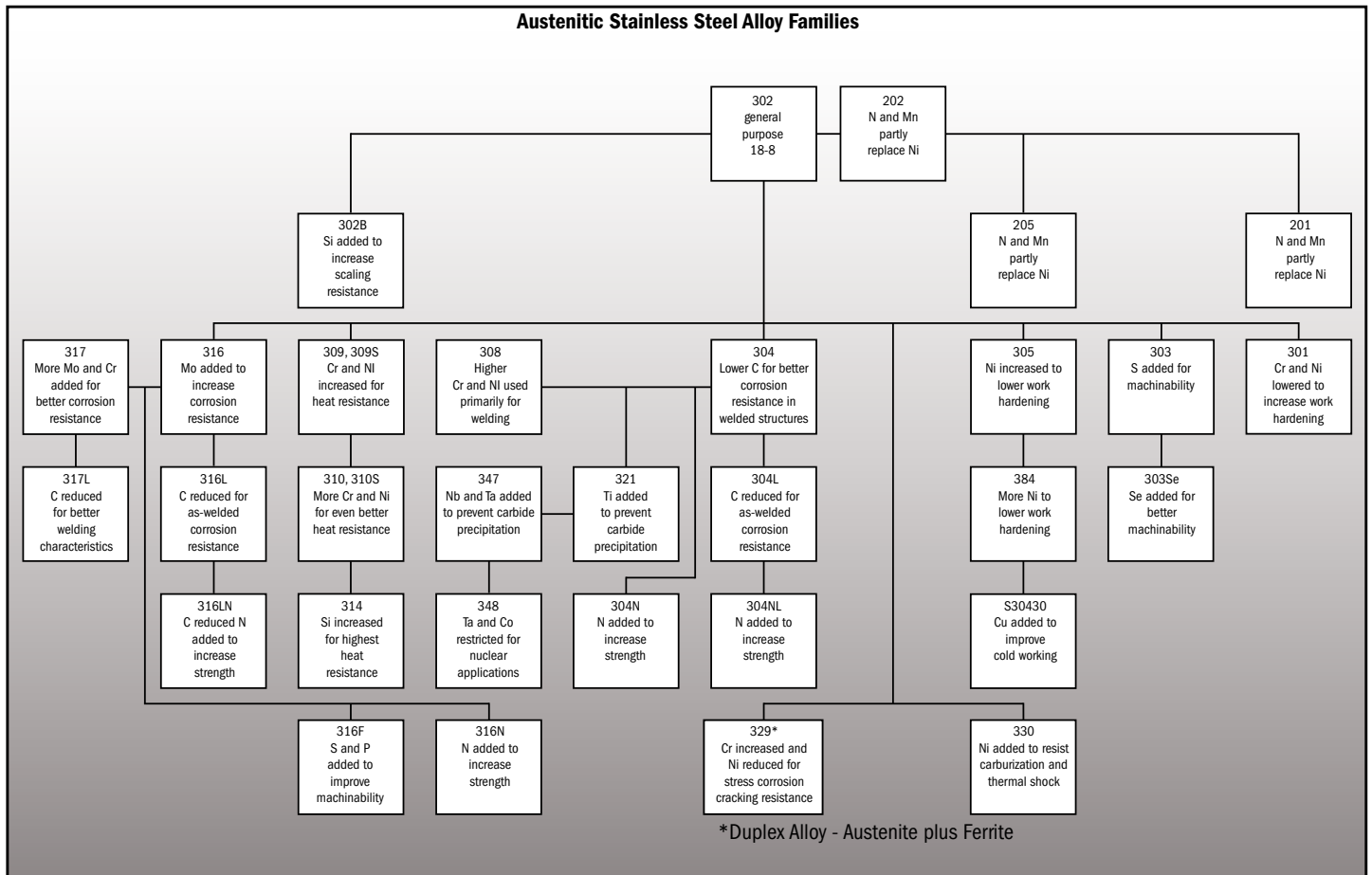


**Figure 14 – 304 Stainless Steel Uns Number: S30400 Annealed 5 Minutes at 1950°F and Cooled in Air. Structure Consists of Equiaxed Austenite Grains 250X Magnification Using a 10 MI Nitric Acid, 10 MI Acetic Acid, 15 MI Hydrochloric Acid and 2 Drops Glycerol to Etch the Surface.**

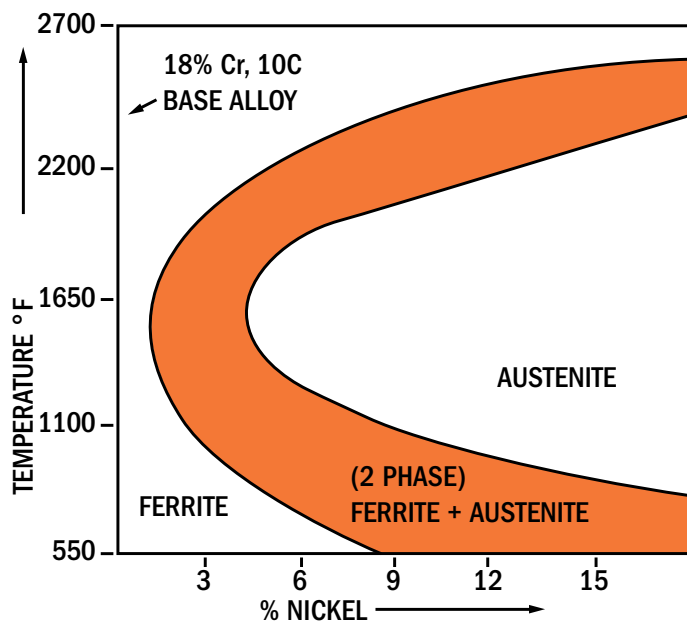
<b>Austenitic Stainless Steels</b>									
<b>Chemical Analysis Percent (Maximum unless noted otherwise)</b>									
<b>AISI Type (UNS)***</b>	<b>C</b>	<b>Mn</b>	<b>P</b>	<b>S</b>	<b>Si</b>	<b>Cr</b>	<b>Ni</b>	<b>Mo</b>	<b>Other</b>
201 (S20100)	0.15	5.50/7.50	0.60	0.30	1.00	16.00/18.00	3.50/5.50		0.25 N
202 (S20200)	0.15	7.50/10.00	0.060	0.030	1.00	17.00/19.00	4.00/6.00		0.25 N
205 (S20500)	0.12/0.25		0.030	0.030	0.50	16.50/18.00	1.0/1.75		0.32/0.40 N
301 (S30100)	0.12	2.00	0.045	0.030	1.00	16.00/18.00	6.00/8.00		
302 (S30200)	0.15	2.00	0.045	0.030	1.00	17.00/19.00	8.00/10.00		
302B (S30215)	0.15	2.00	0.045	0.030	2.00/3.00	17.00/19.00	8.00/10.00		
303 (S30300)	0.15	2.00	0.20	0.15 (Min)	1.00	17.00/19.00	8.00/10.00	0.60*	
303Se (S30323)	0.15	2.00	0.20	0.060	1.00	17.00/19.00	8.00/10.00		0.15 Se (min)
304 (S30400)	0.08	2.00	0.045	0.030	1.00	18.00/20.00	8.00/10.50		
304L (S30403)	0.030	2.00	0.056	0.030	1.00	18.00/20.00			
S30430	0.08	2.00	0.045	0.030	1.00	17.00/19.00	8.00/10.00		3.00/4.00 Cu
304N (S30451)	0.08	2.00	0.045	0.030	1.00	18.00/20.00	8.00/10.50		0.010/0.16 N
305 (S30500)	0.12	2.00	0.045	0.030	1.00	17.00/19.00	10.50/13.00		
308 (S30800)	0.08	2.00	0.045	0.030	1.00	19.00/21.00	10.00/12.00		
309 (S30900)	0.20	2.00	0.045	0.030	1.00	22.00/24.00	12.00/15.00		
309S (S30908)	0.08	2.00	0.045	0.030	1.00	22.00/24.00	12.00/15.00		
310 (S31000)	0.25	2.00	0.045	0.030	1.50	24.00/26.00	19.00/22.00		
310S (S31008)	0.08	2.00	0.045	0.030	1.50	24.00/26.00	19.00/22.00		
314 (S31400)	0.25	2.00	0.045	0.030	1.50/3.00	23.00/26.00	19.00/22.00		
316 (S31600)	0.08	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00	
316F (31620)	0.08	2.00	0.20	0.10 (min)	1.00	16.00/18.00	10.00/14.00	1.75/2.50	
316L (S31603)	0.030	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00	
316N (S31651)	0.08	2.00	0.045	0.030	1.00	16.00/18.00	10.00/14.00	2.00/3.00	0.10/0.16 N
317 (S31700)	0.08	2.00	0.045	0.030	1.00	18.00/20.00	11.00/15.00	3.00/4.00	
317L (S31703)	0.030	2.00	0.045	0.030	1.00	18.00/20.00	11.00/15.00	3.00/4.00	
321 (S32100)	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/12.00		5xC Ti (min)
329** (S32900)	0.10	2.00	0.040	0.030	1.00	25.00/30.00	3.00/6.00	1.00/2.00	
330 (N08330)	0.08	2.00	0.040	0.030	0.75/1.50	17.00/20.00	34.00/37.00		0.10 TA 0.20Cb
347 (S34700)	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/13.00		10xC Cb+Ta (min)
348 (S34800)	0.08	2.00	0.045	0.030	1.00	17.00/19.00	9.00/16.00		10xC Cb+T (min) (Ta 0.10 max) 0.20 Co
384 (S38400)	0.08	2.00	0.045	0.030	1.00	15.00/17.00	17.00/19.00		

\* May be added at manufacture's option.  
\*\* Duplex alloy - Austenite + Ferrite  
\*\*\* ASTM-SAE unified numbering system.

**Figure 15 - Austenitic Stainless Steels Chemical Analysis Percent.**



**Figure 16 – Austenitic Stainless Steel Family Tree.**



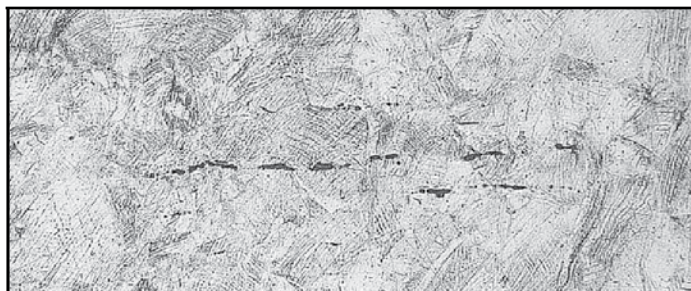
**Figure 17 – Effect of Increasing Nickel on an 18% Cr, 10C Base Alloy. Transformation of Austenite Is Suppressed so That It Is the Major Phase Even at Room Temperature.**

Because these steels are primarily austenitic, they are essentially non-magnetic and not subject to arc blow in welding. Magnetic characteristics of austenitic stainless steel weld metals will actually vary from non-magnetic, as in fully austenitic Types 310, 320 and 330, to noticeably magnetic, as in Type 312, which contains more than 25% ferrite – the phase responsible for magnetic characteristics. Most common austenitic stainless steels, such as 308(L), 309(L), 316(L) and 347, are slightly magnetic due to the presence of some ferrite. Although fully annealed austenitic stainless steels are non-magnetic, some degree of magnetism can be induced by subsequent cold working of lower alloyed grades such as Type 304 (Figure 18).

### They Are Different

Although the 300 series austenitic stainless steels are welded with greater ease than the 400 series, there are several factors peculiar to this class that must be considered to ensure the production of satisfactory weldments. When compared with plain carbon, low alloy or 400 series stainless steels the austenitic types have lower melting





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200  $\mu\text{m}$

**Figure 18 – Type 304 Wrought Austenitic Stainless Steel Uns Number: S30400 Cold Worked. The Microstructure Shows Grain Boundaries Barely Visible. A High Amount of Slip Lines Are Visible From the Cold Working. The Image Was Created Using 100X Magnification and an Electrolytic Etch With Oxalic Acid to Etch the Surface.**

points, higher electrical resistance, lower coefficients of thermal conductivity (about 1/3 of plain carbon steel) and coefficients of expansion as much as 50% greater. For these reasons less heat input (less current) is required for fusion. Lower thermal conductivity results in a greater tendency for heat to concentrate in a small zone adjacent to the weld. Higher thermal expansion characteristics can result in warping or distortion, especially in thin sections, suggesting greater need for jiggling to maintain dimensional control. See Figure 8 on page 7 for comparison of carbon steel 400 series (straight chromium) and austenitic series (chromium-nickel) stainless steels.

Welding procedures must reconcile the differences discussed above. Filler metals specified should be compatible with the base metal and provide crack-resistant deposits which are equal to or better than the base metal in terms of soundness, corrosion resistance, strength, and toughness. Since weld metal with composition equivalent to base metal does not usually match the properties or performance of wrought base metal, it is common practice to enrich weld metal alloy content. For example, in AISI 316, the Cr and Ni ranges are 16-18% and 10-14% respectively; in E316-16 covered electrode deposits, the Cr and Ni ranges are 17-20% and 11-14% respectively.

Design engineers should be aware of several potential problems caused by the differential in expansion characteristics in dissimilar metal welding using austenitic stainless steel filler metal. The effect of cyclic temperature changes must be considered. Thermal stress relief may be counter-productive due to the stresses imposed during subsequent cooling of the welded joint.

Cleanliness is particularly important in welding austenitic stainless steels. The weld joint area must be free of dirt, grease, crayon marks, etc. to avoid porosity and pick-up of carbon. Only stainless steel wire brushes which are used for stainless material only should be used on finished welds; carbon steel brushes could introduce contamination, causing surface rusting.

## Carbide Precipitation

A distinctive characteristic of austenitic stainless steels such as Types 304 or 316 is chromium carbide precipitation at grain boundaries when exposure within a temperature range of about 800-1600°F is of sufficient time duration. Less than a minute is required at 1200°F and with a carbon level of about 0.07%.

The rapid heating and cooling of the base metal in the heat-affected zone of a weld results in a zone immediately adjacent to the weld that is annealed or solution treated by the heat of welding but is cooled rapidly enough to avert carbide precipitation. However, about 1/8" away from the weld a narrow zone in which lower heating and cooling rates prevail is exposed to a temperature range of about 1200 to 1600°F for sufficient time to permit chromium carbide precipitation. The actual effective temperature range will vary with time at temperature and alloy composition. Subsequent exposure of the weldment for a sufficient time within the critical temperature range would result in "sensitizing" the whole weldment – the entirety of the weld metal and the base metal would exhibit carbide precipitation.



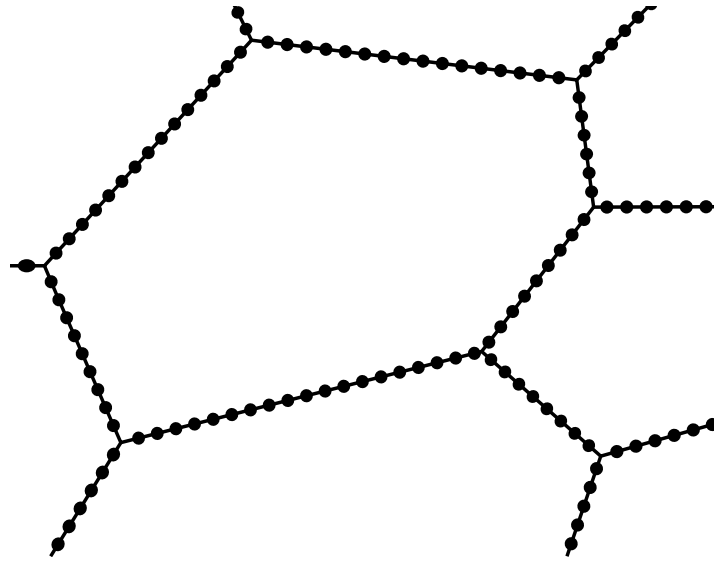
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100  $\mu\text{m}$

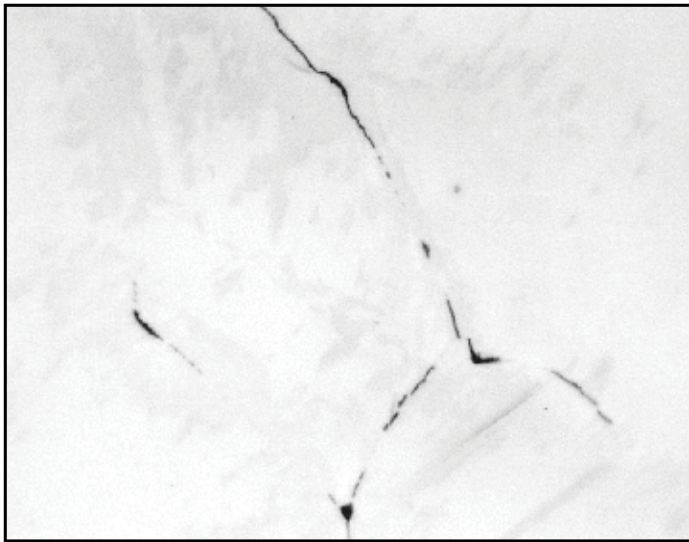
**Figure 19 – Carbide Precipitation in Annealed and Sensitized Type 330 Austenitic Wrought Stainless Steel Uns Number: N08330. The Image Was Created Using 200X Magnification and an Electrolytic Etch With Oxalic Acid to Etch the Surface.**

The propensity for carbide precipitation will vary somewhat with stainless steel grades. Nitrogen (N) alloying of base metals reduces the tendency for intergranular carbide precipitation by inhibiting carbon diffusion, thereby increasing resistance to intergranular corrosion. Whether N performs the same way in weld metals has not been documented. Molybdenum also tends to raise the tolerable level of carbon and/or heat input with respect to averting carbide precipitation.

If the "CROX" theory is accepted – that a thin film of chromium oxide provides passivity – it follows that if chromium oxide is restricted or decreased, the condition changes from more passive to less passive, with loss of some degree of stainlessness. The chromium impoverishment theory suggests that precipitation of chromium carbides around grain boundaries results in chromium-lean areas immediately adjacent to the grain boundaries, hence lack of chromium to produce a full complement of the much exalted "CROX." This is illustrated in Figure 21.



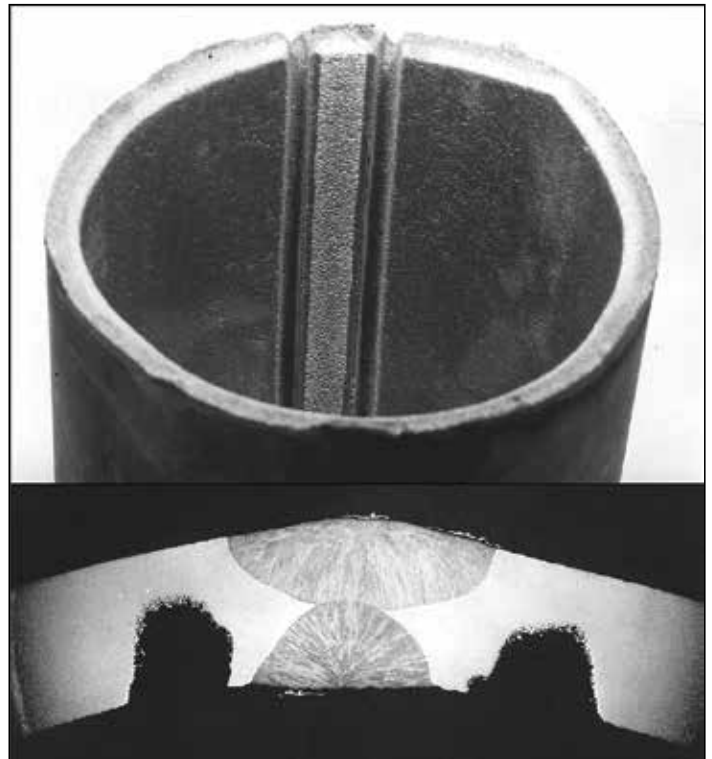
**Figure 21 – Schematic Presentation of Chromium Carbides (Dots) Around Austenite Grain Boundaries. The Shaded (Grey) Areas Show Chromium Depletion.**



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20  $\mu\text{m}$

**Figure 20 – Carbide Precipitation in As-Cast Chromium-Nickel Steel (Austenitic Cast Stainless Steel) Depicting Grain Boundaries at Which Carbides Have Precipitated.**



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**Figure 22 – (Top) Section of a 4-In. Diameter Type 304 Pipe Taken Out of a Hot Dilute Nitric Process Line. Intergranular Corrosion Is Indicated on Both Sides of the Weld.**

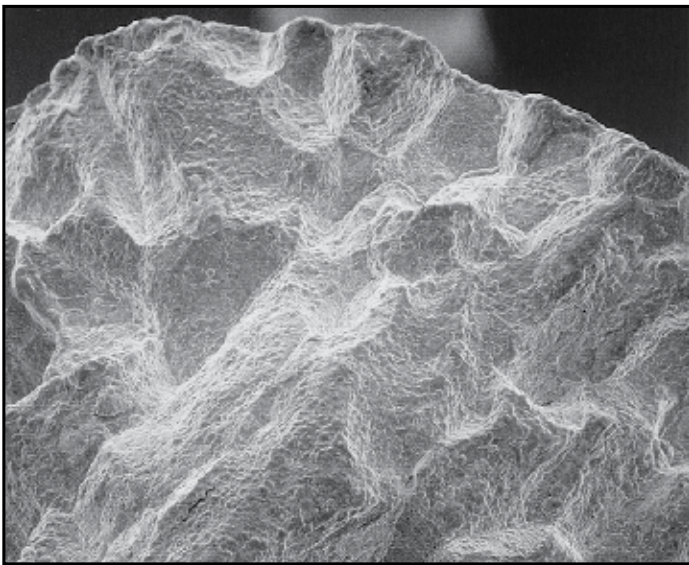
The narrow “sensitized” zones of a weld where carbide precipitation has occurred will not be cause for concern in many industrial applications. Any Type 304 weldment will contain sensitized zones of carbide precipitation, but as long as the service environment is such that sufficient passivity is maintained, sensitivity can be tolerated. However, in unfriendly corrosive environments such as nitric acid, which become more aggressive with increased concentration and temperature, selective attack around grain boundaries (intergranular corrosion) can eventually cause physical separation of the grains and gradual removal of the sensitized base metal in the zones affected. A dramatic example of this is illustrated in Figure 22.

Sensitization (the condition of susceptibility to intergranular attack in the presence of a suitable electrolyte such as oxygenated water, water which contains chlorides, hot nitric acid, etc.) is a time-temperature-alloy composition-dependent function. Thus, for a given alloy the TIME within the critical 800-1600°F temperature range will determine the EXTENT of carbide precipitation and therefore the DEGREE of vulnerability to

intergranular corrosive attack. For this reason, welding procedures – particularly for unstabilized or non-low carbon grades such as AISI 304 – should require that preheat temperatures (perhaps used for drying) be under 100°F and interpass temperatures below 350°F.

Premature failure may occur in the heat-affected zones related to specific welds, whereas the heat-affected zones related to adjacent welds on plate of the same mill heat number and filler metal of the same lot number (put in by a different welder or by the same welder except that in adjacent welds he followed acceptable procedure) may show no early evidence of weld-related attack. For unstabilized or non-low carbon grades such as AISI 304, it is particularly important to limit heat input to 30-35 kilojoules to minimize corrosive attack in unfriendly environments (aggressive solutions).

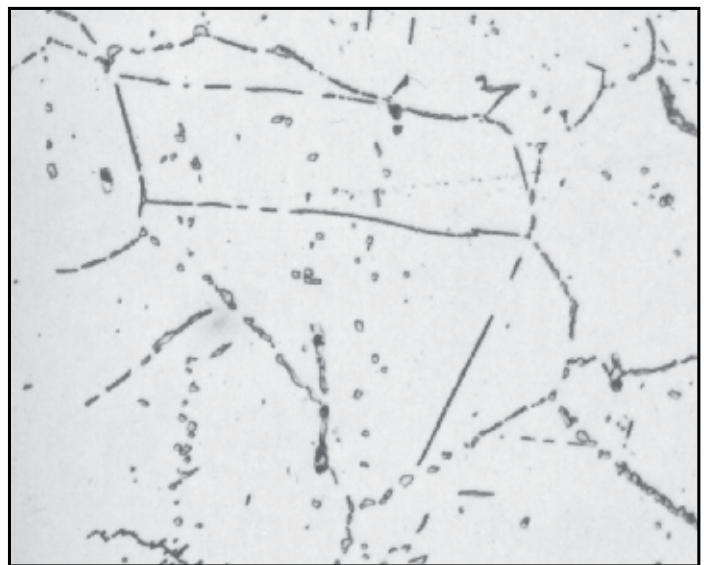
$$\text{Heat Input in Kilojoules per inch} = \frac{\text{Volts} \times \text{Amperes} \times 60}{\text{Travel Speed (ipm)} \times 1000}$$



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250 μm

**Figure 23 – Intergranular Creep at Leading Edge of a Turbine Vane on Type 310 (Uns Number S31000) Austenitic Wrought Stainless Steel. Images Is From Scanning Electron Microscopy (SEM).**



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25 μm

**Figure 24 – Annealed 316 Stainless After Exposure for 1000 Hours at 1500°F. This Temperature Produced Sigma and Chi Phases (Small, Outlined Particles) as Well as Precipitation of Chromium Carbide at Grain Boundaries. Image Was Created Using 500X Magnification, and Picral and Hydrochloric Acid to Etch the Surface**



## Combating Chromium Carbide Precipitation

Theoretically, if cooling in the heat-affected zone is rapid enough, carbide precipitation can be averted. Attempts to beat carbide precipitation such as wrapping the heat-affected zones in dry ice, use of chillbars, etc. are not practical and usually do not work. One way to take care of the problem is to let it happen then anneal at about 1950-2000°F (which dissolves the carbides) and quench in water, thus passing through the critical temperature range rapidly enough to avoid carbide precipitation. However, this alternative may be cumbersome and can cause distortion and excessive scaling.

There are two accepted approaches to averting carbide precipitation in austenitic stainless steels: reducing the carbon level to the point where precipitation doesn't normally occur in welding, or doing something to prevent the formation of chromium carbides by adding niobium or titanium to tie up (stabilize) the carbon so that it does not migrate to the grain boundaries and commence the chromium carbide caper. Niobium (Nb) is the designation for the element formerly designated Columbium (Cb). Some materials, handbooks, and older publications still use Columbium (Cb). They are one and the same.

The maximum C content is 0.03% for low carbon (L) grade wrought material like AISI 304L; 0.03% for bare welding wire such as ER308L; and 0.04% for covered electrodes e.g. E308L. There is always some pick-up of C from the covering materials on stick electrodes, hence a deposit composition of 0.04% C maximum rather than 0.03% C maximum. At these low carbon levels, the heating and cooling cycle of welding provides insufficient exposure time within the sensitization temperature range to produce carbide precipitation in the heat-affected zones of the base metal.

Addition of about 0.5% to 0.75% columbium or titanium is more than sufficient to tie up 0.04% carbon. The columbium or titanium carbides are more stable than chromium carbides and remain within the austenite matrix rather than migrating to grain boundaries. Bare wire electrodes are available in the columbium (ER347) or titanium (ER321) stabilized grades but covered electrodes are only available in the columbium grade (E347) since recovery of titanium across the arc of covered electrodes is poor.

Selection of an L or a stabilized grade will be influenced by several factors. In the first place, if the base metal is not an L or stabilized grade there is little point in worrying about the weld metal since the heat-affected zone will be sensitized anyway.

An L grade will avert excess carbide precipitation in the welded joint, but there are several applications where a stabilized grade may be preferred. Design engineers must recognize that L grades are lower in strength than stabilized grades (a fact that must be reconciled when working to the ASME Code) and that stabilized grades have higher strength at elevated temperatures. Where subsequent heat treatment or service requirements are such that exposure to the sensitizing temperature range is of long duration, some carbide precipitation of an L grade can occur. Other things being equal, during welding a stabilized grade may be slightly more crack sensitive than an L grade. Columbium is a ferritizer, which tends to reduce cracking by virtue of tendency for ferrite formation. But, at a specific ferrite level an austenitic stainless steel containing Cb may be more crack sensitive than one without Cb. Hence, the necessity exists for careful ferrite control in stabilized grades.

A weldment consisting of an "L" or stabilized base metal such as 304L or 347 and welded with 308 filler metal (unprotected from sensitization) will not exhibit sensitization within the weld metal from the first pass. However, cross-over welds would produce sensitized zones in what would then become the heat-affected zones in the first pass weld metal. For this reason, the filler metal specified for "L" or stabilized base metal should also be sensitization-resistant.

With respect to sensitization, stabilized, austenitic stainless steel base metal or filler metal in weldments does not always provide complete protection. The "belt and suspenders" approach is to specify grades containing low carbon plus a carbide stabilizer. This dual approach is common in overlay filler metals, for example, the use of 309 CbL deposited over mild steel to ensure, after dilution, a respectable 347 composition in the weld metal overlay.

Another example of the dual low carbon plus stabilized approach is specification of Type 3XX CbL base metal to avert "knife-line attack." In weldments involving Types 347 or 321 stabilized base metals there is a very narrow zone of base metal, immediately adjacent to the weld metal, which becomes exposed to a temperature high enough to largely dissolve the columbium or titanium carbides. If, after welding, these zones are then reheated to the vicinity of 1200°F, at which temperature the solubility of carbides of Cb, Ti, and Cr is very low, chromium carbides will preferentially precipitate at grain boundaries because of the greater amount of Cr in the alloy. The very narrow "knife-line" base metal zones thereby become sensitized and susceptible to intergranular attack.

Knife-line attack can occur in some corrosive environments. It has been observed in Type 347 weldments exposed to sulphate-containing acids in refineries. Type 321 is more susceptible to knife-line sensitization



than Type 347 since Ti carbides are dissolved at a lower temperature than Cb carbides, resulting in a wider sensitized zone than would occur with Type 347.

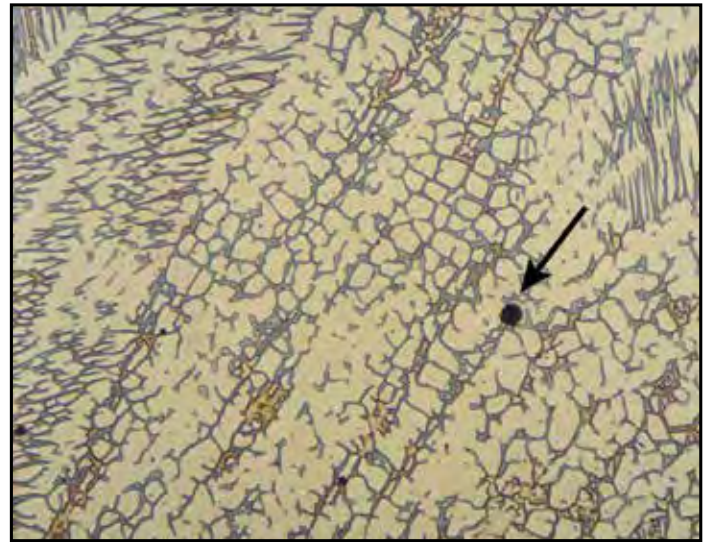
One way of avoiding knife-line attack in stabilized base metal is to reheat the joint area of the weldment to 1600°F. This produces, in the knife-line zones, selective precipitation of Cb and Ti carbides – the solubility of which is lower than that of Cr carbides. Subsequent exposure under service conditions to temperatures in the vicinity of 1200°F will not result in sensitization. If low carbon plus stabilized base metal such as Type 308 CbL is specified, the 1600°F treatment would not be required to prevent knife-line sensitization.

Within the limitations previously discussed, many weldments would be acceptable and free from carbide precipitation in the heat-affected zone where L, Cb or Ti grades are mixed or matched. That is, you could use 304L to weld 321 or 347 base metal, or 347 to weld 304L base metal etc.

## Ferrite in Austenitic Stainless Steel Weld Metal

What's so formidable about ferrite? It's not so formidable, it just makes things "tough". The structure of austenitic stainless steel weld metals varies from fully austenitic, as in 310, to dual phase austenitic-ferritic, as in 308, 309, 312, 316 etc., which contain a small volume of the ferrite phase. In most cases, some ferrite is desired for crack resistance. The extent of the ferrite phase depends mainly on composition, but for a given analysis will increase with the rate of cooling from elevated temperatures. For example, a 20Cr, 10Ni alloy cooled through the temperature range of about 2550 to 1850°F will contain more ferrite at room temperature if cooled rapidly as in welding than if cooled slowly as in casting.

Microfissuring and cracking can occur when low temperature melting compounds of P, S, Si, and Cb or other tramp elements tend to segregate intergranularly, thus setting the stage for hot cracking. Since these low melting compounds are much more soluble in ferrite than in austenite, a small amount of ferrite can "absorb" significant quantities of the impurities and reduce segregation to grain boundaries. With relatively small amounts of ferrite these boundaries are discontinuous, thus interrupting any cracking paths. Therefore, resistance to cracking can be enhanced by inducing the formation of ferrite in what might otherwise be a fully austenitic weld deposit. See Figure 25.



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25  $\mu$ m

**Figure 25 – 500X Magnification of Type 312 Austenitic Wrought Stainless Steel Weld Metal Showing Delta Ferrite Colored Blue and Brown in an Austenitic Matrix. The Arrow Points to a Slag Inclusion in the Weld Nugget. Image Captured From an Optical Microscope Using Murakami Reagent (Modified): 30 G Sodium Hydroxide, 30 G Potassium Ferricyanide, 100 MI Water at 100 Deg C (212°F) for 10 Seconds.**

### Frightful Ferrite?

Is ferrite always desirable? Ferrite can get you into trouble in some areas. In molybdenum-bearing grades like 316 and 317 and their L versions, ferrite can cause a major decrease in corrosion resistance in hot oxidizing media (e.g. urea). In cryogenic applications the low temperature impact strength decreases with increasing ferrite. A closely balanced FN is required to ensure adequate crack resistance and good low temperature impact strength. Above about 10FN there is danger of ferrite (which contains some Cr in solid solution) transforming to brittle sigma phase when the service temperature is in the 1000-1650°F range. In some multipass welds the exposure to the heat of welding alone may produce sigma phase in high ferrite welds. For elevated temperature service, 309L, with a relatively low FN would be preferred. The effect of adding Mo to the latter would promote sigma and some chi phases at elevated temperatures but would increase crack resistance at normal temperatures.

## Determination of Ferrite Level

The ferrite content in austenitic stainless steel weld metal can be controlled by varying the composition. Chromium promotes ferrite formation while nickel opposes it. Other elements with varying degrees of potency act in the same manner as either chromium or as nickel. Thus we have a chromium equivalent (ferritizers) vs. a nickel equivalent (austenitizers). With known composition we can add up the ferritizers vs. the austenitizers, using the guidelines of the DeLong diagram (Figure 26) and plot these two values on the diagram to establish the calculated ferrite anticipated in the weld deposit. Note that the actual deposit ferrite may drop about 1 FN for GTAW and about 4 FN for GMAW because of pick-up of N where gas coverage is inadequate.

It must be recognized that the Welding Research Council (WRC) DeLong diagram is an empirical device developed mainly around common welding alloys of the 1960s and early 1970s. The diagram may not be accurate when compositions depart appreciably from the common welding alloys of that period. Considerable evidence exists that Mn at high levels (above 2%) does not act as an austenitizer, so the diagram tends to underestimate ferrite in high Mn weld metals. There is also some evidence that, for alloys at the rich extremes of Type 309 and beyond, the diagram tends to over-estimate ferrite. Whenever possible, direct measurement of ferrite is preferable to estimates using the diagram. Nevertheless, the diagram continues to be a useful tool so long as its limitations are understood.

A predictive diagram for ferrite in stainless steels that is considered more accurate than either of the Schaeffler or DeLong diagrams has been developed. See Figure 26 and Welding Research Supplement Page 289-S *Welding Journal December, 1988*.

Ferrite is magnetic and austenite is not, so the magnetic attraction is directly proportional to the amount of ferrite present. The WRC Ferrite Number (FN) system is generally accepted as the best method for measuring and specifying ferrite content in austenitic stainless steel weld metals. They abandoned the notion of defining a volume percent ferrite for weld metal in favor of an arbitrary scale of Ferrite Number (FN).

The FN scale is defined by a set of National Bureau of Standards coating thickness standards. Each thickness of non-magnetic plating over a magnetic substrate is assigned an FN and a series of these standards is used to develop a calibration procedure. The basic instrument of the WRC FN system is a Magne-Gage which uses a small magnet that is pulled from the specimen by a spring force. The spring force is related to the FN by the calibration line using a "white dial" scale on the instrument.

The white dial scale on a Magne-Gage has 100 divisions and is usually calibrated by the manufacturer so that a little more than one revolution of the white dial scale covers the range of 0-28 FN with the #3 magnet. The white dial readings decrease as the FN increases so that 0 FN usually corresponds to a WD greater than 100 (e.g. 110). The Magne-Gage is very accurate but is not an all-position production tool.

An Inspector Gage gives a direct reading and can be used in all positions. The Severn Gage can be used in all positions but provides a bracket FN rather than a direct reading – the FN determined is more than one reading but less than another. The Ferritescope utilizes a magneto-inductive method to determine the permeability and hence the ferrite content of production welds.

## How Much Ferrite Is Enough?

Excluding environments like urea or cryogenic applications, how much ferrite is enough? An aim of about 5-10 FN is good general practice to mitigate micro cracking and stress-corrosion cracking. The nuclear industry specifies 5FN minimum. Some say 2 FN is adequate, others that 3FN is required for multipass welds.

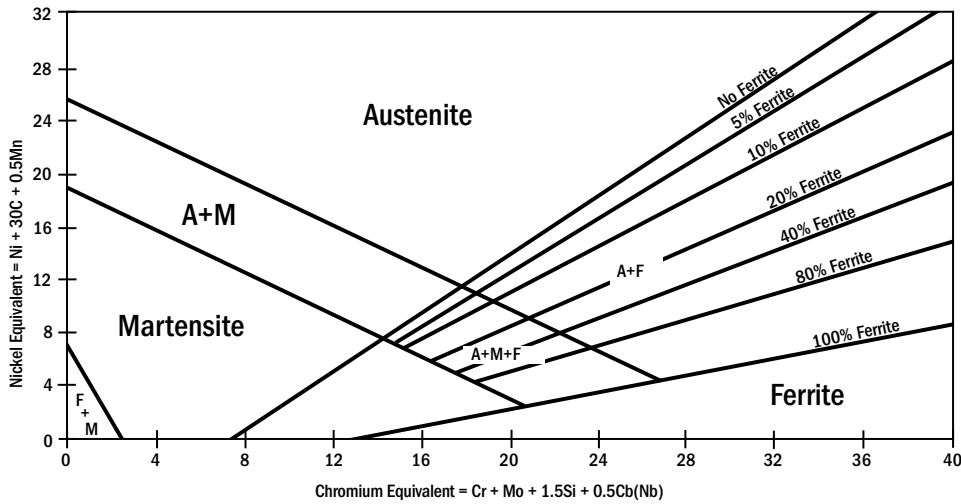
It should be noted that when welding with austenitic stainless steel covered electrodes in the vertical-up position the ferrite content in the deposit will likely be lower than when welding in the flat position. This may be due to the greater pick-up of nitrogen and greater carbon recovery coincident with vertical-up weaving technique.

## Ferrite And Magnetic Permeability – Probable Relationship

Producers of austenitic stainless steel filler metals are very aware of the desirability for products that exhibit high operator appeal. However, some applications call for products where "magnetic personality" is a liability and filler metals with low magnetic permeability are required.

One such application is in the welding of hulls and related structures for minesweeper ships. Another is in fusion reactor development where the feasibility of thermonuclear fusion is under exploration. In the latter application, it is critically important that extremely powerful, superimposed magnetic fields be virtually free of uncontrolled perturbation (disturbance or disruption). Hence low magnetic permeability stainless steel is specified for the reactor vessel and associated structures.

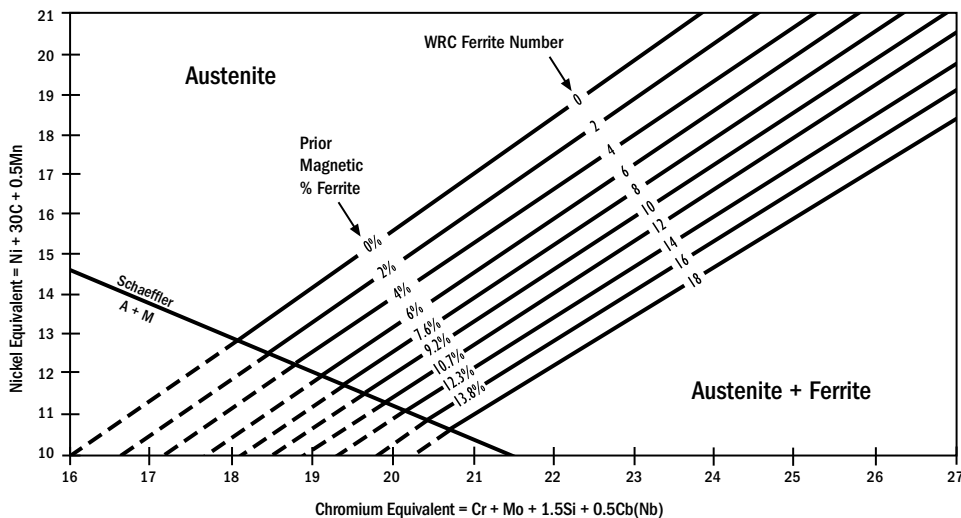
## Schaeffler Constitution Diagram



Calculate the nickel and chromium equivalents from the weld metal analysis. If nitrogen analysis of the weld metal is not available, assume 0.06% for GTAW and covered electrodes or 0.08% for GMAW weld metals.

If the chemistry is accurate, the diagram predicts the WRC Ferrite Number within  $\pm 3$  in approximately 90% of the tests for the 308, 309, 316, and 317 families.

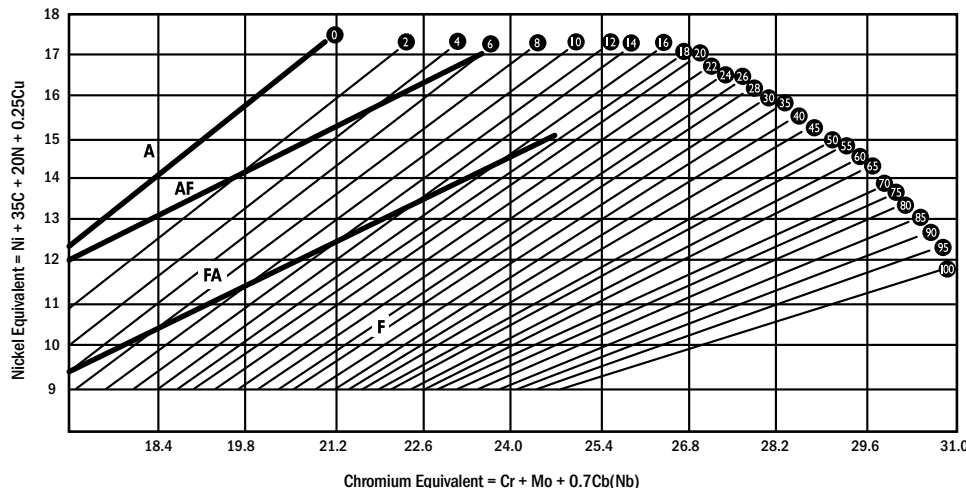
## DeLong Constitution Diagram



Comparison with Schaeffler Diagram:

1. The Nickel Equivalent allows for a nitrogen pick-up of 30N.
2. Ferrite Numbers for 308, 308L, and 347 covered electrodes are similar. The higher alloy 309, 316, and 317 families have about 2 to 4 higher FN on this diagram.
3. Generally, this diagram correlates better with GTAW and GMAW weld metals because it allows for nitrogen pick-up.
4. The Schaeffler austenite-martensite boundary has been included here for reference.

## 1992 WRC Constitution Diagram



Comparison with Schaeffler and DeLong Diagrams:

1. Considered more accurate for predicting ferrite in higher-alloyed stainless steels.
2. Copper (Cu) has been added to help determine the FN of duplex stainless steel welds.
3. This diagram should be limited to welds that contain less than 3Mo, less than 1Si, less than 10Mn and less than 0.2N.

A = Entirely austenite  
 AF = Austenite with some ferrite  
 FA = Ferrite with islands of austenite  
 F = Ferrite alone

Figure 26 - Schaeffler, DeLong and 1992 WRC Constitution Diagrams for Predicting Ferrite Levels.

## What Is Magnetic Permeability?

Gauss and oersted are terms involved in the definition of magnetic permeability. Simply defined these terms are as follows:

**Gauss** – a unit of magnetic induction such that an induction of one gauss will result in one volt per cm of length in a linear conductor moved perpendicularly across the conductor at a speed of one cm per sec.

**Oersted** – a unit of magnetic reluctance (resistance offered to the magnetic lines of force) equal to the reluctance of a cm cube of vacuum between parallel surfaces.

Magnetic permeability, expressed in units of MU, is the magnetic permeance of a material compared with air. Air = 1.0 MU. Magnetic permeability is the ratio of magnetic flux density in the material (units of gauss) to the field intensity (units of oersted). Thus units of MU are Gauss/Oersted. Loosely, the magnetic permeability of a material can be viewed as its ability to concentrate or distort a magnetic field.

## Measurement of Magnetic Permeability

Military Specification MIL-I-17214A describes a low MU (GO-NOGO) permeability indicator for use in determining the permeability of feebly magnetic materials in all forms used in ship construction. It is capable of differentiating materials of four different permeability levels: 1.2, 1.6, 2.0 and 2.5 (Air = 1.0). Permeability standards may be obtained from the Engineering Experiment Station, Annapolis, Maryland.

Severn Engineering Company manufactures such a high-sensitivity, low-MU permeability indicator permitting bracketing of magnetic permeability between two values. With this all-position instrument, values of less than 2 MU can be readily established.

## Estimating Magnetic Permeability (Mu) From Ferrite Level (Fn)

Although a direct relationship between ferrite and permeability is evasive, Figure 27 (adapted from data published by Ebasco Services) provides an educated guess of what magnetic permeability to expect with ferrite levels of 0 to 5 FN.

The data in Figure 27 and Figure 28 indicates that a weld metal Magne-Gage ferrite of 5FN could very well indicate less than 1.75 MU. Therefore, for a magnetic permeability of 2MU maximum, there is reasonable assurance that this requirement can be safely met by specifying a maximum 5 FN (Magne-Gage) and probably met by specifying a maximum of 6 FN.

For Delta Ferrite of:	There is an Approximate Probability:	That Magnetic Permeability (MU) Will Be Less Than:
0 FN	80%	1.10
1 FN	76%	1.10
	96%	1.20
2 FN	61%	1.10
	88%	1.20
	98%	1.30
3 FN	45%	1.10
	74%	1.20
	92%	1.30
	98%	1.40
4 FN	51%	1.20
	81%	1.30
	94%	1.40
	98%	1.50
5 FN	60%	1.30
	82%	1.40
	94%	1.50
	99%	1.75

**Figure 27 – Magnetic Permeability Vs. Delta Ferrite in Weld Metal. Actual Checks Using Hobart Secondary Ferrite Standards Weld Pads (Aws A4.2) With Severn Permeability Indicator Support the Validity of the Data in Figure 28**

## Ferrite in Standard AWS Pads Vs. Production Welds

For a given metal composition and welding process the magnetic response of a standard weld pad prepared as illustrated in Figure 29 may be somewhat different from the response of individual beads or layers in a production weld. Why? Because of dilution with parent metal, welding practice (arc length, atmospheric contamination and welding current) and varying cooling rates.

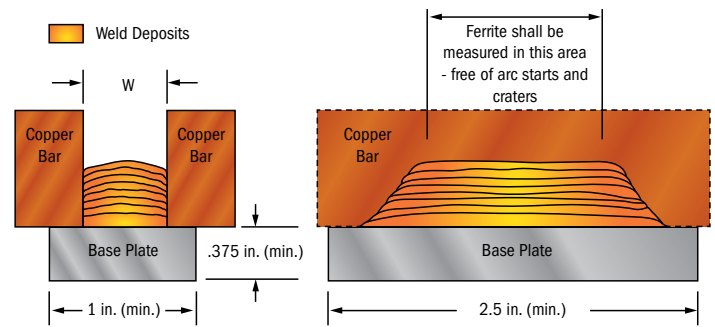
## How to Weld the Low Ferrite Austenitic Stainless Steels

Carefully! All phases of welding and inspection require greater attention with wholly-austenitic stainless steel filler metal grades such as 310, 320 and 330 since they are more crack sensitive than their ferrite-fortified cousins. Part of the damage can occur during cooling down from the solidification temperature to about 1800°F. Therefore, anything that will relieve stress during this period will help. Welding procedures and practice should minimize restraint. Heat input should be kept low. Keep the interpass temperature



Ferrite (FN) of Hobart Secondary Ferrited Standard	Corresponding Test Results With Severn Permeability Indicator	
	MU is less than	MU is greater than
FN		
0.8	1.10	1.07
0.9	1.2	1.10
1.0	1.2	1.10
1.3	1.2	1.10
1.4	1.2	1.10
2.0	1.5	1.2
3.5	1.5	1.2
4.7	1.5	1.2
5.0	1.8	1.5
7.2	-	2.0

**Figure 28 – Permeability Indications on Secondary Ferrite Standards.**



Electrode diameter (in.)	Welding current (amperes)	Dimension of deposit (approx., in.)	
		W	L
1/16	35-45	0.25	1.25
5/64	45-55	0.25	1.25
3/32	65-75	0.3	1.5
1/8	90-100	0.4	1.5
5/32	120-140	0.5	1.5
3/16	165-185	0.6	1.5
1/4	240-260	0.7	1.5

**Figure 29 – Standard AWS Ferrite Pad.**

below 210°F. Thin, narrow (stringer) beads are preferred as they reduce contraction stresses (cooling occurs more rapidly during the hot-short temperature range). Weld craters should be filled and crater cracks ground out before resuming welding.

Fill the craters by holding a short arc and moving back over the finished bead before breaking the arc. Clean each bead thoroughly before welding over it.

The benefits of low heat input also are metallurgical in nature. Avoiding excessive grain growth minimizes grain boundary accumulation of low melting non-metallics that play a major role in the cause of cracking. Preheating of the heat-affected zone may increase fissures (microcracks) by a factor of 10. Low heat practice tends to minimize this phenomenon.

Since high silicon weld metal is more susceptible to cracking than low silicon weld metal, in the case of submerged arc welding, filler metal silicon content must be controlled and consideration given to possible pickup of silicon from the welding flux. Phosphorus and sulphur are major deleterious residuals that should be avoided both in plate and weld metal.

With the most crack-sensitive grades (310, 310Cb, 320, 330) it is desirable to avoid pretty beads. Smooth, flat, well-washed beads crack readily. Ugly, crowned beads are more crack-resistant. For the above grades it is important to keep the weld heating cycle as fast as possible.

## Austenitic Stainless Steel Weld Metals for Cryogenic Applications

For a detailed discussion of cryogenic toughness of weld metal deposited with stainless steel covered electrodes, request Hobart Welding Products Publication No. 1235. Cryogenic properties of austenitic weld metal deposited by covered electrodes vary widely from grade to grade. For a specific grade optimum properties may be obtained if weld metal has the following properties:

- Low in ferrite – preferably 0 FN
- Low in nitrogen – preferably less than 0.05%
- Low in carbon – preferably less than 0.04%
- XXX-15 (Lime type covering).

For service at -320°F, Type 316L filler metal is superior to Type 308L filler metal. To reduce the Ms (start of the martensite transformation) temperature to -320°F, a minimum of 10.3% Ni is required for 308L, and for 316L a minimum of 10.1% Ni. With 316L the Ni range of 11-14% will always be above the 10.1% minimum required. With 308L (9-11% Ni) only the very narrow range of 10.3 to 11% Ni is safe; this part of the range will have very low ferrite. Furthermore, type 316L weld metal is much more crack resistant than 308L weld metal when the composition is adjusted to obtain low ferrite contents necessary for adequate lateral expansion at -320°F.

# Precipitation Hardening (PH) Stainless Steels

## What Are They?

The PH stainless steels are a family of Fe-Cr-Ni alloys with additives such as copper, molybdenum, niobium, titanium and aluminum. The principle of precipitation hardening is that a supercooled solid solution (solution annealed) changes its metallurgical structure on aging. The advantage of a PH steel is that components can be fabricated in the annealed condition and subsequently hardened (strengthened) by treatment at 900-1100°F, minimizing the problems associated with high temperature treatments. Strength levels up to 260 KSI can be achieved (exceeding the strength of martensitic stainless steels) with corrosion resistance similar to that of Type 304.

PH steels are utilized for aerospace and marine components, fuel tanks, landing gear covers, pump parts, shafting, bolts, saws, knives and flexible bellows-type joints. They fall within three general groups – martensitic PH, semi-austenitic PH, and austenitic PH stainless steels. Figure 30 lists several proprietary grades.

## Martensitic PH Stainless Steels – Single Treatment

The martensitic PH group (typified by 17/4 PH, where copper is the hardener) is predominantly austenitic at the solution-annealing temperature of 1900-1950°F. Subsequent rapid cooling in air or oil results in retention of the additives such as copper and columbium etc. in solid solution at room temperature. Within the temperature range of about 300°F to room temperature there is an austenite-to-martensite transformation. Reheating of the super-saturated solid solution martensite matrix to the aging temperature of 900-1100°F triggers the precipitation of submicroscopic particles with resultant increase in hardness and strength.

## Semi-Austenitic PH Stainless Steels – Double Treatment

When cooled rapidly from the annealing temperature to room temperature the semi-austenitic PH steels (typified by 17/7 PH, where aluminum is the hardener) retain their austenitic structure – offering good toughness and ductility in cold forming operations, where martensitic PH steels would be too hard.

Precipitation Hardened Stainless Steels							
Proprietary Grade	Typical Composition, %						
	C	Cr	Ni	Cu	Mo	Ai	Other
<b>Single Treatment (Martensitic) Steels</b>							
Stainless "W"	0.07	17	7.0			0.2	Ti - 0.7
17-4 PH	0.04	17	4.0	1.0			Cb - 0.3
15-5 PH	0.04	15	5.0	4.0			Cb - 0.3
PH 13-8 Mo	0.04	13	8.0		2.0	1.0	
<b>Double Treatment (Semi-Austenitic) Steels</b>							
17-7 PH	0.07	17	7.0			1.0	
PH 15-7 Mo	0.07	15	7.0		2.0	1.0	
PH 14-8 Mo	0.04	14	8.0		2.0	1.0	
AM 350	0.08	17	4.0		3.0		
Alloy 355 (AISI 134)	0.12	15.5	4.5		3.0		N - 0.10
<b>Austenitic Precipitation Hardening Steels</b>							
17-10 P	0.12	17	10.0				P - 0.25
HNM Alloy	0.03	19	9.0				Mn - 3.5, P - 0.3
A 286	0.05	15	25.0		1.5	0.15	Ti - 2.2, V - 0.3

Figure 30 – Precipitation Hardened Stainless Steels.

To produce hardening and strengthening, some transformation from austenite to martensite must first be induced to facilitate response to subsequent treatment at the aging temperature. When semi-austenitic PH steels are heated to 1200-1600°F, carbides are precipitated thereby depleting the matrix of some austenite-stabilizing elements and permitting some transformation to martensite upon cooling to room temperature.

Partial martensite transformation can also be accomplished by refrigerating below the Ms (start of martensite transformation) temperature or by cold working.

Strengthening of the semi-austenitic PH stainless steels is therefore accomplished in a two-stage or double treatment. After the initial treatment to develop martensite, the second treatment – exposure to the aging temperature of 850-1100°F – results in precipitation, hence hardening and strengthening.

## Austenitic PH Stainless Steels

The austenitic group (typified by 17-10 P, where phosphorus is the additive) have alloy content such that an austenitic, non-magnetic structure is maintained after annealing and even after any aging (hardening) treatment.

When reheated to 1200-1400°F, compounds are precipitated and a lattice straining action is exerted, increasing the hardness and strength of the austenitic structure – but not to the extent achieved with the martensitic or semi-austenitic PH grades. Weldability of the austenitic PH steels is very poor due to hot shortness caused, in the case of 17-7 PH, by phosphorus-rich compounds at grain boundaries.

## Welding PH Stainless Steels

The heat from welding will invariably cause solution treated or annealed base metal zones. Postweld heat treatments required to develop hardness in these zones may involve single or double heat treatments. The steel producer should be consulted, or pertinent steel producer literature referenced for recommended welding and subsequent treatment procedures for the specific PH proprietary grade involved.

Relatively thin PH stainless steels do not require preheating prior to welding. The martensitic PH grades are low in carbon and not full hardening as in martensitic stainless steels such as Type 410.

The weld metal and heat-affected zones of single pass welds will respond fairly uniformly to postweld precipitation hardening treatments. Multiple pass welds respond less uniformly, resulting in significant variations in the structure of weld metal, heat-affected zones, and base

metal. Annealing after welding will provide a more uniform structure capable of responding uniformly to subsequent precipitation hardening treatments.

In welding, maintain a short arc (a long arc causes loss of chromium through oxidation) and keep the heat input low (for best ductility and toughness). Use stringer beads, avoid wide weaving, and avoid stress raisers such as sharp corners, threads, and partial penetration welds. Where possible, use starting and run-off tabs, fill craters, and grind out any crater cracks that may appear before continuing welding. When matching filler metal is not required, an austenitic stainless steel filler metal of the 309 type can be used and will provide greater ductility. The low carbon (309L) or stabilized (309Cb) versions are preferred to prevent chromium carbide precipitation if the weldment is to be postweld heat-treated in the sensitizing temperature range.

Welding of 17/4 PH plate under 4 inch in thickness can be done without preheating but interpass temperatures up to 300°F are commonly specified. With thickness of 17/4 PH plate exceeding 4 inch, preheating to 200°F and maintenance of an interpass temperature of 200-500°F is considered necessary in many applications. When welding 17/4 PH with bare ER630 wire use argon or helium gas for GTAW (TIG) welding but only argon for GMAW (MIG) welding. See section on dissimilar metal welding (Page 28) for comments on welding 15-5 PH and 17-7 PH steels with 17-4 PH (630) filler metal.

## Duplex Stainless Steels

### What Are They?

Duplex stainless steels are so-called because their microstructure is part austenite and part ferrite. In wrought or cast duplex stainless steels, this microstructure is generally obtained by heat treatment in the temperature range of 1900-2100°F. As cast, these steels generally contain about 80% ferrite or more, and in addition to a small amount of austenite, they often contain brittle intermetallic compounds (sigma and/or chi phases). The heat treatment temperature is high enough to dissolve the intermetallic compounds but low enough so that some of the ferrite transforms to austenite. A very rapid cool (usually water quench) from the heat treatment temperature prevents new intermetallic compound formation and leaves a room temperature microstructure that is generally 40-60% ferrite with austenite as the balance.

Besides a tendency to form intermetallic compounds during slow cooling or holding in the temperature range of 1000-1700°F, duplex stainless can experience another form of metallurgical damage known

Composition of Several Proprietary Duplex Stainless Steels (%)											
Proprietary Grade	C	Mn	Si	P	S	Cr	Ni	Mo	N	Cu	W
Proprietary Duplex Stainless Steels											
Carpenter 7-Mo Plus (Type 329) (UNS S32900)	.10 max.	2.00 max.	.75 max.	.04 max.	.03 max.	25/30	3/6	1/2			
Sandvik 3RE60	.03 max.	1.5	1.7	.03 max.	.03 max.	18.5	4.7	2.7			
Cabot Ferralium 255	.04	.80	.45			25.5	5.2	3.5	.17	.17	
Uddeholm 44LN	.03 max.	1.7	.40			25	6.2	1.7	.17		
Sandvik 2205 (UNS S31903)	.03 max.	2.0 max.	1.0 max.	.03 max.	.02 max.	22	5.5	3	.14		
Mannesmann AF22	.03 max.	2.0 max.	1.0 max.			21/23	4.5/6.5	2.5/3.5	.08/.20		
Sumitomo DP3	.03 max.	1.0 max.	.75 max.	.03 max.	.03 max.	24/26	5.5/7.5	2.5/3.5	.10 min.	.2/.8	.1/.4

**Figure 31 – Composition of Several Proprietary Duplex Stainless Steels (%).**

as “885°F (475° C) embrittlement”. This embrittlement occurs due to the precipitation of chromium-rich ferrite (“alpha prime”) within the iron-rich ferrite.

Even properly heat-treated duplex stainless steels lose useful toughness below about – 50°F because the ferrite phase undergoes a ductile-to-brittle fracture transition with declining temperature. This factor along with the 885°F embrittlement phenomenon noted above limits the useful range of service temperatures for duplex stainless steels to the temperature interval of -50°F to 500°F, in contrast to the much broader interval of austenitic stainlesses (-456°F to as high as 1600°F or more).

In addition to alloying with chromium and nickel, duplex stainlesses generally contain additions of nitrogen (.10-.20%) and molybdenum (1.0-4.0%). The nitrogen increases yield strength and slows the formation of brittle intermetallic compounds. The molybdenum improves pitting resistance and crevice corrosion resistance of the alloys. Figure 31 lists compositions of several commercial duplex alloys.

### Why Are They?

Austenitic stainless steels are vulnerable to stress-corrosion cracking (SCC) in chloride environments but have excellent weldability. Ferritic stainless steels tend to be brittle and are difficult to weld but resist SCC. Duplex stainless steels combine some of the better features of austenitic and ferritic stainless steels.

Compared with austenitic grades, duplex austenitic-ferritic stainless steels exhibit higher strength (more than twice the yield strength)

and dramatically better resistance to SCC in chloride solutions at the expense of slightly lower ductility and toughness and slightly more difficulty in welding.

### Where They’re Used

Proprietary duplex stainless steel alloys have been successfully used in heat exchanger tubing, oil country tubing and piping, off-shore platforms, gas wells, line pipe, cast pump and valve bodies, and fittings for handling sea water or sour gas or oil, etc. Their use in geothermal service may prove them to be far superior to any of the austenitic stainless steel grades. Alloy 2205 may be in great demand in the chemical processing industry since it offers chloride pitting and crevice corrosion resistance at least as good as 317L with better SCC resistance than 304L or 316L.

### Filler Metals For Duplex Stainless Steels – Necessity To Balance For Optimum Phase Distribution

Autogenous (filler-less) fusion welds in duplex stainless steels cause the weld metal to revert back to approximately the as-cast microstructure (often 80% ferrite or more). Such a microstructure has very poor ductility and will almost invariably result in brittle fracture of a bend test.

Use of filler metal, matching that of the base metal composition, generally does little or no better in the as-welded condition because the as-cast (matching) weld metal is often 80% ferrite or more. In order to overcome this ductility difficulty in the as-welded condition, filler metals enriched in nickel (8-10% Ni vs. 5-6% Ni in the base metals)

are preferred. Such weld metal, in the as-welded condition, has a ferrite content similar to that of the heat treated base metal, and therefore has more than adequate ductility to pass a bend test while having corrosion resistance comparable to the base metal.

A region of special concern in welding duplex stainlesses for use in the as-welded condition is the highly diluted root pass. Since a considerable fraction of the root pass will be made up of the lower nickel base metal, its overall nickel content will be less than that of the undiluted weld metal. Thus the higher ferrite root pass will have lower ductility than the rest of the weld. To deal with this concern, it is useful to employ filler metal with a built-in “ferrite cushion” in the form of somewhat more nickel than the bare minimum needed to hold all-weld metal ferrite levels low enough for good ductility. Then diluted root areas can be ductile in the as-welded condition, particularly if reasonable precautions are taken to avoid excessive dilution. Avoid feather edges. A tight root will result in more dilution than an open root with a land.

For applications where solution annealing (1900-2100°F) is to follow welding (for example, in repair of duplex stainless steel castings), filler metals of matching composition to the base metal are suitable because the heat treatment will reduce the as-welded ferrite content. When a higher nickel weld metal receives a solution anneal, its ferrite content will also be reduced and, as a result, its yield strength may decrease somewhat. This will depend upon the extent of dilution and the time and temperature of heat treatment. In extreme cases, enriched nickel filler metal may prove unsuitable for use after heat treatment.

### Ferrite Measurement In Duplex Stainless Steel Weld Metal

In wrought and cast duplex stainless steels after heat treatment, the ferrite content can be determined by metallographic techniques

with good reproducibility from one measurer to another. Such is not the case in weld metal, however, because the ferrite is very fine and very irregularly shaped. Even measurements made with a scanning computer-controlled camera are plagued by excessive variation from one measurer to another due to variation in etching procedures.

To overcome this difficulty and permit two or more measurers to agree on a duplex weld metal ferrite content, Hobart has developed a method for specifying and measuring ferrite in duplex alloy weld metal. By adding counterweights to a Magne-Gage, its working range can be extended beyond the normal 28 FN range. Hence an Extended Ferrite Number (EFN) can be used for determining or specifying ferrite level in duplex stainless steel weld metal.

In general, an EFN of 30-60 assures good ductility, yield strength, and corrosion resistance.

### 2209 Covered Electrodes

2209 “stick” electrodes are intended for welding one of the most commonly used duplex stainless steels – the “2205” type – where weldments are to be used in the as-welded condition. Depending upon dilution and specifics of heat treatment, this electrode may or may not be suitable for use in the solution annealed condition.

2209 duplex stainless steel electrodes operate at the same currents used for standard, austenitic AC-DC stainless electrodes such as 308-16. Spatter, slag cover, slag removal, bead configuration and out-of-position welding characteristics are also similar to standard austenitic AC-DC electrodes.

Chemical composition requirements of undiluted E2209-XX weld metal are shown in Figure 32.

Typical Undiluted Weld Metal Composition (%)									
AWS A5.4	C	Mn	Si	Cr	Ni	Mo	Cu	N	Ferrite EFN
E2209-XX	.04	0.5-2.0	1.0	21.5-23.5	8.5-10.5	2.5-3.5	.75	0.08-0.20	>20

Figure 32 – Typical Undiluted Weld Metal Composition (%).



## Welding Procedure

Under normal conditions, little difficulty is anticipated when welding the duplex stainless steels. Most of the 2205 type plate material in use is under 1 inch, with 1/2 inch and 3/4 inch sizes predominant. However, the base metal and weld metal are in the high strength range (110,000 to 115,000 psi tensile strength) and hydrogen could be a problem because of the high ferrite content.

Preheating to 200-300°F may be necessary in sections over 1 inch and/or where heavily restrained conditions prevail. In all cases, interpass temperatures should be limited to 500°F maximum. Dwelling in the 600-1000°F range could produce 885°F embrittlement. Similarly, dwelling in the 1000-1700°F range could produce brittle sigma phase. Hence, beware of undue exposure in the 600-1700°F range.

Excessive dilution into the base metal should be avoided to avert loss of ductility and toughness in the initial layer of weld metal. Refer again to the passage on “Filler Metals for Duplex Stainless Steels.”

In contrast to procedures for welding many other steels, including austenitic stainlesses, in general high welding heat inputs are preferred for duplex stainless steels, especially if the weldment is to be used in the as-welded condition. High welding heat input is mainly for the benefit of the heat-affected zone. In the heat-affected zone, close to the fusion line, peak temperatures sufficient to cause nearly all of the microstructure to revert to ferrite are reached. High welding heat input results in better heat-affected zone ductility by slowing down the cooling from these peak temperatures and permitting a greater percentage of this “reverted” ferrite to transform back to austenite as the weldment cools.

## Dissimilar Metal Welding – A Few Guidelines

In transition joints (welding two members of dissimilar composition) or in welding like members of a weldment with non-matching filler metals, differences in properties of the weld metal, heat-affected zone, and base metal together with the consequences of postweld heat treatment and end use should be duly considered. Weldments produced with dissimilar filler metal are often put into service as welded. The following comments reflect some of the best practices currently followed.

- Where preheating or postheating of martensitic grades is impractical, austenitic filler metals such as 309(L) or 312 can be used with less chance of cracking – the increased ductility of the filler metal taking up the shrinkage stresses of the cooling weld.

(If the service temperature is above 800°F, Type 312 should be avoided due to potential embrittlement from sigma phase). Note that the statement above refers to less chance of cracking with austenitic filler metal. In highly restrained joints this approach would be risky since the heat-affected zones of the weldment would be prone to hydrogen-related cracking.

- Never use 308 to join austenitic stainless steel to plain carbon or low alloy steel. Sometimes it works, but if the resultant dilution produces a weld composition with less than about 17Cr/7Ni cracking may result. Type 310 is often used successfully for this application since it takes care of a lot of dilution and has a lower coefficient of expansion than 308; however, type 310 has no ferrite and is therefore sensitive to microcracking. Never use 310 on some weathering steels such as Cor-Ten A, Cor-Ten High-Temp or Mayari R which may contain 0.07-0.15% P.
- The two leading austenitic stainless steel filler metal contenders for dissimilar metal welding are 309(L) and 312. The “magic” companies that do an excellent job in maintenance and repair welding all favor a version of Type 312 for most applications. This grade takes care of dilution and contains a level of ferrite in excess of 25 FN which provides crack resistance and high strength. Type 309(L) is also widely used, particularly where service temperatures exceed 800°F; however, with a lower ferrite level (perhaps 7-12 FN) it is not as crack resistant as 312. Types 309Mo and 310 have also been used successfully. For submerged arc applications (which result in relatively high penetration, hence greater dilution) 312 is preferred over 309(L).
- Because of thermal expansion mismatch – causing thermal fatigue at high temperatures – austenitic stainless steel filler metal should not be used to join ferritic low alloy steels like 2.25 Cr, 1 Mo to austenitic stainless steel where the service temperature exceeds 800°F (e.g. power plants). Some success in applications of this type has been attained using nickel base ERNiCr-3 filler metal which has a coefficient of thermal expansion between these two base metals.
- In highly stressed applications use of a buttering technique – providing a transition deposit of 309(L), 310 or 312 weld metal on the mild steel or low alloy steel member of a weldment prior to welding to the stainless member – has been successful where other procedures have failed. In some cases a successful joint can even be made with 308 instead of 309(L) or 312 since dilution on the buttered side would be less of a problem.

- A general rule in welding dissimilar grades of austenitic stainless steels is to use filler metal of the lower alloy composition. For example, use 309(L) filler metal to join Type 310 to Type 304 base metals.
- Welding of 17-4 PH to 15-5 PH precipitation hardening stainless steels can be successfully accomplished with 17-4 PH filler metal (AWS E630 or ER630) since the two grades have the same general welding and heat treating characteristics. For welding 17-4 PH to a plain carbon or low alloy steel, Type 309(L) filler metal is suggested.
- Since there are no 17-7 covered electrodes produced (because of the problem of loss of aluminum across the arc) welding of 17-7 PH steel is sometimes done with 17-4 PH covered electrodes. The welding technique should involve a weaving motion that includes a short dwell on the 17-7 PH base metal. This ensures enough dilution to adequately enrich the weld metal such that it may be capable of at least limited response to the double treatment of the 17-7 PH base metal. If high strength is not required at the 17-7 PH weld joint, Type 309L or 309Cb covered electrodes may be considered.
- For joining cast iron to steel, use AWS ENiFe-CL.
- For joining ENiFe-Cl cast iron stainless steel, first butter the stainless side with Cast-Alloy 60 (using relatively low currents and overlapping of weld beads to minimize dilution), then join the cast iron to the buttered stainless steel with the same type of electrode.
- For hardsurfacing cast iron, For joining ENiFe-Cl cast iron stainless steel (low currents and overlapping of beads) then follow with one or two layers of Hobart Hardalloy 148, 140 or 155.
- For joining cast iron to austenitic manganese steels, use ENiFe-Cl. Buttering of the cast iron with ENiFe-Cl may be necessary before making the joint. A more cautious approach would be to butter both the cast iron and the austenitic manganese before making the weld with the nickel-iron ENiFe-Cl electrodes.

## Overlay and Clad Steel Welding – A Few Guidelines

### Overlays

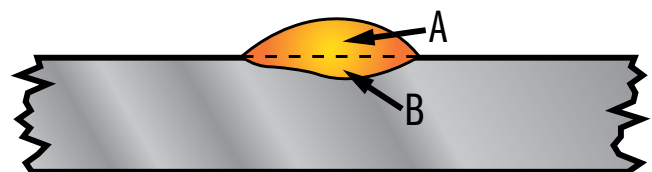
What you SEE is NOT what you GET where “what you see” is the filler metal composition and “what you get” is the weld deposit overlay composition resulting from dilution or the admixture of all-weld metal

	<b>C</b>	<b>Cr</b>	<b>Ni</b>
<b>With 308</b>	<b>0.06</b> $0.75 \times 0.06 = 0.045$ $0.25 \times 0.30 = \underline{0.075}$ 0.12 C	<b>20</b> $0.75 \times 20 =$ 15 Cr	<b>9.6</b> $0.75 \times 9 =$ 6.75 Ni
<b>With 312</b>	<b>0.10</b> $0.75 \times 0.10 = 0.075$ $0.25 \times 0.30 = \underline{0.075}$ 0.15 C	<b>29</b> $0.75 \times 29 =$ 21.75 Cr	<b>9</b> $0.75 \times 9 =$ 6.75 Ni
<b>With 309</b>	<b>0.07</b> $0.75 \times 0.07 = 0.0525$ $0.25 \times 0.30 = \underline{0.075}$ 0.1275 C	<b>24</b> $0.75 \times 24 =$ 18 Cr	<b>12.5</b> $0.75 \times 12.5 =$ 9.38 Ni
<b>With 309L</b>	<b>0.035</b> $0.75 \times 0.35 = 0.026$ $0.25 \times 0.30 = \underline{0.075}$ 0.101 C	<b>24</b> $0.75 \times 24 =$ 18 C	<b>12.5</b> $0.75 \times 12.5 =$ 9.38 Ni
<b>With 309L and 40% Dilution</b>	<b>0.035</b> $0.60 \times 0.035 = 0.02$ $0.40 \times 0.30 = \underline{0.12}$ 0.14 C	<b>24</b> $0.60 \times 24 =$ 14.4 Cr	<b>12.5</b> $0.60 \times 12.5 =$ 7.5 Ni

Required: To deposit weld metal composition of type 308 on AISI 1030 in one pass.

Assume 25% Dilution

$$\% \text{ Dilution} = \frac{B}{A + B} \times 100$$



<b>Effects on % Carbon in Weld Deposit when 1025 or 1020 Steels are Substituted for 1030</b>		
<b>Alloy</b>	<b>1025</b>	<b>1020</b>
308 - 25% Dilution	0.108	0.095
312 - 25% Dilution	0.138	0.095
309 - 25% Dilution	0.115	0.103
309L - 25% Dilution	0.089	0.078
309L - 40% Dilution	0.12	0.10

Figure 33 – Overlays and Dilution.

and parent metal. To end up with an overlay of a specified composition, the filler metal must be enriched sufficiently to reconcile dilution. With any given filler metal composition, changes in weld procedure can cause variation in dilution and, consequently, undesirable overlay composition. Therefore, to ensure consistent satisfactory results the welding procedure must be carefully controlled.

In the example in Figure 34, Type 309L filler metal at 25% dilution produces a reasonable 308 weld nugget, although C is higher than the 0.08% maximum specified for 308. A second pass, using 308L, would produce about 0.05C, 19.5Cr and 9.5Ni – a more respectable 308 composition. Substitute 1020 for the 1030 in the example and the single pass deposit with 309L would be about 0.076%C. A change in welding procedure causing a dilution increase from 25% to 40% would, in a one-pass application of 309L on 1030, result in unsatisfactory C, Cr and Ni contents.

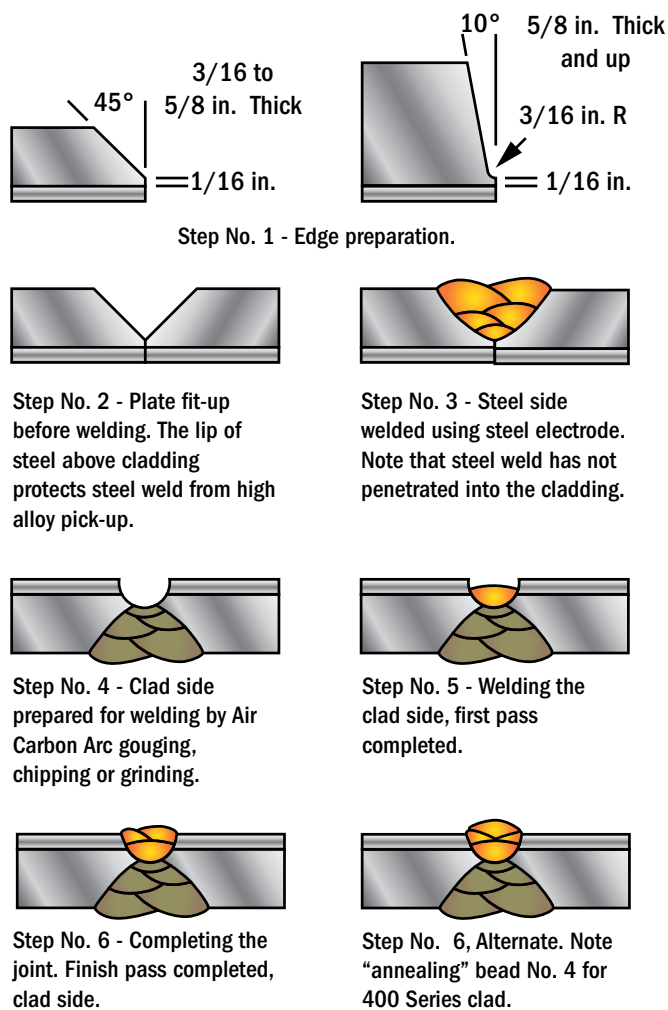
It is often necessary to consider multiple pass overlays to assure composition enrichment. For example, if a 347 deposit over mild steel is required, the first pass could be with 309L and the second with 347; use of a special filler metal like 309L Cb might be satisfactory in one pass but C would be a little on the high side. Where a 316 composition is required over mild steel, two passes with 309L Mo would be satisfactory. Remember – welding parameters and procedure control can result in variation in dilution with consequent variation in composition. Procedure qualification should include chemical analysis on the weld nugget. There are no shortcuts.

To overcome cracking tendencies in deposits of 309L over carbon or low alloy steel base metals such as 4130, consider Type 312 for the first pass and 309L for the second pass (assuming that the service temperature is not over 800°F). Note that overlapping of weld beads minimizes dilution.

## Clad Steels

When welding clad steels the dilution effects discussed in the section Overlays are of equal importance. Stainless clad carbon or low alloy steel plates are sometimes welded with stainless filler metal throughout the whole thickness, however, carbon or low alloy steel filler metal is usually used on the unclad side followed by removal of a portion of the cladding and completion of the joint with stainless.

Inexperienced fabricators should consult the manufacturer of the clad steel for detailed welding procedure and subsequent postweld heat treatment recommendations. Joining of clad steel to unclad steel



**Figure 34 – Typical Welding Procedure.  
Note That the Steel Side Is Welded First.**

sections normally requires buttering or surfacing of the clad section before joining to an unclad stainless steel section.

A typical welding procedure for stainless clad steel is shown in Figure 35. Note that Step No. 6, alternate, shows a center "annealing" bead technique for use when 400 series stainless cladding is used.

Careful consideration of filler metals is required. The unclad side requires a low carbon or low alloy filler metal of appropriate composition (XX18 for stick electrodes). For the clad side types 309L could be used for 405, 410, 430, 304 or 304L; 309Cb for 321 or 347; 310 for 310; and 309Mo for 316. Some applications may require essentially matching composition in the case of 400 series clad.

### Application of Some Common Stainless Steel Grades\*

Corrosion Level Application	Increasing Strength Levels →			
	Severe Corrodents	320		
Chemicals	316			
Food Processing And Mild Corrodents	304	630		
Industrial Atmospheres	430	431		
Mild Atmospheres	405	410	420	440-C
	Less Than 50,000	Yield Strength, PSI		
		Up to 175,000	Up to 250,000	Over

- \*Selection is determined by a number of factors:
- Actual corrodent
  - Operating temperature
  - Fabrication characteristics
  - Corrodent Concentration (%)
  - Mechanical properties required
  - Machineability
  - Weldability

**Figure 35 – Stainless Steel Grades and Corrosion Resistance.**

## Corrosion Of Stainless Steels – An Overview

### General Comments

While general comments may be offered about the resistance of some stainless grades to corrosion (such as 316 and 320 resisting attack by sulphuric acid, and 316 and 317 resisting attack in chloride solutions) the specification of stainless steels for specific service use is not in the province of suppliers of filler metals. Selection of a stainless grade is based on a number of factors. Some of these are summarized in Figure 36. Once the grade of stainless is chosen by the fabricator upon specification of his customer or in concert with corrosion/design engineers, the filler metal producer can suggest for filler metal alloys that are matching or compatible.

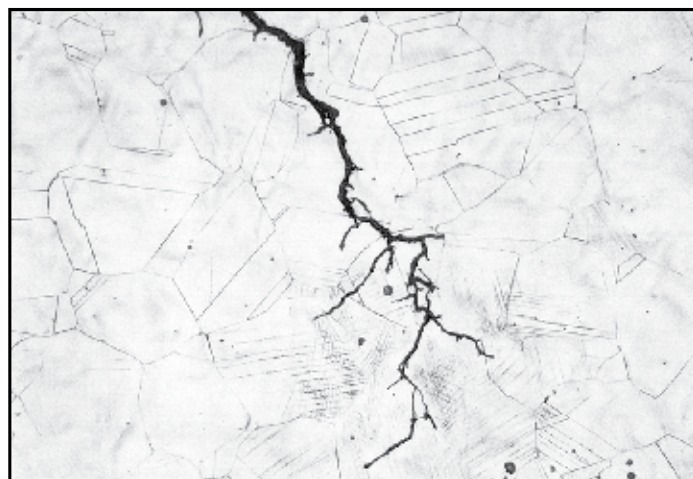
Corrosion of stainless steels in unfriendly media can occur uniformly or as pitting corrosion, crevice corrosion, intergranular corrosion, or stress-corrosion cracking.

### Pitting Corrosion

Pitting corrosion occurs transgranularly (across the grains) when the protective oxide film (CROX) is destroyed in small localized areas. Once begun, the attack may accelerate because of differences in electrical potential between the large area of passive surface (cathode) versus the small area of the active pit (anode). Type 304 is susceptible to pitting when exposed to halide salts. Type 316 and 317, with 2-3% and 3-4% respectively of Mo, reduce pitting tendency.

### Crevice Corrosion

Crevice Corrosion is a description of pitting that results from local differences in oxygen concentration associated with crevices under gaskets, lap joints, and fasteners, and also with deposits that accumulate on metal surfaces. Once begun, attack progresses rapidly. Crevice corrosion is most frequently associated with chloride environments. Mo helps to minimize crevice corrosion. Intelligent design to avoid crevices and a periodic cleaning schedule are also necessary for long range success.



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100 μm

**Figure 36 – 200X Magnification of a Transgranular Stress-Corrosion Crack That Cuts Across Grains in Type 310 Austenitic Wrought Stainless Steel Uns Number S31000 Using an Electrolytic Etch: Oxalic Acid.**

## Intergranular Corrosion

This has been discussed and illustrated in the austenitic stainless steel section “Carbide Precipitation” on page 15.

## Stress-Corrosion Cracking

Stress-corrosion cracking (SCC) occurs where there is a combination of unacceptable stress together with corrosive attack in a damaging environment in the presence of oxygen and over a sufficient period of time. SCC appears primarily transgranularly. See Figure 37. Stress relieving heat treatment is often helpful in reducing susceptibility of stainless steels to SCC. For this reason stress relieving subsequent to welding should be considered.

## Rusting Of 300 Series Austenitic Stainless Steels And Contamination Due To Welding

Rusting of austenitic stainless steels may be caused when a surface embedded with particles of free iron or of a surface contaminated by debris ground into the surface during storage or fabrication is exposed to moist air or water. The larger particles of embedded iron can initiate crevice corrosion.

Iron pick-up can occur from contaminated pickling solutions, grinding wheels, steel tools, welding fixtures, sandblasting operations, dust from manufacturing operations, airborne sand and iron oxide particles, particles from chipping and filing operations, and carbon steel or even 400 series stainless steel wire brushes. Only 300 series stainless steel wire brushes that are designated for use only on 300 series stainless steels should be used.

In GTAW, GMAW and FCAW processes, weld bead discoloration may occur due to contaminated shielding gases. Incursion of air through faulty equipment or poor procedure may reduce the ferrite content, making the weld deposit less resistant to cracking.

Arc strikes, weld stops, spatter, slag and heat tints can also affect the surface of stainless steel weldments.

The effect of arc strikes and weld stops can be averted by using run-out tabs at the beginning and end of a weld (where possible). Striking an arc on the weld deposit just ahead of a weld stop and then welding over the weld stop is also good practice.

Application of spatter-prevention paste on either side of the weld joint may prevent spatter from adhering tightly to the steel. Slag particles must be removed; in undercut areas they create crevices and can cause crevice corrosion.

There may be aesthetic reasons for removal of heat tint. However, the need to remove heat tint is greatest when environments are so aggressive that the stainless steel approaches the useful limits of its ability to resist corrosion. Heat tints may be removed by immersion in nitric/hydrofluoric acids, application of a pickling paste, glass bead blasting, or local electropolishing. For “how to” references see the passage on passivity on page 2.



# Effects of Alloying Elements and Impurities in Stainless Steels And High Strength Heat-Resisting Alloys

## Aluminum (Al)

- A strong ferrite former. Added to type 405 12% straight chrome weld metal to make it non-hardening (ferritic)
- Used to improve high temperature scaling resistance
- Added with titanium to some high strength alloys for age hardening effects
- Strong nitride former

## Carbon (C)

- A strong austenite former
- Added to some high strength alloys for hardening and strengthening effects
- Adversely affects weld metal corrosion resistance and toughness at low temperatures

## Columbium (Niobium) Cb(Nb)

- A strong carbide former. Used to stabilize austenitic stainless steels against precipitation of chromium carbides in the range of 800-1600°F
- Moderate ferrite former
- Added to some high strength alloys for hardening and strengthening effects
- Added to some martensitic straight chromium stainless steels to tie up the carbon and reduce the hardening tendency of the steels

## Cobalt (Co)

- Added to various alloys to impart strength and creep resistance at high temperatures

## Chromium (Cr)

- A ferrite and carbide former
- Primary contributor to scaling and corrosion resistance
- In the stainless steels, this element has little or no effect on high temperature strength and creep strength

## Copper (Cu)

- Used to improve corrosion resistance of stainless steel in many liquids which are reducing rather than oxidizing

## Molybdenum (Mo)

- A ferrite and carbide former
- Used to improve high temperature strength and creep resistance
- Used to improve general corrosion resistance of steels in non-oxidizing media, and the resistance to pitting corrosion in all media

## Manganese (Mn)

- Austenite former
- Improves weld metal crack resistance in fully austenitic alloys

## Nitrogen (N)

- A strong austenite former
- Used to minimize grain grown in high chromium straight chromium steels at high temperatures
- Adversely affects weld metal toughness at cryogenic temperatures
- Raises strength

## Nickel (Ni)

- An austenite former
- Used to improve the general corrosion resistance against non-oxidizing liquids
- Sometimes added in small amounts to straight chromium grades to improve the mechanical properties
- Generally improves weld metal toughness

## Phosphorus (P) Sulphur (S) Selenium (Se)

- One of these three elements is occasionally added to stainless steels in conjunction with a small amount of Molybdenum or Zirconium to improve machinability of the steel
- All three promote cracking in weld metal

## Silicon (Si)

- A ferrite former
- Used to increase the corrosion resistance of austenitic steels
- Used to improve high temperature scaling resistance
- Used to improve resistance of high temperature steels to carburization

## Titanium (Ti)

- A strong carbide and nitride former. Used to stabilize austenitic stainless steels against precipitation of chromium carbides in the range of 800-1600°F
- A strong ferrite former
- Added to some high strength heat resisting alloys for its hardening and strengthening effects
- Added with aluminum to some high strength heat resisting alloys for age hardening effects

## Tungsten (W)

- Improves the high temperature strength and creep resistance of some high temperature alloys
- A strong ferrite former
- Stainless Steel Covered Electrodes
- Electrode Identification
- Commercial stainless electrodes are imprinted with the AWS grade and, frequently, a lot number

# Stainless Steel Covered Electrodes

## Electrode Information

Stainless steel electrodes are produced in four coating (covering) types.

- EXXX-15
- EXXX-16
- EXXX-17
- EXXX-26

Each type has distinctly different operational characteristics. However, for a given AWS classification (such as E309), rigid composition control, maintained through individual batch release procedures, results in essentially the same deposit composition from a given diameter and heat of core wire regardless of coating type specified. Many grades of coated stainless electrodes are commercially available. Recommended welding currents, and storage and rebaking temperatures are shown on page 36. Chemical composition limits for American Welding Society grades are listed on page 40.

### EXXX-15

EXXX-15 electrodes operate on direct current electrode positive (DCEP) only. Welding in all positions is possible with these type of electrodes.

### EXXX-16

EXXX-16 electrodes operate on either alternating current or direct current electrode positive (DCEP). The coating contains dominant amounts of rutile (titania), medium amounts of limestone and limited amounts of fluorspar. Transfer is spray-like, arc stability excellent, and spatter loss low. All sizes strike and restrike easily. The slag is easily

controlled and does not interfere with the arc action. Weld beads are smooth, uniform, and of excellent appearance (flat to slightly convex). The electrode can be used in any standard position without difficulty.

### EXXX-17

Compared to conventional AC-DC stainless steel electrodes the transfer is more spray-like and operation is possible over a much broader current range with direct current electrode positive (DCEP) preferred. Performs satisfactorily at normal currents; for optimum performance, use currents 15-25 amperes higher. Sterling electrodes have 10-30% faster deposition, smoother arc action, lower and finer spatter, and more attractive transfer. Finely-rippled bead feathers well into base metal and eliminates sharp notches. Beads in fillets are concave and require less polishing, thus reducing finishing costs. Great in flat and horizontal positions; limited for out-of-position applications. Not recommended for highly restrained deep groove welds.

### EXXX-26

These electrodes are designed for flat and horizontal fillet welding and have limited out of position characteristics. They can utilize alternating current (AC) or direct current electrode positive (DCEP). Most of these electrodes give higher deposition rates and have thicker coatings that contain higher levels of metal powders. The thicker coating provides larger fillet welds that are typically flat to concave. The slag system of these electrodes is similar to those of the -16 and -17 designations. Compared to the all-positional types, -26 electrodes usually require higher currents to achieve acceptable penetration.

<b>Suggested Currents in Amperes (DCEP)† For Stainless Covered Electrodes (SMAW)</b>		
<b>Electrode Diameter (In./mm)</b>	<b>Sterling AP</b>	<b>Sterling</b>
	<b>AMP Range</b>	<b>AMP Range</b>
3/32 (2.4)	60 - 80	35 - 60
1/8 (3.2)	80 - 100	40 - 80
5/32 (4.0)	100 - 140	80 - 120
3/16 (4.8)	140 - 220	150 - 190

† Polarity has been expressed as DCEP (Direct Current Electrode Negative) and DCEN (Direct Current Electrode Positive)

**Figure 37 – Suggested Current in Amperes.**

<b>Suggested Storage and Recondition Baking Temperatures for Stainless Covered Electrodes (SMAW)</b>		
<b>Coating Type</b>	<b>Storage Temperature for Open Containers</b>	<b>Recondition Baking Temperature for Overexposed Electrodes</b>
EXXX-16	215 - 300°F	660°F 2 hrs
EXXX-17	215 - 300°F	660°F 2 hrs

**Figure 38 – Suggested Storage and Recondition Baking  
Temperatures for Stainless Covered Electrodes.**

## Storage and Reconditioning Electrodes

Welding electrodes and wires may be damaged by atmospheric moisture. Figure 38 provides the proper storage conditions, and the time and temperature for reconditioning electrodes and wires that have absorbed excessive moisture. Figure 39 shows an oven used for storage and reconditioning of electrodes.

Pallets and unopened cartons of electrodes and wires should be stored away from exposure to water in the form of rain, snow, spray, or humidity. Only hermetically-sealed cans are safe against these conditions. Damaged cartons permit the entry of damp air which may be picked up by the product and lower its quality.

Low hydrogen electrodes should not be reconditioned more than one to two times, because that may cause a higher moisture absorption rate when exposed to the atmosphere. Over-reconditioning can be as damaging as excessive moisture.



**Figure 39 – Electrode Storage Oven.**

## Self-Shielded Wires

Recommended parameters for self-shielded wires are shown in Figure 40 along with typical deposition rates and efficiency. Loss of ferrite due to pick-up of nitrogen in the arc may be experienced with voltage too high or with current and wire extension too low. These effects are, in general, more pronounced with 3/32 inch diameter wire than with 1/16 inch diameter wires.

Suggested Parameters and Typical Deposition Data for Self-Shielded Wires					
Diameter (in.)	Electrical Stick-Out (in.)	Voltage (Volts)	Current (Amperes) DCEP (Rev. Pol.)	Deposition Rate lbs./hr.	Deposition Efficiency %
1/16	1/2 - 1	26 - 32	150 - 275	9 - 15	85 - 88
5/64	3/4 - 1-1/4	26 - 32	200 - 300	12 - 16	85 - 88
3/32	1 - 1-1/2	26 - 30	225 - 350	13 - 17	85 - 88

**Figure 40 – Suggested Parameters and Typical Deposition Data for Self-Shielded Wires.**

## Tubular and Solid Stainless Steel Wires

Increased voltage means a longer arc and a correspondingly larger volume of N-containing gas or plasma the metal must pass through; therefore, N increases and FN decreases. Increased current means higher wire feed speed rates; therefore, more metal per unit of time is passing through a given arc volume so that N is diluted by additional metal, resulting in N decreases and FN increases. Increased wire extension (stick-out) means decreased arc voltage (since part of the “fixed” voltage in a CV system is in the arc and part in the wire extension) and a shorter arc resulting in correspondingly smaller amounts of N and, consequently, an increase in FN.

These effects can be briefly expressed as follows:

$$\begin{aligned}
 -V \uparrow &= N \uparrow \text{ resulting in } FN \downarrow \\
 I \uparrow &= N \downarrow \text{ resulting in } FN \uparrow \\
 W.E. \uparrow &= N \downarrow \text{ resulting in } FN \uparrow
 \end{aligned}$$

Stainless steel wires are quite popular because of high operator appeal, good bead appearance and tie-in, and a cool arc compared with the G/S wires that are operated in inert gas. The ability to be used with these gases has solved the problems of the fabricator who is not permitted to use an “open arc” type cored wire or, because of poor parameter control or dilution is not producing satisfactory levels of ferrite in the weld deposit. If a shielding gas is used, CO<sub>2</sub> is preferred for best operation but some C pick-up (up to about 0.01%) may be expected. Operation is fair with 75/25 argon-CO<sub>2</sub> gas and unsatisfactory with gases of higher argon content.

## Type XXXT0 and XXXT1 Wires

XXXT0 cored stainless steel wires are designed for flat and horizontal welding of stainless steel. XXXT1 wires are for out-of-position welding of stainless steel.

XXXT0 and XXXT1 wires require external gas shielding. Preferred gas is 75% argon - 25% CO<sub>2</sub>. 100% CO<sub>2</sub> also be used. Do Not use 99-1 or 98-2 argon-oxygen gases.

## T0 And T1 Operational Characteristics - Welding Parameters – Technique

XXXT0 and XXXT1 wires used with Argon-CO<sub>2</sub> shielding gas produce a spray-like transfer with no spatter at high currents (160 amperes or higher with 0.045 inch wire or 180 amperes or higher with 1/16 inch wire). At lower currents or in CO<sub>2</sub> gases, a small ball transfer is produced. These wires, characterized by a dense and thick slag cover, operate satisfactorily over fairly wide current and voltage ranges. Optimum welding parameters are influenced by equipment, joint configuration, plate thickness, length of cables, quality of work connection, and operator skill. Suggested parameters, together with typical deposition rates, are shown in Figure 47. Deposition efficiency is typically 84-86%. A shielding gas flow rate of 25-35 CFH is suggested.

In the flat position, a number of welding techniques provide acceptable results. It should be noted that at high welding currents the spray transfer becomes so intense that the core of the wire extends out of the end of the wire into the arc. In this situation, it is important to adjust the welding voltage high enough that the core tip remains above the surface of the weld pool. If the wire core touches the weld pool, this will most likely cause slag entrapment in the weld pool, as evidenced by scattered slag indications in radiographs. However, when the voltage is set properly, the core tip is kept above the weld pool and excellent X-ray quality can be obtained.



In overhead welding, excessive electrical stick-out (contact tip to work distance) tends to cause the metal transfer to be a larger ball and excessive spatter may be noticeable to the extent that the shielding gas cup may become blocked. This effect is readily eliminated by maintaining a short stick-out. In fillet welds or tight grooves in the overhead position, adjust the contact tip so that it is nearly flush with the end of the gas cup.

In vertical-up welding, best results are usually obtained by directing the wire perpendicular to the joint. It is important to avoid contact between

the gas cup and the slag cover below the arc because contact will cause the still partially molten slag to tear and allow the molten metal behind the slag dam to run out of the joint. To initiate a vertical-up weld bead, it is sometimes best to strike the arc slightly to the side of the weld centerline (perhaps 1/8 inch or more away) and begin weaving slightly. Once the slag starts to set up, you can run a stringer or weave as desired. A stringer is easier at lower currents in Argon-CO<sub>2</sub>.

In the vertical-up position, do not try to travel upward too fast. If you outrun the slag cover, you will drop the metal out of the joint. If you look

Operating Ranges and Deposition Rates for T0 and T1 wires							
Weld Position	Diameter	Shielding Gas	Amperes*	Volts*	Wire Extension (in.)	Wire Feed (ipm)	Deposition Rate (lb/hr)
Overhead	0.045	Argon - CO <sub>2</sub>	140 - 240	24 - 32	1/4 - 1/2	230 - 630	4.3 - 11.8
Overhead	0.045	CO <sub>2</sub>	130 - 230	24 - 32	1/4 - 1/2	235 - 585	4.4 - 10.9
Vertical - Up	0.045	Argon - CO <sub>2</sub>	110 - 210	23 - 30	1/4 - 5/8	190 - 570	3.6 - 10.7
Vertical - Up	0.045	CO <sub>2</sub>	100 - 175	24 - 30	1/4 - 5/8	175 - 460	3.3 - 8.6
Vertical - Down	0.045	Argon - CO <sub>2</sub>	130 - 245	24 - 33	1/4 - 1/2	230 - 585	4.3 - 10.9
Vertical - Down	0.045	CO <sub>2</sub>	125 - 270	25 - 34	1/4 - 1/2	230 - 645	4.3 - 12.0
Flat	0.045	Argon - CO <sub>2</sub>	110 - 270	23 - 34	1/4 - 3/4	190 - 720	3.6 - 13.5
Flat	0.045	CO <sub>2</sub>	110 - 255	24 - 40	1/4 - 3/4	175 - 720	3.3 - 13.5
Overhead	1/16	Argon - CO <sub>2</sub>	180 - 260	24 - 30	3/8 - 5/8	140 - 240	5.0 - 8.8
Overhead	1/16	CO <sub>2</sub>	150 - 250	24 - 30	3/8 - 5/8	140 - 240	5.0 - 8.8
Vertical - Up	1/16	Argon - CO <sub>2</sub>	130 - 250	23 - 31	3/8 - 3/4	100 - 280	3.8 - 10.3
Vertical - Up	1/16	CO <sub>2</sub>	135 - 230	24 - 31	3/8 - 3/4	120 - 250	4.4 - 9.2
Vertical - Down	1/16	Argon - CO <sub>2</sub>	150 - 340	24 - 34	3/8 - 5/8	120 - 400	4.4 - 14.7
Vertical - Down	1/16	CO <sub>2</sub>	135 - 340	24 - 34	3/8 - 5/8	120 - 400	4.4 - 14.7
Flat	1/16	Argon - CO <sub>2</sub>	130 - 400	24 - 37	3/8 - 3/4	100 - 600	3.8 - 22.0
Flat	1/16	CO <sub>2</sub>	130 - 400	24 - 37	3/8 - 3/4	100 - 600	3.8 - 22.0

\*Voltage and current should be in phase. If voltage is at the low end of the range, current should also be at the low end. Follow the same practice for high side settings. For very long secondary cables, appreciably higher voltage at the power source may be required for optimum results.

**Figure 41 – Operating Ranges and Deposition Rates for T0 and T1 Wires.**

over the gas cup at the weld puddle, you should see the slag-metal interface at the front edge of the puddle. If you cannot see the slag-metal interface, chances are you are traveling upward too fast and will get a sagging bead or a drop-out.

The minimum thickness that can be welded easily vertical-up is about four times the wire diameter. That is, for 0.045 inch wire, the minimum base metal thickness is 3/16 inch. For 1/16 inch wire, the minimum base metal thickness is 1/4 inch.

Vertical-down welding is only suggested on material too thin for vertical-up welding. Spray transfer is better with higher voltage and rapid travel

speed to prevent the puddle from overrunning the arc. A concave bead will result.

The best overhead technique involves no weave. A steady linear travel generally produces best results; low travel speed will produce excessive droop of the weld metal. A dragging torch angle (wire inclined perhaps 30° from perpendicular to the joint, directed back toward the solidifying weld bead) is generally optimum for bead shape.

Cladding of a vertical wall can be accomplished by two techniques. One is to stack horizontal fillet beads one atop the other up the face of the wall. The other is a vertical weave much like capping off the face of a

groove weld. The vertical-up weave technique results in optimum surface profile when the weave is limited to about 1 inch in width.

In joining mild steel or low alloy steel to stainless steel in out-of-position welding, the same techniques work as those given for stainless-to-stainless joints. Removing the mill scale from the carbon or low alloy steel, especially in vertical-up welding, improves bead shape (flatness). If mill scale or rust is not removed, the iron oxide, when added to the XXXT0 and XXXT1 slag system, tends to make the slag more fluid and may result in a weld profile more convex than desired. Especially for vertical-up welding where penetration is higher, only high ferrite weld metal is recommended (grade 309LT1) because excess dilution tends to result in centerline cracking. When finishing a vertical-up joint of this type, it can be useful to run off the joint on the stainless side slightly to avoid crater cracks. Especially for a root pass, lower penetration with small ball transfer, rather than spray transfer, also helps to avoid cracking problems.

In any welding position, it should be noted that the slag of XXXT1 wires freezes much more quickly than the weld pool freezes. Because

of this, the weld bead surface is generally almost free of ripples. This relationship of slag freezing temperature to weld metal freezing temperature is essential for out-of-position welding. In the flat position, or in horizontal fillets, the lack of ripple might be considered unappealing by some users. If a rippled surface is considered more attractive for flat or horizontal applications, then XXXT0 self-shielded flux cored wires might be preferred.

Weld metal deposited in the flat or horizontal position with XXXT0 wires will be sound, provided that high current-low voltage conditions are avoided. The conditions recommended for vertical-up or overhead welding are generally suitable for flat welding. If higher currents are desired for increased deposition rates, then 30 volts or more may be necessary to produce X-ray quality welds. At high currents, the core of the wire will be noted to protrude from the end of the wire by as much as 1/4 inch. If this touches the bottom of the weld puddle, slag entrapment will result. Increased voltage keeps this from occurring.

Typical Parameters For Spray Transfer Welding With Bare Stainless Wire				
Wire Diameter (in.)	Amperes DCEP	Voltage (Volts)	Electrode Extension (in.)	Ar + 2% O <sub>2</sub> Flow Rate (CFH)
0.030	130 - 200	24 - 26	1/2 - 3/4	35
0.035	150 - 200	24 - 26	1/2 - 3/4	35
0.045	200 - 325	24 - 26	1/2 - 3/4	35
1/16	300 - 350	24 - 26	1/2 - 3/4	35

Figure 42 - Typical Parameters for Spray Transfer Welding With Bare Stainless Wire.

Typical Parameters For Short-Circuiting Welding With Bare Stainless Wire				
Wire Diameter (in.)	Amperes DCEP	Voltage (Volts)	Electrode Extension (in.)	90% He - 7.5% Ar - 2.5% CO <sub>2</sub>
0.030	50 - 150	18 - 22	3/8 - 1/2	25
0.035	60 - 200	18 - 22	3/8 - 1/2	25
0.045	75 - 225	18 - 22	3/8 - 1/2	25
1/16	100 - 250	18 - 22	3/8 - 1/2	25

Figure 43 - Typical Parameters for Short-Circuiting Welding With Bare Stainless Wire.

Typical Welding Procedure For Manual Gas Tungsten Arc Welding Of Stainless Steel*			
Material Thickness (in.)	1/16 - 1/8	1/8 - 1/4	1/4 - 1/2
Joint Design	Straight Butt	Single V-Groove	Double V-Groove
Current (Amperes)	50 - 90	70 - 120	100 - 150
Polarity	DCEN	DCEN	DCEN
Arc Voltage (Volts)	12	12	12
Travel Speed	As Required	As Required	As Required
Electrode Type	EWTh-2	EWTh-2	EWTh-2
Electrode Size (in.)	3/32	3/32	3/32
Filler Metal Type	ER-308	ER-308	ER-308
Filler Metal Size (in.)	1/16 or 3/32	3/32 or 1/8	3/32 or 1/8
Shielding Gas	Argon	Argon	Argon
Shielding Gas Flow Rate (cfh)	20	20	25
Purging Gas	Argon	Argon	Argon
Purging Gas Flow Rate (cfh)	5 - 7	5 - 7	5 - 7
Nozzle Size (in.)	3/8	3/8	1/2
Nozzle-to-Work Distance (in. max.)	1/2	1/2	1/2
Preheat (min.)	60°F	60°F	60°F
Interpass Temperature (max.)	500°F	500°F	500°F
Postweld Heat Treatment	None	None	None
Welding Position	F, H, V, OH	F, H, V, OH	F, H, V, OH

\* AWS C5.5-80, Recommended practice for Gas Tungsten Arc Welding.  
Note: Poor technique can result in nitrogen inversion with consequent loss of ferrite in weld deposits.

Figure 44 - Typical Welding Procedures for Manual Gas Tungsten Arc Welding of Stainless Steel.

Work	Weld		TWCH	Filler Rod	Current (Flat Welding)		Gas			Speed	Remarks
Thickness (in.)	Type	Number	Tungsten Elec- trode Diameter	(If Any) Diameter	Type	Amperes ○	Type	Flow CFH	PSI	Inches Per Minute	
<b>Stainless Steel</b>		<b>Manual Welding</b>			Direct Current Electrode Negative (DCEN)						
1/16	butt	1	1/16	1/16	DC	△ 80 - 100	Argon	11	20	12	
	lap	4,5	1/16	1/16	DC	△ 100 - 120	Argon	11	20	10	
	corner	6,7,9	1/16	1/16	DC	△ 80 - 100	Argon	11	20	12	
	fillet	10	1/16	1/16	DC	△ 90 - 100	Argon	11	20	10	
3/32	butt	1	1/16	1/16 or 3/32	DC	△ 100 - 120	Argon	11	20	12	
	lap	4,5	1/16	1/16 or 3/32	DC	△ 110 - 130	Argon	11	20	10	
	corner	6,7,9	1/16	1/16 or 3/32	DC	△ 100 - 120	Argon	11	20	12	
	fillet	10	1/16	1/16 or 3/32	DC	△ 110 - 160	Argon	11	20	10	
1/8	butt	1	1/16	3/32	DC	△ 120 - 140	Argon	11	20	12	
	lap	4,5	1/16	3/32	DC	△ 130 - 150	Argon	11	20	10	
	corner	6,7,9	1/16	3/32	DC	△ 120 - 140	Argon	11	20	12	
	fillet	10	1/16	3/32	DC	△ 130 - 150	Argon	11	20	10	
3/16	butt	1	3/32	1/8	DC	△ 200 - 250	Argon	13	20	10	
	lap	5	3/32 or 1/8	1/8	DC	□ 225 - 275	Argon	13	20	8	
	corner	6,7,9	3/32	1/8	DC	△ 200 - 250	Argon	13	20	10	
	fillet	10	3/32 or 1/8	1/8	DC	□ 225 - 275	Argon	13	20	8	
1/4	butt	1,2	1/8	3/16	DC	□ 275 - 350	Argon	13	20	5	one or two passes
	lap	5	1/8	3/16	DC	□ 300 - 375	Argon	13	20	5	one or two passes
	corner	6,7,8	1/8	3/16	DC	□ 275 - 350	Argon	13	20	5	one pass
	fillet	10	1/8	3/16	DC	□ 300 - 375	Argon	13	20	5	
1/2	butt	2,3	1/8 or 3/16	1/4	DC	□ 350 - 450	Argon	13	20	☆	two or three passes
	lap	5	1/8 or 3/16	1/4	DC	□ 375 - 475	Argon	15	20	☆	three passes
	corner	8,	1/8 or 3/16	1/4	DC	□ 375 - 475	Argon	15	20	☆	three passes
	fillet	10	1/8 or 3/16	1/4	DC	□ 375 - 475	Argon	15	20	☆	three passes

In TIG welding of stainless steel, welding rods having the AWS prefixes of E or ER can be used as filler rods. However, only bare uncoated rods should be used. Stainless steel can be welded using AC high-frequency stabilized current, however for Direct Current Electrode Negative (DCEN) current recommendations must be increased 25%. Light gauge metal less than 1/16 in. thick should always be welded with Direct Current Electrode Negative (DCEN) using Argon gas. Follow the normal precautions for welding stainless such as clean surfaces and dry electrodes. Use only stainless steel tools and brushes. Carefully remove soap from welds after pressure testing, and keep stainless from coming into contact with other metals.

- Notes:
- Reduce current 10 to 20% for vertical and overhead welds.
  - △ Ceramic cup should be used for currents up to 250 amps.
  - Water-cooled cup should be used for currents above 250 amps.
  - ☆ Welding speed for multiple passes cannot be accurately predicted.

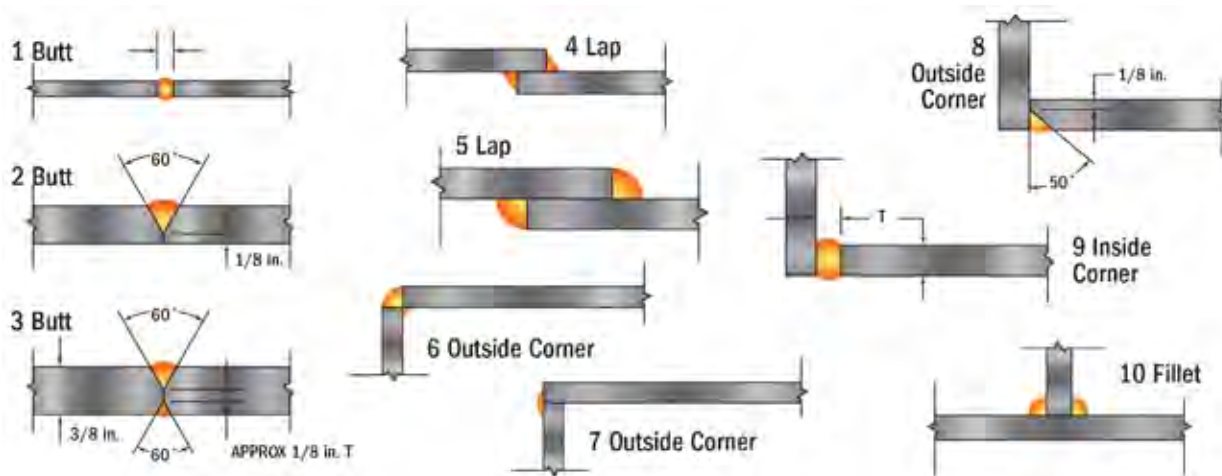


Figure 45 - TIG Welding Parameters.



Chemical Composition Requirements for the Undiluted Weld Metal Weight Percent <sup>a,b</sup>												
AWS Classification <sup>c</sup>	UNS Numbers <sup>d</sup>	C	Cr	Ni	Mo	Cb (Nb) + Ta	Mn	Si	P	S	N	Cu
E209-XX <sup>e</sup>	W32210	0.06	20.5 - 24.0	9.5 - 12.0	1.5 - 3.0	-	4.0 - 7.0	0.90	0.04	0.03	0.10 - 0.30	0.75
E219-XX	W32310	0.06	19.0 - 21.5	5.5 - 7.0	0.75	-	8.0 - 10.0	1.00	0.04	0.03	0.10 - 0.30	0.75
E240-XX	W32410	0.06	17.0 - 19.0	4.0 - 6.0	0.75	-	10.5 - 13.5	1.00	0.04	0.03	0.10 - 0.30	0.75
E307-XX	W30710	0.04 - 0.14	18.0 - 21.5	9.0 - 10.7	0.5 - 1.5	-	3.30 - 4.75	0.90	0.04	0.03	-	0.75
E308-XX	W30810	0.08	18.0 - 21.0	9.0 - 11.0	0.75	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E308H-XX	W30810	0.04 - 0.08	18.0 - 21.0	9.0 - 11.0	0.75	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E308L-XX	W30813	0.04	18.0 - 21.0	9.0 - 11.0	0.75	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E308Mo-XX	W30820	0.08	18.0 - 21.0	9.0 - 12.0	2.0 - 3.0	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E308MoL-XX	W30823	0.04	18.0 - 21.0	9.0 - 12.0	2.0 - 3.0	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E309-XX	W30910	0.15	22.0 - 25.0	12.0 - 14.0	0.75	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E309L-XX	W30913	0.04	22.0 - 25.0	12.0 - 14.0	0.75	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E309Cb-XX	W30917	0.12	22.0 - 25.0	12.0 - 14.0	0.75	0.70 - 1.00	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E309Mo-XX	W30920	0.12	22.0 - 25.0	12.0 - 14.0	2.0 - 3.0	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E309MoL-XX	W30923	0.04	22.0 - 25.0	12.0 - 14.0	2.0 - 3.0	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E310-XX	W31010	0.08 - 0.20	25.0 - 28.0	20.0 - 22.5	0.75	-	1.0 - 2.5	0.75	0.03	0.03	-	0.75
E310H-XX	W31015	0.35 - 0.45	25.0 - 28.0	20.0 - 22.5	0.75	-	1.0 - 2.5	0.75	0.03	0.03	-	0.75
E310Cb-XX	W31017	0.12	25.0 - 28.0	20.0 - 22.0	0.75	0.70 - 1.00	1.0 - 2.5	0.75	0.03	0.03	-	0.75
E310Mo-XX	W31020	0.12	25.0 - 28.0	20.0 - 22.0	2.0 - 3.0	-	1.0 - 2.5	0.75	0.03	0.03	-	0.75
E312-XX	W31310	0.15	28.0 - 32.0	8.0 - 10.5	0.75	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E316-XX	W31610	0.08	17.0 - 20.0	11.0 - 14.0	2.0 - 3.0	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E316H-XX	W31610	0.04 - 0.08	17.0 - 20.0	11.0 - 14.0	2.0 - 3.0	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E316L-XX	W31613	0.04	17.0 - 20.0	11.0 - 14.0	2.0 - 3.0	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E317-XX	W31710	0.08	18.0 - 21.0	12.0 - 14.0	3.0 - 4.0	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E317L-XX	W31713	0.04	18.0 - 21.0	12.0 - 14.0	3.0 - 4.0	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E318-XX	W31910	0.08	17.0 - 20.0	11.0 - 14.0	2.0 - 3.0	-	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E320-XX	W88021	0.07	19.0 - 21.0	32.0 - 36.0	2.0 - 3.0	6xC, min to 1.00 max	0.5 - 2.5	0.60	0.04	0.03	-	3.0 - 4.0
E320LR-XX	W88022	0.03	19.0 - 21.0	32.0 - 36.0	2.0 - 3.0	8xC, min to 1.00 max	1.50 - 2.50	0.30	0.020	0.015	-	3.0 - 4.0
E330-XX	W88331	0.18 - 0.25	14.0 - 17.0	33.0 - 37.0	0.75	-	1.0 - 2.5	0.90	0.04	0.03	-	0.75
E330H-XX	W88335	0.35 - 0.45	14.0 - 17.0	33.0 - 37.0	0.75	-	1.0 - 2.5	0.90	0.04	0.03	-	0.75
E347-XX	W34710	0.08	18.0 - 21.0	9.0 - 11.0	0.75	8xC, min to 1.00 max	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E349-XX <sup>e,f,g</sup>	W34910	0.13	18.0 - 21.0	8.0 - 10.0	0.35 - 0.65	0.75 - 1.20	0.5 - 2.5	0.90	0.04	0.03	-	0.75
E383-XX	W88028	0.03	26.5 - 29.0	30.0 - 33.0	3.2 - 4.2	-	0.5 - 2.5	0.90	0.02	0.02	-	0.6 - 1.5
E385-XX	W88904	0.03	19.5 - 21.5	24.0 - 26.0	4.2 - 5.2	-	1.0 - 2.5	0.75	0.03	0.02	-	1.2 - 2.0
E410-XX	W41010	0.12	11.0 - 13.5	0.7	0.75	-	1.0	0.90	0.04	0.03	-	0.75
E410NiMo-XX	W41016	0.06	11.0 - 12.5	4.0 - 5.0	0.40 - 0.70	-	1.0	0.90	0.04	0.03	-	0.75
E430-XX	W43010	0.10	15.0 - 18.0	0.6	0.75	-	1.0	0.90	0.04	0.03	-	0.75
E502-XX <sup>h</sup>	W50210	0.10	4.0 - 6.0	0.4	0.45 - 0.65	-	1.0	0.90	0.04	0.03	-	0.75
E505-XX <sup>h</sup>	W50410	0.10	8.0 - 10.5	0.4	0.85 - 1.20	-	1.0	0.90	0.04	0.03	-	0.75
E360-XX	W37410	0.05	16.0 - 16.75	4.5 - 5.0	0.75	0.15 - 0.30	0.25 - 0.75	0.75	0.04	0.03	-	3.25 - 4.00
E16-8-2-XX	W36810	0.10	14.5 - 16.5	7.5 - 9.5	1.0 - 2.0	-	0.5 - 2.5	0.60	0.03	0.03	-	0.75
E7Cr-XX <sup>h</sup>	W50310	0.10	6.0 - 8.0	0.4	0.45 - 0.65	-	1.0	0.90	0.04	0.03	-	0.75
E2209-XX	W39209	0.04	21.5 - 23.5	8.5 - 10.5	2.5 - 3.5	-	0.5 - 2.0	0.90	0.04	0.03	0.08 - 0.2	0.75
E2553-XX	W39553	0.06	24.0 - 27.0	6.5 - 8.5	2.9 - 3.9	-	0.5 - 1.5	1.0	0.04	0.03	0.10 - 0.25	1.5 - 2.5

- a. Analysis shall be made for the elements for which specific values are shown in the table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements, except iron, is not present in excess of 0.50%.
- b. Single values are maximum percentages.
- c. Classification suffix XX be -15, -16, -17, -25, or -26. See Section A8 of the appendix for an explanation.
- d. SAE/ASTM Unified Number System for Metals and Alloys.
- e. Vanadium shall be 0.10 to 0.30%.
- f. Titanium shall be 0.15% max.
- g. Tungsten shall be from 1.25 to 1.75%.
- h. This grade also will appear in the next revision of AWS A5.5, Specification for Low Alloy Steel Electrodes for Shielded Metal Arc Welding. It will be deleted from A5.4 at the first revision of A5.4 following publication of the revised A5.5.

**Figure 46 – American Welding Society A5.4 - 92 Specifications for Covered Corrosion Resisting Chromium and Chromium - Nickel Steel Welding Electrodes.**

### All-weld-metal chemical composition requirements

AWS Classification	C	Cr	Ni	Mo	Cb + Ta	Mn	Si	P	S	Fe	Cu
E307TX-X	0.13	18.0 - 20.5	9.0 - 10.5	0.5 - 1.5	-	3.3 - 4.75	1.0	0.04	0.03	Rem	0.5
E30BTX-X	0.08	18.0 - 21.0	9.0 - 11.0	0.5	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E30BLTX-X	a	18.0 - 21.0	9.0 - 11.0	0.5	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E30BMoTX-X	0.08	18.0 - 21.0	9.0 - 12.0	2.0 - 3.0	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E30BMoLTX-X	a	18.0 - 21.0	9.0 - 12.0	2.0 - 3.0	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E309TX-X	0.10	22.0 - 25.0	12.0 - 14.0	0.5	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E309CbLTX-X	a	22.0 - 25.0	12.0 - 14.0	0.5	0.70 - 1.00	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E309LTX-X	a	22.0 - 25.0	12.0 - 14.0	0.5	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E310TX-X	0.20	25.0 - 28.0	20.0 - 22.5	0.5	-	1.0 - 2.5	1.0	0.03	0.03	Rem	0.5
E312TX-X	0.15	28.0 - 32.0	8.0 - 10.5	0.5	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E316TX-X	0.08	17.0 - 20.0	11.0 - 14.0	2.0 - 3.0	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E316LTX-X	a	17.0 - 20.0	11.0 - 14.0	2.0 - 3.0	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E317LTX-X	a	18.0 - 21.0	12.0 - 14.0	3.0 - 4.0	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E347TX-X	0.08	18.0 - 21.0	9.0 - 11.0	0.5	8xC min to 1.0 max	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E409TX-Xb	0.10	10.5 - 13.0	0.60	0.5	-	0.80	1.0	0.04	0.03	Rem	0.5
E410TX-X	0.12	11.0 - 13.5	0.60	0.5	-	1.2	1.0	0.04	0.03	Rem	0.5
E410NiMoTX-X	0.06	11.0 - 12.5	4.0 - 5.0	0.40 - 0.70	-	1.0	1.0	0.04	0.03	Rem	0.5
E410NiTiTX-Xb	a	11.0 - 12.0	3.6 - 4.5	0.05	-	0.70	0.50	0.03	0.03	Rem	0.5
E430TX-X	0.10	15.0 - 18.0	0.60	0.5	-	1.2	1.0	0.04	0.03	Rem	0.5
E502TX-X	0.10	4.0 - 6.0	0.40	0.45 - 0.65	-	1.2	1.0	0.04	0.03	Rem	0.5
E505TX-X	0.10	8.0 - 10.5	0.40	0.85 - 1.20	-	1.2	1.0	0.04	0.03	Rem	0.5
E307T0-3	0.13	19.5 - 22.0	9.0 - 10.5	0.5 - 1.5	-	3.3 - 4.75	1.0	0.04	0.03	Rem	0.5
E308T0-3	0.08	19.5 - 22.0	9.0 - 11.0	0.5	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E308LT0-3	0.03	19.5 - 22.0	9.0 - 11.0	0.5	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E308MoT0-3	0.08	18.0 - 21.0	9.0 - 12.0	2.0 - 3.0	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E308MoLT0-3	0.03	18.0 - 21.0	9.0 - 12.0	2.0 - 3.0	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E309T0-3	0.10	23.0 - 25.5	12.0 - 14.0	0.5	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E309LT0-3	0.03	23.0 - 25.5	12.0 - 14.0	0.5	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E309CbLT0-3	0.03	23.0 - 25.5	12.0 - 14.0	0.5	0.70 - 1.00	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E310T0-3	0.20	25.0 - 28.0	20.0 - 22.5	0.5	-	1.0 - 2.5	1.0	0.03	0.03	Rem	0.5
E312T0-3	0.15	28.0 - 32.0	8.0 - 10.5	0.5	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E316T0-3	0.08	18.0 - 20.5	11.0 - 14.0	2.0 - 3.0	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E316LT0-3	0.03	18.0 - 20.5	11.0 - 14.0	2.0 - 3.0	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E317LT0-3	0.03	18.5 - 21.0	13.0 - 15.0	3.0 - 4.0	-	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E347T0-3	0.08	19.0 - 21.5	9.0 - 11.0	0.5	8xC min to 1.0 max	0.5 - 2.5	1.0	0.04	0.03	Rem	0.5
E409T0-3b	0.10	10.5 - 13.0	0.60	0.5	-	0.80	1.0	0.04	0.03	Rem	0.5
E410T0-3	0.12	11.0 - 13.5	0.60	0.5	-	1.0	1.0	0.04	0.03	Rem	0.5
E410NiMoT0-3	0.06	11.0 - 12.5	4.0 - 5.0	0.40 - 0.7	-	1.0	1.0	0.04	0.03	Rem	0.5
E410NiTiT0-3 <sup>b</sup>	0.04	11.0 - 12.0	3.6 - 4.5	0.05	-	0.70	0.50	0.03	0.03	Rem	0.5
E430T0-3	0.10	15.0 - 18.0	0.60	0.5	-	1.0	1.0	0.04	0.03	Rem	0.5
EXXXT-G	As agreed upon between supplier and purchaser.										

a. Titanium -10 x C min to 1.5% max.

**NOTES:**

1. The "-X" as specifically presented in this table indicates a classification covering the shielding designation for both the '1' and '2' categories. See data below.
2. Analysis shall be made for the elements for which specific values are shown in this table. If however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements, except iron, is not present in excess of 0.50%.
3. Single values shown are maximum percentages.

Classification System and Shielding Medium		
AWS designations (all classifications)	External shielding <sup>b</sup> medium	Current and polarity
E307TX-1 E307TX-3 E307TX-4 E307TX-G	CO2 None 75-80% Ar/Remainder CO2 Not Specified	DC Electrode Positive Not specified

- a. The letters 'XXX' stand for the chemical composition; see table above.
- b. The requirement for the use of specified external shielding media for classification purposes shall not be construed to restrict the use of other media for industrial use as recommended by the producer.

**Figure 47 – American Welding Society AS.22-80 Specification for Flux-Cored Corrosion Resisting Chromium and Chromium-Nickel Steel Welding Electrodes.**

Chemical Composition Requirements													
AWS Classification <sup>c,d</sup>	UNS Number <sup>e</sup>	Composite Weight Percent <sup>1b</sup>										Other Elements	
		C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu	Element	Amount
ER209	S20980	0.05	20.5 - 24.0	9.5 - 12.0	1.5 - 3.0	4.0 - 7.0	0.90	0.03	0.03	0.10 - 0.30	0.75	V	0.10 - 0.30
ER218	S21880	0.10	16.0 - 18.0	8.0 - 9.0	0.75	7.0 - 9.0	3.5 - 4.5	0.03	0.03	0.08 - 0.18	0.75	-	-
ER219	S21980	0.05	19.0 - 21.5	5.5 - 7.0	0.75	8.0 - 10.0	1.00	0.03	0.03	0.10 - 0.30	0.75	-	-
ER240	S24080	0.05	17.0 - 19.0	4.0 - 6.0	0.75	10.5 - 13.5	1.00	0.03	0.03	0.10 - 0.30	0.75	-	-
ER307	S30780	0.04 - 0.14	19.5 - 22.0	8.0 - 10.7	0.5 - 1.5	3.3 - 4.75	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER308	S30880	0.08	19.5 - 22.0	9.0 - 11.0	0.75	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER308H	S30880	0.04 - 0.08	19.5 - 22.0	9.0 - 11.0	0.50	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER308L	S30883	0.03	19.5 - 22.0	9.0 - 11.0	0.75	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER308Mo	S30882	0.08	18.0 - 21.0	9.0 - 12.0	2.0 - 3.0	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER308LMo	S30886	0.04	18.0 - 21.0	9.0 - 12.0	2.0 - 3.0	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER308S1	S30881	0.08	19.5 - 22.0	9.0 - 11.0	0.75	1.0 - 2.5	0.65 - 1.00	0.03	0.03	-	0.75	-	-
ER308LSi	S30888	0.03	19.5 - 22.0	9.0 - 11.0	0.75	1.0 - 2.5	0.65 - 1.00	0.03	0.03	-	0.75	-	-
ER309	S30980	0.12	23.0 - 25.0	12.0 - 14.0	0.75	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER309L	S30983	0.03	23.0 - 25.0	12.0 - 14.0	0.75	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER309Mo	S30982	0.12	23.0 - 25.0	12.0 - 14.0	2.0 - 3.0	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER309LMo	S30986	0.03	23.0 - 25.0	12.0 - 14.0	2.0 - 3.0	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER309Si	S30981	0.12	23.0 - 25.0	12.0 - 14.0	0.75	1.0 - 2.5	0.65 - 1.00	0.03	0.03	-	0.75	-	-
ER309LSi	S30988	0.03	23.0 - 25.0	12.0 - 14.0	0.75	1.0 - 2.5	0.65 - 1.00	0.03	0.03	-	0.75	-	-
ER310	S31080	0.08 - 0.15	25.0 - 28.0	20.0 - 22.5	0.75	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER312	S31380	0.15	28.0 - 32.0	8.0 - 10.5	0.75	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER316	S31680	0.08	18.0 - 20.0	11.0 - 14.0	2.0 - 3.0	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER316H	S31680	0.04 - 0.08	18.0 - 20.0	11.0 - 14.0	2.0 - 3.0	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER316L	S31683	0.03	18.0 - 20.0	11.0 - 14.0	2.0 - 3.0	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER316Si	S31681	0.08	18.0 - 20.0	11.0 - 14.0	2.0 - 3.0	1.0 - 2.5	0.65 - 1.00	0.03	0.03	-	0.75	-	-
ER316LSi	S31688	0.03	18.0 - 20.0	11.0 - 14.0	2.0 - 3.0	1.0 - 2.5	0.65 - 1.00	0.03	0.03	-	0.75	-	-
ER317	S31780	0.08	18.5 - 20.5	13.0 - 15.0	3.0 - 4.0	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER317i	S31783	0.03	18.5 - 20.5	13.0 - 15.0	3.0 - 4.0	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER31B	S31980	0.08	18.0 - 20.0	11.0 - 14.0	2.0 - 3.0	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	Cb <sup>g</sup>	8xC min/1.0 max
ER320	N08021	0.07	19.0 - 21.0	32.0 - 36.0	2.0 - 3.0	2.5	0.60	0.03	0.03	-	3.0 - 4.0	Cb <sup>g</sup>	8xC min/1.0 max
ER320LR	N08022	0.025	19.0 - 21.0	32.0 - 36.0	2.0 - 3.0	1.5 - 2.0	0.15	0.015	0.02	-	3.0 - 4.0	Cb <sup>g</sup>	8xC min/0.40 max
ER321	S32180	0.08	18.5 - 20.5	9.0 - 10.5	0.75	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	Ti	9xC min/1.0 max
ER330	N08331	0.18 - 0.25	15.0 - 17.0	34.0 - 37.0	0.75	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER347	S34780	0.08	19.0 - 21.5	9.0 - 11.0	0.75	1.0 - 2.5	0.30 - 0.65	0.03	0.03	-	0.75	Cb <sup>g</sup>	10xC min/1.0 max
ER347Si	S34788	0.08	19.0 - 21.5	9.0 - 11.0	0.75	1.0 - 2.5	0.65 - 1.00	0.03	0.03	-	0.75	Cb <sup>g</sup>	10xC min/1.0 max
ER383	N08028	0.025	26.5 - 28.5	30.0 - 33.0	3.2 - 4.2	1.0 - 2.5	0.50	0.02	0.03	-	0.70 - 1.5	-	-
ER385	N08904	0.025	19.5 - 21.5	24.0 - 26.0	4.2 - 5.2	1.0 - 2.5	0.50	0.02	0.03	-	1.2 - 2.0	-	-
ER409	S40900	0.08	10.5 - 13.5	0.6	0.50	0.8	0.8	0.03	0.03	-	0.75	Ti	10xC min/1.5 max
ER409Cb	S40940	0.08	10.5 - 13.5	0.6	0.50	0.8	1.0	0.04	0.03	-	0.75	Cb <sup>g</sup>	10xC min/0.75 max
ER410	S41080	0.12	11.5 - 13.5	0.6	0.75	0.6	0.5	0.03	0.03	-	0.75	-	-
ER410NiMo	S41086	0.06	11.0 - 12.5	4.0 - 5.0	0.4 - 0.7	0.6	0.5	0.03	0.03	-	0.75	-	-
ER420	S42080	0.25 - 0.40	12.0 - 14.0	0.6	0.75	0.6	0.5	0.03	0.03	-	0.75	-	-
ER430	S43080	0.10	15.5 - 17.0	0.6	0.75	0.6	0.05	0.03	0.03	-	0.75	-	-
ER446LMo	S44687	0.015	25.0 - 27.5	1	0.75 - 1.50	0.4	0.4	0.02	0.02	0.015	-	-	-
ER502h	S50280	0.10	4.6 - 6.0	0.6	0.45 - 0.65	0.6	0.5	0.03	0.03	-	0.75	-	-
ER505h	S50480	0.10	8.0 - 10.5	0.5	0.8 - 1.2	0.6	0.5	0.03	0.03	-	0.75	-	-
ER630	S17480	0.05	16.0 - 16.75	4.5 - 5.0	0.75	0.25 - 0.75	0.75	0.03	0.03	-	3.25 - 4.00	Cb <sup>g</sup>	0.15 - 0.30
ER19-10H	S30480	0.04 - 0.08	18.5 - 20.0	9.0 - 11.0	0.25	1.0 - 2.0	0.30 - 0.65	0.03	0.03	-	0.75	Cb <sup>g</sup>	0.05
												Ti	0.05
ER16-8-2	S16880	0.10	14.5 - 16.5	7.5 - 9.5	1.0 - 2.0	1.0 - 2.0	0.30 - 0.65	0.03	0.03	-	0.75	-	-
ER2209	S39209	0.30	21.5 - 23.5	7.5 - 9.5	2.5 - 3.5	0.50 - 2.0	0.90	0.30	0.03	0.08 - 0.20	0.75	-	-
ER2553	S39553	0.04	24.0 - 27.0	4.5 - 6.5	2.9 - 3.9	1.5	1.0	0.04	0.03	0.10 - 0.25	1.5 - 2.5	-	-
ER3556	R30556	0.05 - 0.15	21.0 - 23.0	19.0 - 22.5	2.5 - 4.0	0.50 - 2.00	0.20 - 0.80	0.04	0.015	0.10 - 0.30	-	Co	16.0 - 21.0
												W	2.0 - 3.5
												Cb	0.30
												Ta	0.30 - 1.25
												Al	0.10 - 0.50
												Zr	0.001 - 0.10
												La	0.005 - 0.10
												B	0.02

- Analysis shall be made for the elements for which specific values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total, excluding iron, does not exceed 0.50 percent.
- Single values shown are maximum percentages.
- In the designator for composite, stranded, and strip electrodes, the "R" shall be deleted. A designator "C" shall be used for composite and stranded electrodes and a designator "Q" shall be used for strip electrodes. For example, ECXX designates a solid wire and EQXX designates a strip electrode of the same general analysis, and the same UNS number. However, ECXXX designates a composite metal cored or stranded electrode and may not have the same UNS number. Consult ASTM/SAE Uniform Numbering System for the proper UNS Number.
- For special applications, electrodes and rods may be purchased with less than the specified silicon content.
- ASTM/SAE Uniform Number System for Metals and Alloys.
- Nickel + copper equals 0.5% maximum.
- Cb(Nb) may be reported as Cb(Nb) + Ta.
- These classifications also will be included in the next revision of ANSI/AWS A5.28, Specification for Low Alloy Steel Filler Metals for Gas Shielded Metal Arc Welding. They will be deleted from ANSI/AWS A5.9 in the first revision following publication of the revised ANSI/AWS A5.28 document.

**Figure 48 – American Welding Society A5.9-93 Specification for Corrosion Resisting Chromium and Chromium-Nickel Steel Bare and Composite Metal-Cored and Stranded Welding Electrodes and Welding Rods.**

<b>Filler Metals Suggested for Wrought Stainless Steels</b>		
<b>Base Metal</b>	<b>Filler Metal</b>	<b>Comments</b>
<b>AUSTENITIC STAINLESS STEELS</b>		
201, 202, 205	308	200 Series has Mn replacing some Ni
301, 302, 304, 304N	308	
303	312	Butter with 312 first and lots of luck
304L	308L	321 wire and 347 wire or stick may be acceptable
308	308	
309,309S	309	
310, 310S	310	
316,316N	316	Use 316 HF if 5FN min. required
316L	316L	
317	317	
317L	317L	
321	321 wire; 347 wire or stick	308L (if lower tensile strength ok)
330	330	
347	347	321 (wire) or 308L may be acceptable
348	347	Ta content to be 0.10 max.
384	309	
<b>MARTENSITIC STAINLESS STEELS (Preheat and Postheat)</b>		
403, 410, 414, 431	410	410NiMo may be acceptable
416	312	Butter with 312 first, and lots of luck
420	410, 410NiMo	420 carbon content is higher
440A, 440B, 440C	312	Butter with 312 first, and lots of luck
NOTE: Austenitic (309, 310, 312) may also be used if application permits.		
<b>FERRITIC STAINLESS STEELS (Preheat Advisable)</b>		
405, 409	409, 410NiMo	
429, 430	430	
442	442	
446	446	
NOTE: Austenitics (309, 310, 312) may also be used if application permits.		
<b>PRECIPITATION HARDENING STAINLESS STEELS (Minimize Heat Input)</b>		
17/4 PH	630	630-15 preferred over 830-16 stick
15/5 PH	630	Filler metal composition slightly different but compatible.
PH 13/8 Mo	630	
17/7 PH	630, 309L, 309Cb	Filler metals will not match base metal.
<b>DUPLEX STAINLESS STEELS</b>		
329	312Mo	Closest common grade
22Cr/5Ni/3Mo	2209	Special Order

**Figure 49 – Filler Metals Suggested for Wrought Stainless Steels.**

<b>Filler Metals Suggested for Casting Alloys</b>			
<b>Base Metal Alloy Castings Institute (ACI) Casting Alloy Designation</b>	<b>Similar to Wrought Alloy Type</b>	<b>Suggested Filler Metal</b>	<b>Comments</b>
CA-6NM	410NiMo	410NiMo	Preheat may be necessary
CA-15	12Cr	410, 410NiMo	Preheat and Postheat
CA-40	420	410, 410NiMo	Preheat and Postheat
CB-7Cu	Precipitation Hardening	630 (17-4 PH)	Keep Heat Input Low
CB-30	431	410, 410NiMo, 312	Preheat and Postheat
CD-4MCu	Ferralium 255	Ferralium 255 Electrode*	
CF-3	304L	308L	
CF-3M	316L	316L	
CF-8	304	308	
CF-8M	316	316,317	
CF-8C	347	347	
CF-12M	316	316, 317	
CF-20	302	308	
CH-20	309	309	
CG-8M	317	317	
CK-2Q	310	310	
CN-7M	20Cr/30Ni/Mo/Cu	320	Keep Heat Input Low
HA	9Cr/1Mo	505-18, SA5055, SA5050-S	Preheat and Postheat
HC	28Cr	446,312	Preheat and Postheat
HD	327(28Cr,5Ni)	312	
HE	312	312	
HF	19Cr/9Ni	308	
HH	25Cr12Ni	309	
HI	28Cr/15Ni	309	
HK	310H	310H	Special Order
HN	20Cr/25Ni	330	Keep Heat Input Low
HP	26Cr/35Ni	330	Keep Heat Input Low
HT	15Cr135Ni	330	Keep Heat Input Low
HU	19Cr/39Ni	330	Keep Heat Input Low

\*Haynes International, Kokomo, IN (formerly Cabot Corp.)

**Figure 50 – Filler Metals Suggested for Casting Alloys.**



Base Metals	201	202	301	302	302B	303	304	304L	305	308	309	309S	310	310S	314	316	316L	317	317L	321	330	347	348	403	405	410	414	416	420	430	430F	431	440A	440B	440C	446	Base Metals								
	308	308	308	308	308	308 312	308	308	308	308	308	308	308	308	308 312	308	308	308	308	308	308	312 309	308	308	309	309	309	309	309	309	309	309	309	309	309	309	310	201							
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																						330	312 309	312 309	312	312	312	312	312	312	312	312	312	312	312	312	312	330	330						
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																																		309	309	309	309	309	309	309	309	309	309	440C 310	440C 310
																																											312 310	446	
																																											310	310	

## Stainless Steel Dissimilar Welding Chart

This chart is only a suggestion of which filler metals should be adequate for the joining of the stainless steels. This does not mean the other filler metal alloys are not recommended or of less quality. In all instances the chart should be used as a reference only. Actual application should dictate the proper alloy choice.

The gray sections of this chart indicate "free-matching" alloys, which are considered not weldable. This is due to the high percentage of sulphur or other low melting point elements that cause hot cracking. If high-quality joints are required, welding is not generally recommended.

This chart does not indicate welding procedure. Some stainless steels require preheat while others should not have a preheat. Some welds require a buttering layer or other more rigid procedure. Suppliers may be contacted regarding procedure recommendations.



# Stainless Steel

## Technical Welding Guide

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REV 03/21

