Stainless Steels

Welding Guide

LINCOLN ELECTRIC

STAINLESS STEELS PROPERTIES – HOW TO WELD THEM WHERE TO USE THEM

A description of the physical and mechanical properties of a variety of commercial stainless steels. Recommendations on the applications of each type and how to arc weld each including filler materials.

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TABLE OF CONTENTS

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1.0 INTRODUCTION

Stainless steels are defined as iron base alloys which contain at least 10.5% chromium. The thin but dense chromium oxide film which forms on the surface of a stainless steel provides corrosion resistance and prevents further oxidation. There are five types of stainless steels depending on the other alloying additions present, and they range from fully austenitic to fully ferritic.

2.0 TYPES OF STAINLESS STEELS

Austenitic stainless steels include the 200 and 300 series of which type 304 is the most common. The primary alloying additions are chromium and nickel. **Ferritic stainless steels** are non-hardenable Fe-Cr alloys. Types 405, 409, 430, 422 and 446 are representative of this group. **Martensitic stainless steels** are similar in composition to the ferritic group but contain higher carbon and lower chromium to permit hardening by heat treatment. Types 403, 410, 416 and 420 are representative of this group. **Duplex stainless steels** are supplied with a microstructure of approximately equal amounts of ferrite and austenite. They contain roughly 24% chromium and 5% nickel. Their numbering system is not included in the 200, 300 or 400 groups. **Precipitation hardening stainless steels** contain alloying additions such as aluminum which allow them to be hardened by a solution and aging heat treatment. They are further classified into sub groups as martensitic, semiaustenitic

and austenitic precipitation hardening stainless steels. They are identified as the 600-series of stainless steels (e.g., 630, 631, 660).

The alloying elements which appear in stainless steels are classed as ferrite promoters and austenite promoters and are listed below.

2.1 FERRITE PROMOTERS

Chromium – provides basic corrosion resistance.

Molybdenum – provides high temperature strength and increases corrosion resistance.

Niobium (Columbium), Titanium – strong carbide formers.

2.2 AUSTENITE PROMOTERS

Nickel – provides high temperature strength and ductility.

Carbon – carbide former, strengthener.

Nitrogen – increases strength, reduces toughness.

2.3 NEUTRAL EFFECT

- Regarding Austenite & Ferrite

  Manganese – sulfide former

  Silicon – wetting agent

  Sulfur and Selenium – improve machinability, cause hot cracking in welds.

3.0 WELDABILITY OF STAINLESS STEELS

Most stainless steels are considered to have good weldability and may be welded by several welding processes including the arc welding processes, resistance welding, electron and laser beam welding, friction welding and brazing. For any of these processes, joint surfaces and any filler metal must be clean.

The coefficient of thermal expansion for the austenitic types is 50% greater than that of carbon steel and this must be considered to minimize distortion. The low thermal and electrical conductivity of austenitic stainless steel is generally helpful in welding. Less welding heat is required to make a weld because the heat is not conducted away from a joint as rapidly as in carbon steel. In resistance welding, lower current can be used because resistivity is higher. Stainless steels which require special welding procedures are discussed in later sections.

3.1 FERRITIC STAINLESS STEELS

The ferritic stainless steels contain 10.5 to 30% Cr, up to 0.20% C and sometimes ferrite promoters Al, Nb (Cb), Ti and Mo. They are ferritic at all temperatures, do not transform to austenite and therefore, are not hardenable by heat treatment. This group includes the more common types 405, 409, 430, 442 and 446. **Table I** lists the nominal composition

TABLE I — Nominal Compositions of Ferritic Stainless Steels

Type	UNS Number	Composition - Percent *							
		C	Mn	Si	Cr	Ni	P	S	Other
405	S40500	0.08	1.00	1.00	11.5-14.5		0.04	0.03	0.10-0.30 Al
409	S40900	0.08	1.00	1.00	10.5-11.75		0.045	0.045	6 x %C min. TI
429	S42900	0.12	1.00	1.00	14.0-16.0		0.04	0.03	
430	S43000	0.12	1.00	1.00	16.0-18.0		0.04	0.03	
430F**	S43020	0.12	1.25	1.00	16.0-18.0		0.06	0.15 min.	0.06 Mo
430FSe**	S43023	0.12	1.25	1.00	16.0-18.0		0.06	0.06	0.15 min. Se
430Ti	S43036	0.10	1.00	1.00	16.0-19.5	0.75	0.04	0.03	5 x %C - Ti min.
434	S43400	0.12	1.00	1.00	16.0-18.0		0.04	0.03	0.75-1.25 Mo
436	S43600	0.12	1.00	1.00	16.0-18.0		0.04	0.03	0.75-1.25 Mo; 5 x %C min. Nb(Cb) + Ta
442	S44200	0.20	1.00	1.00	18.0-23.0		0.04	0.03	
444	S44400	0.025	1.00	1.00	17.5-19.5	1.00	0.04	0.03	1.75-2.5 Mo, 0.035 N 0.2 + 4 (%C + %N); (Ti +Nb(Cb))
446	S44600	0.20	1.50	1.00	23.0-27.0		0.04	0.03	0.25 N
18-2FM**	S18200	0.08	2.50	1.00	17.5-19.5		0.04	0.15 min.	
18SR		0.04	0.3	1.00	18.0				2.0 Al; 0.4 Ti
26-1 (E-Brite)	S44625	0.01	0.40	0.40	25.0-27.5	0.50	0.02	0.02	0.75-1.5 Mo; 0.015N; 0.2 Cu; 0.5 (Ni+Cu)
26-1Ti	S44626	0.06	0.75	0.75	25.0-27.0	0.5	0.04	0.02	0.75-1.5 Mo; 0.04 N; 0.2 Cu; 0.2-1.0 Ti
29-4	S44700	0.01	0.30	0.20	28.0-30.0	0.15	0.025	0.02	3.5-4.2 Mo
29-4-2	S44800	0.01	0.30	0.20	28.0-30.0	2.0-2.5	0.025	0.02	3.5-4.2 Mo
Monit	S44635	0.25	1.00	0.75	24.5-26.0	3.5-4.5	0.04	0.03	3.5-4.5 Mo; 0.3-0.6 (Ti + Nb(Cb))
Sea-cure/ Sc-1	S44660	0.025	1.00	0.75	25.0-27.0	1.5-3.5	0.04	0.03	2.5-3.5 Mo; 0.2 + 4 (%C + %N) (Ti + Nb(Cb))

*Single values are maximum values.

**These grades are generally considered to be unweldable.

(From *ASM Metals Handbook*, Ninth Edition, Volume 3)

of a number of standard and several non-standard ferritic stainless steels. They are characterized by weld and HAZ grain growth which can result in low toughness of welds.

To weld the ferritic stainless steels, filler metals should be used which match or exceed the Cr level of the base alloy. Type 409 is available as metal cored wire and Type 430 is available in all forms. Austenitic Types 309 and 312 may be used for dissimilar joints. To minimize grain growth, weld heat input should be minimized, Preheat should be limited to 300-450°F and used only for the higher carbon ferritic stainless steels (e.g., 430, 434, 442 and 446). Many of the highly alloyed ferritic stainless steels are only available in sheet and tube forms and are usually welded by GTA without filler metal.

3.2 MARTENSITIC STAINLESS STEELS

The martensitic stainless steels contain 11 to 18% Cr, up to 1.20% C and small amounts of Mn and Ni and, sometimes, Mo. These steels will transform to austenite on heating and, therefore, can be hardened by formation of martensite on cooling. This group includes Types 403, 410, 414, 416, 420, 422, 431 and 440. Both standard and non-standard martensitic stainless steels are listed in **Table II**. They have a tendency toward weld cracking on cooling when hard brittle martensite is formed.

Chromium and carbon content of the filler metal should generally match these elements in the base metal. Type 410 filler is available as covered electrode, solid wire and cored wire and can be used to weld types 402, 410, 414 and 420 steels. Type 410NiMo filler metal can also be used. When it is necessary to match the carbon in Type 420 steel, Type 420 filler, which is available as solid wire and cored wire, should be used. Types 308, 309 and 310 austenitic filler metals can be used to weld the martensitic steels to themselves or to other steels where good as-deposited toughness is required.

Preheating and interpass temperature in the 400 to 600°F (204 to 316°C) range is recommended for most

TABLE II — Nominal Compositions of Martensitic Stainless Steels

Type	UNS Number	Composition - Percent *							
		C	Mn	Si	Cr	Ni	P	S	Other
403	S40300	0.15	1.00	0.50	11.5-13.0		0.04	0.03	
410	S41000	0.15	1.00	1.00	11.5-13.0		0.04	0.03	
410Cb	S41040	0.18	1.00	1.00	11.5-13.5		0.04	0.03	0.05-0.3 Nb(Cb)
410S	S41008	0.08	1.00	1.00	11.5-13.5	0.6	0.04	0.03	
414	S41400	0.15	1.00	1.00	11.5-13.5	1.25-2.50	0.04	0.03	
414L		0.06	0.50	0.15	12.5-13.0	2.5-3.0	0.04	0.03	0.5 Mo; 0.03 Al
416	S41600	0.15	1.25	1.00	12.0-14.0		0.04	0.03	0.6 Mo
416Se**	S41623	0.15	1.25	1.00	12.0-14.0		0.06	0.06	0.15 min. Se
416 Plus X**	S41610	0.15	1.5-2.5	1.00	12.0-14.0		0.06	0.15 min.	0.6 Mo
420	S42000	0.15 min.	1.00	1.00	12.0-14.0		0.04	0.03	
420F**	S42020	0.15 min.	1.25	1.00	12.0-14.0		0.06	0.15 min.	0.6 Mo
422	S42200	0.20-0.25	1.00	0.75	11.0-13.0	0.5-1.0	0.025	0.025	0.75-1.25 Mo; 0.75-1.25 W; 0.15-0.3 V
431	S43100	0.20	1.00	1.00	15.0-17.0	1.25-2.50	0.04	0.03	
440A	S44002	0.60-0.75	1.00	1.00	16.0-18.0		0.04	0.03	0.75 Mo
440B	S44003	0.75-0.95	1.00	1.00	16.0-18.0		0.04	0.03	0.75 Mo
440C	S44004	0.95-1.20	1.00	1.00	16.0-18.0		0.04	0.03	0.75 Mo

*Single values are maximum values.   **These grades are generally considered to be unweldable.   (From *ASM Metals Handbook*, Ninth Edition, Volume 3)

martensitic stainless steels. Steels with over 0.20% C often require a post weld heat treatment to soften and toughen the weld.

3.3 AUSTENITIC STAINLESS STEEL

The austenitic stainless steels contain 16-26% Cr, 8-24% Ni + Mn, up to 0.40% C and small amounts of a few other elements such as Mo, Ti, Nb (Cb) and Ta. The balance between the Cr and Ni + Mn is normally adjusted to provide a microstructure of 90-100% austenite. These alloys are characterized by good strength and high toughness over a wide temperature range and oxidation resistance to over 1000°F (538°C). This group includes Types 302, 304, 310, 316, 321 and 347. Nominal composition of these and other austenitic stainless steels are listed in **Table III**. Filler metals for these alloys should generally match the base metal but for most alloys, provide a microstructure with some ferrite to avoid hot cracking as will be

discussed further. To achieve this, Type 308 is used for Type 302 and 304 and Type 347 for Type 321. The others should be welded with matching filler. Type 347 can also be welded with Type 308H filler. These filler materials are available as coated electrodes, solid bare wire and cored wire. Type 321 is available on a limited basis as solid and cored wire.

Two problems are associated with welds in the austenitic stainless steels: 1) sensitization of the weld heat affected zone, and 2) hot cracking of weld metal.

3.3.1 SENSITIZATION:

Sensitization leads to intergranular corrosion in the heat affected zone as shown in **Figure 1**. Sensitization is caused by chromium carbide formation and precipitation at grain boundaries in the heat affected zone when heated in the 800 to 1600°F (427 to 871°C) temperature range. Since most carbon is found near grain boundaries, chromium carbide formation removes some chromium from solution near the grain

boundaries, thereby reducing the corrosion resistance of these local areas. This problem can be remedied by using low carbon base material and filler material to reduce the amount of carbon available to combine with chromium. Welds should be made without preheat and with minimum heat input to shorten the time in the sensitization temperature range.

The degree of carbide precipitation increases with:

1. Higher carbon content (for example, because 301 and 302 grades have a maximum carbon content of 0.15% they are more susceptible to carbon precipitation than grade 304 which has a maximum carbon content of only 0.08%).

2. Time at the critical mid-range temperatures – a few seconds at 1200°F (649°C) can do more damage than several minutes at 850°F (454°C) or 1450°F (788°C).

Welding naturally produces a temperature gradient in the steel. It ranges from melting temperature at the weld to room temperature some

distance from the weld. A narrow zone on each side of the weld remains in the sensitizing temperature range for sufficient time for precipitation to occur. If used in severely corrosive conditions, lines of damaging corrosion appear alongside each weld.

Control of Carbide Precipitation

The amount of carbide precipitation is reduced by promoting rapid cooling. Fortunately, the copper chill bars, skip welding and other techniques needed to control distortion in sheet metal (see pg 34) help reduce carbide precipitation. Annealing the weldment at 1900°F (1038°C) or higher, followed by water quench, eliminates carbide precipitation, but this is an expensive and often impractical procedure. Therefore, when weldments operate in severe corrosive applications or within the sensitizing temperature range, either ELC or stablilized grades are needed.

Another remedy is to use stabilized stainless steel base metal and filler materials which contain elements that will react with carbon, leaving all the chromium in solution to provide corrosion resistance. Type 321 contains titanium and Type 347 contains niobium (columbium) and tantalum, all of which are stronger carbide formers than chromium.

ELC – Extra Low Carbon – Grades (304L, 308L)

The 0.04% maximum carbon content of ELC grades helps eliminate damaging carbide precipitation caused by welding. These grades are most often used for weldments which operate in severe corrosive conditions at temperatures under 800°F (427°C).

ELC steels are generally welded with the ELC electrode, AWS E308L-XX. Although the stabilized electrodes AWS E347-XX produce welds of equal resistance to carbide precipitation and similar mechanical properties, the ELC electrode welds tend to be less crack sensitive on heavy sections and have better low temperature notch toughness.

The low carbon content in ELC grades leaves more chromium to provide resistance to intergranular corrosion.

Stabilized Grades (321, 347, 348)

Stabilized grades contain small amounts of titanium (321), niobium (columbium) (347), or a combination of niobium and tantalum (347, 348). These elements have a stronger affinity for carbon then does chromium, so they combine with the carbon leaving the chromium to provide corrosion resistance.

These grades are most often used in severe corrosive conditions when service temperatures reach the sensitizing range. They are welded with the niobium stabilized electrodes, AWS E347-XX.

Type 321 electrodes are not generally made because titanium is lost in the arc. AWS E347-XX is usually quite satisfactory for joining type 321 base metal.

Molybdenum Grades (316, 316L, 317, 317L, D319)

Molybdenum in stainless steel increases the localized corrosion resistance to many chemicals. These steels are particularly effective in combatting pitting corrosion. Their most frequent use is in industrial
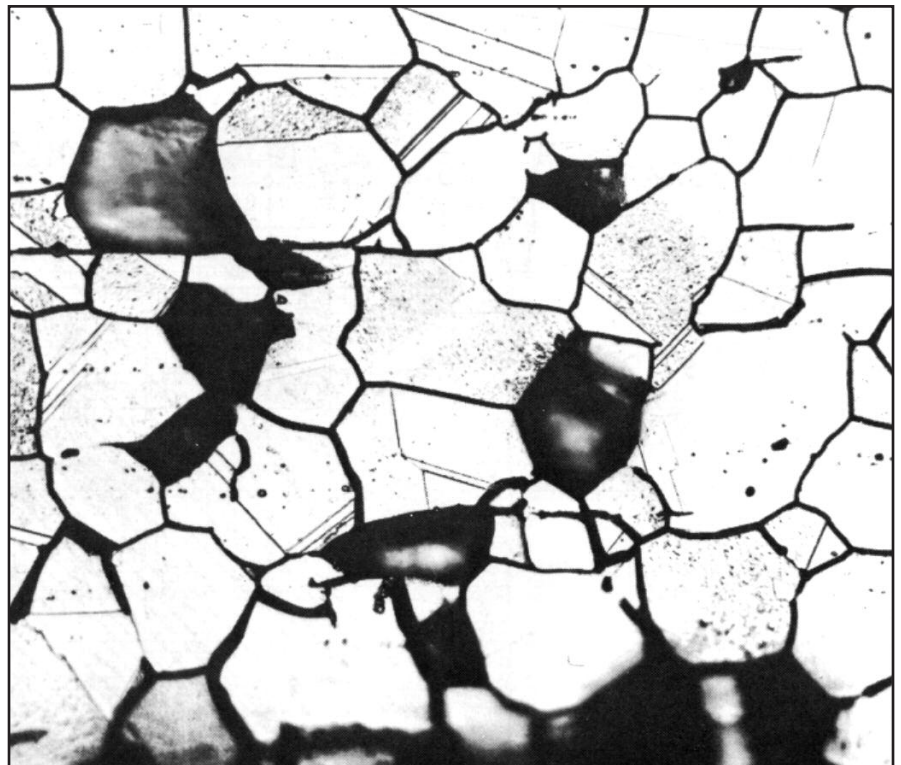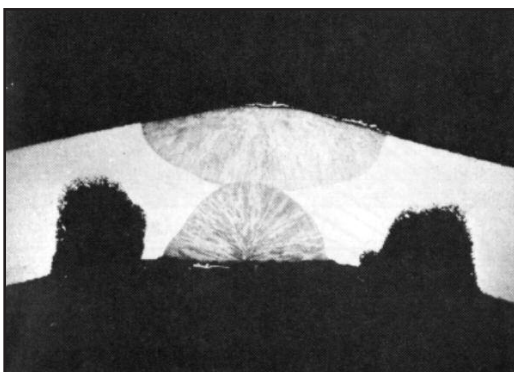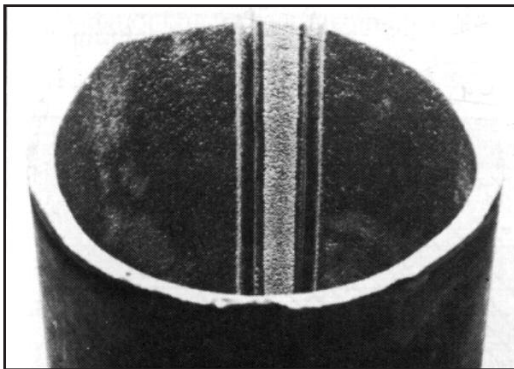

FIGURE 1

TABLE III — Nominal Compositions of Austenitic Stainless Steels

Type	UNS Number	Composition - Percent *							
		C	Mn	Si	Cr	Ni	P	S	Other
201	S20100	0.15	5.5-7.5	1.00	16.0-18.0	3.5-5.5	0.06	0.03	0.25 N
202	S20200	0.15	7.5-10.0	1.00	17.0-19.0	4.0-6.0	0.06	0.03	0.25 N
205	S20500	0.12-0.25	14.0-15.5	1.00	16.5-18.0	1.0-1.75	0.06	0.03	0.32-0.40 N
216	S21600	0.08	7.5-9.0	1.00	17.5-22.0	5.0-7.0	0.045	0.03	2.0-3.0 Mo; 0.25-0.5 N
301	S30100	0.15	2.00	1.00	16.0-18.0	6.0-8.0	0.045	0.03	
302	S30200	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.045	0.03	
302B	S30215	0.15	2.00	2.0-3.0	17.0-19.0	8.0-10.0	0.045	0.03	
303**	S30300	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.20	0.15 min.	0.6 Mo
303Se**	S30323	0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.20	0.06	0.15 min. Se
304	S30400	0.08	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	
304H	S30409	0.04-0.10	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	
304L	S30403	0.03	2.00	1.00	18.0-20.0	8.0-12.0	0.045	0.03	
304LN	S30453	0.03	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.15 N
S30430	S30430	0.08	2.00	1.00	17.0-19.0	8.0-10.0	0.045	0.03	3.0-4.0 Cu
304N	S30451	0.08	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.16 N
304HN	S30452	0.04-0.10	2.00	1.00	18.0-20.0	8.0-10.5	0.045	0.03	0.10-0.16 N
305	S30500	0.12	2.00	1.00	17.0-19.0	10.5-13.0	0.045	0.03	
308	S30800	0.08	2.00	1.00	19.0-21.0	10.0-12.0	0.045	0.03	
308L		0.03	2.00	1.00	19.0-21.0	10.0-12.0	0.045	0.03	
309	S30900	0.20	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	
309S	S30908	0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	
309S Cb	S30940	0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	8 x %C - Nb(Cb)
309 Cb + Ta		0.08	2.00	1.00	22.0-24.0	12.0-15.0	0.045	0.03	8 x %C (Nb(Cb) + Ta)
310	S31000	0.25	2.00	1.50	24.0-26.0	19.0-22.0	0.045	0.03	
310S	S31008	0.08	2.00	1.50	24.0-26.0	19.0-22.0	0.045	0.03	
312		0.15	2.00	1.00	30.0 nom.	9.0 nom.	0.045	0.03	
254SMo	S31254	0.020	1.00	0.80	19.5-20.5	17.50-18.5	0.03	0.010	6.00-6.50Mo; 0.18-0.22N; Cu=0.5-1.00
314	S31400	0.25	2.00	1.5-3.0	23.0-26.0	19.0-22.0	0.045	0.03	
316	S31600	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316F**	S31620	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.20	0.10 min.	1.75-2.5 Mo
316H	S31609	0.04-0.10	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316L	S31603	0.03	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo
316LN	S31653	0.03	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo; 0.10-0.30 N
316N	S31651	0.08	2.00	1.00	16.0-18.0	10.0-14.0	0.045	0.03	2.0-3.0 Mo; 0.10-0.16 N
317	S31700	0.08	2.00	1.00	18.0-20.0	11.0-15.0	0.045	0.03	3.0-4.0 Mo
317L	S31703	0.03	2.00	1.00	18.0-20.0	11.0-15.0	0.045	0.03	3.0-4.0 Mo
317M	S31725	0.03	2.00	1.00	18.0-20.0	12.0-16.0	0.045	0.03	4.0-5.0 Mo
321	S32100	0.08	2.00	1.00	17.0-19.0	9.0-12.0	0.045	0.03	5 x %C min. Ti
321H	S32109	0.04-0.10	2.00	1.00	17.0-19.0	9.0-12.0	0.045	0.03	5 x %C min. Ti
329	S32900	0.10	2.00	1.00	25.0-30.0	3.0-6.0	0.045	0.03	1.0-2.0 Mo
330	N08330	0.08	2.00	0.75-1.5	17.0-20.0	34.0-37.0	0.04	0.03	
AL6-XN	N80367	0.030	2.00	1.00	20.0-22.0	23.5-25.5	0.04	0.03	6.00-7.00Mo; 0.18-0.25N; Cu=0.75
330HC		0.40	1.50	1.25	19.0 nom.	35.0 nom.			
332		0.04	1.00	0.50	21.5 nom.	32.0 nom.	0.045	0.03	
347	S34700	0.08	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	10 x %C min. Nb(Cb) +Ta
347H	S34709	0.04-0.10	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	10 x %C min. Nb(Cb) + Ta
348	S34800	0.08	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	0.2 Cu; 10 x %C min. Nb(Cb) + Ta(c)
348H	S34809	0.04-0.10	2.00	1.00	17.0-19.0	9.0-13.0	0.045	0.03	0.2 Cu; 10 x %C min. Nb(Cb) + Ta
384	S38400	0.08	2.00	1.00	15.0-17.0	17.0-19.0	0.045	0.03	
Nitronic 32	S24100	0.10	12.0	0.50	18.0	1.6			0.35 N
Nitronic 33	S24000	0.06	13.0	0.5	18.0	3.0			0.30 N
Nitronic 40	S21900	0.08	8.0-10.0	1.00	18.0-20.0	5.0-7.0	0.06	0.03	0.15-0.40 N
Nitronic 50	S20910	0.06	4.0-6.0	1.00	20.5-23.5	11.5-13.5	0.04	0.03	1.5-3.0 Mo; 0.2-0.4 N; 0.1-0.3 Cb; 0.1-0.3 V
Nitronic 60	S21800	0.10	7.0-9.0	3.5-4.5	16.0-18.0	8.0-9.0	0.04	0.03	1.5-3.0 Mo; 0.2-0.4 N;

**These grades are generally considered to be unweldable.

processing equipment. 316 and 316L are welded with AWS E316L-XX electrodes.

316L and 317L are ELC grades that must be welded with ELC type electrodes to maintain resistance to carbide precipitation. 317 and 317L are generally welded with E317 or E317L electrodes respectively. They can be welded with AWS E316-XX electrode, but the welds are slightly lower in molybdenum content than the base metal with a corresponding lower corrosion resistance.

When hot oxidizing acids are encountered in service, E316, E316L, E317 or E317L welds may have poor corrosion resistance in the as-welded condition. In such cases, E309 or E309Cb electrodes may be better. As an alternative, the following heat treatment will restore corrosion resistance to the weld:

1. For 316 or 317 – full anneal at 1950-2050°F (1066-1121°C).

2. For 316L and 317L – stress relieve at 1600°F (871°C).

High Temperature Grades
(302B, 304H, 309, 309S, 310, 310S)

These high alloy grades maintain strength at high temperatures and have good scaling resistance. They are primarily used in industrial equipment at high service temperatures – sometimes over 2000°F (1093°C).

AWS E310-XX electrodes are needed to match the high temperature properties and scaling resistance of grades 310 and 310S.

302B and 309 grades are generally welded with E309-XX electrodes. 304H is generally welded with E308H-XX electrodes. E310-XX electrodes can be used on light plate.

E310-XX welds on heavy plate tend to be more crack sensitive than E309-XX weld metals.

Free Machining Grades
(303, 303Se)

Production welding of these grades **is not recommended** because the sulfur or selenium and phosphorus cause severe porosity and hot short cracking.

If welding is necessary, special E312-XX or E309-XX electrodes are recommended because their high ferrite reduces cracking tendencies. Use techniques that reduce admixture of base metal into the weld metal and produce convex bead shapes.

3.3.2 HOT CRACKING:

Hot cracking is caused by low melting materials such as metallic compounds of sulfur and phosphorous which tend to penetrate grain boundaries. When these compounds are present in the weld or heat affected zone, they will penetrate grain boundaries and

cracks will appear as the weld cools and shrinkage stresses develop.

Hot cracking can be prevented by adjusting the composition of the base material and filler material to obtain a microstructure with a small amount of ferrite in the austenite matrix. The ferrite provides ferrite-austenite grain boundaries which are able to control the sulfur and phosphorous compounds so they do not permit hot cracking. This problem could be avoided by reducing the S and P to very low amounts, but this would increase significantly the cost of making the steel.

Normally a ferrite level of 4 FN minimum is recommended to avoid hot cracking. Ferrite is best determined by measurement with a magnetic instrument calibrated to AWS A4.2 or ISO 8249. It can also be estimated from the composition of the base material and filler material with the use of any of several consti-tution diagrams. The oldest of these is the 1948 Schaeffler Diagram. The Cr equivalent (% Cr + % Mo + 1.5 x % Si + 0.5 x % Cb) is plotted on
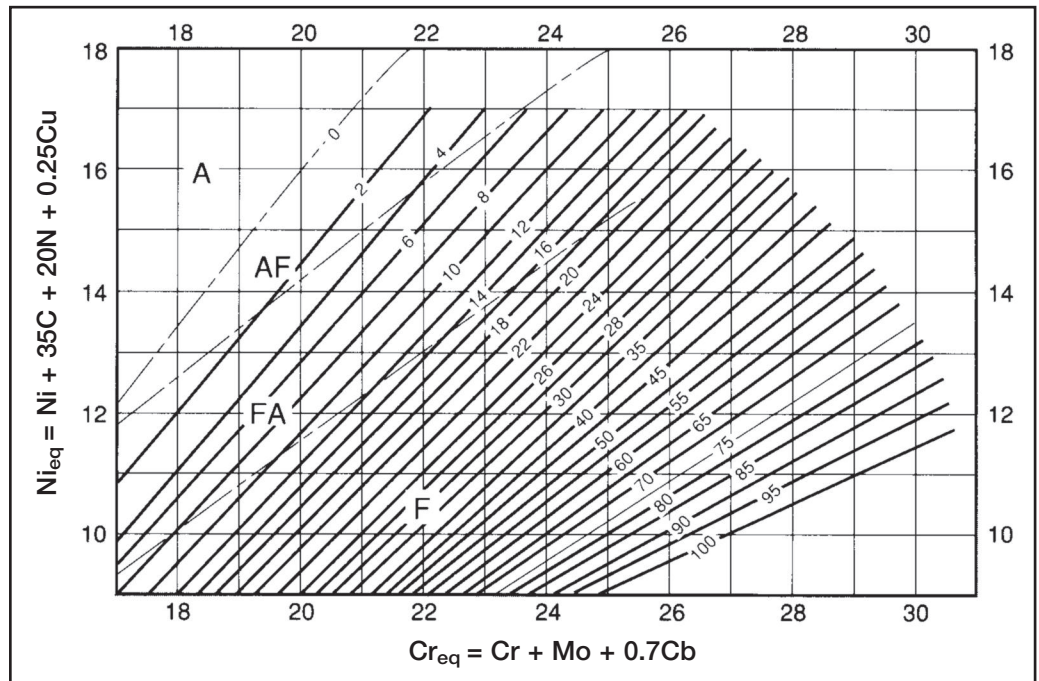

FIGURE 2 — New 1992 WRC diagram including solidification mode boundaries. (Updated from T.A. Siewert, C.N. McCowan and D.L. Olson – Welding Journal, December 1988 by D.J. Kotecki and T.A. Siewert - Welding Journal, May 1992.)

TABLE IV — Nominal Compositions of Precipitation Hardening and Duplex Stainless Steels

Type	UNS Number	C	Mn	Si	Cr	Ni	P	S	ASTM A GRADE	Other
Precipitation-Hardening Types										
PH 13-8 Mo	S13800	0.05	0.10	0.10	12.25-13.25	7.5-8.5	0.01	0.008		2.0-2.5 Mo; 0.90-1.35 Al; 0.01 N
15-5 PH	S15500	0.07	1.00	1.00	14.0-15.5	3.5-5.5	0.04	0.03		2.5-4.5 Cu; 0.15-0.45 Nb(Cb) + Ta
17-4 PH	S17400	0.07	1.00	1.00	15.5-17.5	3.0-5.0	0.04	0.03	630	3.0-5.0 Cu; 0.15-0.45 Nb(Cb) + Ta
17-7 PH	S17700	0.09	1.00	1.00	16.0-18.0	6.5-7.75	0.04	0.03	631	0.75-1.15 Al
PH 15-7 Mo	S15700	0.09	1.00	1.00	14.0-16.0	6.5-7.75	0.04	0.03		2.0-3.0 Mo; 0.75-1.5 Al
17-10 P		0.07	0.75	0.50	17.0	10.5	0.28			
A286	S66286	0.08	2.00	1.00	13.5-16.0	24.0-27.0	0.040	0.030	660	1.0-1.5 Mo; 2 Ti; 0.3 V
AM350	S35000	0.07-0.11	0.5-1.25	0.50	16.0-17.0	4.0-5.0	0.04	0.03		2.5-3.25 Mo; 0.07-0.13 N
AM355	S35500	0.10-0.15	0.5-1.25	0.50	15.0-16.0	4.0-5.0	0.04	0.03		2.5-3.25 Mo
AM363		0.04	0.15	0.05	11.0	4.0				0.25 Ti
Custom 450	S45000	0.05	1.00	1.00	14.0-16.0	5.0-7.0	0.03	0.03		1.25-1.75 Cu; 0.5-1.0 Mo 8 x %C - Nb(Cb)
Custom 455	S45500	0.05	0.50	0.50	11.0-12.5	7.5-9.5	0.04	0.03		0.5 Mo; 1.5-2.5 Cu; 0.8-1.4 Ti; 0.1-0.5 Nb(Cb)
Stainless W	S17600	0.08	1.00	1.00	16.0-17.5	6.0-7.5	0.04	0.03		0.4 Al; 0.4-1.2 Ti
Duplex Types										
2205	S32205	0.03	2.0	1.0	22.0	5.5	0.03	0.02		3.0 Mo; 0.18 N
2304	S32304	0.03	2.5	1.0	23.0	4.0				0.1 N
255		0.04	1.5	1.0	25.5	5.5				3.0 Mo; 0.17 N; 2.0 Cu
NU744LN		0.067	1.7	0.44	21.6	4.9				2.4 Mo; 0.10 N; 0.2 Cu
2507	S32750	0.03	1.2	0.8	25	5.5	0.035	0.020		4 Mo; 0.28 N

*Single values are maximum values.   (From *ASM Metals Handbook*, Ninth Edition, Volume 3) and ASTM A638

the horizontal axis and the nickel equivalent (% Ni + 30 x % C + 0.5 x % Mn) on the vertical axis. Despite long use, the Schaeffler Diagram is now outdated because it does not consider nitrogen effects and because it has not proven possible to establish agreement among several measurers as to the ferrite percent in a given weld metal.

An improvement on the Schaeffler Diagram is the 1973 WRC-DeLong Diagram, which can be used to estimate ferrite level. The main differences are that the DeLong Diagram includes nitrogen (N) in the Ni equivalent (% Ni + 30 x % C x 30 x % N + 0.5 x % Mn) and shows Ferrite Numbers in addition to "percent ferrite." Ferrite Numbers at low levels may approximate "percent ferrite." The most recent diagram, the WRC-1992 Diagram, **Figure 2**, is considered to be the most accurate predicting diagram at present. The WRC-1992 Diagram has replaced the WRC-DeLong Diagram in the ASME Code with publication of the 1994-95 Winter Addendum. Its Ni equivalent

(% Ni + 35 x % C + 20 x % N + 0.25 Cu) and Cr equivalent (% Cr + % Mo + 0.7 x % Cb) differ from those of Schaeffler and WRC-DeLong.

Ferrite Number may be estimated by drawing a horizontal line across the diagram from the nickel equivalent number and a vertical line from the chromium equivalent number. The Ferrite Number is indicated by the diagonal line which passes through the intersection of the horizontal and vertical lines.

Predictions by the WRC-1992 and WRC-DeLong Diagrams for common grades like 308 are similar, but the WRC-1992 diagram generally is more accurate for higher alloy and less common grades like high manganese austenitic or duplex ferritic-austenitic stainless steels.

Ferrite Number can be measured directly on weld deposits from the magnetic properties of the ferrite. Several instruments are available commercially, including the Magne Gage, the Severn Gage, the Inspector Gage and the Ferritescope

which can be calibrated to AWS A4.2 or ISO 8249 and provide readings in Ferrite Number.

The amount of ferrite normally should not be greater than necessary to prevent hot cracking with some margin of safety. The presence of ferrite can reduce corrosion resistance in certain media and excess ferrite can impair ductility and toughness.

3.4 PRECIPITATION HARDENING STAINLESS STEELS

There are three categories of precipitation hardening stainless steels – martensitic, semiaustenitic and austenitic.

The martensitic stainless steels can be hardened by quenching from the austenitizing temperature [around 1900°F (1038°C)] then aging between 900 to 1150°F (482 to 621°C). Since these steels contain less than 0.07% carbon, the marten-

site is not very hard and the main hardening is obtained from the aging (precipitation) reaction. Examples of this group are 17-4PH, 15-5PH and PH13-8Mo. Nominal compositions of precipitation hardening stainless steels are listed in **Table IV**.

The semiaustenitic stainless steels will not transform to martensite when cooled from the austenitizing temperature because the martensite transformation temperature is below room temperature. These steels must be given a conditioning treatment which consists of heating in the range of 1350 to 1750°F (732 to 954°C) to precipitate carbon and/or alloy elements as carbides or intermetallic compounds. This removes alloy elements from solution, thereby destabilizing the austenite, which raises the martensite transformation temperature so that a martensite structure will be obtained on cooling to room temperature. Aging the steel between 850 and 1100°F (454 to 593°C) will stress relieve and temper the martensite to increase toughness, ductility, hardness and corrosion resistance. Examples of this group are 17-7PH, PH 15-7 Mo and AM 350.

The austenitic precipitation hardening stainless steels remain austenitic after quenching from the solutioning temperature even after substantial amounts of cold work. They are hardened only by the aging reaction. This would include solution treating between 1800 and 2050°F (982 to 1121°C), oil or water quenching and aging at 1300 to 1350°F (704 to 732°C) for up to 24 hours. Examples of these steels include A286 and 17-10P.

If maximum strength is required in martensitic and semiaustenitic precipitation hardening stainless steels, matching or nearly matching filler metal should be used and the component, before welding, should be in the annealed or solution annealed condition. Often, Type 630 filler metal, which is nearly identical with 17-4PH base metal, is used for martensitic and semiaustenitic PH stainlesses. After welding, a complete solution heat treatment plus an aging treatment is preferred. If the post weld solution treatment is not feasible, the components should be solution treated before welding then aged after welding. Thick sections of highly restrained parts are sometimes welded in the overaged condition. These would require a full heat treatment after welding to attain maximum strength.

The austenitic precipitation hardening stainless steels are the most difficult to weld because of hot cracking. Welding should preferably be done with the parts in the solution treated condition, under minimum restraint and with minimum heat input. Nickel base alloy filler metals of the NiCrFe type or conventional austenitic stainless steel type are often preferred.

3.5 DUPLEX STAINLESS STEELS

Duplex Ferritic – Austenitic Stainless Steels

Duplex stainless steels solidify as 100% ferrite, but about half of the ferrite transforms to austenite during cooling through temperatures above approx. 1900°F (1040°C). This behavior is accomplished by increasing Cr and decreasing Ni as compared to austenitic grades. Nitrogen is deliberately added to speed up the rate of austenite formation during cooling. Duplex stainless steels are ferromagnetic. They combine higher strength than austenitic stainless steels with fabrication properties similar to austenitics, and with resistance to chloride stress corrosion cracking of ferritic stainless steels. The most common grade is 2205 (UNS S32205), consisting of 22%Cr, 5%Ni, 3%Mo and 0.15%N.

TABLE V — Physical Properties of Groups of Stainless Steels

Property	Austenitic Types	Ferritic Types	Martensitic Types	Precipitation Hardening Types
Elastic Modulus; 10^6 psi	28.3	29.0	29.0	29.0
GPa	195	200	200	200
Density; lb./in.^{3}	0.29	0.28	0.28	0.28
g/cm^3	8.0	7.8	7.8	7.8
Coeff. of Therm. Expansion: µin./in. °F	9.2	5.8	5.7	6.0
µm/m °C	16.6	10.4	10.3	10.8
Thermal. Conduct.; Btu/hrft. °F	9.1	14.5	14.0	12.9
w/mk	15.7	25.1	24.2	22.3
Specific Heat; Btu/lb. °F	0.12	0.11	0.11	0.11
J/k °K	500	460	460	460
Electrical Resistivity, µΩcm	74	61	61	80
Magnetic Permeability	1.02	600-1,100	700-1000	95
Melting Range °F	2,500-2,650	2,600-2,790	2,600-2,790	2,560-2,625
°C	1,375-1,450	1,425-1,530	1,425-1,530	1,400-1,440

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TABLE VI — Properties of Austenitic Stainless Steels

Type	Condition	Tensile Strength		0.2% Yield Strength		Elong.	R.A.	Hardness
		Ksi	MPa	Ksi	MPa	%	%	Rockwell
201	Anneal	115	793	55	379	55		B90
201	Full Hard	185	1275	140	965	4		C41
202	Anneal	105	724	55	379	55		B90
301	Anneal	110	758	40	276	60		B85
301	Full Hard	185	1275	140	965	8		C41
302	Anneal	90	620	37	255	55	65	B82
302B	Anneal	95	655	40	276	50	65	B85
303	Anneal	90	620	35	241	50	55	B84
304	Anneal	85	586	35	241	55	65	B80
304L	Anneal	80	552	30	207	55	65	B76
304N	Anneal	85	586	35	241	30		
304LN	Anneal	80	552	30	207			
305	Anneal	85	586	37	255	55	70	B82
308	Anneal	85	586	35	241	55	65	B80
308L	Anneal	80	551	30	207	55	65	B76
309	Anneal	90	620	40	276	45	65	B85
310	Anneal	95	655	40	276	45	65	B87
312	Anneal	95	655			20		
314	Anneal	100	689	50	345	45	60	B87
316	Anneal	85	586	35	241	55	70	B80
316L	Anneal	78	538	30	207	55	65	B76
316F	Anneal	85	586	35	241	55	70	B80
317	Anneal	90	620	40	276	50	55	B85
317L	Anneal	85	586	35	241	50	55	B80
321	Anneal	87	599	35	241	55	65	B80
347/348	Anneal	92	634	35	241	50	65	B84
329	Anneal	105	724	80	552	25	50	B98
330	Anneal	80	550	35	241	30		B80
330HC	Anneal	85	586	42	290	45	65	
332	Anneal	80	552	35	241	45	70	
384	Anneal	80	550					

(From *ASM Metals Handbook*, 8th Edition, Volume 1; and 9th Edition, Volume 3 and ASTM standards)

4.0 PHYSICAL PROPERTIES

Average physical properties for each of the main groups of stainless steel are listed in **Table V**. This includes elastic modulus, density, coefficient of thermal expansion, thermal conductivity, specific heat, electrical resistivity, magnetic permeability and melting range. These values should be close enough for most engineering purposes. If more precise data is required for a particular type of stainless steel, it can be found in the *ASM Metals Handbook*, Ninth Edition, Volume 3.

5.0 MECHANICAL PROPERTIES

Nominal mechanical properties of austenitic and ferritic stainless steels in the annealed condition are listed in **Table VI** and **Table VII** respectively. The austenitic stainless steels generally have higher tensile strengths and elongation than the ferritic stainless steels but lower yield strengths. Reduction in area is about the same for both groups. Nominal mechanical properties of martensitic stainless steels in both the annealed and tempered condition are listed in **Table VIII**. The tempered condition involves heating to austenitize, cooling to form martensite and reheating to the indicated temperature to increase toughness. **Table IX** lists the mechanical properties of the precipitation hardening stainless steels as solution annealed and after aging treatments at the temperature indicated. Properties of three duplex stainless steels are included.

TABLE VII — Nominal Mechanical Properties of Ferritic Stainless Steels

| Type | Condition | Tensile Strength | | 0.2% Yield Strength | | Elong. | R.A. | Hardness |
		Ksi	MPa	Ksi	MPa	%	%	Rockwell
405	Anneal	70	480	40	275	30	60	B80
409	Anneal	65	450	35	240	25		B75M
429	Anneal	71	490	45	310	30	65	B88M
430	Anneal	75	515	45	310	30	60	B82
430F	Anneal	80	550	55	380	25	60	B86
430Ti	Anneal	75	515	45	310	30	65	
434	Anneal	77	530	53	365	23		B83M
436	Anneal	77	530	53	365	23		B83M
442	Anneal	80	550	45	310	25	50	B85
444	Anneal	60	415	40	275	20		B95M
446	Anneal	80	550	50	345	23	50	B86
26-1EBrite	Anneal	65	450	40	275	22		B90M
26-1Ti	Anneal	68	470	45	310	20		B95M
29-4	Anneal	80	550	60	415	20		B98M
29-4-2	Anneal	80	550	60	415	20		B98M
18SR	Anneal	90	620	65	450	25		B90
Monit	Anneal	94	650	80	550	20		B100M
Sea-cure/SC-1	Anneal	80	550	55	380	20		B100M

M = Maximum   (From *ASM Metals Handbook*, 8th Edition, Volume 1; and 9th Edition, Volume 3)

TABLE VIII — Nominal Mechanical Properties of Martensitic Stainless Steels

| Type | Condition | Tensile Strength | | 0.2% Yield Strength | | Elong. | R.A. | Hardness |
		Ksi	MPa	Ksi	MPa	%	%	Rockwell
403	Anneal	75	517	40	276	30	65	B82
403	*Temp. 800°F	195	1344	150	1034	17	55	C41
410	Anneal	75	517	40	276	30	65	B82
410	*Temp. 800°F	195	1344	150	1034	17	55	C41
410S	Anneal	60	414	30	207	22		B95M
410Cb	Anneal	70	483	40	276	13	45	
410Cb	*Temp. (Int.)	125	862	100	689	13	45	
414	Anneal	120	827	95	655	17	55	C22
414	*Temp. 800°F	200	1379	150	1034	16	58	C43
414L	Anneal	115	793	80	552	20	60	
416 Plus X	Anneal	75	517	40	276	30	60	
420	Anneal	95	655	50	345	25	55	B92
420	*Temp. 600°F	230	1586	195	1344	8	25	C50
422	Temp., Int.	140	965	110	758	13	30	
431	Anneal	125	862	95	655	20	60	C24
431	*Temp. 800°F	205	1413	155	1069	15	60	C43
440A	Anneal	105	724	60	414	20	45	B95
440A	*Temp. 600°F	260	1793	240	1655	5	20	C51
440B	Anneal	107	738	62	427	18	35	B96
440B	*Temp. 600°F	280	1931	270	1862	3	15	C55
440C	Anneal	110	758	65	448	13	25	B97
440C	*Temp. 600°F	285	1965	275	1896	2	10	C57

*Tempered after austentizing and cooling to room temperature.
M = Maximum   (600°F = 315°C)
Int. = Intermediate temper hot finished   (800°F = 427°C)
(From ASM Metals Handbook, 8th Edition, Volume 1; and 9th Edition, Volume 3)

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TABLE IX — Nominal Mechanical Properties of Precipitation Hardening and Duplex Stainless Steels

Type	Condition	Tensile Strength		0.2% Yield Strength		Elong.	R.A.	Hardness
		Ksi	MPa	Ksi	MPa	%	%	Rockwell
Precipitation Hardening Types								
Ph13-8 Mo	H950	220	1517	205	1413	8	45	C45
15-5PH	H900	190	1310	170	1172	10	35	C44
15-5PH	H1150	135	931	105	724	16	50	C32
17-4PH	Sol. Ann.	150	1034	110	758	10	45	C33
17-4PH	H900	200	1379	178	1227	12	48	C44
17-7PH	Sol. Ann.	130	896	40	276	35		B85
17-7PH	RH950	235	1620	220	1517	6		C48
PH15-7 Mo	Sol. Ann.	130	896	55	379	35		B88
PH15-7 Mo	RH950	240	1655	225	1551	6	25	C48
17-10P	Sol. Ann.	89	613	37	255	70	76	B82
17-10P	H1300	143	986	98	676	20	32	C32
A286	H1350	130	896	85	586	15		
AM350	Sol. Ann.	160	1103	55	379	40		B95
AM350	DA	195	1344	155	1069	10.5		C41
AM355	Sol. Ann.	175	1207	65	448	30		B95
AM355	DA	195	1344	155	1069	10		C41
Custom 450	Anneal	125	862	95	655	10	40	C30
Custom 450	H900	180	1241	170	1172	10	40	C40
Custom 455	H900	235	1620	220	1517	8	30	C47
Stainless W	Sol. Ann.	120	827	75	517	7		C30
Stainless W	H950	195	1344	180	1241	7	25	C46
Duplex Types								
2205		120	827	65	448	25		
2304		110	758	60	414	25		
255		110	758	80	552	15		
2507		116	800	80	550	15		

From *ASM Metals Handbook*, 8th Edition, Volume 1; and 9th Edition, Volume 3

6.0
SELECTION OF A STAINLESS STEEL

The selection of a particular type stainless steel will depend on what is required by the application. In most cases the primary consideration is corrosion resistance, tarnish resistance or oxidation resistance at elevated temperature. In addition to these requirements, the selected stainless steel must have some minimum mechanical properties such as strength, toughness, ductility and fatigue strength. Several types and grades of stainless steel may provide the corrosion resistance and mechanical properties required. In this case the final selection should be made on the basis of the lowest cost available alloy which will fulfill the service requirements. Generally, selection of the type of stainless steel is made by the designer of the equipment or component based on his knowledge, experience and data on corrosion behavior of various alloys in the environment of interest. The responsibility of the welding engineer normally does not include selection of the base alloy, only selection of the filler material, welding process and welding procedure.

If it becomes necessary for the welding engineer to select a base alloy, information should be gathered on the service environment, expected life of the part and extent of corrosion which is acceptable. To assist in this selection, **Table X** lists corrosion resistance of several standard types of stainless steel to a number of corrosive media. This indicates that austenitic types and higher chromium types generally are more corrosion resistant than the martensitic and lower chromium ferritic types. A great deal of test data has been generated on the corrosion behavior of many metals and alloys in many kinds of corrosive media. This information on stainless steels is available from several sources which are listed as references.

Other factors which must be considered in selecting a stainless steel are resistance to pitting, crevice corrosion and intergranular attack. Intergranular attack is caused by carbide precipitation in weld heat affected zones and methods of preventing this problem were discussed previously. If the application involves service at elevated temperature, then elevated temperature mechanical properties such as creep strength, stress rupture strength and oxidation resistance must be considered.
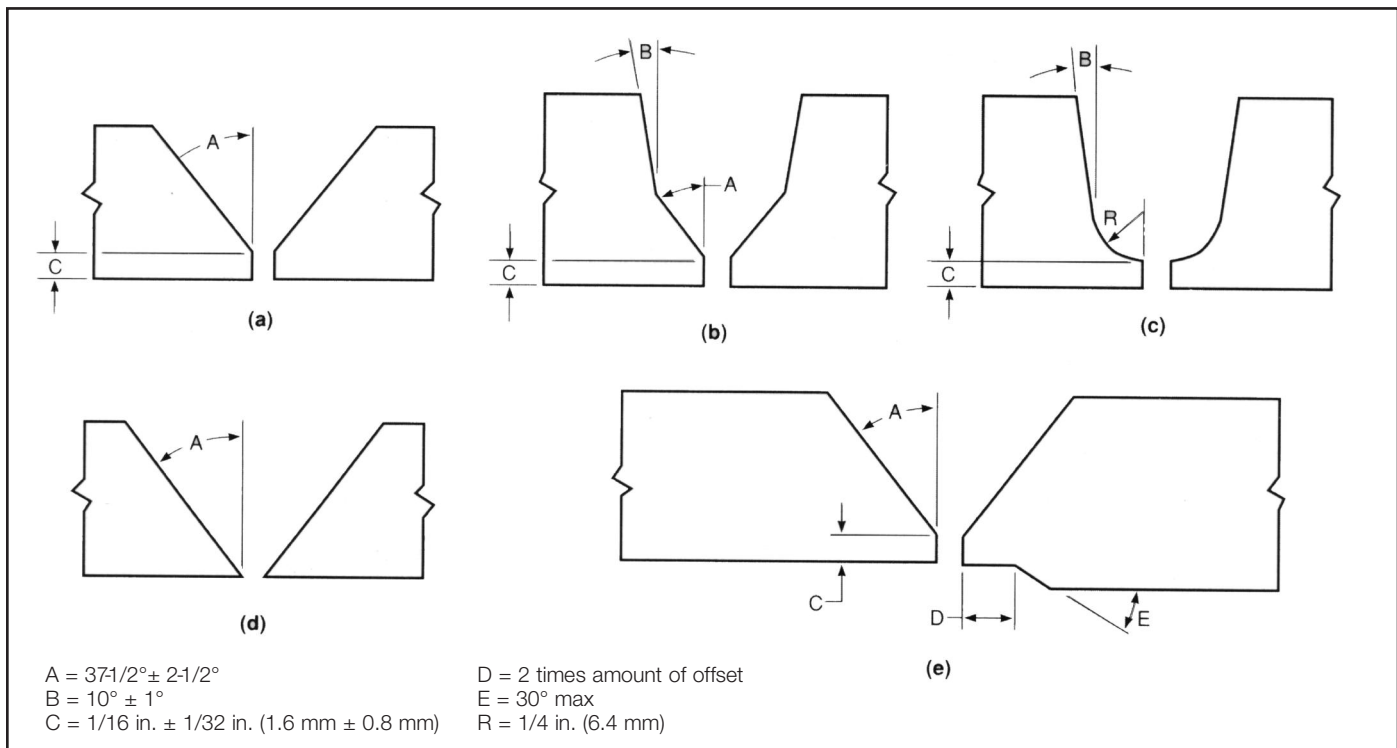
With the corrosion and oxidation test data derived from the handbooks and other references, a stainless steel or other alloy may be selected for a particular application. Once the

TABLE X — Corrosion Resistance of Stainless Steel in Various Environments

Type Stainless Austenitic	Atmospheric				Fresh Water	Salt Water	Soil	Chemical
	Industrial	Marine	City	Rural				
201	5	2	1	1	1		3	7
202	5	2	1	1	1		3	7
205	5	2	1	1	1		3	7
301	5	2	1	1	1		3	7
302	5	2	1	1	1		3	7
302B	5	2	1	1	1		3	7
303	5	2	1	1	1		3	7
303Se	5	2	1	1	1		3	7
304	5	2	1	1	1	3	3	7
304H	5	2	1	1	1	3	3	7
304L	5	2	1	1	1	3	3	7
304N	5	2	1	1	1	3	3	7
305	5	2	1	1	1		3	7
308	5	2	1	1	1		3	7
309	5	2	1	1	1	3	3	7
309S	5	2	1	1	1	3	3	7
310	5	2	1	1	1	3	3	7
310S	5	2	1	1	1	3	3	7
314	5	2	1	1	1			7
316	3	1	1	1	1	3	1	7
316F	3	1	1	1	1	3	1	7
316H	3	1	1	1	1	3	1	7
316L	3	1	1	1	1	3	1	7
316N	3	1	1	1	1	3	1	7
317	3	1	1	1	1	3	1	7
317L	3	1	1	1	1	3	1	7
321	5	2	1	1	1	3	3	7
321H	5	2	1	1	1	3	3	7
329	3	2	1	1	1	1	3	7
330	3	1	1	1	1		3	7
347	5	2	1	1	1	3	3	7
347H	5	2	1	1	1	3	3	7
348	5	2	1	1	1	3	3	7
348H	5	2	1	1	1	3	3	7
384		2	1	1	1		3	7
Ferritic Types								
405	6	4	2	1	3	6	6	7
409	6	4	2	1	3	6	6	7
429	3	4	2	1	1	6	6	7
430	3	4	1	1	1	6	6	7
430F	3	4	1	1	1	6	6	7
430FSe	3	4	1	1	1	6	6	7
434	3	4	1	1	1			7
436	3	4	1	1	1			7
442	3	2	1	1	1			7
446	3	2	1	1	1	3		7
Martensitic Types								
403	6	4	2	1	3	6	6	7
410	6	4	2	1	3	6	6	7
414	6	4	2	1	3	6	6	7
416	6	4	2	1	3	6	6	7
416Se	6	4	2	1	3	6	6	7
420	6	4	2	1	3	6	6	7

Code: 1 – No rust, staining or pitting,
2 – Light rust or stains, no pitting,
3 – Light rust or stains, light pitting,
4 – Rust covered or stained,
5 – Rust covered and pitted,
6 – Rust and severe pitting,
7 – Corrosion and pitting in chemical media varies widely with media, concentration, temperature and agitation. Consult literature and handbooks for data on specific application.

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A = 37-1/2°± 2-1/2°
B = 10° ± 1°
C = 1/16 in. ± 1/32 in. (1.6 mm ± 0.8 mm)

D = 2 times amount of offset
E = 30° max
R = 1/4 in. (6.4 mm)

FIGURE 3 — Typical joint designs for welding austenitic stainless steel pipe.

stainless steel is selected, it is the welding engineer's responsibility to design the joints, select the weld filler metal, welding process and welding procedure.

7.0
DESIGN FOR STAINLESS STEELS

Since the coefficient of thermal expansion for austenitic stainless steels is relatively high, the control of distortion must be considered in designing weldments of these alloys. The volume of weld metal in joints must be limited to the smallest size which will provide the necessary properties. In thick plate, a "U" groove, **Figure 3(c)**, which gives a smaller volume than a "V" groove, should be used. If it is possible to weld from both sides of a joint, a double "U" or "V" groove joint preparation should be used. This not only reduces the volume of weld metal required but also helps to balance the shrinkage stresses.

Accurate joint fitup and careful joint preparation which are necessary for high quality welds also help minimize distortion.

Joint location and weld sequence should be considered to minimize distortion.

Strong tooling and fixturing should be employed to hold parts in place and resist tendencies for components to move during welding. When any of the gas shielded processes are used, the tooling should also provide an inert gas backup to the root of the weld to prevent oxidation when the root pass is being made. This is particularly important when GTA welding pipe with insert rings to allow the weld metal to wet and flow together at the root of the joint.

In welding pipe, insert rings, **Figure 4**, of the same composition as the filler metal should be used for the root pass and be welded by the GTAW process. If copper chills are to be used near a weld area, they should be nickel plated to prevent copper pickup. If copper is in contact with the high temperature region of the

heat affected zone, it can melt and penetrate the grain boundaries of austenitic stainless steel causing cracking.

8.0
SELECTION OF FILLER METALS

Filler metals for welding stainless steels are produced as coated electrodes (AWS A5.4), solid and metal core wire (AWS A5.9) and flux core wire (AWS A5.22). The various electrodes, solid wires, metal cored wires and flux cored wires are contained in AWS "Filler Metal Comparison Charts", latest edition.

According to these charts, matching filler metal should be available for almost every type of austenitic stainless steel available, although many types may be produced in small quantities by only a few companies and may not be readily available. For example, E219-16 and E240-16 electrodes are produced by
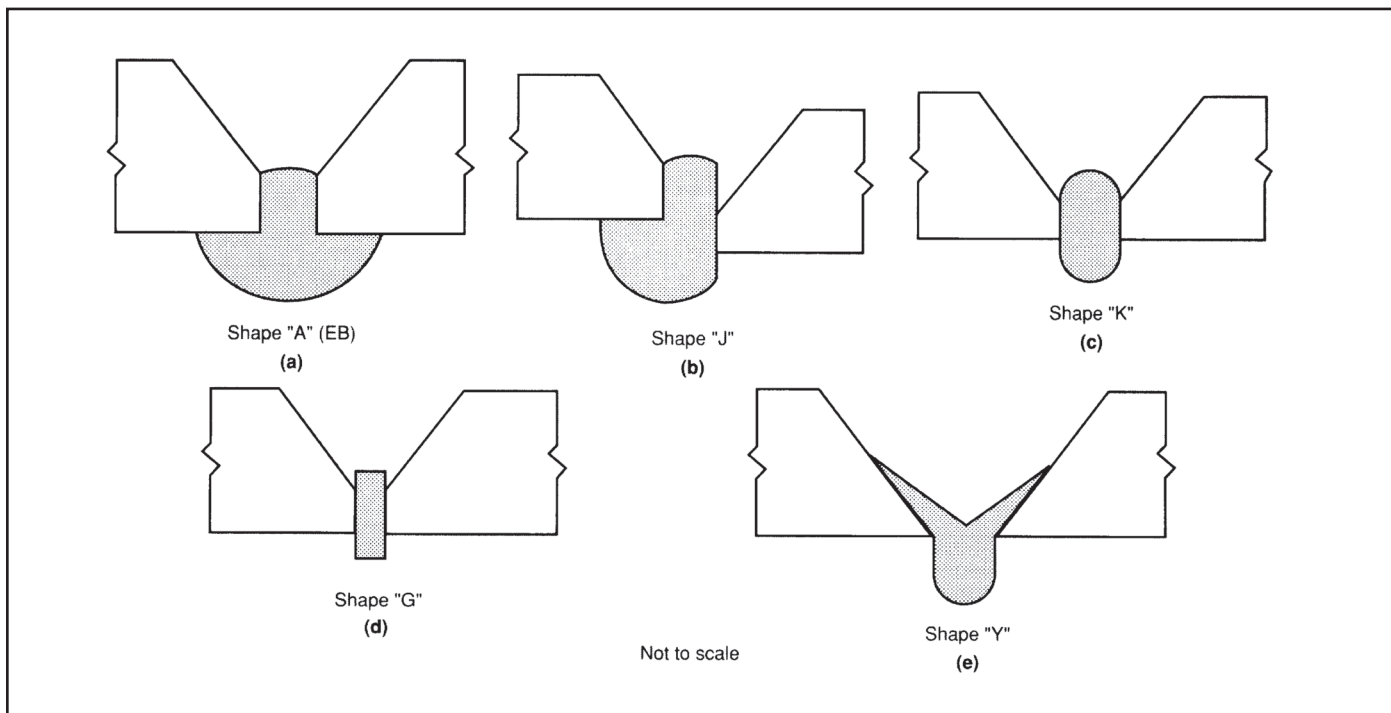
FIGURE 4 — Standard consumable inserts.

only two U.S. companies and no foreign companies. By contrast, the more popular electrodes, E308-16, E308L-16, E309-16, E310-16, E316-16, E316L-16 and E347-16 are produced by about 40 U.S. companies and 20 to 30 foreign companies. Most electrodes are available with a lime coating (-15) (for use with DC only), a titania coating (-16) (for use with AC or DC) or a silica-titania coating (-17) (for use with AC or DC mainly in the downhand or horizontal positions) and in the standard or low carbon variety.

Most alloys which are available as coated electrodes are also available as either solid wire, metal cored wire or flux cored wire. A few are available only as coated electrodes. These are 310H, 310Cb, 310Mo and 330H. As was mentioned previously, filler metal for austenitic stainless steels should match or exceed the alloy content of the base metal. If a filler material of the correct match is not available, a filler with higher alloy content normally should be used.

There are several austenitic stainless types for which no exact matching fillers are made. Examples are 201,

202, 205, 216, 301, 302, 304 and 305. The filler materials recommended for these base alloys are somewhat higher in Cr and Ni content. For example, 308 is used for 301, 302, 304 and 305 and may be used for 201, 202, 205 and 216 if 209, 219 or 240 are not available. The 6% molybdenum stainless steels 254SMo and AL6-XN are generally welded with higher molybdnum nickel-base alloys. The recommended filler materials in the form of coated electrodes, solid and metal core wire and flux core wire are listed in **Tables XI, XII** and **XIII** for austenitic, ferritic and martensitic stainless steels respectively. Note that a modification of a basic type should be welded with a filler material of that same modification, for example, Type 316L should be welded with E316L-XX, ER316L, ER316LS, or E316LT-X.

Except for E630 electrodes and ER630 bare wires which match 17-4PH, matching filler materials for the precipitation hardening stainlesses are not listed in the AWS Filler Metals Comparison Charts, or in any of the AWS filler metal specifications. Matching filler metals are produced

and available in the form of coated electrodes and solid wire for some of the precipitation hardening stainless steels and these are listed in **Table XIV**. Where no matching filler is available, standard austenitic or nickel base filler materials are recommended as indicated in **Table XIV.**

If maximum strength properties and corrosion resistance are required for the application, a filler metal of matching or similar composition to the base metal should be used. For martensitic or semiaustenitic base alloys, the weldment should then be given the full solution and aging heat treatment if feasible. If not, the components should be solution treated before welding, then given a postweld aging treatment after welding. It is recommended that the austenitic precipitation hardening stainless steels not be heat treated after welding because of cracking problems. In fact, these alloys are difficult to weld for this reason and some are considered unweldable. Nickel base and conventional austenitic filler metals can be used for these alloys, especially if high strength weld metal is not required

TABLE XI — Filler Metals for Welding Austenitic Stainless Steels

Base Stainless Steel		Recommended Filler Metal		
Wrought	Cast	Coated Electrode	Solid, Metal Core Wire	Flux Core Wire
201		E209, E219, E308	ER209, ER219, ER308, ER308Si	E308TX-X
202		E209, E219, E308	ER209, ER219, ER308, ER308Si	E308TX-X
205		E240	ER240	
216		E209	ER209	E316TX-X
301		E308	ER308, ER308Si	E308TX-X
302	CF-20	E308	ER308, ER308Si	E308TX-X
304	CF-8	E308, E309	ER308, ER308Si, ER309, ER309Si	E308TX-X, E309TX-X
304H		E308H	ER308H	
304L	CF-3	E308L, E347	ER308L, ER308LSi, ER347	E308LTX-X, E347TX-X
304LN		E308L, E347	ER308L, ER308LSi, ER347	E308LTX-X, E347TX-X
304N		E308, E309	ER308, ER308Si, ER309, ER309Si	E308TX-X, E309TX-X
304HN		E308H	ER308H	
305		E308, E309	ER308, ER308Si, ER309, ER309Si	E308TX-X, E309TX-X
308		E308, E309	ER308, ER308Si, ER309, ER309Si	E308TX-X, E309TX-X
308L		E308L, E347	ER308L, ER308LSi, ER347	E308LTX-X, E347TX-X
309	CH-20	E309, E310	ER309, ER309Si, ER310	E309TX-X, ER310TX-X
309S	CH-10	E309L, E309Cb	ER309L, ER309LSi	E309LTX-X, E309CbLTX-X
309SCb		E309Cb		E309CbLTX-X
309CbTa		E309Cb		E309CbLTX-X
310	CK-20	E310	ER310	E310TX-X
310S		E310Cb, E310	ER310	E310TX-X
312	CE-30	E312	ER312	E312T-3
314		E310	ER310	E310TX-X
316	CF-8M	E316, E308Mo	ER316, ER308Mo	E316TX-X, E308MoTX-X
316H	CF-12M	E316H, E16-8-2	ER316H, ER16-8-2	E316TX-X, E308MoTX-X
316L	CF-3M	E316L, E308MoL	ER316L, ER316LSi, ER308MoL	E316LTX-X, E308MoLTX-X
316LN		E316L	ER316L, ER316LSi	E316LTX-X
316N		E316	ER316	E316TX-X
317	CG-8M	E317, E317L	ER317	E317LTX-X
317L		E317L, E316L	ER317L	E317LTX-X
321		E308L, E347	ER321	E308LTX-X, E347TX-X
321H		E347	ER321	E347TX-X
329		E312	ER312	E312T-3
330	HT	E330	ER330	
330HC		E330H	ER330	
332		E330	ER330	
347	CF-8C	E347, E308L	ER347, ER347Si	E347TX-X, E308LTX-X
347H		E347	ER347, ER347Si	E347TX-X
348		E347	ER347, ER347Si	E347TX-X
348H		E347	ER347, ER347Si	E347TX-X
Nitronic 33		E240	ER240	
Nitronic 40		E219	ER219	
Nitronic 50		E209	ER209	
Nitronic 60			ER218	
254SMo		ENiCrMo-3	ERNiCrMo-3	
AL-6XN		ENiCrMo-10	ERNiCrMo-10	

From AWS Filler Metal Specifications: A5.4, A5.9, A5.22, A5.14, A5.11

because the lower strength filler can stretch on cooling and minimize the stress on the crack sensitive heat affected zone of the base metal. Nickel base and conventional austenitic stainless steels can also be used to weld the other precipitation hardening stainless steels where full base material strength is not required.

Coated electrodes can be used for welding martensitic and semiaustenitic stainless steels such as 17-4PH, AM350 and AM355 because these alloys do not contain titanium or aluminum which would be lost in the shielded metal arc. Welds can be made in all positions with this process. Electrodes must be dry and stored and handled in the same manner as used for other stainless steel and low hydrogen electrodes as described previously.

Type AMS 5827B (17-4PH) electrodes can be used to weld 17-7 PH steel, and reasonable heat treatment response can be obtained if the weld deposit is highly diluted with base metal.

Welding conditions suitable for conventional stainless steels are generally applicable for joining the PH types. A short arc length should be used to minimize oxidation, loss of chromium, and nitrogen pickup.

Lining

Mild steel process and storage equipment is sometimes lined with stainless steel for corrosion resistance. At least three different methods are used:

TABLE XII — Filler Metals for Welding Ferritic Stainless Steels

| Base Stainless Steel | | Recommended Filler Metal | | |
Wrought	Cast	Coated Electrode	Solid, Metal Core Wire	Flux Core Wire
405		E410NiMo, E430	ER410NiMo, ER430	E410NiMoTX-X
409			ER409, AM363, EC409	E409TX-X
429			ER409Cb	
430	CB-30	E430	ER430	E430TX-X
430F		E430	ER430	E430TX-X
430FSe		E430	ER430	E430TX-X
434			ER434	
442		E442, E446	ER442	
444		E316L	ER316L	
446	CC-50	E446	ER446	
26-1			ER26-1	

From AWS Filler Metal Specifications: A5.4, A5.9, A5.22

TABLE XIII — Filler Metals for Welding Martensitic and Duplex Stainless Steels

| Base Stainless Steel | | Recommended Filler Metal | | |
Wrought	Cast	Coated Electrode	Solid, Metal Core Wire	Flux Core Wire
403		E410	ER410	E410TX-X
410	CA-15	E410, E410NiMo	ER410, ER410NiMo	E410T, E410NiMoTX-X
410S		E410NiMo	ER410NiMo	E410NiMoTX-X
414		E410	ER410	E410TX-X
416		E410	ER312, ER410	
416Se			ER312	
416PlusX			ER312	
420	CA-90	E410, E430	ER420, ER410	E410TX-X
420F			ER312	
431	CB-30	E410, E430	ER410	E410TX-X
440A		a		
440B		a		
440C		a		
	CA-6NM	E410NiMo	ER410NiMo	E410NiMoTX-X
	CA-15	E430	ER430	E430TX-X
2205		E2209	ER2209	
2304		E2209	ER2209	
255		E2553	ER2553	

a = Welding not recommended.   From AWS Filler Metal Specifications: A5.4, A5.9, A5.22

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| Designation	UNS No.	Covered Electrodes	Bare Welding Wire	Dissimilar PH Stainless Steels
Martensitic Types				
17-4PH and 15-5 PH	S17400 S15500	AMS 5827B, E630 (17-4 PH) or E308	AMS 5826 (17-4 PH) or ER308	E or ER309, E or ER309 Cb
Stainless W	S17600	E308 or ENiMo-3[a]	AMS 5805C (A-286) or ERNiMo-3[b]	E or ERNiMo-3, E or ER309
Semiaustenitic Types				
17-7PH	S17700	AMS 5827B (17-4 PH), E308, or E309	AMS 5824A (17-7 PH)	E or ER310, ENiCrFe-2, or ERNiCr-3
PH 15-7Mo	S15700	E308 or E309	AMS 5812C (PH 15-7Mo)	E or ER309, E or ER310
AM350	S35000	AMS 5775A (AM350)	AMS 5774B (AM350)	E or ER308, E or ER309
AM355	S35500	AMS 5781A (AM355)	AMS 5780A (AM355)	E or ER308, E or ER309
Austenitic Types				
A-286	K66286	E309 or E310	ERNiCrFe-6 or ERNiMo-3	E or ER309, E or ER310

a. See AWS A5.11-97, *Specification for Nickel and Nickel Alloy Welding Electrodes for Shielded Metal Arc Welding*
b. See AWS A5.14-97, *Specification for NIckel and Nickel Alloy Bare Welding Electrodes and Rod.*
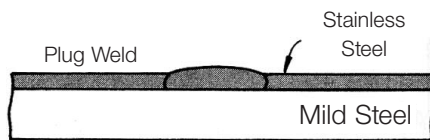
1. Large formed stainless steel sheets are plug welded at frequent intervals to join them closely to the shell.
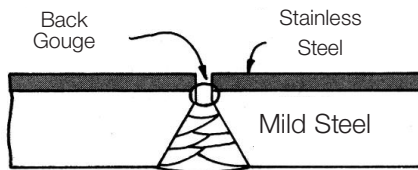

2. Overlapping welds deposited on the steel surface.
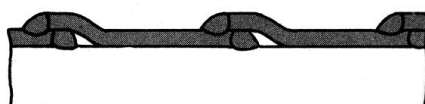
3. Small strips are overlapped or placed side-by-side and welded to the shell. Sometimes this technique is referred to as "wallpapering"

Welding Clad Steel

Clad steel consists of stainless steel sheet permanently bonded to mild steel plate. To join clad steel plates, first weld the mild steel with mild steel electrodes. Do not tie into the stainless cladding with the mild steel electrodes. After gouging the backside of the first mild steel bead, weld from the stainless side using stainless steel electrodes.

Joining Manganese Steel

E308-X or E309-XX electrodes are used to weld manganese steel to carbon steel or to manganese steel. The stainless welds provide excellent joint strength and ductility but are difficult to flame cut. Therefore, when a manganese steel piece must be replaced periodically, such as dipper teeth, Wearshield Mangjet® electrode can be recommended. Wearshield 15CrMn electrode has better crack resistance, but the deposit is difficult to flame cut.

Thick Harfacing Deposits

E308-X or E309-XX deposits increase the toughness of thick hardfacing deposits. For best results, use one layer of stainless between each two layers of hardfacing.

9.0 SELECTION OF A WELDING PROCESS

Joint Cleanliness

For high-quality welds, stainless steel joints must be clean. The choice of power brushing, degreasing, pickling, grinding or simply wiping depends upon the application and amount of dirt. Here are some specific hints:

1. Remove all moisture by blowing with dry air or heating with a torch. Beware of moisture in air lines, damp rags and humidity deposited overnight.

2. Eliminate organic contaminants like oil, paints, anti-spatter compounds, grease, pencil marks, cutting compounds, adhesive from protective paper, soap used for leak testing, etc.

TABLE XV — Standard Sizes for Stainless Electrodes

Form	Diameter, in.	Diameter, mm,
Electrode in coils, with or without support	0.045, 1/16, 5/64, 3/32, 7/64 1/8, 5/32, 3/16, 1/4	1.2, 1.6, 2.0, 2.4, 2.8 3.2, 4.0, 4.8, 6.4
Electrode wound on standard 12-in. O.D. spools	0.030, 0.035, 0.045, 1/16 5/64, 3/32, 7/64	0.8, 0.9, 1.2, 1.6 2.0, 2.4, 2.8
Electrodes wound on lightweight 1-1/2 and 2-1/2 lb., 4-in O.D. spools	0.020, 0.025, 0.030 0.035, 0.045	0.5, 0.6, 0.8 0.9, 1.2
Coated Electrodes		
9 in. length (230 mm)	1/16, 5/64, 3/32	1.6, 2.0, 2.4
12 in. length (305 mm)	3/32	2.4
14 in. length (350 mm)	1/8, 5/32, 3/16, 1/4	3.2, 4.0, 4.8, 6.4

3. Stainless steels cannot be flame cut with a torch. Acceptable results are achieved with an arc plasma cutter.

4. Be particularly careful to avoid zinc contamination. Do not use brushes or tools previously used on galvanized steel.

5. Use only stainless steel wire brushes, and use these brushes only on stainless steel.

The decision on the form of filler metal to be used will depend upon several factors. These include the available forms of the filler material needed, the available welding equipment, the dimensions of the weldment and number of pieces to be welded.

9.1 SHIELDED METAL ARC WELDING

Coated electrodes are available in most stainless compositions in a range of sizes and these can be used to weld joints in thicknesses from 0.05 inch to several inches. Slag from each pass must be completely removed before depositing the next pass to avoid porosity and slag entrapment. Welding equipment for stick electrode welding is the lowest cost but deposition rates are lowest of all the consumable electrode processes.

If it has been decided to perform the welding with stick electrodes, a further decision must be made regarding the electrode coating. When lime (-15), titania (-16), and silica-titania (-17) type coatings are available for a particular type electrode, the decision will be based mainly on the position of welding. Lime-coated electrodes operate on DC only. They are recommended for:

1. Vertical and overhead welding and all position applications such as pipe. The light slag wets rapidly for good wash-in and no undercutting.
2. Root passes on heavy plate. The full throat section of the slightly convex beads help prevent cracking.
3. Fully austenitic stainless steels such as types 330, 320.

Titania-coated electrodes operate on AC or DC, but always use DC when available. They are recommended for:

1. All applications when most of the welding is in the flat position.
2. Vertical up and overhead welding when lime-coated electrodes are not available.

Silica-titania coated electrodes operate also on AC or DC, but DC is usually preferred. They are recommended for:

1. Flat and horizontal position welding when minimum cleanup is desired.

2. Vertical up welding when a wide weave can be used.
3. Overhead welding.

Coated electrodes should be treated and stored as low hydrogen electrodes. They should not be exposed to damp air, and once a sealed container is opened, the electrodes should be used or stored in a holding oven at between 200 and 300°F (93 and 149°C). If the electrodes are exposed to moist air, they can be dried by baking as recommended by the manufacturer. This baking temperature usually is between 500 and 600°F (260 and 316°C), but can be as high as 800°F (427°C). The electrode manufacturer should be consulted for specific recommendations.

The sizes and forms of coated electrodes and also solid and cored wire, which are normally available for welding stainless steels, are listed in **Table XV.**

9.2 SUBMERGED ARC WELDING

Submerged arc welding (SAW) can be employed to join thick sections, usually greater than 0.5 inch, of most of the austenitic stainless steels. For austenitic stainlesses in which ferrite is not possible in the weld metal (types 310 or 330, for example), submerged arc welding is usually best avoided due to hot cracking

problems. Welding is generally done using direct current, electrode positive. Alternating current is sometimes used for moderate penetration and good arc stability.

Since deposit composition depends upon the filler wire composition, any alloy additions to the flux and chromium oxidation and loss to the slag, flux selection and welding conditions must be rigorously controlled. Voltage, current and travel speed variations will influence the amount of flux melted and the resulting weld deposit composition and ferrite content.

Conventional austenitic stainless steel electrodes such as ER308, ER309

and ER316 can be used with conventional stainless steel fluxes for welding most of the austenitic stainless steels except applications where Ferrite Number must be less than 4.

If base metal strength must be attained in martensitic or precipitation hardening stainless steels, special procedures and fluxes must be used with the correct filler metal to provide a weld deposit which will respond to postweld heat treatment. If special fluxes are not used, the weld metal probably will not respond to heat treatment. This is particularly true for aluminum-bearing electrodes where aluminum is lost through metal-slag

reactions. The stainless flux manufacturers should be consulted for recommendation on fluxes and welding procedures.

9.3
GAS METAL ARC WELDING

If the production application involves long joints in relatively thick material or a large number of parts, the GMAW process with solid or metal cored wire may be the best choice.

Solid or metal cored wire will provide the fastest deposition rates with the

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WELDING TECHNIQUES FOR SHIELDED METAL ARC WELDING

Use a short arc without touching the puddle. This minimizes alloy loss in the arc and reduces porosity and spatter. Red Baron and Blue Max electrodes can be dragged.

Weld with a low current consistent with good fusion to minimize heat input for distortion control. The low current also reduces penetration when minimum admixture is needed for corrosion resistance and cracking or porosity resistance.

Stringer beads minimize heat input to control distortion. If weave beads must be used, limit the weave to $2^1/_2$ times the electrode diameter.

Flat beads with good wash-in are needed for easy slag removal, particularly in deep groove welds.

Fill craters by holding a short arc and moving back over the finished bead before breaking the arc. This avoids crater cracks.

Cl*ean each bead* thoroughly before welding over it. Because the slag from lime coated Stainweld XXX-15 electrodes crumbles, particular care is needed to remove all particles.

For vertical and overhead positions, weld with $5/_{32}$" (4.0mm) or smaller electrodes. The easiest to use vertical-up are Stainweld XXX-15 electrodes. Blue Max electrodes require the widest weave for vertical-up. Vertical-down welding is best accomplished with Red Baron -V electrodes.

For vertical-down welding with Red Baron-V electrodes, use a dragging technique and current towards the high end of the recommended range. For vertical-up, Stainweld XXX-15 can be run without weave. All others require a weave – a triangle weave or inverted Vee weave works well.

In the overhead position, Red Baron and Blue Max electrodes work best by a dragging technique. Stainweld electrodes work best with a short arc and slight circular motion during steady forward motion.

Penetration should be only enough to seal openings in root passes and bond to the base plates. Deep penetration can cause cracking and loss of corrosion resistance and provides no advantages.

TABLE XVI — Recommended Current Ranges For Austenitic Stainless Steel Electrodes (DCEP)

Electrode Size		Recommended Current (Amp)		
mm.	inch.	E3XX-15 Electrodes	E3XX-16 Electrodes	E3XX-17 Electrodes
2.4	3/32	30 - 70	30 - 65	40 - 80
3.2	1/8	45 - 95	55 - 95	80 - 115
4.0	5/32	75 - 130	80 - 135	100 - 150
4.8	3/16	95 - 165	120 - 185	130 - 200
6.4	1/4	150 - 225	200 - 275	Consult Manufacturer
		Optimum current for flat position is about 10% below maximum; optimum for vertical-up welding, about 20% below maximum; optimum for vertical-down welding, about maximum.	Optimum current for flat position is about 10% below maximum; AC range is about 10% higher.	Optimum current for flat position is about 10% below maximum.

GMAW process but wire feeding equipment, power supplies and the requirement for inert gas shielding add to the cost of using these fillers. However, there is little need to remove slag between passes. Solid and metal cored wire can be used in shortcircuiting, globular and spray modes of arc operation which gives a wide range of deposition rates and heat input levels. Solid and metal cored wire can therefore be used for welding a wide range of thicknesses.

Gas metal arc welding with spray transfer is used to join sections thicker than about 0.25 inch because deposition rates are higher than with other transfer modes. Welding procedures are simular for conventional austenitic and PH stainless steels.

The shielding gas is generally argon with 1 to 2 percent oxygen added for arc stability. Mixtures of argon and helium are employed if a hotter arc is desired. A small oxygen addition can be added to provide a stable arc, but some aluminum or titanium can be lost from certain PH filler metals during transfer across the arc as a result of oxidation. Response of the weld metal to heat treatment might be less because of this action.

For flat position welding, spray transfer is usually preferred. For other welding positions, shortcircuiting transfer is often used with helium-rich gas such as 90% He 7.5% A -2.5% CO_2 or pulsed spray transfer can be employed using argon or an argon-helium mixture with a small addition of oxygen or carbon dioxide.

9.4
FLUX-CORED ARC WELDING

Flux cored wire uses basically the same wire feed equipment and power supply as solid and metal core wire. Wires can be designed for use with gas shielding (AWS Classes EXXXTX-1 or EXXXTX-4) or without gas shielding (AWS Classes EXXXTO-3). The "-1" indicates CO_2 shielding gas, while the "-4" indicates 75% Argon - 25% CO_2 shielding gas. Although carbon dioxide gas shielding is not recommended for gas metal arc welding, it is commonly used with flux cored arc welding because the slag protects the metal from carbon pickup. Use of EXXXTO-3 with gas will result in high ferrite. Use of EXXXTX-1 or EXXXTX-4 without gas will result in little or no ferrite and possibly porosity. Solid wire, metal core and flux core wire have an advantage over coated electrodes by their continuous nature in that it is not necessary to stop welding to change electrodes.

9.5
GAS TUNGSTEN ARC WELDING

Manual and automatic gas tungsten arc welding (GTAW) processes are frequently used for joining conventional and PH stainless steels, particularly in thicknesses up to about 0.25 inch.

Normally direct current, electrode negative is used with a power supply having drooping volt-amperage characteristic. However, alternating current is sometimes used to weld those steels containing aluminum to take advantage of the arc cleaning action.

10.0
PROCEDURES FOR WELDING STAINLESS STEELS

Once a joint design has been established and a welding process and filler material have been selected, a welding procedure may be developed. For any process, it is important that joint edges and filler material be clean and free of any oxide, organic material or other contamination. Thermal cut edges must be cleaned to remove oxide film. Rough machined surfaces on joint edge preparation should be avoided to

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prevent entrapment of contaminants.

Heat input for arc welding stainless steels should be minimized to minimize distortion and to minimize the possibility of sensitization of the heat affected zone. This is particularly important for standard, nonstabilized austenitic stainless steels.

10.1
WELDING WITH THE SHIELDED METAL ARC PROCESS

All stainless steel shielded metal arc electrode coverings must be protected from moisture pickup. Normally, electrodes packaged in hermetically sealed containers can be stored for several years without deteriorating. However, after the container is opened, the coating begins to absorb moisture and, depending on the ambient air condition, may need to be reconditioned after only four hours of exposure, otherwise porosity may result, especially at arc starts.

Usually, redrying at 500 to 600°F (260 to 316°C) for 1 hour restores the electrode to its original condition, and storing in a holding oven at 300°F (149°C) is satisfactory. Due to differences in materials and processing, the supplier should be consulted if large amounts of electrodes are involved.

DC electrodes (EXXX-15) operate on DC only, have good penetration, produce fillets with a slightly convex profile, and are recommended for:

• Vertical and overhead welding and all position applications such as pipe. The slag has a fast freeze characteristic.

• Root passes on heavy plate. The larger throat section of the convex bead helps prevent cracking.

• Austenitic stainless welds that cannot contain any ferrite.

AC-DC electrodes (EXXX-16 and EXXX-17) are always used on DC when this type of power is available. The fillet profile is flat (EXXX-16) to slightly concave (EXXX-17), the weld surface is smoother and the penetration is less than with EXXX-15 (DC only) electrodes. The larger amount of slag requires more care to avoid slag inclusions. These electrodes are recommended for horizontal fillets and for all flat position welding. EXXX-16 electrodes are also used in all positions by skilled welders. EXXX-17 electrodes can also be used in all positions, but a wider weave is generally necessary in the vertical-up position than is necessary for EXXX-16 electrodes.

Cleaning: For high quality welds, joints must be clean and dry. The choice of power brushing, degreasing, pickling, grinding or merely wiping depends upon the kind and amount of dirt. Some specific recommendations are:

1. Remove moisture by heating or by blowing with dry air (beware of moisture in the air line). Moisture can collect on a weldment overnight in high humidity conditions.

2. Eliminate organic contaminants such as paints, antispatter compounds, grease pencil marks, cutting compounds, adhesive from protective paper and soap used for leak testing.

3. Flame beveling and machining may leave contaminants or oxide films that must be removed.

4. Avoid zinc contamination from brushes or tools that have been used on galvanized steel. Zinc contamination causes cracking. Use only stainless steel wire brushes that have been used only on stainless steel.

5. Avoid copper contamination from rubbing stainless over copper hold-down fixtures, etc. Copper contamination causes cracking.

Welding Techniques: Welding with stainless steel electrodes requires techniques similar to those used for mild steel low hydrogen electrodes. Use a short arc, but keep the coating from touching the puddle. Certain electrodes are designed to be dragged on the base metal in downhand and horizontal welding. Flat beads with good wash-in promote easy slag removal in deep grooves. Fill each crater before breaking the arc to avoid crater cracks. Clean the slag thoroughly from the finish of the bead before starting another electrode, and clean the complete weld before started the next pass. On deep groove butt joints, the root pass should penetrate only enough to fuse to both plates and seal the opening. More penetration may cause cracks.

For vertical and overhead positions never use an electrode larger than 5/32". The DC electrodes (EXXX-15) are preferred, but the AC-DC electrodes (EXXX-16) can be used for welding vertical up (using DC). On thick plate, use the triangular weave or inverted Vee technique, welding vertical up. On thin plate, use small beads, vertical down.

The EXXX-17 AC-DC electrodes are more difficult to use vertical up than the EXXX-16 electrodes. A wider weave is generally necessary.

Welding techniques can help control distortion. Weld with low current consistent with sufficient penetration to reduce the heat input to the work **(Table XVI)**. Use stringer beads at a higher speed rather than wide beads at a slower speed. If weave beads must be made, limit the weave to 2-1/2 times the electrode diameter.

Other means to control distortion are:

• Use rigid fixtures to hold parts in alignment.

• Use chill bars near the weld and backing bars under the weld. Rapid cooling of austenitic stainless steels is beneficial rather than harmful. If copper is used as the chill bar material, care must be exercised to prevent copper grain boundary penetration where the

heat affected zone temperature exceeds the melting temperature of copper. This can be prevented by applying a thin nickel plate to the copper.

• Plan the sequence of welding, using the same techniques as with mild steel such as skip welding and back step welding.

Joining Stainless and Other Steels: In some applications, stainless steel weld metal is applied to mild steel: for example, lining mild steel vessels or containers with stainless steel. For such applications, stainless electrodes with higher alloy content are used so the admixture of the mild steel into the stainless weld deposit does not form an unsatisfactory alloy.

When stainless steel is joined to mild steel, the mild steel is often "buttered" with stainless steel. This technique consists of depositing a layer of stainless on the surface of the mild steel, then completing the joint with stainless electrode, as illustrated in **Figure 5**. The electrode commonly used for buttering is E309. This technique is also used for joining hard-to-weld or high car-bon steels that cannot be preheated.

E308 electrode is used for joining austenitic manganese steel to carbon steel or to manganese steel. However, for the components that must be replaced periodically, such as dipper teeth, a manganese steel electrode is recommended because the stainless weld is more difficult to torch cut.
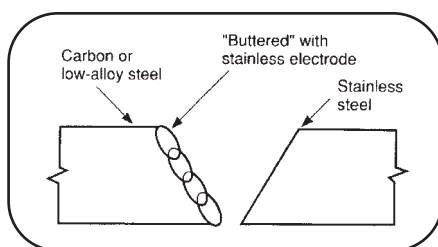

**FIGURE 5 —
Buttering technique for joining mild steel to stainless steel.**

Power Sources: The open circuit voltage of light duty AC transformer welders may not be high enough for larger diameters of EXXX-16 electrodes; otherwise, the same power sources used with steel electrodes are satisfactory for stainless electrodes.

Parameters and procedures for welding stainless steel in thicknesses from 18 gauge to 1/2 inch are given in **Figures 6, 7, 8, 9** and **10**. These show joint designs and backup bars for butt, tee, lap and 90 degree edge joints.

10.2
WELDING WITH THE SUBMERGED ARC PROCESS

The submerged arc process is applicable to the welding of stainless steels where the higher heat input and slower solidification are tolerable. With submerged arc welding, depending upon the flux chosen, the silicon content may be much higher than with other processes, a factor that may promote hot shortness or fissuring when ferrite is less than 4FN.

The submerged arc process is not recommended where a weld deposit is needed that is fully austenitic or is controlled to a low ferrite content (below 4FN). However, high quality welds may be produced for applica-tions in which more than 4FN in weld deposits is allowable. **Figure 11** shows the type of butt joint designs that can be used for submerged arc welding.

Good quality single pass welds up to 5/16 inch thick can be made using the square groove butt joint, **Figure 11 (a)**, without root opening and with suitable backing. Two pass welds up to 5/8 inch thick are also made without root opening. It is essential on two pass welds, however, that the edges be closely butted since weld

backing is not used. The advantage of this joint design is that it requires a minimum of edge preparation, yet produces welds of good quality having adequate penetration.

Single V-groove welds with a root face, **Figure 11 (b)**, are used with nonfusible backing for single pass butt welds of 5/16 inch thickness or greater. For most industrial applications, the maximum thickness is of the order of 1-1/4 to 1-1/2 inch. Root face dimensions are 1/8 to 3/16 inch. This joint is also used for two pass welds without backing where plate thickness exceeds 5/8 inch. The first pass is made in the V of the joint, **Figure 11 (b)**. The work is then turned over and the first pass becomes the backing pass. In this position, the finishing pass is made on the flat side of the joint penetrat-ing into the root of the first pass. The root face is approximately 3/8 inch for two pass welds.

The double V-groove butt, **Figure 11 (d)**, is the basic joint design for submerged arc welding. A large root face is generally used with this design. **Figure 12** shows a typical double V-groove weld in 3/4 inch 304 plate and describes the welding sequence.

A single U-groove butt joint design, **Figure 11 (f)**, is also commonly used. A small manually produced backing weld is often made from the reverse side of the joint. It is usually desirable to fill the U-groove with 2 passes per layer as soon as possible after the root pass. Slag removal from a submerged arc weld pass tieing in to both sides of the groove can be very difficult.

For stainless steel welding, DC power is mostly used on thin sections. Either AC or DC may be used on heavier pieces but DC is preferred. Currents used are about 80% of those used for carbon steel. Single pass techniques usually result in dilution levels of 40% to 60%. This may be decreased by using multipass welds.

Welding Position: Flat
Weld Quality Level: Code
Steel Weldability: Good

18-10 ga (1.3-3.6 mm) — Gap — Copper

60° — 3/16-1/2" (4.8-12.7mm) — Root face — Gap

	0.050 (18 ga)	0.078 (14 ga)	0.140 (10 ga)	3/16	1/4		3/8		1/2	
Plate Thickness in.	0.050 (18 ga)	0.078 (14 ga)	0.140 (10 ga)	3/16	1/4		3/8		1/2	
mm.	1.3	2.0	3.6	4.8	6.4		9.5		12.7	
Pass	1	1	1	1	1	2	1	2-3	1	2-5
Electrode Class	E3XX-16	E3XX-16	E3XX-16	E3XX-16	E3XX-16		E3XX-16		E3XX-16	
Size in.	5/64	3/32	1/8	5/32	5/32	3/16	5/32	3/16	5/32	3/16
mm.	2.0	2.4	3.2	4.0	4.0	4.8	4.0	4.8	4.0	4.8
Current (amp) DC (+)	40*	60	85	125	125	160	125	160	125	160
Arc Speed (in./min.)	14 -16	11.5 - 12.5	8.5 - 9.5	6.7 - 7.3	5.7-6.3	7.6-8.4	5.7-6.3	5.7-6.3	5.7-6.3	5.7-6.3
mm/sec	5.9 - 6.8	4.9 - 5.3	3.6 -4.0	2.8 - 3.1	2.4-2.7	3.2-3.6	2.4-2.7	2.4-2.7	2.4-2.7	2.4-2.7
Electrode Req'd (lb./ft.)	0.020	0.038	0.080	0.150	0.340		0.650		1.06	
kg/m	0.030	0.057	0.119	0.223	0.506		0.968		1.579	
Total Time (hr./ft. of weld)	0.0133	0.0167	0.0222	0.0286	0.0583		0.100		0.167	
hrs./m of weld	0.0436	0.0548	0.0728	0.0938	0.1913		0.3281		0.5479	
Gap (in.)	0	1/32	1/32	1/16	3/32		3/32		3/32	
mm	0	0.8	0.8	1.6	2.4		2.4		2.4	
Root Face (in.)	0	0	0	1/16	1/16		1/16		1/16	
mm	0	0	0	1.6	1.6		1.6		1.6	

*Use DC (–)

Note: AC can be used with 10% increase in current. E3XX-15 electrode can be used with a 10% decrease in current.

FIGURE 6 — Suggested procedures for SMAW of butt joints in austenitic stainless steel from 18 (1.3 mm) gauge to 1/2 inch (12.7 mm) thickness in the flat position.

Submerged arc welding creates a large volume of molten metal that remains fluid for appreciable time. It is essential that this molten metal be supported and contained until it has solidified. The two most common means of weld backing are nonfusible backing and fusible backing.

Copper backing is the most frequently used nonfusible backing in the welding of stainless steel. When copper is used as a chill bar, care must be taken to prevent copper grain boundary penetration. Recommended groove dimensions are shown in **Figure 13**. Ceramic backing tapes are also sometimes used.

With a fusible metallic backing, the weld penetrates into and fuses with the stainless backing, which either temporarily or permanently becomes an integral part of the assembly.

Most submerged arc welding is done in the flat position. This results in the best bead contour and ease of operation. Occasionally, welding is done on circumferential seams. **Figure 14** illustrates the effect of various inclinations.

Submerged arc fluxes are available as proprietary materials for welding stainless steel. Composition of materials fall into two categories – fused type and bonded type. The fused type is glasslike and is produced by melting the ingredients at high temperatures followed by crushing to granulate the flux. The bonded or agglomerated type is produced by mixing the ingredients with a suitable binder and baking the mixture. Lincoln manufactures only bonded fluxes.

Alloying elements can be added to the weld deposit through some bonded fluxes. These include chromium, nickel, molybdenum and niobium (columbium). If alloying additions to the flux are not made,

Welding Position: Vertical and Overhead Weld Quality Level: Code Steel Weldability: Good					

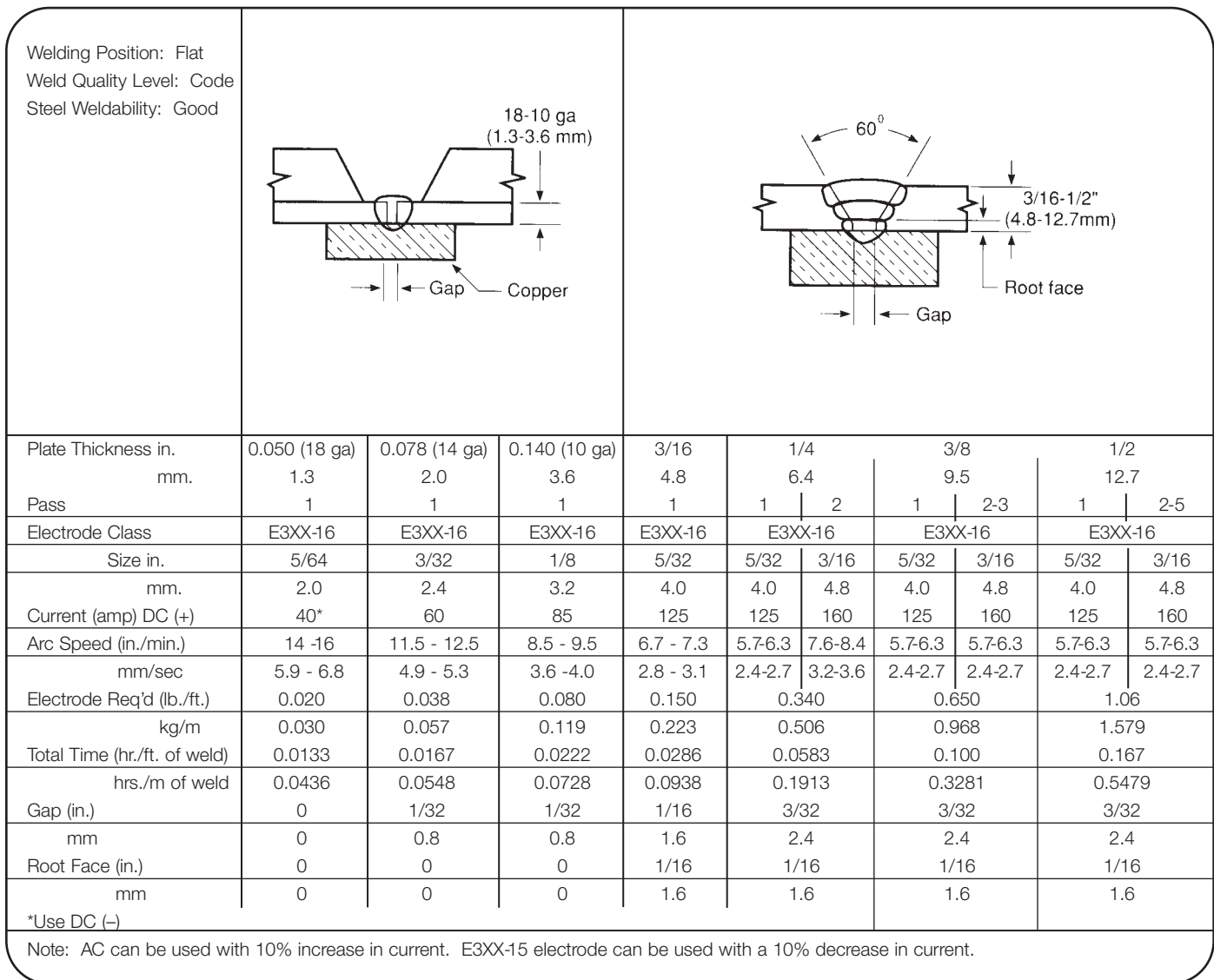| Plate Thickness (in.) | 0.078 (14 ga)* | 0.140 (10 ga) | 3/16 | 1/4 | |
mm.	2.0	3.6	4.8	6.4	
Pass	1	1	1	1	2
Electrode Class	E3XX-15	E3XX-15	E3XX-15	E3XX-15	
Size in.	3/32	1/8	5/32	5/32	
mm.	2.4	3.2	4.0	4.0	
Current (amp) DC(+)	50	75	110	110	
Arc Speed (in./min.)	14 - 16	6.7 - 7.3	5.2 - 5.8	5.2 - 5.8	4.3 - 4.7
mm/sec.	5.9 - 6.8	2.8 - 3.1	2.2 - 2.5	2.2 - 2.5	1.8 - 2.0
Electrode Req'd (lb./ft.)	0.030	0.091	0.160	0.370	
kg/m.	0.045	0.136	0.238	0.551	
Total Time (hr./ft. of weld)	0.0133	0.0286	0.0364	0.0808	
hrs./m of weld	0.0436	0.0938	0.1194	0.2651	
Gap (in.)	0	0	1/16	3/32	
mm.	0	0	1.6	2.4	
Root face (in.)	0	0	1/16	1/16	
mm.	0	0	1.6	1.6	

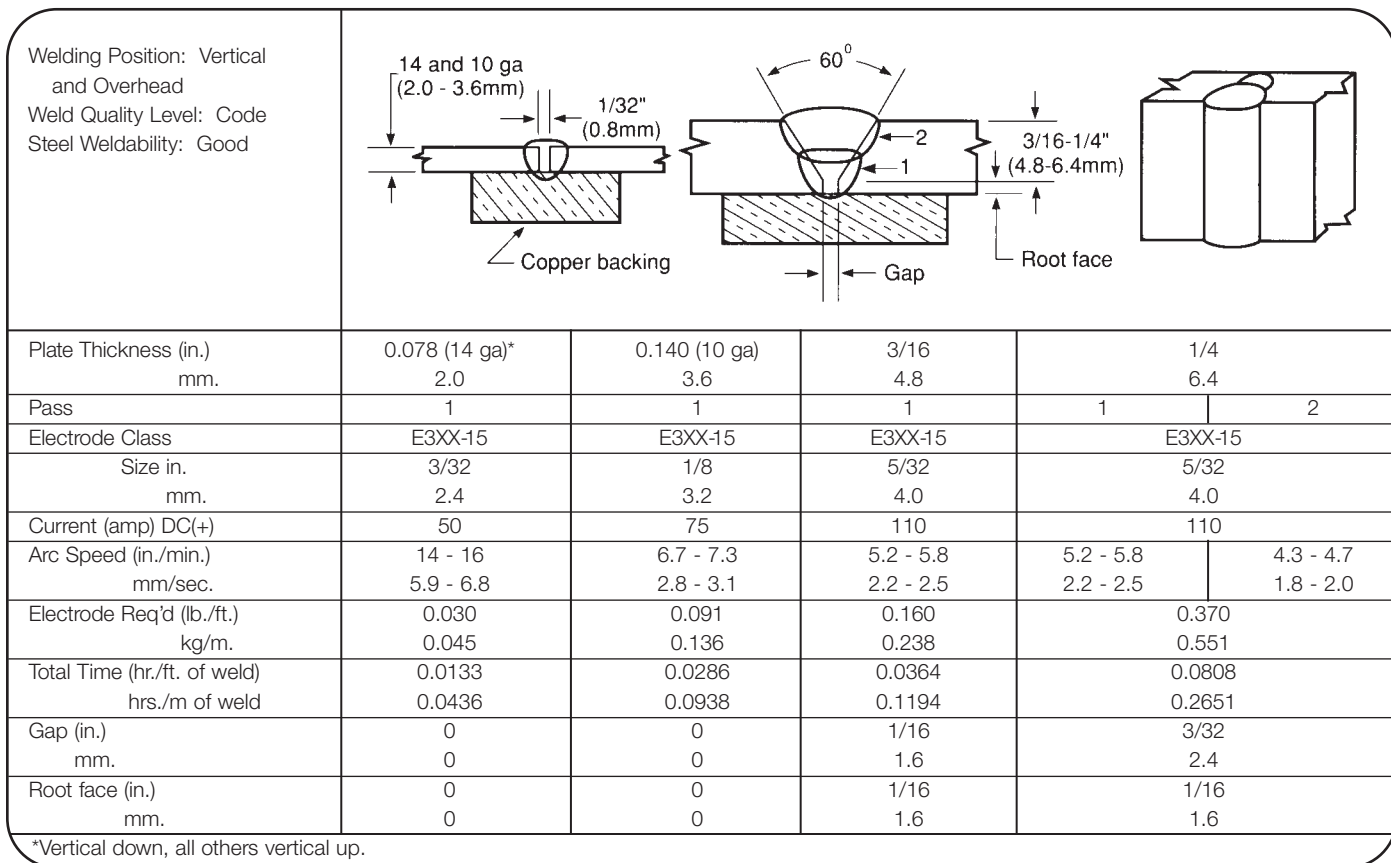*Vertical down, all others vertical up.

FIGURE 7 — Suggested procedures for SMAW of butt joints in austenitic stainless steel 14 gauge (2.0mm) to 1/4 inch (6.4mm) thickness in the vertical and overhead positions.

Welding Position: Flat or Horizontal* Weld Quality Level: Code Steel Weldability: Good						

Weld Size (in.)	3/32	1/8	3/16	1/4	5/16	
mm.	2.4	3.2	4.8	6.4	7.9	
Plate Thickness (in.)	0.078 (14 ga)	0.140 (10 ga)	3/16	1/4	3/8	
mm.	2.0	3.6	4.8	6.4	9.5	
Pass	1	1	1	1	1	2
Electrode Class	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	
Size in.	3/32	1/8	5/32	3/16	3/16	
mm.	2.4	3.2	4.0	4.8	4.8	
Current (amp) DC(+)	60	85	120	160	170	
Arc Speed (in./min.)	12.5 - 13.5	12.5 - 3.5	8.6 - 9.4	6.2 - 6.8	6.2 - 6.8	6.7 - 7.3
mm/sec.	5.3 - 5.7	5.3 - 5.7	3.6 - 4.0	2.6 - 2.9	2.6 - 2.9	2.8 - 3.1
Electrode Req'd (lb/ft)	0.036	0.056	0.120	0.220	0.430	
kg/m.	0.054	0.083	0.178	0.328	0.640	
Total Time (hr/ft of weld)	0.0154	0.0154	0.0222	0.0308	0.0594	
hrs/m of weld	0.051	0.051	0.073	0.101	0.195	

* For vertical and overhead use same procedures as for vertical and overhead butt welds.

Note: AC can be used with a 10% increase in current. E3XX-15 electrode can be used with a 10% decrease in current.
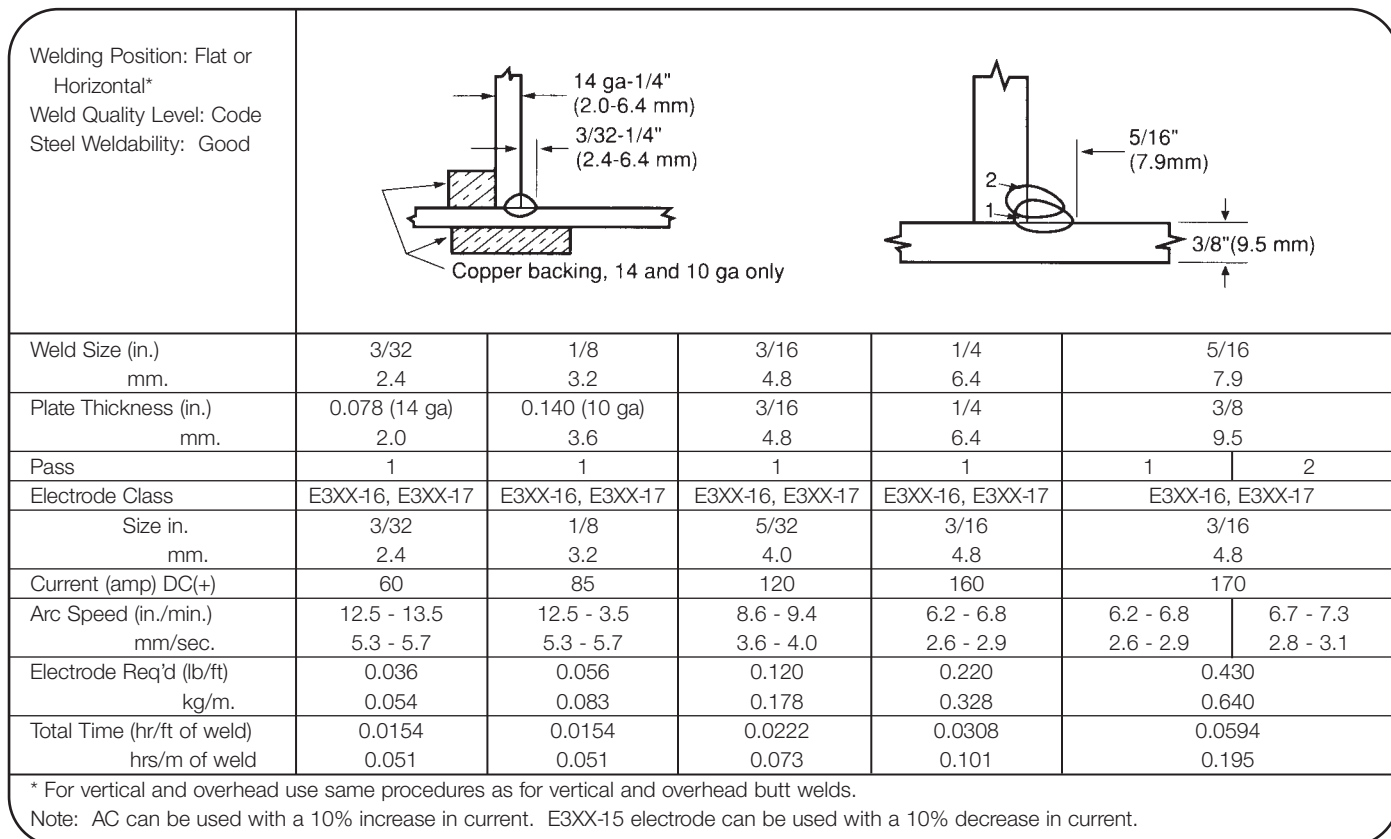
FIGURE 8 — Suggested procedures for SMAW of fillet joints in austenitic stainless steel from 14 gauge (2.0mm) to 3/8 inch (9.5mm) thickness in the flat or horizontal positions.

Welding Position: Horizontal Weld Quality Level: Code Steel Weldability: Good						

14 ga-1/4" (2.0-6.4 mm) · 3/8" (9.5 mm) · Copper backing, 14 and 10 ga only · 2 · 1

Plate Thickness (in.)	0.078 (14 ga)	0.140 (10 ga)	3/16	1/4	3/8	
mm.	2.0	3.6	4.8	6.4	9.5	
Pass	1	1	1	1	1	2
Electrode Class	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	
Size in.	3/32	1/8	5/32	3/16	3/16	
mm.	2.4	3.2	4.0	4.8	4.8	
Current (amp) DC(+)	60	90	125	170	175	
Arc Speed (in./min.)	12.5 - 13.5	12.5 - 13.5	8.6 - 9.4	6.2 - 6.8	6.2 - 6.8	6.7 - 7.3
mm/sec.	5.3 - 5.7	5.3 - 5.7	3.6 - 4.0	2.6 - 2.9	2.6 - 2.9	2.8 - 3.1
Electrode Req'd (lb/ft)	0.036	0.056	0.130	0.240	0.460	
kg/m.	0.054	0.083	0.194	0.357	0.685	
Total Time (hr/ft of weld)	0.0154	0.0154	0.0222	0.0308	0.0594	
hrs/m of weld	0.051	0.051	0.073	0.101	0.195	

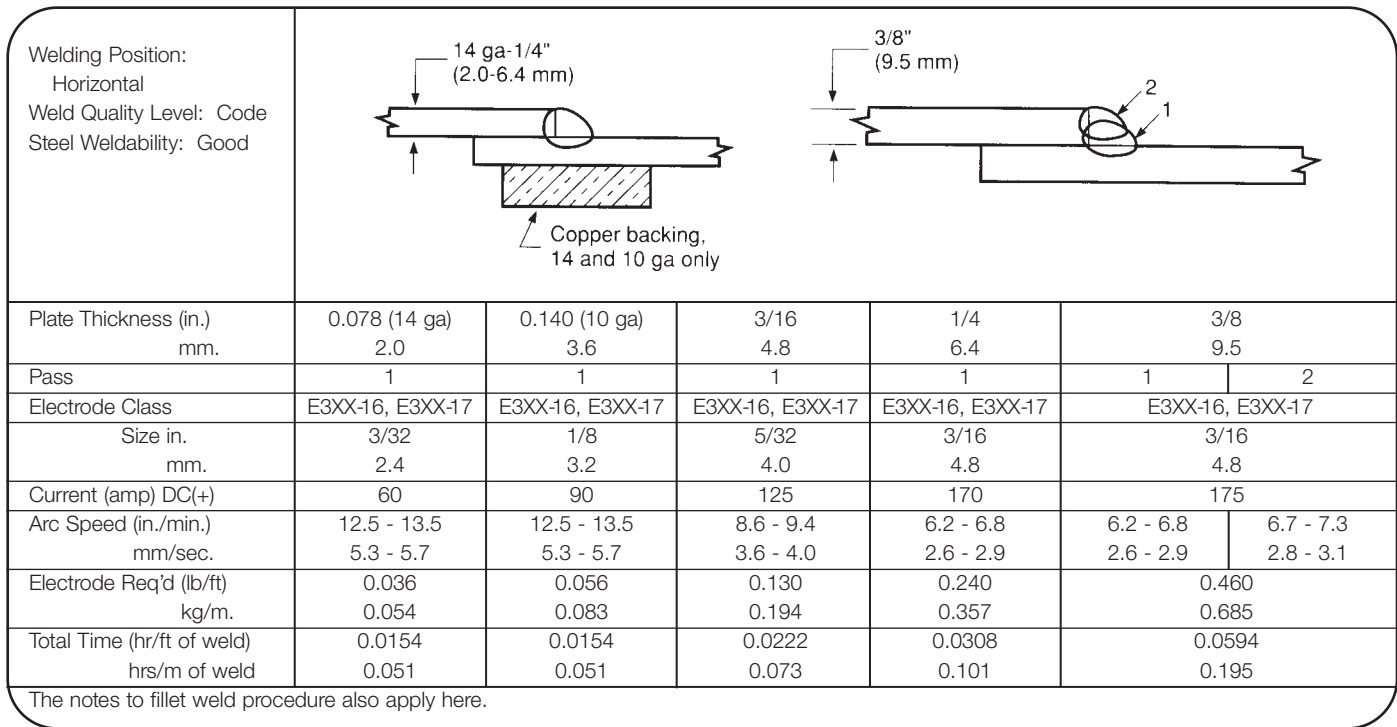The notes to fillet weld procedure also apply here.

FIGURE 9 — Suggested procedures for SMAW of lap joints in austenitic stainless steel from 14 gauge (2.0mm) to 3/8 inch (9.5mm) thickness in the horizontal position.

Welding Position: Flat Weld Quality Level: Code Steel Weldability: Good						

T · 14 ga-1/4" (2.0-6.4 mm) · Copper backing · 3/8" (9.5 mm)

Plate Thickness (in.)	0.078 (14 ga)	0.140 (10 ga)	3/16	1/4	3/8	
mm.	2.0	3.6	4.8	6.4	9.5	
Pass	1	1	1	1	1	2
Electrode Class	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	E3XX-16, E3XX-17	
Size in.	3/32	1/8	5/32	3/16	3/16	
mm.	2.4	3.2	4.0	4.8	4.8	
Current (amp) DC(+)	60	85	125	160	160	175
Arc Speed (in./min.)	14 - 16	12.5 - 13.5	10.5 - 11.5	6.2 - 6.8	6.2 - 6.8	5.7 - 6.3
mm/sec.	5.9 -6.8	5.3 - 5.7	4.4 - 4.9	2.6 - 2.9	2.6 - 2.9	2.4 - 2.7
Electrode Req'd (lb/ft)	0.028	0.056	0.094	0.22	0.45	
kg/m.	0.042	0.083	0.140	0.33	0.67	
Total Time (hr/ft of weld)	0.0133	0.0154	0.0182	0.0308	0.0641	
hrs/m of weld	0.0436	0.0505	0.0597	0.101	0.210	
T (in.)	0.04	1/32	3/64	1/16	0	
mm.	1.0	0.8	1.2	1.6	0	

AC can be used with a 10% increase in current. E3XX-15 electrode can be used with a 10% decrease in current.
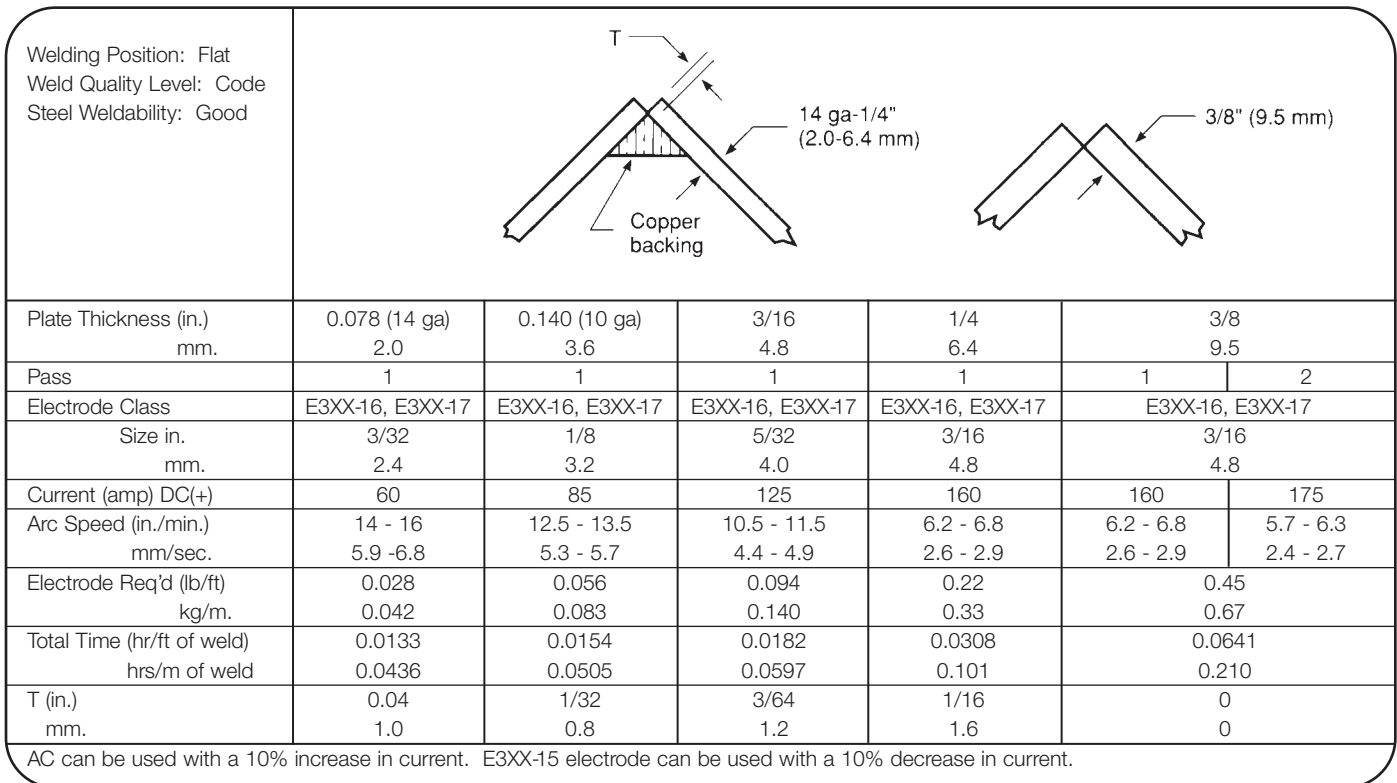
Figure 10 — Suggested procedures for SMAW of corner joints in austenitic stainless steel from 14 gauge (2.0mm) to 3/8 inch (9.5mm) thickness in the flat position.
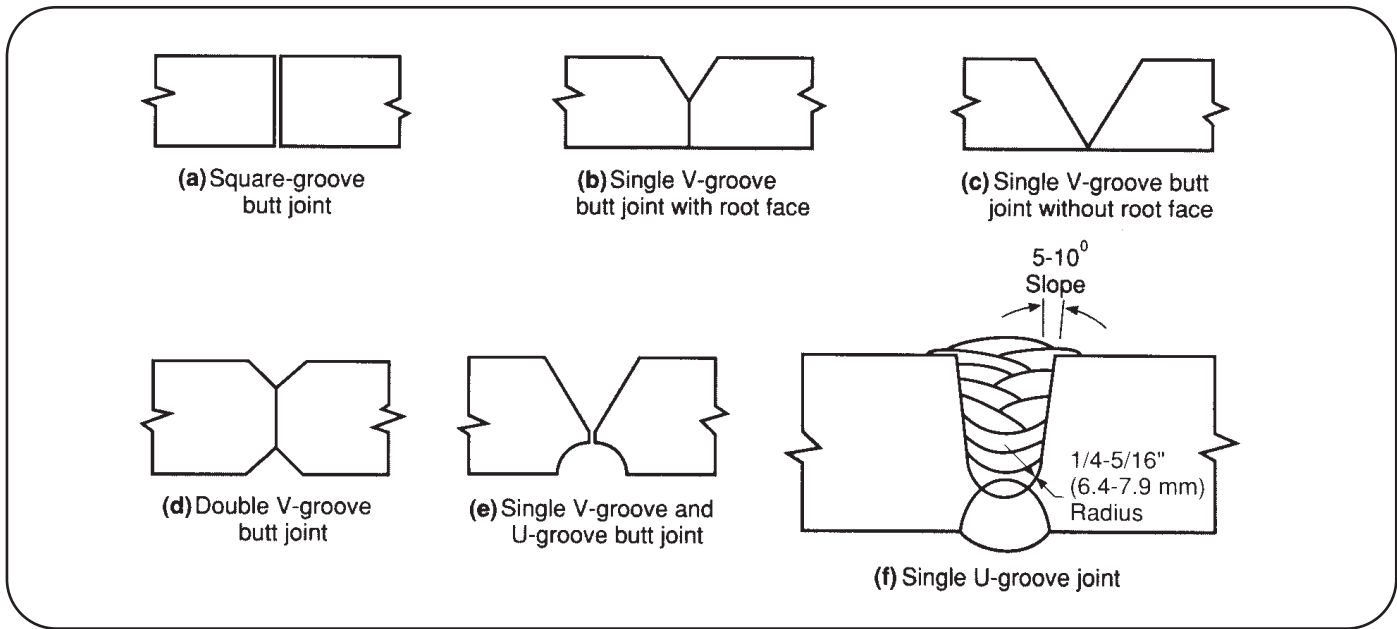
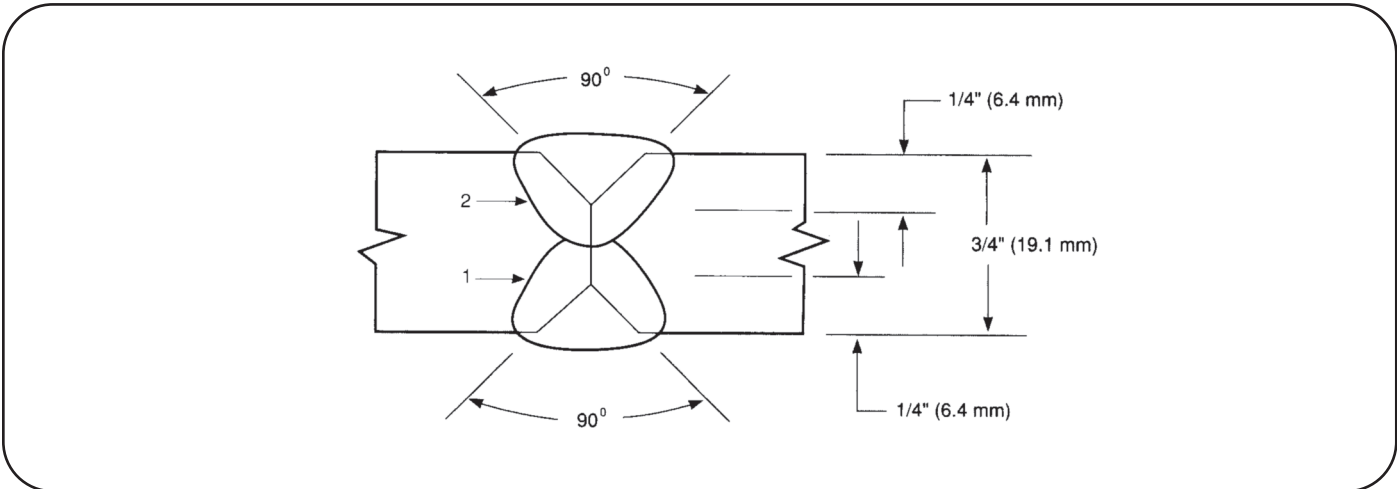**FIGURE 11 — Butt joint designs for submerged-arc welding.**

FIGURE 12 — A typical double-V weld in Type 304 plate. Pass 1 was made at 700 amp, 33 volts, 16 ipm (6.8mm/sec); pass 2 at 950 amp, 35 volts, 12 ipm (5.1mm/sec). The power was DCRP; electrode 3/16-in. (4.8mm). Type 308; neutral flux.
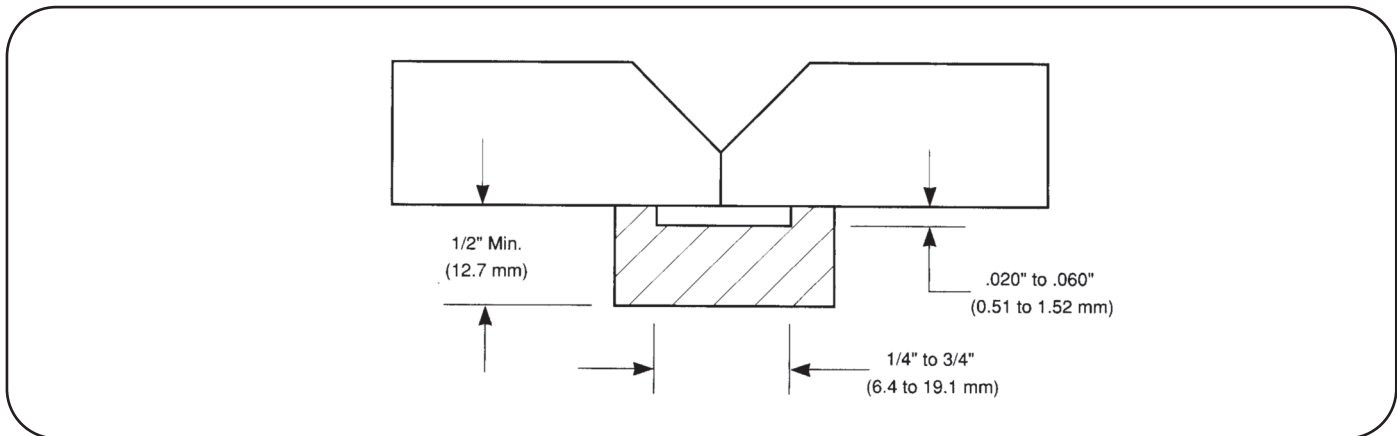

FIGURE 13 — Recommended groove dimensions for copper backing bars in the submerged arc welding of stainless steels.
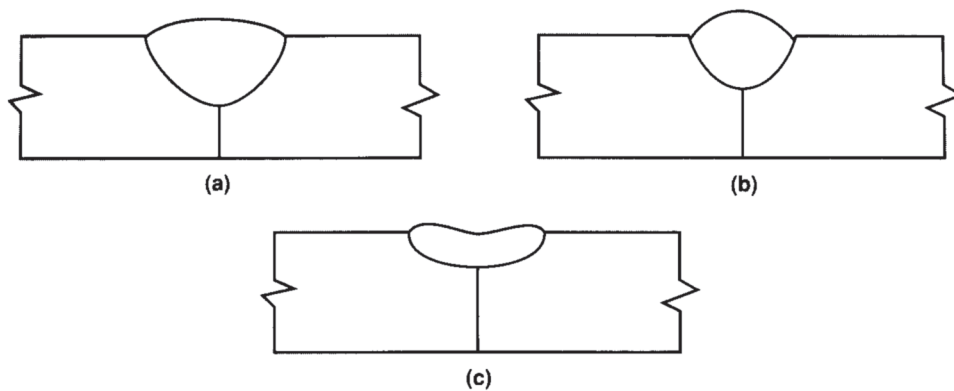
FIGURE 14 — (a) Contour of a weld bead in the flat position with the work horizontal; (b) welding slightly uphill; (c) welding slightly downhill.

the flux is called "neutral." The term neutral is only relative in that the alloy content of the weld is still altered by the flux. Lincoln flux ST-100 is an alloy flux for use with solid stainless steel electrodes. It contains chromium which helps compensate for chromium in the electrode that is oxidized in the arc and therefore not recovered in the weld deposit. Lincoln fluxes 801, 802, 880, 880M, 882, and Blue Max 2000 are neutral fluxes designed for welding with solid stainless steel electrodes. With Nb(Cb) – bearing stainless filler metal (such as ER347), slag removal is often best with Blue Max 2000 or 802 fluxes. Lincoln flux 860 is a neutral flux that can be used with 308L electrode for applications requiring a lower ferrite number. It should be noted that this combination will produce a tighter slag with surface slag sticking. Lincoln MIL-800H flux can be used with ER308L filler metal to produce a 308H (0.04-0.08%C) deposit.

The composition ranges listed in AWS A5.9 are broad. Since composition profoundly affects weld quality and serviceability, the complete range of variations cannot always be tolerated in the deposit. To maintain control, the welding technique, alloy content of the flux or other appropriate changes should be made to compensate for variations in filler metal composition.

The several methods of starting the weld that are commonly in use include:

Scratch Start — In a scratch start, the wire is fed toward the work and the carriage travel is also started. When the wire touches the work, it will not fuse to the workpiece because of the relative motion of the carriage. This type of starting is also called a "flying start."

Retract Starting — The wire is "inched" toward the work and covered with flux. When the weld is started, the wire retracts momentarily and then reverses to feed forward. This method is not recommended for light gauge stainless steel.

Once the arc is initiated, it is important to monitor the various parameters. Welding current is the most influential variable. Next in importance is welding voltage. Welding speed changes conform to a pattern; if the speed is increased, there is less weld reinforcement; if decreased, there is more weld reinforcement. In addition, weld speed can affect depth of penetration.

Cladding with Submerged Arc — SAW is normally a high dilution process, which is undesirable for cladding. A procedure that works well, however, is to change from the normal DC electrode positive polarity

to DC electrode negative polarity, and to limit the wire feed speed to the low end of the normal range – e.g., 60 ipm wire feed for 1/8" electrode, or 80 ipm for 3/32" electrode.

10.3
WELDING WITH THE GAS METAL ARC PROCESS

Stainless steels may be welded by the gas metal arc process, using either spray arc, shortcircuiting or pulsed arc transfer.

Copper backup strips are necessary for welding stainless steel sections up to 1/16 inch thick. Backup is also needed when welding 1/4 inch and thicker plate from one side only.

No air must be permitted to reach the underside of the weld while the weld puddle is solidifying.

Oxygen picked up by the molten metal may reduce the corrosion resistance and ductility of the stainless steel as it cools. To prevent this, the underside of the weld should be shielded by an inert gas such as argon. The shielding gas source can be built into the fixture.

Electrode diameters as large as 3/32 inch, but usually less than 1/16 inch, are used with relatively high currents to create the spray arc transfer. A current of approximately 300-350

amperes is required for a 1/16" electrode, depending on the shielding gas and type of stainless wire being used. The degree of spatter is dependent upon the composition and flow rate of the shielding gas, wire feed speed and the characteristics of the welding power supply. DCEP is used for most stainless steel GMA welding and an argon 1 or 2%-oxygen gas mixture is recommended. Suggested procedures for GMA welding 200 and 300 series stainless steels in the spray transfer mode are given in **Figure 15**.

On square butt welds, a backup strip should be used to prevent weld metal drop-through. When fitup is poor or copper backing cannot be used, drop-through may be minimized by shortcircuiting transfer welding the first pass.

When welding with the semiautomatic gun, forehand ("pushing") techniques are beneficial. Although the operator's hand is exposed to more radiated heat, better visibility is obtained.

For welding plate 1/4 inch and thicker, the gun should be moved back and forth in the direction of the joint and at the same time moved slightly from side to side. On thinner metal, however, only back and forth motion along the joint is used. The more economical shortcircuiting transfer process for thinner material should be employed in the overhead and horizontal position for at least the root and first passes. Although some operators use a short digging spray arc to control the puddle, the weld may be abnormally porous.

Power supply units with slope, voltage and inductance controls are recommended for the welding of stainless steel with shortcircuiting transfer. Inductance, in particular, plays an important part in obtaining proper puddle fluidity.

The shielding gas often recommended for shortcircuiting welding of stainless steel contains 90% helium, 7.5% argon and 2.5% carbon dioxide. The gas gives the most desirable bead contour while keeping the CO_2 level low enough so that is does not influence the corrosion resistance of the metal. High inductance in the power supply output is beneficial when using this gas mixture.

Single pass welds may also be made using argon-oxygen and argon-CO_2 gas mixes. However, arc voltage for steady shortcircuiting transfer may be as much as 6 volts lower than for the helium based gas. The colder arc may lead to lack of fusion defects. The CO_2 in the shielding gas will affect the corrosion resistance of multipass welds made with shortcircuiting transfer due to carbon pickup.

Wire extension or stickout should be kept as short as possible. Backhand welding is usually easier on fillet welds and will result in a neater weld. Forehand welding should be used for butt welds. Outside corner welds may be made with a straight motion.

A slight backward and forward motion along the axis of the joint
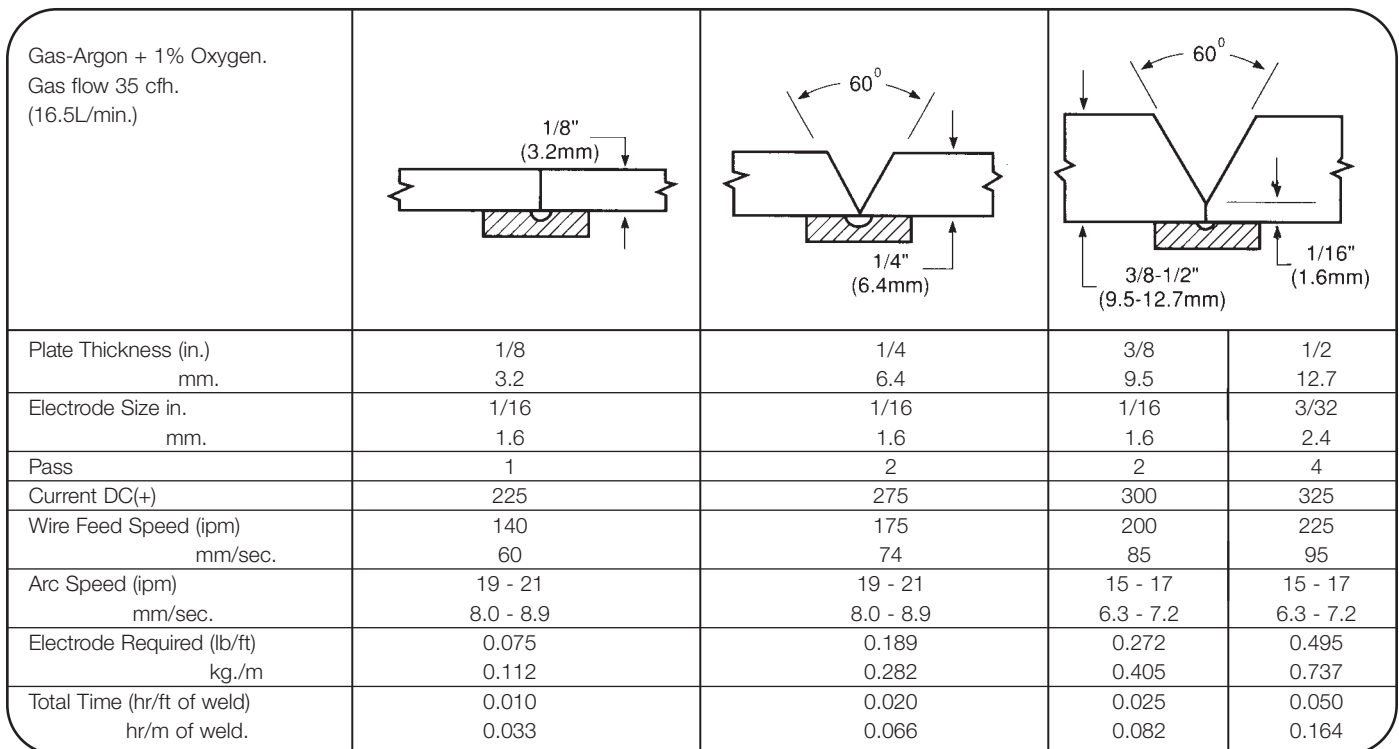
Gas-Argon + 1% Oxygen. Gas flow 35 cfh. (16.5L/min.)			
Plate Thickness (in.)	1/8	1/4	3/8	1/2
mm.	3.2	6.4	9.5	12.7
Electrode Size in.	1/16	1/16	1/16	3/32
mm.	1.6	1.6	1.6	2.4
Pass	1	2	2	4
Current DC(+)	225	275	300	325
Wire Feed Speed (ipm)	140	175	200	225
mm/sec.	60	74	85	95
Arc Speed (ipm)	19 - 21	19 - 21	15 - 17	15 - 17
mm/sec.	8.0 - 8.9	8.0 - 8.9	6.3 - 7.2	6.3 - 7.2
Electrode Required (lb/ft)	0.075	0.189	0.272	0.495
kg./m	0.112	0.282	0.405	0.737
Total Time (hr/ft of weld)	0.010	0.020	0.025	0.050
hr/m of weld.	0.033	0.066	0.082	0.164

FIGURE 15 — Suggested procedures for GMAW of butt joints in 200 and 300 series stainless steels using the spray arc transfer mode.
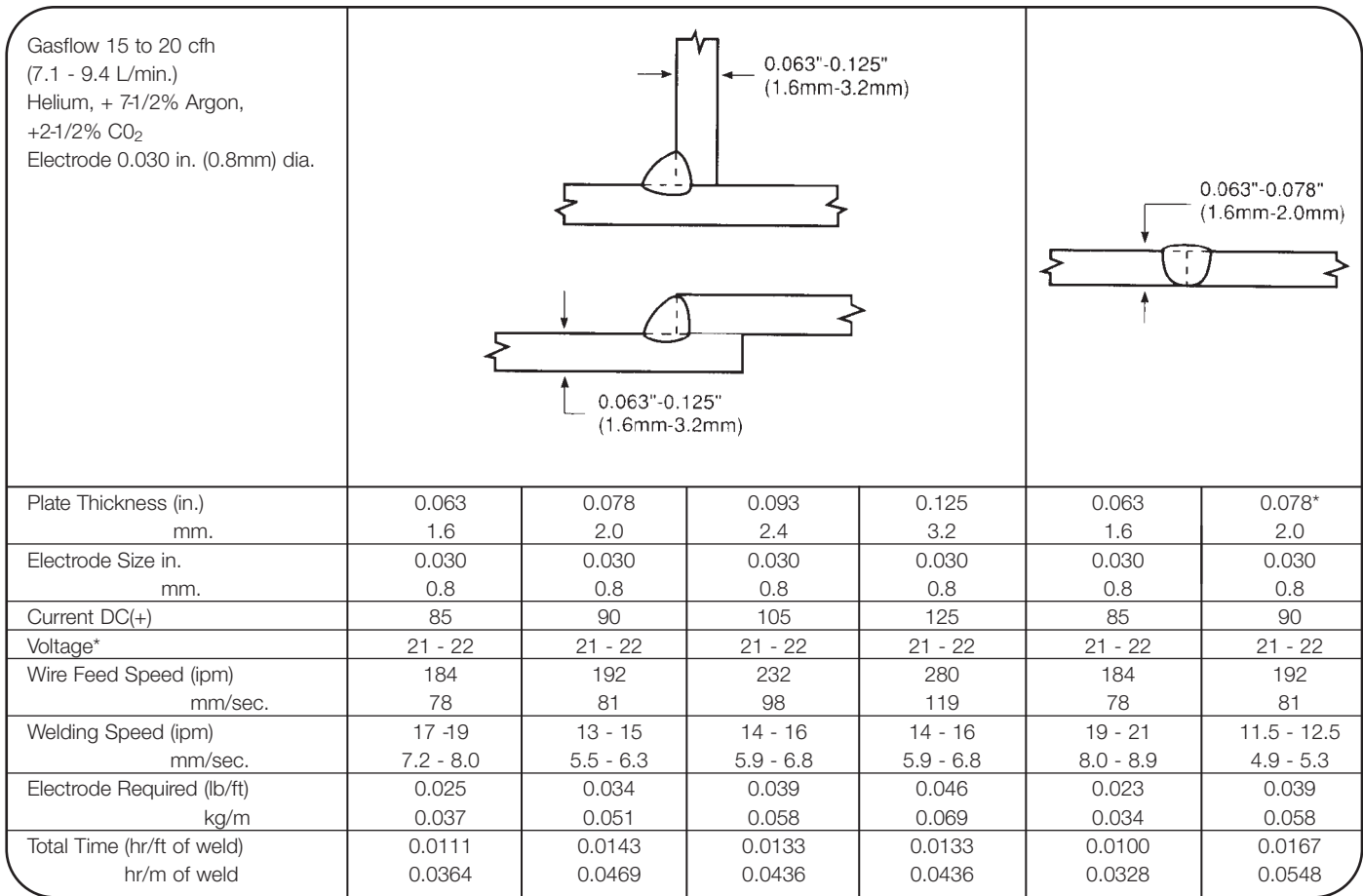
Gasflow 15 to 20 cfh
(7.1 - 9.4 L/min.)
Helium, + 7-1/2% Argon,
+2-1/2% CO_2
Electrode 0.030 in. (0.8mm) dia.

0.063"-0.125"
(1.6mm-3.2mm)

0.063"-0.125"
(1.6mm-3.2mm)

0.063"-0.078"
(1.6mm-2.0mm)

Plate Thickness (in.)	0.063	0.078	0.093	0.125	0.063	0.078*
mm.	1.6	2.0	2.4	3.2	1.6	2.0
Electrode Size in.	0.030	0.030	0.030	0.030	0.030	0.030
mm.	0.8	0.8	0.8	0.8	0.8	0.8
Current DC(+)	85	90	105	125	85	90
Voltage*	21 - 22	21 - 22	21 - 22	21 - 22	21 - 22	21 - 22
Wire Feed Speed (ipm)	184	192	232	280	184	192
mm/sec.	78	81	98	119	78	81
Welding Speed (ipm)	17 -19	13 - 15	14 - 16	14 - 16	19 - 21	11.5 - 12.5
mm/sec.	7.2 - 8.0	5.5 - 6.3	5.9 - 6.8	5.9 - 6.8	8.0 - 8.9	4.9 - 5.3
Electrode Required (lb/ft)	0.025	0.034	0.039	0.046	0.023	0.039
kg/m	0.037	0.051	0.058	0.069	0.034	0.058
Total Time (hr/ft of weld)	0.0111	0.0143	0.0133	0.0133	0.0100	0.0167
hr/m of weld	0.0364	0.0469	0.0436	0.0436	0.0328	0.0548

FIGURE 16 — Suggested procedures for GMAW of butt joints and lap joints in 200 and 300 series stainless steels using the short circuiting transfer mode.
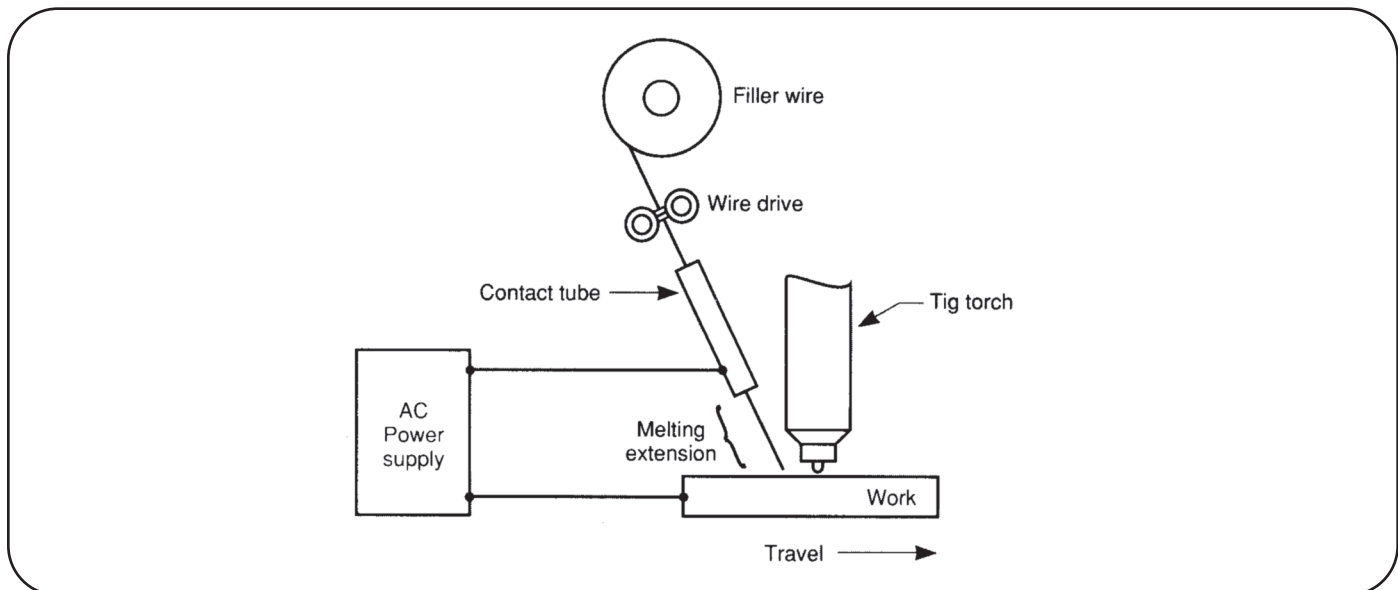

FIGURE 17 — Schematic of the hot-wire system for the automatic TIG welding of stainless steels.

Plate Thickness (in.)	1/16	3/32	1/8	3/16	1/4	1/2
mm.	1.6	2.4	3.2	4.8	6.4	12.7
Current DC(–)	80 - 100	100 - 120	120 - 140	200 - 250	200 - 350	225 - 375
Electrode Diameter (in.)	1/16	1/16	1/16	3/32	1/8	1/8
mm.	1.6	1.6	1.6	2.4	3.2	3.2
Gas Flow, Argon (cfh)	10	10	10	15	20	25
L/min..	4.7	4.7	4.7	7.1	9.4	11.8
Filler-Rod Diameter (in.)	1/16	1/16	3/32	1/8	1/8	1/8
mm.	1.6	1.6	2.4	3.2	3.2	3.2
Arc Speed (ipm)	12	12	12	10	8	8
mm/sec	5.1	5.1	5.1	4.2	3.4	3.4
Total Time (hr/ft of weld)	0.0167	0.0167	0.0167	0.0200	0.0250	0.0250
hr/m. of weld	0.0548	0.0548	0.0548	0.0656	0.0820	0.0820

Plate Thickness, T (in.)	1/16	3/32	1/8	3/16	1/4	1/2
mm.	1.6	2.4	3.2	4.8	6.4	12.7
Current DC(–)	90 - 110	110 - 130	130 - 150	225 - 275	225 - 350	225 - 375
Electrode Diameter (in.)	1/16	1/16	1/16	3/32	1/8	1/8
mm.	1.6	1.6	1.6	2.4	3.2	3.2
Gas Flow, Argon (cfh)	10	10	10	15	20	25
L/min..	4.7	4.7	4.7	7.1	9.4	11.8
Filler-Rod Diameter (in.)	1/16	1/16	3/32	1/8	1/8	1/8
mm.	1.6	1.6	2.4	3.2	3.2	3.2
Arc Speed (ipm)	10	10	10	8	8	8
mm/sec	4.2	4.2	4.2	3.4	3.4	3.4
Total Time (hr/ft of weld)	0.0200	0.0200	0.0200	0.0250	0.0250	0.0250
hr/m. of weld	0.0656	0.0656	0.0656	0.0820	0.0820	0.0820

For vertical-up and overhead, decrease current 10 to 20%.

FIGURE 18 — Suggested procedures for GTAW of butt, corner, tee and lap joints in stainless steels.

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TABLE XVII — Typical Travel Speeds and Deposition Rates with GTAW-Hot Wire

Wire Size:	1.2mm (0.045 in.)
Shielding Gas:	75% He, 25% A
Electrode:	4.0-4.8mm (5/32-3/16 in.) 2% Th

Arc Current Amps	Arc Voltage Volts	Travel Speed		Wire Speed Feed		Deposition Rate	
		mm/Sec	In/Min.	mm/Sec	In/Min.	Kg/Hr	Lbs/Hr
300	10 - 12	1.7 - 4.2	4 - 10	46 - 157	110 - 370	1.4 - 4.5	3 - 10
400	11 - 13	2.5 - 5.9	6 - 14	78 - 188	185 - 445	2.3 - 5.4	5 - 12
500	12 - 15	3.4 - 8.5	8 - 20	125 - 282	295 - 665	3.6 - 8.2	8 - 18

should be used. **Figure 16** summarizes the welding procedures normally used for the shortcircuiting transfer welding of stainless steel.

Shortcircuiting transfer welds on stainless steel made with a shielding gas of 90% He, 7-1/2% A, 2-1/2% CO_2 show good corrosion resistance and coalescence. Butt, lap and single fillet welds in material ranging from .060 inch to .125 inch in 304, 310, 316, 321, 347, 410 and similar stainless steels can be made successfully.

The pulsed arc process, as normally used, is a spray transfer process wherein one small drop of molten metal is transferred across the arc for each high current pulse of weld current. The high current pulse must be of sufficient magnitude and duration to cause at least one small drop of molten metal to form and be propelled by the pinch effect from the end of the wire to the weld puddle. During the low current portion of the weld cycle, the arc is maintained and the wire is heated, but the heat developed is not adequate to transfer any metal. For this reason, the time duration at the low current value must be limited otherwise metal would be transferred in the globular mode.

Wire diameters of 0.045 and 0.035 inch are most commonly used with this process. Gases for pulsed arc welding, such as argon plus 1% oxygen are popular, the same as used for spray arc welding. These and other wire sizes can be welded in the spray transfer mode at a lower average current with pulsed current than with continuous weld current. The advantage of this is that thin material can be welded in the spray transfer mode which produces a smooth weld with less spatter than the shortcircuiting transfer mode. Another advantage is that for a given average current, spray transfer can be obtained with a larger diameter wire than could be obtained with continuous currents. Larger diameter wires are less costly than smaller sizes, and the lower ratio of surface to volume reduces the amount of deposit contamination.

The electrode diameters for gas metal arc welding are generally between 0.030 and 3/32 inch. For each electrode diameter, there is a certain minimum welding current that must be exceeded to achieve spray transfer. For example, when welding stainless steel in an argon-oxygen atmosphere with 0.045 inch diameter stainless steel electrode, spray transfer will be obtained at a welding current of about 220 amp DCRP. It must be kept in mind that, along with the minimum current, a minimum arc voltage must also be obtained. This is generally between 22 and 30 volts.

Electrodes come on spools varying in weight between 2 and 60 lb. Also available are electrodes for welding the straight chromium stainless steels and austenitic electrodes that contain more than the usual amount of silicon. The latter have particularly good wetting characteristics when used with the shortcircuiting transfer process.

Some stainless steel weld metals during welding have a tendency to-ward hot shortness or tearing when they contain little or no ferrite – Type 347, for example. When welding these, more welding passes than indicated in the procedures may be needed. Stringer bead techniques are also recommended rather than weaving or oscillating from side to side. Hot cracking may be eliminated by stringer bead techniques since there is a reduction in contraction stresses, hence cooling is more rapid through the hot short temperature range. A procedure that tends to produce a more convex bead than normal can be very helpful, and care should be taken to fill craters.

Weld metal hot cracking may be reduced by shortcircuiting transfer welding, because of the lower dilution from the base metal. Excessive dilution may produce a completely austenitic weld metal having strong cracking characteristics.

When welding magnetic stainless steels (ferritic and martensitic types) to the relatively nonmagnetic types (austenitic types), it is desirable to:

1. Use a single bevel joint to obtain minimum joint reinforcement.

2. Use low heat input shortcircuiting transfer to minimize the arc deflection encountered when welding magnetic to nonmagnetic steels.

3. For uniform fusion, be sure the wire is kept centered over the nonbeveled edge of the joint.

Parameters and procedures for welding 200 and 300 series stainless

steels by the GMAW spray arc mode are given in **Figure 15**. **Figure 16** gives parameters and procedures for welding the 200 and 300 series stainless steels by the GMAW shortcircuiting mode.

10.4
WELDING WITH THE GAS TUNGSTEN ARC PROCESS

All stainless steel alloys that are considered weldable can be welded readily with the gas tungsten arc process (GTAW).

The preferred electrodes are thoriated, ceriated, or lanthanated tungsten as specified in AWS A5.12. The advantage of these electrodes is that they have a more stable arc and can be used with higher currents than pure tungsten electrodes.

The shielding gas is usually argon, but helium or mixtures of argon and helium are used on heavy sections. The advantages of argon are that flow rates can be lower, the arc is more stable and the arc voltage is somewhat less than with helium. The lower voltage makes it possible to weld thin sheet without burn through.

Filler materials for use with the gas tungsten arc process are in the form of solid wire available in coils for automatic welding or straight lengths for manual welding. These are specified in AWS A5.9 which also applies to filler material for Gas Metal Arc and Submerged Arc welding. Consumable inserts, specified in AWS A5.30, are useful for root passes with gas tungsten arc.

The DC power source for gas tungsten arc welding must be a constant current type, and it is recommended that a high frequency voltage be superimposed on the welding circuit. The high frequency need be on only to start the arc. As the electrode is brought close to the work, the high frequency jumps the gap from the tungsten to the work and ignites the welding arc. Since

the tungsten electrode does not actually touch the work, the possibility of contaminating the stainless steel with tungsten is greatly reduced. Straight polarity (DC-) should be used – which produces a deep, penetrating weld.

A "scratch" start may be used in lieu of a high frequency start, although there is some possibility of tungsten pickup. The arc should not be struck on a carbon block because of the likelihood of carbon contamination.

Stainless steels are readily welded with automatic GTAW. Arc voltage is proportional to arc length – thus a reliable signal can be generated to operate automatic arc voltage control equipment. Filler metal may be used, or light gauge material may be joined by simple fusion of the joint edges. When "cold" filler metal is used, it is always added to the front of the puddle.

The so called "hot wire" method of welding gives greatly increased deposition rates and welding speeds. The wire – which trails the torch, as illustrated in **Figure 17 –** is resistance heated by a separate AC power supply. It is fed through a contact tube and extends beyond the tube. The extension is resistance heated so that it approaches or reaches the melting point before it contacts the weld puddle. Thus, the tungsten electrode furnishes the heat to melt the base metal and the AC power supply furnishes a large portion of the energy needed to resistance melt the filler wire. The hot wire method is, in effect, an adaptation of the long stickout principle used in submerged arc and self-shielded flux cored arc welding. The wire used for hot wire TIG welding is usually 0.045 inch diameter. Since the wire is melted. or very nearly melted by its own power source, the deposition rate can be controlled almost independently of the arc.

Using the GTA hot wire method, deposition rates up to 18 lb/hr can be achieved when welding at 400 to 500

amp DCEN (**Table XVII**). Still greater deposition rates can be obtained using an automatic oscillated welding technique. Voltage control is essential to achieve control of the large puddle when welding at high deposition rates. For this reason, TIG hot wire welding requires the use of voltage control equipment.

By using closely spaced multiple tungsten electrodes, the welding speed can also be increased substantially when GTA welding stainless steel tubing or sheet. Multiple electrodes practically eliminate the problem of undercutting at high speeds.

Procedures and parameters for GTA welding of stainless steel in thicknesses from 1/16 inch to 1/2 inch (1.6 to 12.7 mm) are given in **Figure 18**. These include butt, corner, tee and lap type joints.

Distortion Control in Austenitic, Precipitation Hardening, and Duplex Ferritic–Austenitic Stainless Steels

Austenitic Stainless steels have a 50% greater coefficient of expansion and 30% lower heat conductivity than mild steel. Duplex stainless steels are only slightly better. Allowance must be made for the greater expansion and contraction when designing austenitic stainless steel structures. More care is required to control the greater distortion tendencies. Here are some specific distortion control hints:

Rigid jigs and fixtures hold parts to be welded in proper alignment. Distortion is minimized by allowing the weld to cool in the fixture.

Copper chill bars placed close to the weld zone help remove heat and prevent distortion caused by expansion. Back-up chill bars under the joint are always recommended when butt welding 14 gauge (2.0mm) and thinner material. A groove in the bar helps form the bead shape. **NOTE:** Keep the arc away from the copper. Copper

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contamination of the weld causes cracking.

Without fixtures, tack weld the joint every couple of inches and peen the tacks to remove shrinkage stresses. Finish the joint with a welding sequence designed to minimize distortion.

A planned sequence of welding always helps control distortion. The techniques used in mild steel welding can be used. Skip welding and back-step welding are recommended for light gauge steels.

Low current and stringer beads reduce distortion by limiting the amount of heat at the weld. Also, do not deposit excessive weld metal. It seldom adds to the strength of the weld and does increase heat input and promotes distortion.

If a structure of heavy steel is not rigidly held during welding, many small beads will cause more total distortion than a few large beads.

Distortion Control in Ferritic and Martensitic Stainless Steels

Since they have heat expansion properties similar to mild steel, plate structures of ferritic and martensitic stainless steels are designed and welded with about the same distortion controls and allowances as mild steel. However, because they have lower thermal conductivity than mild steel, the heat remains concentrated in the area of the weld. This causes distortion problems in thin-gauge steel. This distortion can be controlled with suitable jigs and fixtures, proper joint design and a correct welding sequence.

SOURCES OF ADDITIONAL INFORMATION

Additional information on the welding of stainless steels can be obtained from the sources listed below:

The Welding Handbook
7th Edition, Volume 4, Chapter 2 – American Welding Society

ANSI/AWS D10.4
Recommended Practices for Welding Austenitic Stainless Steel Piping and Tubing – American Welding Society

AWS – A4.2
Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal – American Welding Society

AWS – A5.4
Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding – American Welding Society

AWS – A5.9
Specification for Bare Stainless Steel Welding Electrodes and Rods – American Welding Society

AWS – A5.22
Specification Stainless Steel Electrodes for Flux-Cored Arc Welding and Stainless Steel Cored Rods for Gas Tungsten Arc Welding – American Welding Society

AWS – A5.30
Specification for Consumable Inserts – American Welding Society

ASM Metals Handbook
Volume 6 – Welding and Brazing – 8th Edition – ASM International

ASM Metals Handbook
Volume 6 – Welding, Brazing and Soldering – 9th Edition – ASM International

AWS – FMC
Filler Metal Comparison Charts – American Welding Society

Literature from filler metal manufacturers:

ASM Metals Handbook
Volume 1 – Properties and Selection of Metals, 8th Edition – ASM International

ASM Metals Handbook
Volume 3 – Properties and Selection of Stainless Steels, Tool Materials and Special Purpose Metals, 9th Edition – ASM International

The Making, Shaping and Treating of Steel
10th Edition, United States Steel Corporation

ANSI – Z49.1
Safety in Welding, Cutting and Allied Processes – American Welding Society

Welding Metallurgy of Stainless Steels
by Erich Folkhard, Springer - Verlag, New York

WARNING – HEALTH & SAFETY NOTICE

Protect yourself and others. Read and understand the label provided with filler material for welding.

FUMES AND GASES can be dangerous to your health. ARC RAYS can injure eyes and burn skin. ELECTRIC SHOCK can kill.

- Read and understand the manufacturer's instructions and your employer's safety practices.

- Keep your head out of the fumes.

- Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases away from your breathing zone and the general area.

- Wear correct eye, ear and body protection.

- Do not touch live electrical parts or permit electrically live parts or electrodes to contact skin or your clothing or gloves if they are wet.

- Insulate yourself from work and ground.

IMPORTANT:

Special ventilation and/or exhaust are required when welding high chromium alloys such as stainless steels.

Fumes from the normal use of stainless steel filler materials contain significant quantities of chromium compounds. The PEL (OSHA Permissible Exposure Limit for chromium VI (0.005 mg/m^3) will be exceeded before reaching the 5.0 mg/m^3 maximum exposure guideline for total welding fume.

BEFORE USING, READ AND UNDERSTAND THE MATERIAL SAFETY DATA SHEET (MSDS)* FOR THE FILLER MATERIAL TO BE USED.

- See American National Standard Z49.1, *Safety in Welding, Cutting and Allied Processes*, published by the American Welding Society, 550 N.W. LeJeune Road, Miami, Florida 33126; OSHA Safety and Health Standards, 29 CFR 1910, available from the U.S. Government Printing Office, Washington, DC 20402-0001

Lincoln Electric has an extensive standard* line of consumables for welding stainless steels, including:

COATED ELECTRODES FOR SHIELDED METAL ARC WELDING

	AWS A5.4 Classification
Blue Max 308/308L AC-DC	E308L-17, E308-17
Blue Max 309/309L AC-DC	E309L-17, E309-17
Blue Max 316/316L AC-DC	E316L-17, E316-17
Blue Max 347 AC-DC	E347-17
Red Baron 308/308H MR	E308-16, E308H-16
Red Baron 308L MR	E308L-16
Red Baron 309/309L MR	E309-16, E309L-16
Red Baron 310 MR	E310-16
Red Baron 316/316L MR	E316L-16, E316-16
Red Baron 347 MR	E347-16

ELECTRODES OPTIMIZED FOR VERTICAL DOWN WELDING

	AWS A5.4 Classification
Red Baron 308/308L-V MR	E308-15, E308L-15
Red Baron 309/309L-V MR	E309-15, E309L-15
Red Baron 316/316L-V MR	E316-15, E316L-15

SOLID WIRES FOR SUBMERGED ARC WELDING

	AWS A5.9 Classification
Blue Max S308/308L	ER308, ER308L
Blue Max S309/309L	ER309, ER309L
Blue Max S316/316L	ER316, ER316L

SOLID WIRES FOR GAS METAL ARC WELDING AND GAS TUNGSTEN ARC WELDING

	AWS A5.9 Classification
Blue Max MIG 308LSi	ER308LSi, ER308Si
Blue Max MIG 309LSi	ER309LSi, ER309Si
Blue Max MIG 316LSi	ER316LSi, ER316Si

METAL CORED WIRE FOR GAS METAL ARC WELDING

	AWS A5.9 Classification
OUTERSHIELD MC 409	EC409
OUTERSHIELD MC 409W	EC409

* Many other compositions are available on special order. Contact your Lincoln Electric Representative.

FLUXES FOR SUBMERGED ARC WELDING

(No AWS classification is applicable.)

Lincolnweld MIL 800
Lincolnweld 801
Lincolnweld 802
Lincolnweld 860
Lincolnweld 880
Lincolnweld 880M
Lincolnweld 882
Lincolnweld ST-100
Blue Max 2000

FLUX CORED WIRES FOR CO_2 OR 75Ar-25CO_2 WELDING

BLUE MAX FC308L	BLUE MAX FCP309L
BLUE MAX FC309L	BLUE MAX FCP316L
BLUE MAX FC316L	

FLUXES FOR STRIP CLADDING

(No AWS Classification is applicable.)

Blue Max 3000 (for submerged arc)
Blue Max 4000 (for electroslag)

CUT LENGTHS FOR MANUAL GAS TUNGSTEN ARC WELDING

Lincoln	AWS A5.9 Classification
ER308/308L	ER308, ER308L
ER309/309L	ER309, ER309L
ER316/316L	ER316, ER316L