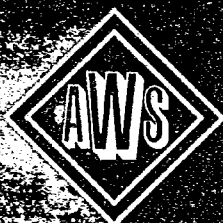
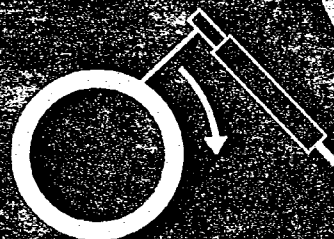
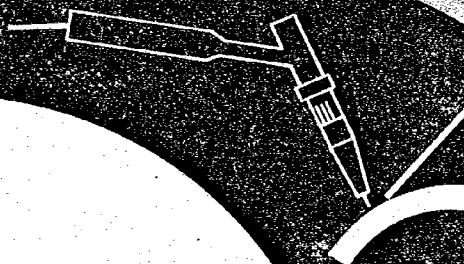
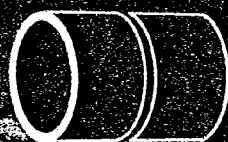


**Recommended Practices
for
Welding Austenitic
Chromium-Nickel Stainless
Steel Piping and Tubing**



AMERICAN WELDING SOCIETY

Key Words — austenitic pipe, chromium-nickel pipe, gas metal arc welding, gas tungsten arc welding, recommended practice, stainless steel pipe, shielded metal arc welding

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Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing

Superseding AWS D10.4-79

Prepared by
AWS Committee on Piping and Tubing

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Approved by
AWS Board of Directors
April 11, 1986

Abstract

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

A number of Figures and Tables illustrate recommended joint designs and procedures. Appendix A presents information on the welding of high-carbon stainless steel cast pipe fittings.

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Foreword

(This Foreword is not a part of D10.4-86, *Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing* but is included for information purposes only.)

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

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

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

The present document further expands and refines this information and, in addition, contains an Appendix which gives recommendations for welding high-carbon stainless steel castings.

Comments or inquiries pertaining to these recommended practices are welcome. They should be addressed to: Secretary, AWS Committee on Piping and Tubing, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, FL 33135.

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Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing

Introduction

The ideal piping system would be a single piece of pipe, so formed, shaped, sized, and directed as to contain or convey the fluid required by the process in which it is involved. For most systems this cannot be. Changes in size, shape, direction, and operating conditions usually preclude such a fabrication. Joints become necessary. Piping systems usually must be made of many different components, and the joints that connect them must be as strong and serviceable as the components themselves. Therefore, engineers and mechanics should try to apply those joining methods which most nearly meet the conditions of one-piece fabrication and also allow for necessary assembly, erection, maintenance, and operation.

Most of the austenitic stainless steels are readily weldable when the proper procedures and techniques are followed. They can be joined by most of the fusion welding processes, and good pipe welders can adapt very quickly from carbon steel or low alloy steel to stainless steel. Orbiting pipe welding machines are also very adaptable to these materials.

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

1. Material Compositions and Specifications

1.1 Compositions. Chemical composition ranges and type numbers for those stainless steels generally available in wrought piping and tubing are listed in Table 1. These are American Iron and Steel Institute (AISI) Standard Compositions. Chemical composition ranges and designations for five stainless steels generally available as cast

pipe are shown in Table 2. These are included because cast valves and fittings are considered part of a piping system.

The weldability of castings may be somewhat less than that of a wrought stainless steel of the same type. This is because fully austenitic castings have much larger grains than similar wrought material. Consequently, there is less grain boundary area along which to disperse the impurities. As a result, there may be a tendency toward hot cracking when welding some castings. However, proper control of the composition of the casting, to obtain four to ten percent delta ferrite, can prevent hot cracking.

1.2 Specifications. Typical American Society for Testing and Materials (ASTM) specifications covering piping and tubing in both cast and wrought form (seamless or welded) are listed in Table 3. ASTM employs the AISI type numbers for designating the austenitic types. However, the ASTM chemical composition requirements differ slightly from the AISI requirements and will vary slightly in different ASTM specifications. The composition ranges specified for cast tubular products are identical with those of the American Castings Institute (ACI). Specifications for covered welding electrodes and welding rods and electrodes are provided in Tables 4 and 5.

2. Base Metals

2.1 Primary Types (304, 305, 309, and 310). These materials have many applications and are widely used for their corrosion and oxidation resistance, high-temperature strength, and low-temperature properties. However, there are a number of welding-related characteristics that may affect all of these, as noted below.

Types 304 and 305 may become sensitized by welding, depending on their carbon content and the manner in which they are welded, and as a result may require solution annealing to restore immunity to intergranular

Table 1
Types of Chromium-Nickel Stainless Steel Available in Piping and Tubing

Type	Chemical Composition Limit, Percent ^a							
	C	Mn	Si	Cr	Ni ^b	P	S	Other Elements
304	0.08	2.00	1.00	18.0–20.0	8.0–10.5	0.045	0.03	—
304H	0.04–0.10	2.00	1.00	18.0–20.0	8.0–10.5	0.045	0.03	—
304L	0.03	2.00	1.00	18.0–20.0	8.0–12.0	0.045	0.03	—
304LN	0.03	2.00	1.00	18.0–20.0	8.0–10.5	0.045	0.03	0.10–0.15 N
304N	0.08	2.00	1.00	18.0–20.0	8.0–10.5	0.045	0.03	0.10–0.16 N
305	0.12	2.00	1.00	17.0–19.0	10.5–13.0	0.045	0.03	—
308	0.08	2.00	1.00	19.0–21.0	10.0–12.0	0.045	0.03	—
309	0.20	2.00	1.00	22.0–24.0	12.0–15.0	0.045	0.03	—
309S	0.08	2.00	1.00	22.0–24.0	12.0–15.0	0.045	0.03	—
310	0.15	2.00	1.50	24.0–26.0	19.0–22.0	0.045	0.03	—
310S	0.08	2.00	1.50	24.0–26.0	19.0–22.0	0.045	0.03	—
316	0.08	2.00	1.00	16.0–18.0	10.0–14.0	0.045	0.03	2.0–3.0 Mo
316H	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	0.03	2.00	1.00	16.0–18.0	10.0–14.0	0.045	0.03	2.0–3.0 Mo
316LN	0.03	2.00	1.00	16.0–18.0	10.0–14.0	0.045	0.03	2.0–3.0 Mo 0.10–0.3 N
316N	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	0.08	2.00	1.00	18.0–20.0	11.0–15.0	0.045	0.03	3.0–4.0 Mo
317L	0.03	2.00	1.00	18.0–20.0	11.0–15.0	0.045	0.03	3.0–4.0 Mo
321	0.08	2.00	1.00	17.0–19.0	9.0–12.0	0.045	0.03	5 × % C min. Ti
321H	0.04–0.10	2.00	1.00	17.0–19.0	9.0–12.0	0.045	0.03	5 × % C min. Ti
347	0.08	2.00	1.00	17.0–19.0	9.0–13.0	0.045	0.03	10 × % C min. Cb + Ta ^c
347H	0.04–0.10	2.00	1.00	17.0–19.0	9.0–13.0	0.045	0.03	10 × % C min. Cb + Ta
348	0.08	2.00	1.00	17.0–19.0	9.0–13.0	0.045	0.03	10 × % C min. Cb + Ta ^c 0.2 Cu
348H	0.04–0.10	2.00	1.00	17.0–19.0	9.0–13.0	0.045	0.03	10 × % C min. Cb + Ta ^c 0.2 Cu

a. Single values are maximums.

b. For some tubemaking processes, the nickel content of certain austenitic types must be slightly higher than shown.

c. Ta is optional.

Table 2
Types of Chromium-Nickel Stainless Steel Castings

ASTM ^b Designation	Nominal Composition	Chemical Composition, Percent ^a							
		C	Mn	P	S	Si	Cr	Ni	Other Elements
CF3	19–9	0.03	1.50	0.04	0.04	2.00	17.0–21.0	8.0–12.0	—
CF8	19–9	0.08	1.50	0.04	0.04	2.00	18.0–21.0	8.0–11.0	—
CF8M	19–10 Mo	0.08	1.50	0.04	0.04	2.00	18.0–21.0	9.0–12.0	2.0–3.0 Mo
CF3M	19–10 Mo	0.03	1.50	0.04	0.04	1.50	17.0–21.0	9.0–13.0	2.0–3.0 Mo
CH8	25–12	0.08	1.50	0.040	0.040	1.50	22.0–26.0	12.0–15.0	—
CPK20	25–20	0.20	1.50	0.040	0.040	1.00	23.0–27.0	19.0–22.0	—
CH20	25–12	0.20	1.50	0.040	0.040	2.00	22.0–26.0	12.0–15.0	—

Note: Chromium-nickel stainless steel castings with carbon content above 0.20% are covered in the Appendix of this report.

a. Single values are maximums.

b. American Society for Testing and Materials.

Table 3
ASTM Specifications
Applicable to Austenitic Stainless Steel
Piping and Tubing Components

Specification Designation	Product
A213	Seamless ferritic and austenitic alloy steel boiler, superheater, and heat-exchanger tubes
A249	Welded austenitic steel boiler, superheater, heat-exchanger, and condenser tubes
A269	Seamless and welded austenitic stainless steel tubing for general service
A270	Seamless and welded austenitic stainless steel sanitary tubing
A271	Seamless austenitic chromium-nickel steel still tubes for refinery service
A312	Seamless and welded austenitic stainless steel pipe
A351	Austenitic steel castings for valves, flanges, fittings, and other pressure-containing parts
A358	Electric fusion welded austenitic chromium-nickel alloy steel pipe for high-temperature service
A376	Seamless austenitic steel pipe for high temperature central-station service
A403	Wrought pipe fittings
A409	Welded large outside diameter light-wall austenitic chromium-nickel alloy steel pipe for corrosive or high-temperature service
A430	Austenitic steel forged and bored pipe for high-temperature service
A451	Centrifugal cast austenitic steel pipe for high-temperature service
A452	Centrifugal cast austenitic cold wrought stainless steel pipe for high-temperature service
A688	Welded tubes

attack when exposed to certain corrosive environments. (See 9.2 for a detailed discussion of this form of corrosive attack.) However, these steels often are used in the as-welded condition when it is known that the service condition does not produce intergranular attack.

The likelihood of corrosive attack on material sensitized by welding is not so great for the higher chromium grades such as Types 309 and 310. However, these types

cannot be considered totally immune to intergranular attack when they are in a sensitized condition.

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

2.3 Stabilized Types (321 and 347). Titanium, columbium and tantalum are carbide stabilizing elements. During the steel making process, they combine with carbon before chromium does. Thus, in subsequent welding, the formation of chromium carbides is minimized. When chromium carbide forms, the adjacent metal is depleted of chromium, thus reducing the materials corrosion resistance.

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

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

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

2.4 Low Carbon Types (304L, 309S, 310S, and 316L). These types are low carbon modifications of the corresponding or primary grades. In Types 304L and 316L, an extra low carbon content (0.030 percent maximum) minimizes the precipitation of chromium carbide both during welding and any sensitizing postweld heat treatment. This in turn preserves the corrosion resistance of the weldment. Similarly, Types 309S and 310S with 0.08 percent maximum carbon, reduces the likelihood of corrosion in comparison with their higher carbon counterparts.

Table 4
Electrodes and Welding Rods used in Welding Specific Cast
and Wrought Austenitic Stainless Steels

Type of Stainless Steel		Composition Nominal	Covered Electrodes, Specification AWS A5.4, Shielded Metal Arc Welding	Bare Welding Rods or Electrodes, Specification AWS A5.9, Gas Tungsten Arc, Gas Metal Arc, and Submerged Arc Welding
Wrought	Cast ^a			
304	CF-8	18-8	—	—
304H	—	18-8	E308	ER308
305	—	20-10	—	—
304L	CF-3	18-8LC	E308L	ER308L
			E347	ER347
309	CH20	25-12	E309	ER309
309S	CH8	25-12LC	E309	ER309
			E309Cb	
310	CPK-20	25-20	E310	ER310
310S	—	25-20LC	E310	ER310
			E310Cb	
316	CF-8M	18-12Mo	E316 ^b	ER316 ^b
316H	CF-12M	18-12Mo	E16-8-2	ER16-8-2
			E316 ^b	ER316 ^b
316L	CF-3M	18-12MoLC	E316L ^b	ER316L
			E318 ^b	
317	—	19-14Mo	E317	ER316
317L	—	19-14MoLC	E317L	ER317L
321	—	18-10Ti	E347 ^c	ER321
321H	—	18-10Ti	—	ER347
347	—	18-10Cb	—	—
347H	—	18-10Cb	—	—
348	—	18-10Cb	E347	ER348
348H	—	18-10Cb	—	—
—	CF-8C	18-10Cb	—	—

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

b. Joints containing 316, 316L, 317, and 318 weld metal may occasionally display poor corrosion resistance in the "as-welded" condition, particularly where hot oxidizing acids are involved. Corrosion resistance of the weldment, for all grades of Cr-Ni-Mo base metal may be restored by rapid cooling from 1950–2050° F (1065–1120° C).

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

2.5 "H" Types (304H, 316H, 321H, 347H, and 348H).

Carbon contributes to the high-temperature strength of austenitic stainless steel. This precludes the application of austenitic Cr-Ni steel having an extra low carbon content in high-temperature service where strength is an important consideration. Five steels are identified with the "H" suffix for use at high temperature. In these steels, the carbon content must be held within a specified range (i.e., 0.04–0.10 percent), rather than being held at or below a maximum carbon level.

2.6 Stainless Steel for Nuclear Service (Types 348 and 348H).

For nuclear applications, where pipe may become radioactive, the long-term serviceability of the steel can be improved by limiting its tantalum content. Type 348 and 348H steels have properties similar to Types 347 and 347H, respectively, except that they contain no more than 0.10 percent tantalum. For this same purpose, limitations may also be placed on the cobalt content.

In most nuclear applications, the most common types of stainless steels have been 304, 304L, 316, and 316L.

Table 5*
Chemical Composition Requirements for Weld Metal
from Corrosion-Resisting Steel Covered Welding Electrodes^{a,b}

AWS Classification ^c	C ^d	Cr	Ni	Mo	Cb plus Ta	Mn	Si	P	S	N	Cu
E307	0.04-0.14	18.0-21.5	9.0-10.7	0.5-1.5	—	3.3-4.75	0.90	0.04	0.03	—	0.75
E308	0.08	18.0-21.0	9.0-11.0	0.75	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E308H	0.04-0.08	18.0-21.0	9.0-11.0	0.75	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E308L	0.04	18.0-21.0	9.0-11.0	0.75	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E308Mo	0.08	18.0-21.0	9.0-12.0	2.0-3.0	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E308MoL	0.04	18.0-21.0	9.0-12.0	2.0-3.0	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E309	0.15	22.0-25.0	12.0-14.0	0.75	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E309L	0.04	22.0-25.0	12.0-14.0	0.75	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E309Cb	0.12	22.0-25.0	12.0-14.0	0.75	0.70-1.00	0.5-2.5	0.90	0.04	0.03	—	0.75
E309Mo	0.12	22.0-25.0	12.0-14.0	2.0-3.0	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E310	0.08-0.20	25.0-28.0	20.0-22.5	0.75	—	1.0-2.5	0.75	0.03	0.03	—	0.75
E310H	0.35-0.45	25.0-28.0	20.0-22.5	0.75	—	1.0-2.5	0.75	0.03	0.03	—	0.75
E310Cb	0.12	25.0-28.0	20.0-22.0	0.75	0.70-1.00	1.0-2.5	0.75	0.03	0.03	—	0.75
E310Mo	0.12	25.0-28.0	20.0-22.0	2.0-3.0	—	1.0-2.5	0.75	0.03	0.03	—	0.75
E312	0.15	28.0-32.0	8.0-10.5	0.75	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E316	0.08	17.0-20.0	11.0-14.0	2.0-3.0	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E316H	0.04-0.08	17.0-20.0	11.0-14.0	2.0-3.0	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E316L	0.04	17.0-20.0	11.0-14.0	2.0-3.0	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E317	0.08	18.0-21.0	12.0-14.0	3.0-4.0	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E317L	0.04	18.0-21.0	12.0-14.0	3.0-4.0	—	0.5-2.5	0.90	0.04	0.03	—	0.75
E318	0.08	17.0-20.0	11.0-14.0	2.0-2.5	6 × C min to 1.00 max	0.5-2.5	0.90	0.04	0.03	—	0.75
E320	0.07	19.0-21.0	32.0-36.0	2.0-3.0	8 × C min to 1.00 max	0.5-2.5	0.60	0.04	0.03	—	3.0-4.0
E320LR	0.035	19.0-21.0	32.0-36.0	2.0-3.0	8 × C min to 0.40 max	1.50-2.50	0.30	0.020	0.015	—	3.0-4.0
E330	0.18-0.25	14.0-17.0	33.0-37.0	0.75	—	1.0-2.5	0.90	0.04	0.03	—	0.75
E330H	0.35-0.45	14.0-17.0	33.0-37.0	0.75	—	1.0-2.5	0.90	0.04	0.03	—	0.75
E347	0.08	18.0-21.0	9.0-11.0	0.75	8 × C min to 1.00 max	0.5-2.5	0.90	0.04	0.03	—	0.75
E349 ^{e,f}	0.13	18.0-21.0	8.0-10.0	0.35-0.65	0.75-1.2	0.5-2.5	0.90	0.04	0.03	—	0.75
E16-8-2	0.10	14.5-16.5	7.5-9.5	1.0-2.0	—	0.5-2.5	0.60	0.03	0.03	—	0.75

*Note: See Table 1, AWS A5.4-81.

a. Analysis shall be made for the elements which for specific values are shown in the table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements, except iron, is not present in excess of 0.50 percent.

b. Single values shown are maximum percentages except where otherwise specified.

c. Suffix -15 electrodes are classified with direct current, electrode positive. Suffix -16 electrodes are classified with alternating current and direct current, electrode positive. Electrodes up to and including 5/32 in. (4.0 mm) in size are usable in all positions. Electrodes 3/16 in. (4.8 mm) and larger are usable only in the flat groove and fillet position and horizontal fillet position.

d. Carbon shall be reported to the nearest 0.01 percent except for the classification E320LR for which carbon shall be reported to the nearest 0.005 percent.

e. Titanium shall be 0.15 percent max.

f. Tungsten shall be from 1.25 to 1.75 percent.

However, problems resulting from the use of these types in certain systems of boiling water reactors have resulted in the development of special nuclear grades. These provide an additional margin of resistance to intergranular stress corrosion cracking in the BWR environment. Other specialized techniques have been developed to minimize this cracking problem with conventional materials.

2.7 High Carbon Cast Types (HF, HH, HK, HE, HT, HI, HU, and HN). In many applications requiring

resistance to oxidation, cast Cr-Ni austenitic heat-resisting steels are used. These castings are modifications of the wrought types. The first five listed are basically the Types 304, 309, 310, 312, and 330 with carbon content increased up to about 0.75 percent. The three other types involve higher carbon content and some changes in the chromium, or nickel, or chromium-nickel composition. These cast alloys are designed for higher temperature service than the primary types.

The welding of high carbon (over 0.20 percent) stainless steel castings requires special high carbon electrodes to match the high-temperature strength and creep prop-

erties. In addition, special welding techniques and procedures are required for these materials to compensate for the low elongation and the aging characteristics associated with these alloys.

Weldability differs greatly between high carbon austenitic stainless steel and both wrought and lower carbon components. Weld techniques, filler metal selection, and special treatments for a particular high carbon stainless steel, HK-40, are given in Appendix A.

2.8 Low Carbon Cast Types (CF3, CF8, CF8C, CF8M, CF3M, CH8, CPK20, and CH20). Table 2 lists the most widely used types of chromium-nickel stainless steel castings with carbon contents under 0.20 percent. These castings, although their compositions are not identical, may be welded in the same way as their wrought equivalents as listed below:

Cast alloy	Wrought equivalent
CF3	304L
CF8	304
CF8M	316
CF3M	316L
CH8	309S
CPK-20	310
CF8C	347
CH20	309

3. Filler Metal

3.1 Selection of Filler Metal. Filler metals that yield weld metal of the same general composition as the base metals are available. However, the selection of a suitable filler metal to join a particular type of base metal is not always accomplished by matching the type numbers or even actual chemical compositions. The performance of present-day welding electrodes and rods has been improved through modifications in composition to control weld structure, which in turn determines the properties of the weld metal. In some instances, new designations are applied to the filler metals because of extensive modifications in composition. The types of austenitic stainless steel used in piping and the filler metals commonly used for joining them are shown in Table 4.

3.2 Welding Electrodes. Chemical composition requirements of weld metal from welding electrodes and rods are given in Tables 5 and 6 and the latest editions of AWS publications; A5.4, *Specification for Covered Corrosion-Resisting Chromium-Nickel Steel Welding Electrodes* and A5.9, *Specification for Corrosion-Resisting Chromium-Nickel Steel Bare and Composite Metal Cored and Stranded Welding Electrodes and Welding Rods*.

3.2.1 Covered Electrodes. There are two kinds of coverings commonly used on stainless steel electrodes, "lime" and "titania." The lime covering is designated by the suffix -15 and the titania by -16. The -15 is for use with direct current, electrode positive, and the -16 for use with alternating current or direct current, electrode positive. Some -16 coverings operate satisfactorily with direct current, electrode negative and may be used in special cases where shallower penetration is desired.

The -16 electrode has a less penetrating arc and produces flatter, smoother welds in the horizontal and flat positions, with easier slag removal than the -15. The original -16 types were distinctly inferior to the -15 types when welding in positions other than flat (out-of-position welding); thus, the -15 type was preferred for this work. Improvement in out-of-position welding characteristics of the -16 types has caused increased use of this type in areas where the -15 type was traditionally used. Where maximum assurance of highest metallurgical quality weld metal is required, the -15 type may still be preferred.

Both types of coverings are hygroscopic, and excessive moisture absorption may cause welding problems such as porosity, flaking and flaring of the covering, and erratic arc action.

For electrodes in opened containers, the humidity, length of time of exposure, types of service, and weld metal quality required are factors which will determine the need for redrying before use. It is preferable to avoid the need for redrying by keeping the electrodes warm and dry at all times. When redrying is necessary, the electrode manufacturer's recommendation should be followed. In general, unless the manufacturer advises to the contrary, long times above 650°F (343°C) temperatures are to be avoided, as the covering may be damaged.

3.2.2 Bare Filler Metal. Since these materials do not have coverings, their storage and care present no problem with respect to moisture absorption. However, storage areas should be dry and clean to avoid contamination from dirt, oils, and other lubricants and extraneous chemicals, such as sulfur bearing materials.

These materials are supplied in straight lengths, in coils with or without support, and on spools.

AWS specification A5.9 has specific requirements for identification of bare filler metal. Cut lengths present an identification problem after they have been removed from the container. However, adhesive tags on one or both ends or identification marking are effective identification methods.

AWS specification A5.30, *Specification for Consumable Inserts*, has specific requirements for identification of consumable inserts. See 7.2 and 7.3 for details of their use.

Table 6*
Chemical Composition Requirements for
Corrosion-Resisting Steel Welding Rods and Electrodes^{a, b}

AWS Classification	C	Cr	Ni	Mo	Cb + Ta	Mn	Si	P	S	N	Cu
ER307	0.04-0.14	19.5-22.0	8.0-10.7	0.5-1.5	—	3.3-4.75	0.30-0.65	0.03	0.03	—	0.75
ER308 ^d	0.03	19.5-22.0	9.0-11.0	0.75	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER308H	0.04-0.08	19.5-22.0	9.0-11.0	0.75	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER308L ^e	0.03	19.5-22.0	9.0-11.0	0.75	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER308Mo	0.08	18.0-21.0	9.0-12.0	2.0-3.0	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER308MoL	0.04	18.0-21.0	9.0-12.0	2.0-3.0	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER309 ^e	0.12	23.0-25.0	12.0-14.0	0.75	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER309L	0.03	23.0-25.0	12.0-14.0	0.75	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER310	0.8-0.15	25.0-28.0	20.0-22.5	0.75	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER312	0.15	28.0-32.0	8.0-10.5	0.75	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER316 ^e	0.08	18.0-20.0	11.0-14.0	2.0-3.0	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER316H	0.04-0.08	18.0-20.0	11.0-14.0	2.0-3.0	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER316L ^e	0.03	18.0-20.0	11.0-14.0	2.0-3.0	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER317	0.08	18.5-20.5	13.0-15.0	3.0-4.0	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER317L	0.03	18.5-20.5	13.0-15.0	3.0-4.0	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER318	0.08	18.0-20.0	11.0-14.0	2.0-3.0	8×C min to 1.0 max	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER320	0.07	19.0-21.0	32.0-36.0	2.0-3.0	8×C min to 1.0 max	2.5	0.60	0.03	0.03	—	3.0-4.0
ER320LR ^d	0.025	19.0-21.0	32.0-36.0	2.0-3.0	8×C min to 0.40 max	1.5-2.0	0.15	0.015	0.020	—	3.0-4.0
ER321 ^e	0.08	18.5-20.5	9.0-10.5	0.75	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER330	0.18-0.25	15.0-17.0	34.0-37.0	0.75	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER347 ^e	0.08	19.0-21.5	9.0-11.0	0.75	10×C min to 1.0 max	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER349 ^f	0.07-0.13	19.0-21.5	8.0-9.5	0.35-0.65	1.0-1.4	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75
ER16-8-2	0.10	14.5-16.5	7.5-9.5	1.0-2.0	—	1.0-2.5	0.30-0.65	0.03	0.03	—	0.75

*Note: See Table 1, AWS A5.9-81.

a. Analysis shall be made for the elements for which specific values are shown in this table. If, however, the presence of other elements is indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements, except iron, is not present in excess of 0.50 percent.

b. Single values shown are maximum percentages.

c. These grades are available in high silicon classifications which shall have the same chemical composition requirements as given below with the exception that the silicon content shall be 0.65 to 1.00 percent. These high silicon classifications shall be designated by the addition "Si" to the standard classification designations indicated below. The fabricator should consider carefully the use of high silicon filler metals in highly restrained fully austenitic welds.

d. Carbon shall be reported to the nearest 0.01 percent except for the classification E320LR for which carbon shall be reported to the nearest 0.005 percent.

e. Titanium—9×C min to 1.0 max.

f. Titanium—0.10 to 0.30. Tungsten is 1.25 to 1.75 percent.

4. Ferrite

4.1 Weld Metal Structure. The microstructure of austenitic stainless steel weld metal in the as-welded condition is quite different from that of wrought base metal and plays a major role in controlling cracking tendency, mechanical properties, and corrosion resistance. These alloys are sluggish in their cooling transformations because of the presence of chromium, and, in the as-welded condition, exhibit some metastable delta ferrite in the structure. In wrought products, this phase usually has become transformed to austenite, and these steels are thus nonmagnetic as supplied by the mill.

4.2 Ferrite Phase. It may come as a surprise, at first, to find that austenitic stainless steel welds may be magnetic, especially those in autogenous GTA welds on nonmagnetic base metal.

The delta ferrite phase is responsible for the magnetism. Delta ferrite forms in the weld metal at its solidus temperature (freezing point) and persists down to room temperature untransformed. The quantity present is principally determined by the composition of the weld metal. By varying the composition of the filler metal, weld metal can be made completely austenitic (such as with Type 310 weld metal) or partially ferritic (such as with Types 308, 309, and 312 weld metal). Since some

stainless steel filler metals meeting all specification requirements (such as 309 and 316) are supplied with some, or even no ferrite, or with a typical ferrite number (FN) of 4 to 10, the ferrite content of austenitic stainless steel filler metals should be considered when they are being ordered.

The attention given to ferrite here is an indication of its importance in the soundness of some stainless steel weld metals as well as the subsequent performance of the weldment in service. Ferrite has eight major effects in austenitic stainless steel weld metal:

(1) Fully austenitic weld deposits are sometimes prone to hot cracking. This susceptibility seems to arise from the low melting constituents (compounds of phosphorus, sulfur, silicon, columbium, and other elements) that make up the grain boundaries in the final stages of solidification of the weld. Delta ferrite islands, which form first during solidification, have greater solubility for the impurities than the constituents which form later. The presence of ferrite also means that there are more interphase boundaries available to reduce the low melting grain boundary films.

(2) The presence of ferrite increases tensile strength.

(3) High ferrite contents may improve resistance to stress-corrosion cracking.

(4) Conversely, the ferromagnetic ferrite phase may interfere in applications requiring weld metal with low magnetic permeability, such as the war-time non-magnetic mine sweepers and certain control pads in nuclear reactors.

(5) Ferrite present in a relatively continuous network decreases corrosion resistance of the molybdenum-containing weld metals in certain environments.

(6) Long-term creep strength may be lowered in partially ferritic welds.

(7) During welding itself (in extreme cases) and during exposure (in heat treatment or in service) to temperatures in the range of 1100° to 1700°F (590° to 925°C) or lower, welds with high ferrite content become embrittled through formation of the sigma phase, a brittle intermetallic micro-constituent. Sigma reduces the ductility, impact strength, and corrosion resistance of the weld metal (see 9.3).

(8) Ferrite lowers energy absorption at cryogenic temperatures.

4.3 Measurement of Ferrite. It is difficult to accurately determine how much ferrite is present in stainless steel weld metal. The Advisory Subcommittee on Welding Stainless Steels and the High Alloys Committee of the Welding Research Council have attempted to resolve this problem by establishing an arbitrary, standardized value known as "ferrite number" (FN) to designate the ferrite content of austenitic stainless steel weld metal.

The ferrite content should be specified and measured in terms of a ferrite number. A ferrite number is not necessarily a true absolute ferrite percentage, but below 10FN it is very close to the actual ferrite content. There is general agreement between laboratories when measuring ferrite using the new standard technique and the ferrite numbers.

A standard procedure for calibrating magnetic instruments to measure the delta ferrite content of austenitic stainless steel weld metal, AWS A4.2, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal*, has been published by the American Welding Society. (See latest edition.) Further information on ferrite measurement and calculation is available in the AWS Welding Handbook, Vol. 4, 7th Edition.

4.4 Importance of Ferrite. Fine surface cracks commonly occur in fully austenitic weld metal strained 20 percent, as in a bend test. Hot-short cracks are seen in heavily restrained welds. Now that ferrite can be measured consistently in ferrite numbers, researchers have found that a delta level of at least 3FN will eliminate fine surface cracking in welds made with the commonly used austenitic filler metals E16-8-2, E316L, E308, E316, and E308L. A ferrite level of 4FN is required with E309, 5FN with E318, and 6FN with E347 welds, to assure freedom from cracks.

Over the years, manufacturers of stainless steel covered electrodes and welding rods had found, through experience, that a ferrite-containing weld metal usually was more dependable for securing crack-free welds than weld metal without ferrite, and it was preferred by most fabricators. With an agreed-upon measurement at hand in the FN system, electrodes and welding rods may now be designed to produce weld metal with specified amounts of ferrite.

Type 308 filler metal may be designated to produce weld metal containing ferrite, which helps prevent hot cracking. Type 310 weld metal, on the other hand, is fully austenitic, cannot contain ferrite, and thus is more susceptible to hot cracking.

Types 316 and 317 filler metals may also be designed to produce weld metal containing ferrite; for this reason and possibly because of some beneficial influence of the molybdenum, their cracking resistance is satisfactory. The corrosion resistance of partially ferritic weld metal produced from Types 316 and 317 may require special attention under certain conditions. Any 18 percent Cr-12 percent Ni-Mo weld metal (including Types 316L and 318) may display poor corrosion resistance to certain media in the as-welded condition. Such poor corrosion resistance, which is manifested by a highly localized attack on the ferrite, does not occur in all media, nor

does it occur under all circumstances. It seems most likely to occur when certain hot, oxidizing acids are present. Preventive measures are to anneal the joint after welding or to adjust the composition to eliminate any ferrite in the weld metal.

Type 347 filler metal is usually formulated to produce a larger amount of ferrite in the weld metal as a means of suppressing cracking. Ferrite is particularly helpful in this alloy because columbium, in the quantities used in this steel, promotes cracking in fully austenitic weld metal.

Weld metal from E310Cb electrodes, if selected for a particular application, would require special consideration. There is no possibility of obtaining any ferrite at all from this composition, and the weld metal may be especially crack-sensitive.

Electrodes of the E16-8-2 type, containing approximately 16 percent chromium, 8 percent nickel, and 2 percent molybdenum, are used primarily for the welding of Type 316 stainless steel when employed in high-pressure, high temperature piping systems. The weld metal has good hot ductility, which offers greater freedom from base metal heat-affected zone cracking under conditions of restraint. The weld metal also has excellent mechanical properties in either the as-welded or solution-treated condition.

4.5 Ferrite in Root Passes and Subsequent Passes. The control of weld cracking by introducing delta ferrite in the weld metal requires control of the weld metal composition. The weld is formed from the base metal and the filler metals. Dilution of the filler metal by admixture with base metal, oxidation losses to the arc atmosphere or flux, or nitrogen absorption from the atmosphere, alters the composition of the weld metal from the original filler metal composition.

Dilution may be 50 percent in the root pass of a shielded metal arc welding (SMAW) or gas tungsten arc welding (GTAW) pipe weld. As an example, if the pipe weld metal has no ferrite (or even an excess of austenitic-forming elements), the filler metal will need 6FN or higher to produce weld metal with 3FN. Also, a consumable insert, if employed, should have a sufficient ferrite (11FN, for example); to withstand the dilution obtained with the parent metal when making the root pass so the weld will contain at least 3FN.

Nevertheless, the detrimental effects of ferrite in high temperature and cryogenic applications, and in certain corrosive media, dictate an upper limit on the amount of ferrite to be permitted. Therefore, extra delta ferrite should not always be added just to make sure there is plenty of ferrite. In practice, the control of delta ferrite begins by specifying the acceptable ferrite number range for the filler metal.

4.6 Effect of Welding Conditions on Ferrite. The AWS Advisory Committee on Welding Stainless Steel conducted a test program to determine the consistency of delta ferrite obtainable in welds made from the same box of welding electrodes. With each laboratory checking on the other laboratories and using prescribed welding conditions, each laboratory produced weld pads that had 95 percent of the FN readings between 4.8 and 7.2FN for welding electrodes with a mean of 6FN. The weld pads were tested according to AWS A4.2-74 procedures.

However, the method of making a weld alters the ferrite content of the weld metal. The tests conducted by the Advisory Committee studied four weld pad procedures. An electrode normally producing weld metal of 6FN, yielded 5.1 in one procedure and 7.6 in another. Chemical composition of the weld bead, and therefore, its ferrite content, will be noticeably modified by such variations as a long arc rather than a short arc, welding an exposed weld face pass rather than in a protected deep groove, and welding with turbulent, aspirant shielding gas flow rather than with smooth inert gas shielding. Melting the root faces of a groove weld, compared to the multiple beads of subsequent layers in the same groove, will noticeably vary the percentage dilution of the filler metal by base metal, and so will affect the ferrite content. Extreme variations may cause as much as a 5 or 6FN change, either plus or minus. However, the ferrite number resulting from such large variations can be measured and used as a first step toward correcting the technique.

Good welding procedure requires testing of planned welds to assure adequate, but not excessive, ferrite content. Adhering to such a procedure and using the same lot of filler metal will give the same planned weld metal within about ± 2 FN.

Excessive delta ferrite has been shown to be detrimental to both high-temperature creep strength and low-temperature toughness. A well-planned test program and consultation with a reliable filler metal producer are recommended for critical applications.

5. Welding Processes

Shielded metal arc and gas tungsten arc are the processes most commonly used to weld stainless steel piping. Gas metal arc is also used, but to a lesser extent. Submerged arc welding, although used, is quite limited in this application. Complete details of these processes will be found in the *AWS Welding Handbook*, 7th Ed., Vol. 2.

5.1 Shielded Metal Arc Welding (SMAW). Shielded metal arc welding of austenitic stainless steel piping and tubing may be performed with either dc or ac welding power sources and covered electrodes suitable for use

with the corresponding power source. Welds of a quality acceptable for pressure piping service may be made with either ac or dc power, but each exhibits certain inherent advantages and problems.

Working conditions will have some influence on the type of welding equipment selected and, therefore, the type of welding electrode used. In isolated field applications where an electric power line is not available, it is necessary to utilize portable welding units operated by an internal combustion engine driving a generator. Direct current welding power is almost exclusively used for field welding. In shop work, where an electric power line is available, a wider choice of welding equipment is possible.

There are three principal types of dc welding units: (1) the electric motor-generator, (2) the gasoline or diesel engine-driven generator, and (3) the rectifier.

The shielded metal arc welding process is often used for welding stainless steel piping; however, the welding of thin-walled, small diameter pipe is difficult with this process. The problems encountered are associated with the need to maintain proper current density and provide satisfactory metal transfer, yet avoid overheating and creating holes.

5.2 Gas Tungsten Arc Welding (GTAW). In this welding process, an arc is maintained between a tungsten electrode and the workpiece. A sheath of shielding gas, either helium or argon, or a mixture of the two, is projected around the arc. Fluxes are not necessary when welding with this process. Because fluxes are not available to remove impurities, special precautions must be taken to assure the surface cleanliness of base metals and filler metals. Wind and drafts must be avoided because they disturb the gas shield.

The use of direct current electrode negative (DCEN) is necessary when GTA welding stainless steel pipe. Argon shielding gas is used for most applications. For equal arc lengths and welding currents, the tungsten arc voltage in helium will be about 50 percent higher than the tungsten arc voltage in argon. While this permits more uniform joint penetration and higher welding speed, it also limits the use of this combination to thick sections. On thin sections, it has been found that the colder arc in argon assists in avoiding excessive root reinforcement. The division between "thin" and "thick" sections is about 14 gage Birmingham Wire Gage (0.074 in. 1.88 mm).

Thin-walled, stainless steel pipe (schedule 5 and, in some cases, schedule 10) may be welded without the addition of filler metal simply by fusing the edges together. On thick-walled pipe, filler metal for the root pass may be provided by the use of consumable inserts. For subsequent passes, filler metal may be introduced by manual or machine feeding. The gas tungsten arc weld-

ing process is used extensively for welding the root pass in pipe of heavier-walled thicknesses, with subsequent passes made by shielded metal arc, submerged arc, or gas metal arc welding.

Heated filler metal should be protected by shielding gas to prevent oxidation. The root side of the weld should also be protected by a suitable shielding gas.

A distinctive feature of the gas tungsten arc welding process is its ability to transfer filler metal to the weld with a minimum loss of alloying elements. One problem associated with this process is tungsten contamination of the weld metal. This condition occurs when the end of the tungsten electrode is inadvertently dipped into the weld pool and could occur when the arc is started without benefit of high frequency equipment.

Gas tungsten arc welding is usable on any thickness of pipe. It is most advantageous on thin-walled sections, such as schedule 5 and 10, and for root passes on thick-walled pipe.

5.3 Gas Metal Arc Welding (GMAW). In this process, the arc is maintained between the workpiece and a filler metal in wire form, fed from a spool or reel. Shielding gas is projected around the arc. The primary gas shield is a monatomic inert gas, such as helium or argon. The primary shielding gas may be supplemented with active gas additions, such as oxygen or carbon dioxide. Complete equipment includes a gun that provides a means for supplying welding power to the filler metal and conducting shielding gas to the arc. The process may be either semiautomatic or automatic. In the high energy mode, it is characterized by high welding speeds and high deposition rates and is essentially limited to the flat and horizontal welding positions. In the low energy mode (short circuiting type of metal transfer), it is readily utilized for the vertical, overhead, and horizontal welding positions and especially for welding thin-walled pipe.

Power for welding stainless steel is generally direct current electrode positive (DCEP), although direct current electrode negative (DCEN) and even alternating current can be used with specially made electrodes. Either argon or helium may be used as shielding gas, depending on the specific arc characteristics required for certain job conditions. Spatter is higher with helium. Helium may be added to argon (up to 75 percent He, 25% Ar) to control joint penetration and bead contour. Oxygen (up to 5 percent) may also be added to the helium, argon, or helium-argon mixtures to stabilize the arc and reduce undercut. For welding with the short circuiting type of metal transfer, argon plus carbon dioxide (up to 25 percent CO₂) may be used. Oxygen may be substituted for part of the carbon dioxide. A mixture that has given very satisfactory results is 90 percent helium, 7½ percent argon and 2½ percent carbon diox-

ide. Pure carbon dioxide is not suitable as a shielding gas for welding stainless steel.

Welding of larger diameter pipe may be accomplished in all of the pipe welding positions. The smaller diameters [below 6 in. (152.4 mm) pipe size] are difficult to weld in the fixed pipe welding positions. The gas metal arc welding process retains the composition of the filler metal in the weld metal. Mechanical properties of welds made with this process are comparable to those obtained with other processes.

5.4 Submerged Arc Welding (SAW). In this process, an arc is maintained between a bare electrode and the workpiece. Multiple arcs are sometimes used. The welding arc is shielded by a blanket of granular flux. The normal functions of a submerged arc flux are to shield and stabilize the arc, protect the weld metal, and control the bead contour. However, stainless steel weld metals are now frequently required to meet rather narrow ranges of chemical composition and delta ferrite. To adequately satisfy requirements in this area, as well as perform its other functions, the flux must be carefully formulated and reinforced with metallic compounds to offset losses of elements such as chromium, columbium, manganese, etc., that occur during transfer across the arc. When especially critical control of weld metal composition and delta ferrite is required, a specific lot of flux is often formulated to be used with a specific heat of electrode wire. When use of a neutral (no metallic compound) flux is specified, and close control of weld metal composition and delta ferrite is required, the composition of the electrode wire must be high enough in alloy content to compensate for loss of elements across the arc.

The submerged arc welding process is usually characterized by high welding currents and relatively deep joint penetration. When this process is used on stainless steel pipe, the current is usually lower than the current used on ferritic steels. Welding power may be ac or dc. This process is limited to the flat or horizontal rolled positions.

5.5 Other Welding Processes. Because of the high chromium content of austenitic stainless steels and the affinity of this element for carbon and oxygen, the austenitic stainless steels require good protection from carburization and oxidation during welding. The latter requirement precludes the use of unshielded welding processes for critical work. If the oxyacetylene process is used, a neutral flame is mandatory.

6. Welding of Dissimilar Stainless Steel Joints

The selection of an appropriate filler metal for dissimilar stainless steel joints is important for the same reasons noted in section 3, Filler Metal. Table 7 presents a guide

for the selection of filler metals for welding various dissimilar austenitic stainless steel joints. Where both the dissimilar stainless steels are either stabilized or have a low carbon content, the filler metal must also be stabilized or have a low carbon content. However, as Table 7 indicates, when a stabilized or low carbon stainless steel is to be joined to another austenitic stainless steel that is not stabilized or does not have a low carbon content, it is satisfactory to select a filler metal that is not stabilized or does not have a low carbon content. For example, if Type 347 were to be joined to Type 304 stainless steel, Type 308 filler metal may be used. Nothing would be gained by using Type 347 filler metal, because one-half of the joint is unstabilized.

Most austenitic stainless steels have nearly equivalent coefficients of thermal expansion, so that differential thermal expansion is not a problem.

In all cases where dissimilar stainless steel joints are to be subjected to severe operating conditions, the joint should be thoroughly analyzed to assure safe operation.

7. Welded Pipe Joints

7.1 Joint Design. There are several factors that must be considered when designing edge preparations for austenitic stainless steel welded pipe joints.

Since these steels have a thermal expansion about 50 percent greater than that of carbon steel, the corresponding weld shrinkage is greater. In addition, these steels have thermal conductivities less than one-half that of carbon steel. These factors make shrinkage and distortion matters of major consideration. To control the effects of shrinkage and distortion, joints to be welded should be designed to require a minimum amount of weld metal. In general, butt joints without backing are welded using a root opening of about 3/32 in. (2.4 mm) after tack welding. However, because of the effects of weld shrinkage, openings this size may be excessively reduced during the process of welding. This can be prevented by using a wider opening or by in-process grinding. For wall thicknesses greater than 3/4 in. (19 mm), U-grooves or modified U-grooves may be used to reduce the width across the weld face (see Figure 1). These designs will keep the amount of weld metal to a minimum.

Distortion may be controlled by balancing the sequence of root passes and placing equal amounts of the root bead on opposite sides of the pipe until the root is completed.

Joint alignment should be maintained by the use of jigs and fixtures or tack welding.

Another factor to be considered in welded joint design is the use of gas tungsten arc welding for root passes in thick-walled piping, for complete welding of wall thicknesses under 3/8 in. (9.5 mm), or for any joints where

Table 7
General Guide for Selecting Welding Electrodes and Rods
for Joints in Dissimilar Austenitic Stainless Steel Pipe and Tube*

AISI Type	304L	308	309	309S	310	310S	316 316H	316L	317	321 321H	347, 347H 348, 348H
304, 304H, 305	308	308	308 309	308 309	308 309 310	308 309 310	308 316	308 316	308 316 317	308	308
304L		308	308 309	308 309	308 309 310	308 309 310	308 316	308L 316L	308 316 317	308L 347	308L 347
308			308 309	308 309	308 309 310	308 309 310	308 316	308 316	308 316 317	308	308 347
309				309	309 319	309 319	309 316	309 316	309 316	309 347	309 347
310							316 310 310Mo	316 310Mo 310	317 310Mo 310	308 310	308 310
316, 316H								316	317 316	308 316 347	308 316
316L									317	316L	316L 347
317										308 317	308 317 347
317, 321H											308L 347

*Electrodes and welding rods listed are not in any preferred order.

complete joint penetration and a smooth root surface contour are required. Typical weld joint designs currently used for welding austenitic stainless steel piping are shown in Figure 1.

Figure 1(a) shows a basic joint design which has been in use since pipe assembly went from threaded and screwed joints to welded sections. In some instances, the "A" angle of 37-1/2 degrees has been changed to 30 degrees to reduce the volume of weld metal. For better control of weld quality in the root bead through use of GTAW, the root face dimension "C" is 1/16 in $\pm$ 1/32 in. (1.6 mm $\pm$ 0.8 mm).

The joint design on Figure 1(b) is recommended for wall thicknesses above 3/4 in. (19 mm). The "A" angle of 37-1/2 degrees is maintained for 3/4 in. (19 mm) from the pipe wall at the root side. The "B" angle of 10 degrees is used for the remaining pipe thickness.

The U-groove type joint design, shown in Figure 1(c), is used where tightly butted root faces are fused without

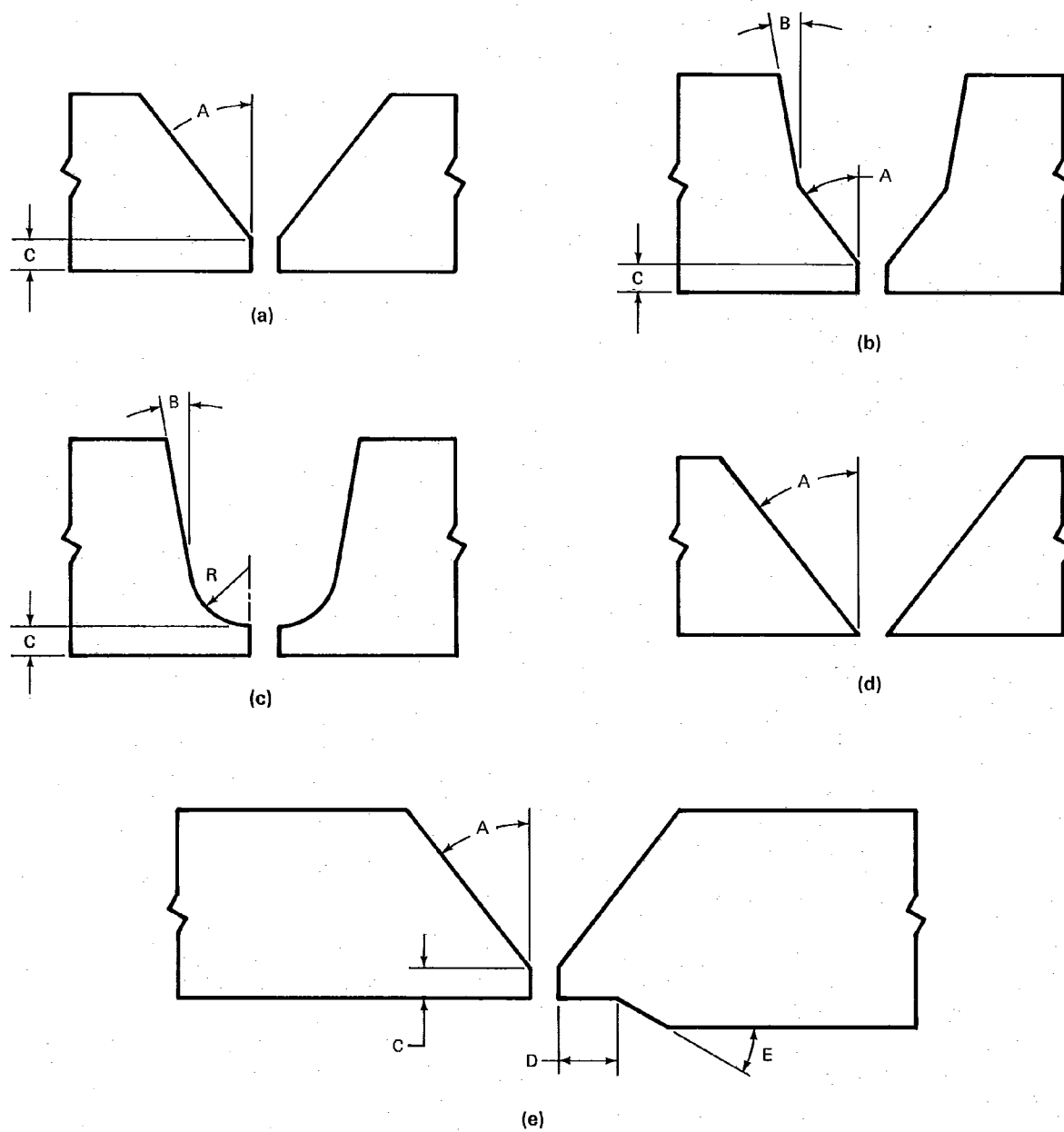
the addition of filler metal. This edge preparation is also used for some consumable inserts to allow the torch access to the root area.

The joint design shown in Figure 1(d) is the same basic design as shown by Figure 1(a); however, the root face is reduced to zero. This edge preparation is also required for some configurations of consumable inserts.

Figure 1(e) represents a transition joint between pipes of different wall thicknesses. The groove faces may be adjusted as required for the wall thicknesses involved.

Pipe with wall thickness under 3/16 in. (4.8 mm) may or may not require edge preparation, depending upon service conditions.

Another consideration for joint design is that austenitic filler metal is generally designed to produce a crack-resistant microstructure that is slightly different from the base metal. The joint design and the composition of the filler metal must be considered together to assure a weld metal composition within the range of



$A = 37\text{-}1/2^\circ \pm 2\text{-}1/2^\circ$
 $B = 10^\circ \pm 1^\circ$
 $C = 1/16 \text{ in.} \pm 1/32 \text{ in.} (1.8 \text{ mm} \pm 0.9 \text{ mm})$
 $D = 2 \text{ times amount of offset}$
 $E = 30^\circ \text{ max}$
 $R = 1/4 \text{ in.} (6.4 \text{ mm})$

Figure 1 — Typical Joint Designs for Welding Austenitic Stainless Steel Pipe

crack-resistant compositions. It has been determined that a delta ferrite level in the weld metal of 6 to 11FN further increases resistance to cracking. The formation of delta ferrite is a function of chemical constituents and can be controlled by the addition of filler metal with an adjusted chemical composition. Small diameter, thin wall pipe is frequently welded without the addition of filler metal. In these cases, base metal composition should be considered in determining weld metal crack sensitivity.

Because stainless steels are used to a large extent in corrosive services, pipe joints should be designed and welding procedures developed to avoid discontinuities that would promote the formation of stress concentrations, or create areas of stagnant fluid that would promote concentration-cell or galvanic corrosion. Consequently, welds should have complete joint penetration with as smooth an inner surface as is practical. For this reason, lap or socket type joints should be avoided where a corrosive medium is encountered.

7.2 Consumable Inserts. High quality root pass welds can be made using a butt joint without backing and a root shielding gas. This is common in industries where skilled welders are available.

The use of solid backing rings is not encouraged. A welded joint made with a backing ring results in the formation of two crevices. These crevices act as stress concentrators and are focal points for crevice corrosion.

Tack welds, oxidized because of poor shielding, must be removed in advance of welding or poor welds may result. Also, irregular deposition of manually applied filler metal can result in corresponding weld irregularities which may be cause for weld rejection.

Preplaced consumable inserts have been used in an effort to eliminate these difficulties. These inserts have proven to be of value in assuring complete joint penetration and uniformity and good contour of root reinforcement. Commonly used consumable insert configurations are shown in Figure 2. The following descriptions use generally accepted terminology. (For the standard AWS consumable insert classification system, see the latest edition of AWS A5.30.)

Figure 2(a) illustrates a shape "A" insert, formerly called EB.

Figure 2(b) shows a variation of shape "A", called "J", which is designed to allow for a certain amount of joint misalignment. These inserts are normally provided in coil form, or as formed rings with an overlap or split butted rings, to allow for variations in the pipe inside diameter (I.D.).

Figure 2(c) represents an insert shape derived from the initial practice of rolling round welding wire into a rectangular shape. They are provided as coiled wire, pre-

formed rings, or split butted rings with an overlap. This shape is commonly designated as a "K" shape.

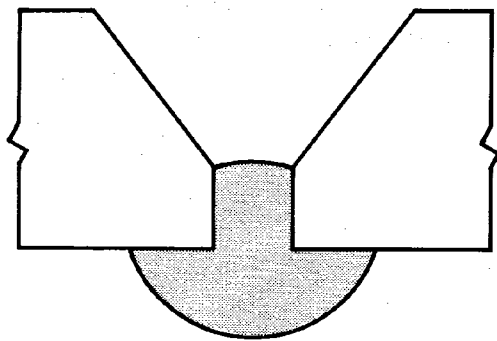
Figure 2(d) shows a flat, washer type insert called shape "G" joint backing. Its average dimensions are 1/16 in. (1.6 mm) wide by 3/16 in. (4.8 mm) deep. It is commonly described as a "flat" ring. It is a continuous ring, not split.

Figure 2(e) represents an insert configuration designated as a "Y" type. The insert is formed from welding wire and provided in coil form. Rings having diameters to 2 in. (51 mm) are provided as split rings without an overlap. Above 2 in. (51 mm), there is a ring overlap for fitting to I.D. variations.

Figure 3 shows typical pipe sections with two types of consumable inserts.

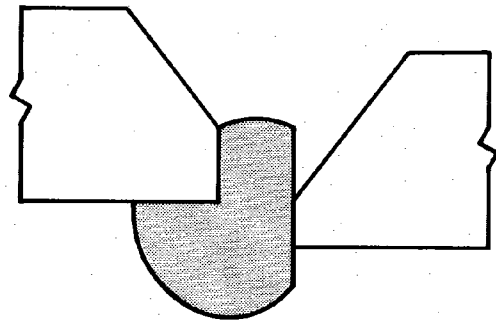
7.3 Insert Application. Consumable insert rings of the required chemical composition are inserted into the joint, as shown in Figure 3. The joint is then aligned and tack welded. Care and caution must be taken when tacking inserts in order to avoid prestressing the weld joint. Improperly placed tack welds may break, causing discontinuities or joint distortion, or both. When the preplaced insert is fused into the root opening with properly adjusted welding procedures, a high quality root bead can be obtained. The success of this procedure is dependent upon welder proficiency with the gas tungsten arc process and adequacy of interior gas purge. Complete fusion of the insert pipe is obtained, and a controlled contour root reinforcement surface results. With experience, the welder is able to recognize when there is complete fusion of the insert. When the molten pool reaches proper height and width, as determined by the type of insert used, the proper root reinforcement has been formed. Speed of travel is adjusted accordingly. Less skill may be required to weld joints with consumable inserts than to weld joints without either backing or consumable inserts.

Consumable inserts also are preplaced filler metal and provide a means of modifying the chemical composition of the root bead as necessary for weld soundness or serviceability. The addition of filler metal is especially useful with stainless steels, which require ferrite control to produce sound, crack-free welds. Consumable inserts provide more consistent control of composition and microstructure than other root pass methods where filler metal is added manually during welding. In general, visible weld face irregularities on a root bead made with a consumable insert indicate irregularities on the inner surface. This allows for visual inspection and repair of irregularities by remelting the area involved. However, this must be done with caution. Remelting any root bead, and especially an insert root bead, may increase its crack sensitivity. This is because wrought stainless steel



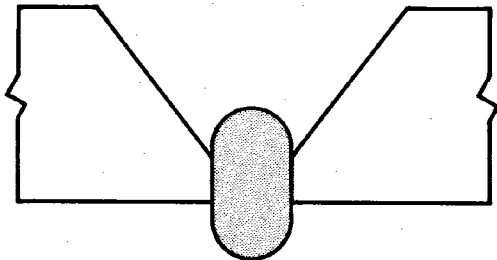
Shape "A" (EB)

(a)



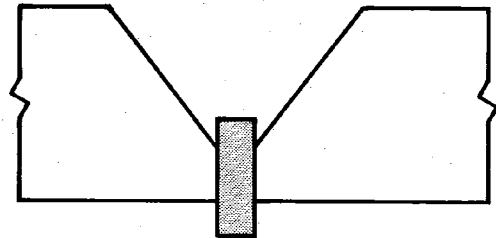
Shape "J"

(b)



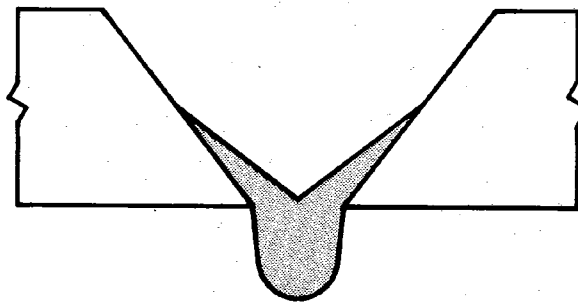
Shape "K"

(c)



Shape "G"

(d)



Shape "Y"

(e)

Not to scale

Figure 2 — Standard Consumable Inserts

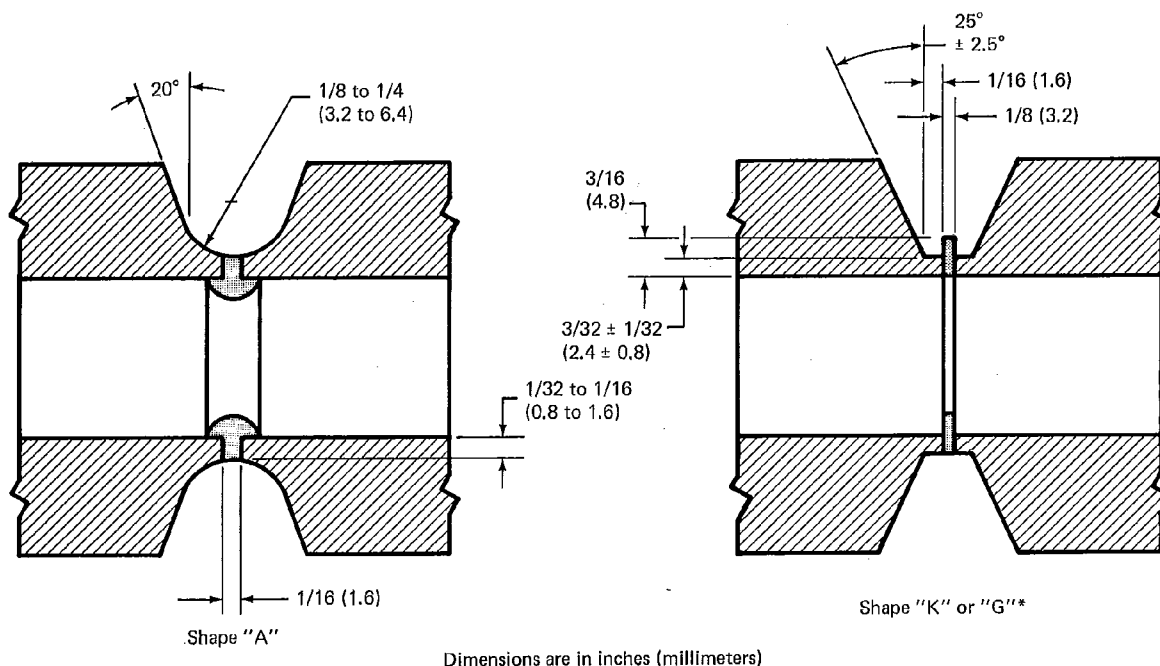
base metals are sometimes fully austenitic, depending on the chromium-nickel balance. Remelting the root bead must be performed in a manner which minimizes further dilution by base metal. Added amounts of base metal in the weld metal may result in a reduction of ferrite in the weld metal. Any reduction in ferrite below the critical levels discussed in section 4, Ferrite, will increase sensitivity to cracking. For some austenitic base metals, consumable inserts provide better initial ferrite control and permit more remelting of the root bead than most other root pass welding methods. Ferrite control can also be assured when sufficient root opening is used to permit the addition of sufficient filler metal to form adequate ferrite.

Well-positioned inserts have an outside diameter flush with or above the root faces of the joint, depending upon configuration. Under a gas tungsten arc, the heat of welding simultaneously melts both inner and outer insert surfaces and fuses them into the joint root faces and inside pipe surface. The root surface contour may be controlled from convex, to flush, to concave, by adjustments in welding current or speed of travel. Pipe end preparation and insert placement are as shown in Figures 2 and 3.

Metallurgically satisfactory welds are best obtained with insert rings of welding grade composition rather than base metal composition. The information previously given regarding welding filler metal, in general, applies also to consumable inserts. Rings are available for most types of austenitic stainless steels, including 308, 308L, 309, 310, 316L, 317, and 347.

7.4 Inert Gas Purging. Elimination of an oxidizing interior atmosphere is a requirement when using the gas tungsten arc process for root bead welding of austenitic stainless steels. The purge gas protects the root surface of the weld and adjacent base metal surfaces from oxidation during welding. Because of oxidation protection and the related effect on surface tension and weld pool characteristics, purge gas aids in obtaining complete fusion in the root bead and also good contour and surface uniformity. It also lessens the tendency for root bead cracking.

One of the most common causes of poor root bead quality is inadequate purging prior to the start of welding. Anything less than substantial elimination of oxygen (1 percent or less) contributes to root bead defects



*Note: In type K or G, placing the consumable insert ring so that it protrudes into the bevel at the top of the pipe (top) and closer to the pipe centerline at the bottom compensates for the sagging effects which occur in the weld pool.

Figure 3 — Typical Sections Showing Two Types of Consumable Inserts

such as (a) surface oxidation, (b) incomplete joint penetration, (c) irregular bead pattern, and (d) incomplete fusion of the insert where a consumable insert is used.

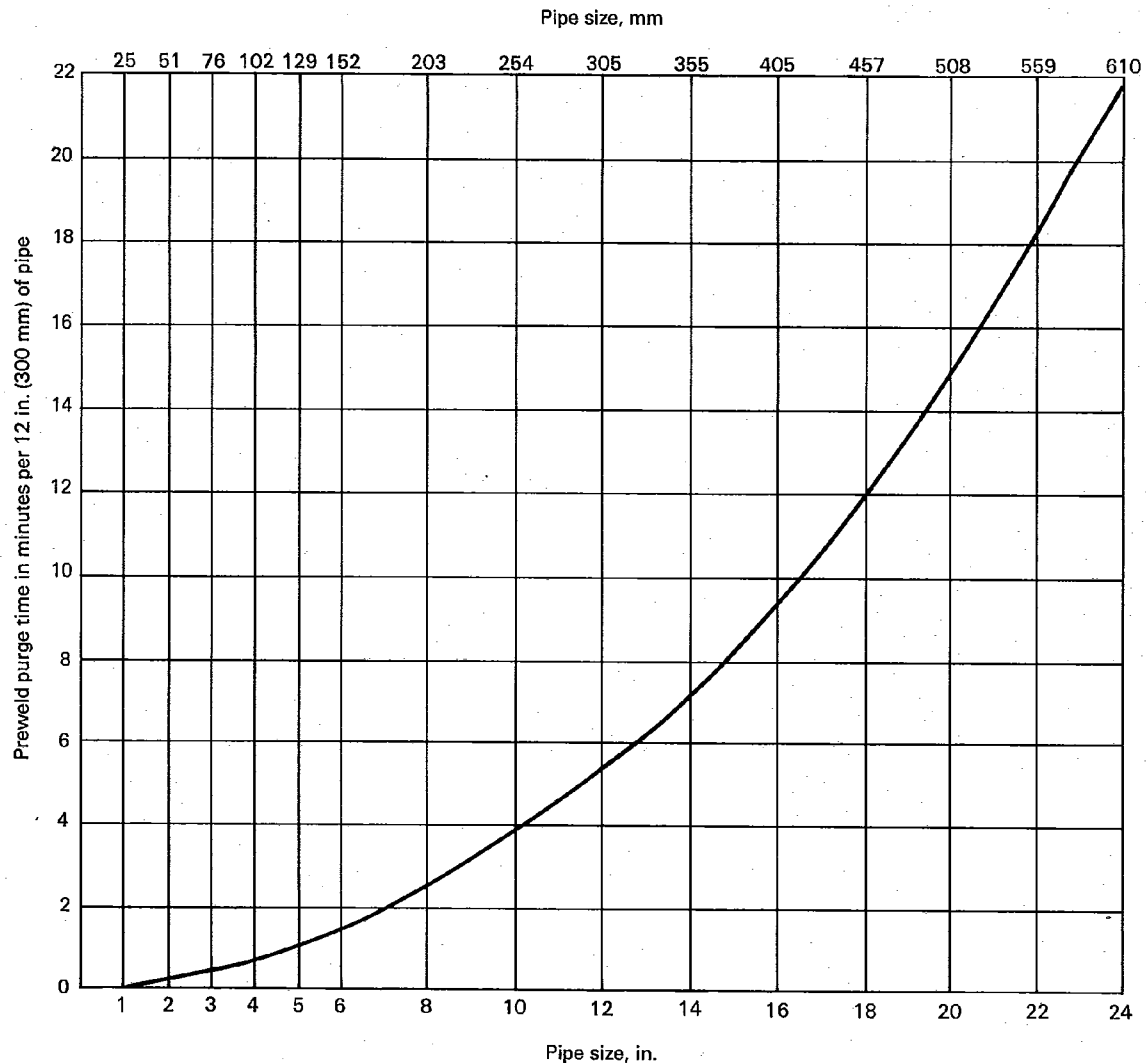
Preliminary steps to a prepurging evacuation cycle are as follows:

- (1) All weld joints of the assembly should be tape sealed.
- (2) The end of all branch connections should be vented to eliminate air entrapment.

(3) The venting arrangement should be determined to be adequate to accommodate the flow rate of the purging gas.

The approximate time for adequate purging of a pipe run can be determined from Figure 4. Upon completion of the preweld purging period determined from Figure 4, the following procedure should be established:

- (1) Vents in all branch connections should be closed, with venting through main header or pipe run only.



Preweld purge time for 12 in. (300 mm) of pipe at a flow rate of 50 cu ft per hr (23.5 liters per minute)

To calculate the purge time for any length of pipe, multiply the value obtained from the chart by the length of pipe.

Example: Find time required for purging of 200 ft (60 meters) of 5 in. (127 mm) pipe. From chart, read one min per 12 in. (300 mm) of pipe x 200 ft (60 meters) = 200 minutes or 3 hours 20 minutes.

Figure 4 — Preweld Purging of Oxidizing Atmosphere

(2) The gas venting orifice should have a flow capacity equal to or greater than that of the input side for assurance of a near zero interior purge gas pressure. (A purge gas pressure buildup during welding will often cause root surface concavity.)

During welding:

(1) Seal-tape should be left on all joints except the one to be welded.

(2) In joints without either backing or consumable insert, the tape should be removed just in advance of welding progression around the joint. This is to minimize purge gas loss and atmospheric contamination through the root opening. Another procedure is to use a tape which will burn off as welding proceeds.

(3) Purge gas flow should be adjusted to maintain zero interior gage pressure, normally between 6 to 10 ft³/h (3 to 5 liters per min).

The gas purge is to be maintained until at least two additional layers of weld metal have been made in each joint of the assembly. Purge blocks or soluble paper dams are frequently used on each side of the joint to localize the area under purge.

The gases used for weld root purging are generally argon and helium. It has been established that nitrogen may be used satisfactorily for purging purposes when welding stainless steel pipe. Where weld discoloration due to slight surface oxidation is not objectionable, use of commercial or standard dry nitrogen is acceptable. It should be recognized that nitrogen absorption can reduce the ferrite content of the root pass.

7.5 Open Butt Welding. Experienced welders may be able to achieve good results with an open root joint with a root opening of about 3.32 in. (2.4 mm)¹ and the manual addition of filler metal. In order to produce good results with this technique, the filler metal must be added continuously and uniformly, rather than intermittently. This technique requires very careful selection and control of welding variables such as joint geometry, welding current, filler rod size, and speed of travel. An open joint does not permit the maintenance of constant and uniform purge pressure. Pressure-sensitive tape may be used on rotated welds where outside access to the joint interior allows for tape placement. Tape should be used with caution due to possible carbon contamination. For more detailed information, refer to the latest edition of AWS D10.11, *Recommended Practices for Root Pass Welding and Gas Purging*.

¹ However, as previously stated, root openings this size may be excessively reduced through the effects of weld shrinkage during welding. A wider opening or inprocess grinding is then required.

8. Welding Techniques

The following recommendations apply to most arc welding processes, including shielded metal arc welding and gas tungsten arc welding. For the latter process, the smallest, lightest, and most flexible water-cooled torch obtainable should be used. The tungsten electrode (AWS A5.12, EWTH-2) should be 3/32 or 1/8 in. (2.4 or 3.2 mm) in diameter and should be tapered approximately 1/4 in. (6 mm) from the end to a point; then the point should be slightly flattened on a grinding wheel. The flat face on the tungsten electrode approximates 0.020 in. (0.5 mm) for a 3/32 or 1/8 in. size electrode.

8.1 Starting the Arc. Haphazard striking of the electrode on the base metal to establish the arc should be avoided because it mars the surface of the pipe. These arc strikes have acted as focal points for cracking and corrosion. The arc should be struck either in the joint where the metal surface will subsequently be fused into the weld or on a starting tab. High-frequency starting may be employed for gas tungsten arc welding, especially when high quality welds are required.

A stainless steel starting block may be used. A carbon steel block should not be used because of possible contamination of the base metal. Starting aids are generally not necessary with thoriated tungsten electrodes.

Before striking an arc on a weld bead using the shielded metal arc process, the weld bead should be cleaned of any slag present by use of a chipping hammer and stainless steel wire brush. If the bead has a convex face, it is particularly important to remove particles of slag from the hollows along the edges of the bead. For best results, the arc should not be extinguished in the weld crater. It is usually recommended that the arc crater be filled in before the arc is removed. Equipment to gradually reduce the current (a "decay" switch or crater eliminator) may also be used to extinguish the arc.

8.2 Welding Position and Electrode Handling. Welding in the flat position is recommended where practical. The flat position is preferred to the horizontal, vertical, or overhead positions because welding in this position is faster and easier.

The attitude of a covered electrode in relation to the work will vary, depending upon such factors as the type of covering, the kind of joint, and the welding position, etc. Usually, the covered electrode is directed toward the progress of welding (forehand), as is the practice in welding carbon steel. However, the angle of inclination may be more critical because stainless steel molten weld metal is less fluid, the volume of slag is greater, and it is important to maintain good arc shielding.

A short arc length is desirable. A long arc favors oxidation of elements such as chromium, silicon, man-

ganese, and columbium and can affect the corrosion resistance and mechanical properties of the weld metal.

Weaving of the electrode during welding should be carefully controlled. A slightly transverse oscillation, as opposed to a string bead technique, is often helpful in avoiding entrapped slag along the groove and minimizes the number of beads needed to fill a joint. However, if the weaving motion is excessive, the weld pool may not be adequately protected by the shielding medium at all times. The weave width usually should not exceed three times the electrode core wire diameter when welding with covered electrodes. The maximum weave permissible in gas tungsten arc welding is determined largely by the size and shape of the gas nozzle on the torch, the composition of the weld metal, and the geometry, position, and location of the joint being welded.

8.3 Weld Size and Contour. Tensile strength, fatigue strength, etc., are normal considerations when determining the size and shape of welds, but austenitic stainless steel welds deserve further attention, particularly if they are the fully austenitic, crack-sensitive type. Microcracking, hot cracking, or both are promoted by increasing the width of the bead and by decreasing the bead thickness. When making a weld of crack-susceptible composition, a wide bead with a concave face will have a greater tendency to produce longitudinal hot cracking in the center of the bead than a narrow or stringer bead with a flat or convex face.

Unnecessarily heavy weld face reinforcement or a sharp change in section thickness between weld and base metals should be avoided because of the problems that arise from stress concentration at the toe of the weld. Since the strength of the weld metal often exceeds that of the base metal, the face reinforcement usually can be held to a minimum. Overlap or undercut should not be present.

8.4 Travel Speed. Travel speed is an important factor in arc welding because of its influence on joint penetration. Covered stainless steel electrodes do not have the ability to penetrate into the base metal as do many types of carbon or low alloy steel electrodes, and difficulty is sometimes encountered in securing adequate penetration in a stainless steel welded joint. The advantages of edge preparation in obtaining proper penetration have been discussed in 7.1. Circumstances, however, may require deeper joint penetration. An increase in welding current alone is not an efficient method for producing deeper penetration. A more effective technique involves an increase in travel speed with a commensurate increase in current so that the arc impinges on the base metal ahead of the weld pool.

8.5 Welding Current. Recommended ranges of welding current are provided by electrode manufacturers. Generally, the current should be held as low as possible within the recommended range but should be high enough to produce complete fusion and the required joint penetration. High welding current should be used with caution, since hot cracking may occur as a result of alloy loss, excessive dilution, or poor weld bead shape.

Conventionally, welding current for the gas tungsten arc process has been direct current electrode negative (DCEN). Pulsed current welding is a modification of this type of current, involving a power supply or attachment for existing equipment which has an adjustable variation in arc current that is best described as a pulsing type arc action. This action results in a momentary reduction of welding current and a corresponding cooling cycle in the weld pool. This duplicates the manual welding practice of moving the arc forward, then back, into the weld pool. The first general use of this current pattern was for machine orbiting pipe welding units, where the pulsed current allows for 360 degrees of travel around the pipe in one direction, either clockwise or counterclockwise. Units with this output characteristic are available for manual welding applications. Where a consumable insert is used, direction of welding may be established at any point on fixed position pipe, with travel maintained in one direction to completion of the root pass.

8.6 Extinguishing the Arc with SMAW. For reasons previously mentioned in 8.1, the electrode should not be drawn away from a joint in a manner that will mar the base metal surface. Common practice is to extinguish the arc over the crater by increasing the arc length, but this seemingly simple procedure has its shortcomings. If the electrode is removed suddenly, the underfilled crater may display crater cracking or a center segregation that can affect corrosion resistance. If the electrode is withdrawn slowly to fill the crater as much as possible with metal, the last droplets may not receive adequate protection from oxidation and may not form a sound weld. Crater cracking or crater segregation cannot be consistently melted out by the start of the subsequent bead.

The following methods have been used to avoid difficulty at the weld crater or stopping point. The welding conditions involved in each application will determine which of these suggested methods would be best applied:

- (1) The entire crater area of bead should be removed by grinding or chipping.
- (2) The bead starts should be ground to provide a ramp, and the individual weld beads should be backstepped.
- (3) A device in the welding current circuit should be employed to allow the welder to gradually reduce the

current at the end of the bead to fill the crater as the arc fades out.

(4) The size of the crater should be diminished by advancing rapidly ahead on the groove face, always holding a short arc.

Two types of weld metal most likely to display crater cracking are (1) those which have a fully austenitic structure, such as from Type 310, and (2) columbium-bearing types, such as from Type 347. Crater segregation of sufficient degree to affect corrosion resistance is most likely to be found in the weld metals containing columbium, such as from Types 347 and 309Cb.

8.7 Cleaning and Finishing. When welding stainless steel piping and tubing, it is very important to maintain cleanliness on and around all the materials and equipment used and to apply proper procedures for cleaning and finishing the completed weld. Acid cleaning may be employed (see 9.2.2), as well as mechanical means. Stainless steel wool or brushes should always be employed for this purpose. The deleterious effect of a carbonaceous contaminant has been well publicized, but experience has shown that other contaminating elements, such as copper, iron, sulfur, zinc, and lead, can also cause much difficulty.

8.7.1 Welding Flux and Slag. The need for removing slag between passes is well known and has been previously emphasized. It is also good practice to remove all flux and slag from the completed weldment to help prevent concentration cell corrosion (see 9.2.4). The mineral fluxes employed in welding stainless steels often contain fluorides and other compounds that, if left on the weld, can attack the surface of the stainless steel when high temperatures are encountered. Such attack could conceivably occur during annealing or in high-temperature service. No backing material or flux containing boron should be used, because this element diffuses into the heated austenitic stainless steel and causes embrittlement and cracking.

It should be noted that some slag will be formed on the root surface of the bead of shielded metal arc welded root passes. Whenever slag can cause some of the problems mentioned above, only inert gas welding processes should be employed for root passes if the root surface of the weld can not be cleaned and inspected.

8.7.2 Discoloration and Scale. Heating discolorations can sometimes affect the corrosion resistance of stainless steels. Good finishing practice requires complete removal of surface oxidation from welds by a suitable method to allow the development of a uniform passive surface.

8.7.3 Carbonaceous Contaminants. Stainless steels, when heated, quickly absorb carbon because of the strong affinity of chromium for this element. The carbon

content of most austenitic stainless steel base and filler metals is held to a low level, but an undesirable increase in carbon can easily occur if a carbon-containing foreign material comes in contact with the heated metal around the weld or the weld pool. Possible sources of extraneous carbon are grease or oil on the base or filler metals, markings made with a graphite pencil, fuel gas used for root purging, and other oxyfuel gas flames.

8.7.4 Contamination by Sulfur. Care should be taken to remove materials containing any form of sulfur, especially when the weldment is to be heat treated or exposed to high-temperature service. Sulfur can contaminate the surface and seriously affect the corrosion and scaling resistance. For example, ordinary hand soap containing a sulfonated detergent is sometimes used to make a solution for pressure (bubble) testing of welded pipe joints. In a case on record, this soap solution was permitted to dry and remain on a piping system fabricated for high-temperature service. A disastrous failure occurred from localized scaling on the contaminated joints.

8.7.5 Contamination by Carbon Steel. The presence of small particles of carbon steel on the surface of stainless steel is objectionable because of the superficial rusting that quickly takes place on the contaminant. If not removed, the rust particles can nucleate corrosive attack. This form of contamination can be from forming tools and dies, carbon steel wire cleaning brushes, the metal powder used in oxygen cutting, and grinding wheels or sandblasting sand used previously on carbon steels.

8.7.6 Contamination by Chlorides and Fluorides. Probably the worst contaminants are chlorides and fluorides. They can cause aggressive pitting of stainless steels, and the chlorides can cause stress corrosion cracking. For these reasons, care should be exercised to remove chlorides and fluorides.

8.7.7 Other Contaminants. Other harmful elements that have been encountered are copper and zinc. When copper is melted by a welding arc, the molten copper can penetrate the heated base and weld metals and may cause intergranular cracking. When the surface of an austenitic stainless steel is contaminated with zinc and heated, cracking will almost invariably result. Other contaminants that should be removed are liquid penetrants used for inspection purposes.

8.8 Repair. In general, any repair welding on an unsatisfactory joint calls for removal of the defective area by a suitable method. Attempts to remove porosity, cracking, or other forms of unsoundness by remelting or to cover these defects by welding over them are seldom satisfactory. Machining, grinding, and chipping are the more dependable methods of metal removal. Chemical flux cutting, metal powder cutting, or air carbon arc cutting

may be used, provided consideration is given to the nature of the defect. When employing the air carbon arc gouging process, consideration must be given to the molten metal generated during the operation. This fused metal is ordinarily blown out of the joint. However, any that remains on the gouged surface must be removed. It is necessary to remove all oxides from the surface and obtain shiny metal by machining or grinding. Removing a few thousands of an inch of base metal will assure freedom from retained carburized steel. A few specifications for extra critical applications have mandated up to 1/8 in. (3.2 mm) of metal removal by mechanical means. Common practice is to remove 1/16 in. (1.6 mm).

Rewelding can be done using the parameters given in Tables 8, 9, and 10. These parameters will vary for different conditions and individuals but, in general, will produce a high quality welded joint.

9. Problems Related to Welded Joints

Millions of welded joints in austenitic chromium-nickel stainless steel piping assemblies have been fabricated successfully and have performed well in the intended service. However, several problems are sometimes encountered during fabrication and in service. These are cracking, corrosion, and embrittlement at elevated temperatures.

9.1 Cracking. Cracking is occasionally encountered in welding austenitic chromium-nickel stainless steel piping and tubing. Such cracking occurs more frequently as the diameter and wall thickness of the pipe increase. Cracks can appear in the weld metal or in the base metal adjacent to the weld. This cracking is related to the chemical and metallurgical characteristics of the weld metal and the base metal. For instance, when hot cracking occurs, it takes place as the weld metal solidifies and the weld is in a weak condition. Cracking of the base metal may occur due to propagation of the hot cracks formed during welding. The following are suggested to help avoid cracking:

(1) Welders should be well trained and qualified. Poor workmanship alone can cause cracking.

(2) The intended welding procedure should be carefully qualified. A composition of filler metal that will eliminate cracking and at the same time satisfy service conditions should be selected (see Table 6 for recommended electrodes and welding rods).

(3) The volume of a weld metal should be kept to a minimum. Choose a joint preparation with as small a root opening as possible, commensurate with complete joint penetration.

(4) Any external restraint on the pipe during welding should be avoided or minimized.

(5) Where possible, the use of filler metals (such as Type 347) that are prone to cracking should be avoided.

Table 8
Procedure for Welding Open Root with GTAW Argon Shielding and Purge DCEN

Welding Current amps	Volts	Speed ipm	Electrode Diameter	Filler Metal Diameter	Root Opening	Root ^a Face
<i>5 G Position</i>						
Root pass	55-70	7-10	1.8-2.5	3/32 in. (2.4 mm)	3/32 in. (2.4 mm)	3/32-1/8 in. (2.4-3.2 mm)
2nd layer	60-85	7-10	2-3	3/32 in. (2.4 mm)	3/32 in. (2.4 mm)	1/32-3/32 in. (0.8-2.4 mm)
3rd layer to finish	80-110	8-12	2-1/2-3-1/3	3/32-1/8 in. (2.4-3.2 mm)	3/32-1/8 in. (2.4-3.2 mm)	
<i>2 G Position</i>						
Root pass	50-65	7-10	2-3	3/32 in. (2.4 mm)	3/32 in. (2.4 mm)	3/32-1/8 in. (2.4-3.2 mm)
2nd layer	55-80	7-10	2-3-1/2	3/32 in. (2.4 mm)	3/32-1/8 in. (2.4-3.2 mm)	1/32-3/32 in. (0.8-2.4 mm)
3rd layer to finish	70-110	7-12	2-4	3/32-1/8 in. (2.4-3.2 mm)	3/32-1/8 in. (2.4-3.2 mm)	

a. Heat input (volts, amps and welding speed) should be lower for smaller root faces and higher for larger root faces.

Table 9
Procedure for Welding Consumable Insert
with GTAW Argon Shielding and Purge DCEN

Welding Current amps	Volts	Speed ipm	Electrode Diameter	Filler Metal Diameter	Joint Design
<i>5 G Position</i>					
Root pass	60-80	7-10	1.5-2.5	3/32 in. (2.4 mm)	none
2nd layer	60-85	7-10	1.8-2.5	3/32 in. (2.4 mm)	3/32 in. (2.4 mm)
3rd layer to finish	80-110	8-12	2.5-3.5	3/32-1/8 in. (2.4-3.2 mm)	3/32-1/8 in. (2.4-3.2 mm)
<i>2 G Position</i>					
Root pass	55-75	7-10	2-3	3/32 in. (2.4 mm)	none
2nd layer	60-80	7-10	2-3.5	3/32 in. (2.4 mm)	3/32 in. (2.4 mm)
3rd layer to finish	70-110	8-12	2-4	3/32 in. (2.4 mm)	3/32-1/8 in. (2.4-3.2 mm)

Follow insert
manufacturer's
recommendation

Notes:

- General welding parameters are listed. The mass of the insert must be considered when determining heat input. For G and K shaped inserts, the lower end of the range should be used; for half Y and Y inserts the middle of the range and for EB inserts, the upper part of the range.
- For all cases, maintain low heat input (consistent with good fusion) for both the root and second layer to prevent excessive melt-through.
- The SMAW process may be used after the second layer when the wall thickness is over 3/8 in. (9.5 mm).

Table 10
Procedure for Welding Open Root
with GMAW Gas Shielding and Purge

Weld Pass	Diameter Electrode	Arc Current	Arc Voltage	Shielding* Gas	Argon Purge
1	0.035-0.045 in. (0.8-1.2 mm)	110-140	10-20	20-35 CFH	5 CFH
2	0.035-0.045 in. (0.8-1.2 mm)	120-160	12-24	20-35 CFH	5 CFH
3	0.035-0.045 in. (0.8-1.2 mm)	140-180	12-24	20-35 CFH	
4 to last	0.035-0.045 in. (0.8-1.2 mm)	140-200	12-24	20-35 CFH	

*Shielding gas: 90% He, 7-1/2% Ar, 2-1/2% CO₂

Notes:

- Root pass downwards, fill passes upwards.
- Joint design—75 degree included angle; 0-1/16 in. (0-1.6 mm) root face and 3/32-5/32 in. (2.4-3.9 mm) root opening.

(6) The use of a fully austenitic weld metal should be avoided because this type of structure is also prone to hot cracking (see 4.1).

(7) A filler metal and welding procedure that will produce a weld metal having a ferrite number of 4 or higher should be used (see 4.2).

9.2 Corrosion

9.2.1 Intergranular Corrosion. One cause of failure by corrosion in austenitic stainless steels is carbide precipitation. When unstabilized or high carbon stainless steels are held in the sensitizing range between 800 and 1500°F (425 and 815°C), as occurs during welding, chromium carbides are precipitated in the grain boundaries, leaving adjacent areas deficient in chromium. These grain boundaries are subject to accelerated attack by specific solutions. However, it must be emphasized that there are many solutions that will not cause accelerated attack even though chromium carbides have been precipitated. If there is any possibility of such effects, corrosion tests should be made on welded specimens in the proposed environment before the welding process and heat treatment are selected.

Intergranular attack generally occurs parallel to the weld, a short distance away, in the base metal. It is located where the heat from welding is at the most damaging temperature for the longest time (i.e., when the time at temperature is long enough to precipitate chromium carbides). The weld metal in a single bead is not generally susceptible to intergranular attack because the cooling rate from the welding temperature through the carbide precipitation range is rapid enough to prevent chromium carbide formation. However, one weld bead can sensitize a bead under it in intersecting multiple-pass welds. Also, starting a new weld bead will sensitize an adjacent zone in the previous bead.

Intergranular carbides precipitate in a more or less complete network when the Cr-Ni or Cr-Ni-Mo steels with a carbon content of about 0.03 percent or more are heated to within the sensitizing temperature range. The network will be more complete with higher carbon contents and when the material remains in the sensitizing temperature range for a longer period of time. The rate of precipitation also varies over the range of sensitizing temperature. It is very low over the 800 to 900°F (425 to 480°C) end of the range and most rapid at approximately 1200°F (650°C). Consequently, when stainless steels containing more than 0.03 percent carbon are welded (or where extra low carbon stainless steel has absorbed extraneous carbon from the surroundings), any zones of metal which enter the temperature range of 800 to 1500°F (425 to 815°C) may become sensitized. In this condition, they will be susceptible to intergranular corrosion in some environments.

The proper postweld heat treatment is to heat to the 1900 to 2050°F (1040 to 1120°C) range and quench. This is called solution heat treatment, because the chromium carbides are redissolved or put into solution. This treatment is impractical for large pipe and tubing systems; therefore, selection of an extra low carbon stainless steel or a stabilized type of stainless steel pipe is advisable where service conditions may cause intergranular attack (see 2.3).

9.2.2 Acid Cleaning Precautions. Occasionally, acid cleaning of welded stainless steel piping systems after welding is required. (Refer to ASTM A380, Sections 5 and 6, for specific details.) Such acid cleaning is usually carried out with a solution containing 15 percent nitric acid. For highly oxidized surfaces, a solution of 15 percent nitric acid and 1/2 to 1-1/2 percent hydrofluoric acid may be employed. Because this cleaning involves the use of acids, the precautions in 9.2.1 should be followed.

9.2.3 Stress Corrosion Cracking. The presence of certain corrosives, such as chlorides or fluorides, in a process solution or vapor coupled with tensile stress may cause stress corrosion cracking in stainless steel pipe welds. The presence of corrosives may be controlled in some cases. However, tensile stress is difficult to control, since even minor residual stresses may be sufficient to cause cracking. It is recommended, in doubtful cases, that stressed specimens containing welds be tested in process streams to evaluate the performance of the selected material.

Stress corrosion cracking is generally transgranular and is always associated with tensile stress. This type of corrosion is manifested by fine many-forked cracks. Such cracks may be longitudinal or transverse to the pipe or components, depending on the stress level and direction.

9.2.4 Concentration Cell Corrosion. Welding technique and joint design may directly affect the life of the weld. Where complete joint penetration has not been obtained or where there is excessive root reinforcement, crevices and protrusions are formed where foreign material can collect. Undercut and other surface discontinuities, such as backing rings, may also cause foreign material to collect. Since the metal under the foreign material is partially shielded from the process stream, a difference in concentration of process solution or oxygen content may result. Such differences in concentration can cause anodic and cathodic areas to be formed, with subsequent corrosion attack.

Craters formed at the completion of welds may also cause such accelerated corrosion. In severe cases (sometimes associated with steam coils), penetration through the pipe wall may be rapid. Such craters are conducive to concentration cell attack when they become filled with

foreign matter. Such corruptions may be eliminated by using suitable crater-eliminating welding techniques.

9.3 Sigma Phase Formation — High-Temperature Service. In general, the austenitic stainless steels are comparatively free from embrittlement effects that may occur in ferritic materials. This is probably due to the inherent toughness of the face-centered cubic lattice structure of these steels. The very high ductility and shock resistance of the austenitic steels in their optimum condition is such that, even if these properties are appreciably reduced, they may still fall within ranges considered satisfactory for most services. Austenitic stainless steel pipe has had considerable use in services where process temperatures are above 1000°F (540°C). In most cases, service life has been long, and no failures have resulted. However, there have been instances where failures have occurred. When the austenitic stainless steels are held in the temperature range from about 1000 to 1700°F (540 to 925°C), an intermetallic compound called *sigma phase* may form. The distribution, particle size, and amount of sigma phase will vary with alloy content, time, temperature, and stress level. The presence of certain ferrite-forming elements promotes the formation of sigma phase (see 4.2). Although it usually requires appreciable time at high temperatures to form this phase, there has been some evidence of the presence of sigma phase after relatively short times at elevated temperatures. Another brittle phase known as *chi* is found in molybdenum-bearing austenitic stainless steels after short periods of time at elevated temperature. This phase has properties similar to sigma phase.

Sigma phase causes lowered ductility and notched bar impact properties in austenitic stainless steels. In extreme cases, room temperature Charpy impact values as low as 5 ft-lb (6.8 joules) may result after 1000 or more hours of exposure in the range of 1300 to 1400°F (705 to 760°C).

The quantity and distribution of sigma is a function of time at temperature, the actual temperature, and the amount of ferrite initially present. Sigma may also form from austenite at these temperatures, but it will form more slowly and to a much lesser degree. Although the detrimental effects of sigma on room temperature mechanical properties have been pointed out in the literature, it should be recognized that many welded joints are performing satisfactorily in service, even though they probably contain significant amounts of sigma. These weldments should be handled carefully when they are at room temperature because of the lowered ductility.

Although it is desirable to balance a weld metal composition to avoid excessive sigma formation in service, a small amount of ferrite is considered essential in 18-8 types of weld metals to avoid cracking during welding.

Commercial practice generally limits the amount of as-welded ferrite to 4-8 FN for high-temperature applications.

Some types of stainless steels (such as Type 310) are fully austenitic and are frequently employed in high-temperature piping. Sound welds can be made with filler metals of proper chemical composition that produce fully austenitic weld metal. However, greater care is advisable in the preparation and evaluation of the welding procedure for such fully austenitic weld metals than with the 18-8 types producing weld metal containing ferrite.

Sigma may be removed by high-temperature heat treatment. However, subsequent exposure to the sigma formation temperature range will cause it to re-form.

9.4 Cryogenic Service. Austenitic stainless steel piping is often specified for cryogenic service because it usually retains strength and ductility at low temperatures. However, there have been cases of reduced energy absorption. The following precautions will help to minimize this condition.

(1) A qualified procedure that has been tested both by destructive methods (root bend, face bend, side bend, Charpy impact, compact tensile and tension tests) and by nondestructive methods (radiography or ultrasonic) should be required. Also each heat or lot of welding consumables scheduled for service below -200°F (-129°C) should be tested for impact strength or fracture toughness, or both.

(2) A slag-free welding process for the root pass should be used.

(3) Nondestructive examination of at least some percentage of production welds should be required.

(4) Complete fusion welds should be required.

(5) The weld face should be smooth, without excessive reinforcement.

(6) The weld root surface should be without unfused consumable inserts or excessive root reinforcement. Any concavity should be shallow and have smooth edges.

(7) Minimal heat input should be required.

(8) Porosity and other discontinuities should be limited.

(9) No arc strikes outside the weld groove faces should be permitted.

(10) No sharp indentations from hammer blows or other hard instruments should be permitted.

(11) Separate welder identification straps on all joints should be required.

(12) Lower FN Numbers may be required.

10. Inspection Methods

Because of the need for good inspection, this section briefly describes several inspection methods that have proven satisfactory for stainless steel pipe welds.

10.1 Visual Inspection. Visual inspection is of greatest importance and is the most versatile method of inspection available. However, the inspection is only as good as the experience, knowledge, and judgment of the inspector. The AWS text, *Welding Inspection*, is suggested as an adequate guide for visual inspection.

10.2 Hydrostatic Testing. A test with water under static pressure will generally reveal only fully penetrating defects which were overlooked during visual inspection. A water pressure test is usually made at one and one-half times the operating pressure, or just below the yield strength of the weakest elements. With the weld under stress, near-penetrating and microthin defects may enlarge sufficiently to seep water. Temperature of the water should be above that of the ambient air to avoid condensation on the pipe which may interfere with the detection of seeping water. Particular care should be taken to avoid entrapment of air when testing. Test pressures for pipe are provided in applicable codes and specifications. Water high in chlorides, such as sea water, should never be employed as the test water. A good rule is to employ only potable water.

10.3 Liquid Penetrant Methods. Several methods of surface testing of welds are in use. Essentially, all utilize a suitable penetrating liquid and a developer to expose surface discontinuities by contrasting color. A few methods use a fluorescent penetrant in the solution which is readily visible under ultraviolet light. The liquid penetrant test methods are particularly adaptable to rapid inspection needs. A smooth, clean surface is preferable; however, defects can be distinguished from surface roughness by experienced personnel. Since chloride can pit or cause cracking of stainless steel, chloride-free cleaners and penetrants should be employed.

10.4 Radiography. Radiographic examination is a non-destructive inspection method which is frequently used to determine surface as well as internal weld defects, such as slag and tungsten inclusions, porosity, cracks, incomplete fusion, and incomplete joint penetration. The acceptance criteria for such defects are covered by established radiographic standards. Experience, knowledge, and good judgment are essential in the proper interpretation of radiographs. Rules, procedures, and standards are available from several sources, such as the AWS publications, *Welding Inspection* and *Welding Handbook*, ASTM Standards, and ASME *Boiler and Pressure Vessel Code*, Sections I, III, V, and VIII.

10.5 Ultrasonic Methods. These methods utilize equipment capable of propagating an electronically-timed ultrasonic beam through the material under inspection. The signals reflected from the surfaces and interior struc-

ture of the metal are indicated on a cathode ray tube for comparison and interpretation. Since sound reflection in stainless steel is complex, the use of the equipment requires a special skill and experience. It is usually not practical to ultrasonically inspect welds involving stainless steel castings because of their large grain structures.

10.6 Inspection with Magnetic Instruments. Checking austenitic Cr-Ni stainless steels with a magnet is a quick and easy way to determine obvious errors in the selection of pipe components or weld metal, since any inadvertently used carbon, ferritic, or martensitic steels will be strongly ferromagnetic. It must be appreciated that the austenitic grades are not always completely nonmagnetic. This is often the case with as-welded weld metal where the microstructure most desirably contains a small amount of ferrite. The presence of small amounts of the ferrite constituent in base or weld metals can be detected by use of a magnetized needle suspended from a thread. This simple instrument is more sensitive than the ordinary horseshoe magnet. Magnetic and electronic measuring instruments, as discussed under 4.3, are also available. Cold-worked austenitic stainless steels are magnetic to a degree proportional to the amount of cold-work.

10.7 Acoustic Emission Testing Methods (AET). These methods consist of the detection of acoustical signals produced by plastic deformation or crack initiation or propagation during loading. Transducers, strategically placed on a structure, are activated by the acoustic signals. Acoustic emission testing has been applied during proof testing, during recurrent inspections, during service, and during fabrication. This technique is considered to be in its early stages of use by industry. More extensive application is to be anticipated in the future.

10.8 Chemical Spot Testing. Spot tests with chemical reagents are used to ascertain the presence of essential elements, such as nickel or molybdenum, in pipe weld metal. Nearly all elements can be spot tested, some with more difficulty than others; however, the tests for nickel and molybdenum are relatively simple.

10.9 Halogen Leak Testing Methods. Basically, these methods involve the detection of a leak in pipe containing a gaseous halide under pressure. Two methods can be used. One employs a probe with an element sensitive to gaseous halides, to provide a meter reading which is a ratio of detectable gas to that in the atmosphere. The other method utilizes the change in color of an acetylene flame. Very small, fully penetrating defects can be detected by these means.

10.10 Mass Spectrometer Testing Method. This method employs an electronic instrument using helium as a tracer gas and is capable of detecting very minute leaks.

Several procedures are available when using the mass spectrometer, including the helium blanket, the helium probe, and the instrument probe techniques. Considerable technical knowledge is required for procedure preparation, but actual operation may be performed by shop personnel after a short training period. This method is generally used only on very critical pipe work.

11. Safety and Health

Use of the welding processes and consumables described in this document is safe, provided proper procedures are followed and precautions taken. If these procedures and precautions are followed, welding can be done safely with minimal health risk.

11.1 Fumes and Gases. Fumes and gases can be dangerous to health. The welder's head should be kept out of the fumes. Use of enough ventilation, exhaust at the work, or both, to keep fumes and gases from the breathing zone and the general area is very important.

11.2 Radiation. Arc rays can injure eyes. Infrared (heat) radiation can cause burns. Ultraviolet radiation can cause skin injury similar to sunburn.

11.3 Electric shock. Electric shock can kill. Contact with live electrical components should be strictly avoided. Reading and understanding the manufacturer's instruc-

tions and employer's safety practices should be mandatory.

11.4 Fire Prevention. A high-temperature heat source is always present in arc and oxyfuel welding processes. Sparks can travel horizontally up to 35 ft (10.7 mm) and fall much greater distances. They can pass through or lodge in cracks or holes in floors and walls. Combustibles should always be removed from the work area or shielded from the welding operation.

11.5 Explosion. Flammable gases, vapors, and dust can form explosive mixtures with air or oxygen. Welding should never be done in an atmosphere where such materials could possibly be present.

11.6 Burns. Burns of the eye and body are serious hazards in arc and oxyfuel welding. Recommended eye protection, welding helmets, and appropriate protective clothing should always be worn.

11.7 Further Information. It should be recognized that the above paragraphs give only a very brief coverage of the subject of safety in welding. Detailed coverage is available in the publications listed in Appendix C. The primary source is ANSI Z49.1, *Safety in Welding and Cutting*, available from the American Welding Society, 550 NW LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

Appendix A

Welding High Carbon Stainless Steels

(This Appendix is not part of D10.4-86, *Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing*, but is included for information purposes only.)

A1. Introduction

HK-40 and similar high carbon stainless steel castings are used by the petroleum and chemical industries for high temperature applications such as primary reformers and steam crackers. Typical service temperatures range from 1400–2000°F (760–1100°C). While these materials are specifically designed to withstand creep and other metallurgical requirements associated with such service, they are also among the most difficult to weld and to repair under both shop and field conditions.

This Appendix discusses the welding of cast HK-40 components which have never been in service. It also discusses the repair welding and the modification of such cast components under field conditions. No attempt has been made to describe the automatic and machine welding processes used successfully by foundries and by furnace tube and header fabricators.

A2. Some Factors Governing Casting Material Use

A2.1 Alloy Availability. To withstand high temperature service requirements up to 2000°F (1100°C), a number of high carbon austenitic stainless steel casting materials are available for furnace tubes and outlet headers. While there are more than a dozen high temperature casting materials listed under ASTM Specifications, such as A297 and A351, the following specific alloys are frequently used:

- (1) HK-40 and CK-40 (0.4% C, 25% Cr, 20% Ni)
- (2) HT-35 (0.35% C, 20% Cr, 35% Ni)
- (3) HU-40 (0.4% C, 18% Cr, 37% Ni)
- (4) HN-40 (0.4% C, 20% Cr, 25% Ni)
- (5) HP-40 (0.4% C, 25% Cr, 35% Ni)

A2.2 Welding Problems. Centrifugal castings are most commonly used for tubular components and are available for some pipe fittings; static castings are employed for most fittings and for internal furnace support structures such as tube sheets. While these cast alloys retain important metallurgical properties, including high creep

strength at elevated temperatures, they present several serious welding problems as outlined below:

(1) Original as-cast and the reconditioned material has low ductility. The typical elongation of 10 percent is much lower than the 25 percent values usually found in wrought steels.

(2) Short time exposure to 1200–1850°F (650–1000°C) during welding and service conditions further reduces the ductility; the average elongation decreases to about three percent and values as low as one and one-half percent have been observed.

(3) Exposure to certain process gases at elevated temperature may carburize the steel, making it unsuitable for welding.

(4) The radiographic acceptance standards for castings are much lower than those for wrought materials. Even the highest quality, commercially available castings contain flaws beyond the standard acceptance limit for weldments. These cause porosity, and a form of cracking known as internal shrinkage, and occur most frequently in static castings. In most cases, it is possible to compensate for the limitations of these alloys through thorough planning, welder training, supervision, and inspection to produce serviceable joints.

A2.3 Thermal Effects. When high carbon austenitic stainless steel alloys are exposed to temperatures in the range of 1200–1850°F (650–1000°C), secondary carbides will form in a very short time. While these secondary carbides improve high temperature creep strength, they also reduce elongation and ductility. The high temperature exposure can reduce the ten percent minimum elongation specified for new HK-40 castings to values as low as one and one-half percent. Such poor ductility decreases and, at times, destroys weldability. Even conventional preheating practices will not overcome this condition, since the low ductility is retained up to temperatures of about 1100°F (600°C).

Solidification and cooling of any weld creates high stresses in the weld metal and in the adjacent base metal. When welding wrought steels with typical elongations exceeding 20 percent, adequate ductility is available to yield or plastically deform under shrinkage stresses. Even new HK-40 and similar castings with 10 percent minimum elongation provide sufficient ductility for carefully

planned, low restraint joints such as pipe groove joints with 75 degree included bevel angles. However, any further reduction in ductility increases the probability of cracking during fabrication and necessitates special procedures. If the ductility is very low, crack-free welding is considered impossible.

A2.4 Postweld Heat Treatment (PWHT). PWHT is not required for any HK-40 welding. The material is not air-hardenable and thus does not have to be softened by any heat treating operation.

Since exposure of HK-40 above 1200°F (650°C) and below 1850°F (1000°C) for even a short time forms secondary carbides, any PWHT within that range will have the same effect. Unless a full solution annealing operation is employed, the subsequent embrittlement can cause failure during handling and during installation.

PWHT is an important problem when attaching air-hardenable steels to HK-40 type materials, such as a Cr-Mo steel flange to a catalyst tube. For such applications, the following procedure has been employed:

- (1) The groove and root faces should be buttered with a non-air hardening material such as Inconel.
- (2) The buttered part should be PWHT, selecting the best temperature for base metal.
- (3) The buttered flange weld preparation should be machined.
- (4) The buttered flange should be joined to the tube using Inconel electrodes.
- (5) There should be no PWHT.

A2.5 Fabrication of New HK-40 Casting Components. The fabrication of new components made with HK-40 alloy involves techniques which are different from those used for the repair of used HK-40 castings. The differences are due mainly to the embrittlement which occurs in service—and this is a primary reason for considering the welding of aged (i.e., used in previous service) castings separately.

It is best to retain maximum ductility during the fabrication of new components. To accomplish this, the castings should be kept as cool as possible during all fabrication phases. The use of thermal cutting tools, such as powder oxyfuel gas torches, should be avoided, and the metal surfaces should not be overheated during grinding or rotary filing.

Similar considerations apply to machining of these castings. Water, air, or coolants can be employed to limit heat input and temperature increase. Air carbon arc cutting can be employed, provided all heat-affected base metal is subsequently removed by grinding, rotary filing, or machining.

A2.6 Joint Preparation and Initial Inspection. Proper preparation and inspection of the joint area is important

for all welding. Since castings have rough outside surfaces (also referred to as areas of unsoundness), removal of the unsound areas is essential prior to welding. This can be achieved by machining the ID and OD for about 1/2 in. (12.7 mm) away from the groove face and providing a gradual taper, as shown in Figure A1. (For bored tubes, no additional ID machining is required).

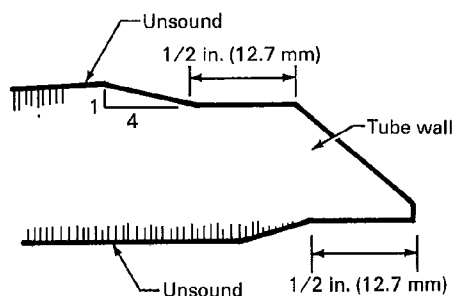


Figure A1 — Procedure for Removal of "Unsound" Areas During Joint Penetration for New KH-40 Type Case Component

This preparation will permit visual surface inspection with and without optical magnification and with dye penetrants (PT). Whenever subsurface defects are suspected, radiography (RT) should be used for further evaluation. Ultrasonics is usually not effective due to the large grains found in austenitic castings.

When probing for defects in centrifugally cast materials, the concentration of defects usually decreases near the center of the material wall thickness. However, for statically cast components, most inclusions and shrinkage defects are in the center of the heaviest sections. The location and type of defect depends upon the casting method used for each component.

Any concentration of shrinkage defects may reduce or destroy weldability in those regions. Thus, when ordering static castings, it is essential to indicate the areas in which welding will be subsequently carried out (e.g., guide pins on return bends). By appropriate design and foundry practice, poor weldability can be eliminated. However, this requires effective communication between the welding shop and the foundry.

A2.7 Welding Processes Selection. While a fabricator may employ automatic and machine welding processes to assemble furnace components, only two types of welding equipment are all that would essentially be required for the work at the site and in the maintenance shops:

- (1) Shielded metal arc welding (SMAW)—motor generator or rectifier.

(2) Gas tungsten arc welding (GTAW)—rectifier with high frequency starting, current decay controls and pure argon or argon plus five percent helium gas. The GTAW process should be used with filler metal and should be used for all root passes of butt and socket joints.

Best results can be achieved by purging the inside of pipe with argon, employing a small root opening and adding filler metal. Whenever an oxide free pipe ID is desired, the purge should be maintained until 3/8 in. (10 mm) thick layer of weld metal has been made. The amount of argon required for purging can be reduced by constructing internal baffles from paper or similar material that disintegrates during hydrostatic testing or subsequent operations. At other times, it may be advisable to employ a special baffle assembly such as the one shown in Figure A2.

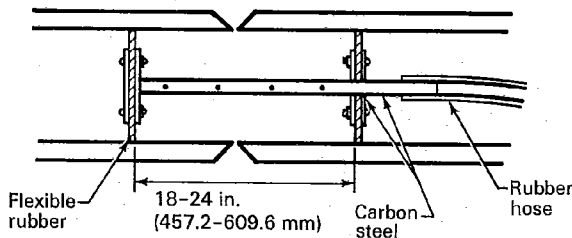


Figure A2 — Purging Baffle Assembly

For the second pass, either SMAW or GTAW may be selected. Subsequent passes for all welds on cast materials should be performed with the SMAW process, since this process minimizes heat input and increases productivity.

For shop fabrication, semiautomatic or automatic welding processes can be employed. Typically, these include autogenous GTAW for root passes of tubular butt joints and GMAW for subsequent passes, fillet welds, and repair activities.

A2.8 Filler Metal Selection. All new HK-40 furnace components which will be exposed to flue gases that may contain sulfur should be welded with high carbon (about 0.4%) 25% Cr, 20% Ni filler metal. These E310HC-40 electrodes are available as a special item from several suppliers. Covered electrodes for SMAW may be shelf items, but quick delivery in bare filler material for GTAW may not be possible. In some cases, E310 with standard carbon (about 0.1%) may be substituted for the root pass only. The use of low carbon filler metal for the entire weld is not acceptable, since it would reduce creep and high temperature tensile strength.

Use of high nickel electrodes for welding of new HK-40 (particularly those components exposed to the furnace

gases) is not recommended because of the lower resistance of the high nickel alloy to sulfur attack. However, for welding of headers and other components not exposed to furnace gases, high nickel electrodes may be acceptable.

All stainless steel and nickel alloy covered electrodes used for this application are of the low hydrogen type and are susceptible to moisture absorption. After opening the containers, the electrodes should be stored at temperatures ranging from 250°–350°F (120–175°C). If moisture absorption or improper storage is suspected, the electrodes should be baked at 600°F (315°C) for 1 h or 500°F (260°C) for 2 h prior to hot box storage. (**Caution:** Electrodes should be removed from plastic container prior to heating.) The bare filler materials for GTAW should be stored in a clean environment, preferably in original containers or plastic bags.

A2.9 Welding Procedure Consideration. In view of the problems associated with high carbon austenitic castings, it is advisable to follow the planning and welding requirements noted below.

(1) For static castings, areas where weldability is required should be specified.

(2) Joints should be designed to minimize stresses.

(3) The filler metal that best matches the properties of the base metal should be selected (i.e., E310HC-40 for HK-40). Factors to be considered include:

- (a) High temperature creep strength
- (b) Alloy content
- (c) Corrosion resistance
- (d) Coefficient of expansion
- (e) Ductility

(4) The welding procedure minimizing heat input and residual stresses should be employed; this can be aided by the following:

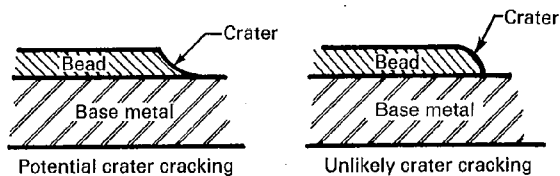
- (a) Small diameter electrodes, 1/8 in. (3.2 mm) maximum, for shielded metal arc welding
- (b) Low welding currents
- (c) High travel speed
- (d) Narrow stringer beads
- (e) Low interpass temperature at 350°F (175°C) max. for joints and 250°F max. (120°C) for repairs
- (f) Multi-bead techniques with final bead near center of each layer

(5) Restraint should be minimized where locating jigs are employed, ensuring that one side is free to move by a sufficient amount to accommodate shrinkage stresses.

(6) Tack welds and the root pass should be initiated and finished on the weld bevel and not in the root, since cracks can be more easily ground out on the bevel.

(7) The weld reinforcement should be ground, blended into base metal, and undercut should be removed to reduce stress risers.

(8) Slightly convex bead shapes and well-filled craters should be employed to minimize shrinkage stresses (see Figure A3).



Note: Use of slightly convex bead shape for helping to minimize effects of shrinkage stresses. At left, shrinkage leads to an increase in surface area at crater while, at right, shrinkage leads to a decrease in surface area at crater

Figure A3 — Contour of Weld Crater Inhibits Crater Cracks

A2.10 Repair Welding of Used Castings. As discussed previously in detail in A2.3, HK-40 and similar materials used for high temperature service only have a fair ductility when the material is new. After exposure to temperatures ranging between 1200°–1850°F (650°–1000°C) for only a short time, secondary carbides form and ductility is drastically reduced.

Material exposed to 1200°–1850°F (650°–1000°C) temperatures for thousands of hours is expected to have less than four percent of elongation. In addition, many castings (especially statically cast components) contain internal flaws in excess of the discontinuities normally accepted for wrought materials. In many cases, it is possible to overcome the internal effects that make weld-more difficult by employing special procedures and by increasing planning, training, and inspection activities.

A2.11 Pre-Weld Correction of Aged Material Condition. Cast austenitic stainless steels often undergo one or more of the following significant changes during service:

(1) Exposure to furnace gases or to oxidizing process gases may result in the formation of a heavy oxide scale on the surface.

(2) Exposure to certain process materials at elevated temperatures may carburize the steel to various depths and cause embrittlement.

(3) Exposure to 1200°–1850°F (650°–1000°C) during fabrication or operating conditions causes the formation of secondary carbides which further reduces the original low ductility.

Of the above three types of change, only the third reaction is metallurgically reversible by a special preweld heat treatment called solution annealing (Ref. 2).

A2.11.1 Removal of Oxide and Surface Defects. Oxide films interfere with welding by reducing the wettability of the base metal by the molten weld metal. When not

removed completely, oxide films can contribute to incomplete fusion, slag, and porosity defects and seriously impair weld quality.

Local corrosion or oxidation should be completely removed in the areas to be welded by grinding or rotary filing techniques prior to repair welding. When the oxide is removed, the surface can be visually and penetrant inspected.

A2.11.2 Carburized Areas Not Weldable. Prior to considering a casting repair, carburization must be evaluated. This can be accomplished by using a standard permanent magnet or a permeability meter. Since austenitic materials are normally non-magnetic and carburized materials are highly magnetic, any attraction of the magnet is an indication of carburization. A suitable magnetic permeability meter is an inexpensive, pocket-sized instrument originally developed for the non-destructive testing of coatings, such as paint, on a magnetic surface.

Attempts should be made to remove the carburized material in the weld area by rotary filing or grinding. If this is not possible, any attempts to repair by welding will probably fail and the component should be replaced. If only a slight magnetism remains after grinding, a test weld can be attempted by making a single production type bead in the doubtful area. After flush grinding the weld, the area is dye-penetrant inspected. If no cracks are detected, it may be possible to achieve a satisfactory repair.

A2.11.3 Solution Annealing Restores Ductility. The loss of ductility associated with exposure to service temperatures ranging from 1200°–1850°F (650°–1000°C) can be overcome by heat treatment. The temperature must be high enough to dissolve all or most of the secondary carbides, and the cooling rate must be fast enough to prevent the reformation of these secondary carbides. This can be accomplished by the following heat treating cycle commonly referred to as solution annealing:

(1) The entire casting or circumferential band should be heated to 2100°–2200°F (1150°–1200°C).

(2) The uniform temperature gradient should be maintained by limiting heating rate.

(3) The casting or circumferential band should be held at temperature for one hour per inch (1 h/25.4 mm), but not less than one hour.

(4) The casting or band should be cooled rapidly in air by removing all heat sources and all insulation materials. (Quenching is neither necessary nor desirable).

Full furnace heat treating represents the easiest tool for solution annealing, but this tool is not suitable for most field applications. The employment of high temperature resistance heating elements in the field was pioneered in 1967 and has since been successfully employed in many refineries and chemical plants.

The areas to be solution annealed by resistance heating must be instrumented with thermocouples, and a minimum of two layers of thermal insulation should be applied to minimize heat loss. End protection should be provided and, if possible, insulation applied to the inside of the pipe. At times, the coils and the insulation can be encased to permit their easy removal and to obtain uniform and rapid air cooling of the pipe.

When pipe sections are annealed in the horizontal position, the use of split coils is recommended wherever the outside diameter exceeds 10 in. (254 mm). This permits separate control of the upper and lower halves and provides a means to compensate for temperature differences. Thermocouple must be located near the 6 and 12 o'clock locations.

Cooling must be fast enough to prevent the reformation of embrittling secondary carbides. However, accelerated cooling is not required; in fact, water cooling produces high thermal stress that can damage the casting by cracking. The removal of all heating coils and all insulation produces adequate air cooling. The inability to remove all heat retaining components (i.e., internal refractory) can be compensated for by a uniform flow of external air.

A.2.12 Filler Metal Selection. For joints involving used austenitic castings, the use of high nickel filler metals is recommended, providing that the weld is not exposed to a sulfur containing environment. High nickel filler materials should not be used if the component is to be exposed to sulfur bearing furnace gases or products containing more than 50 grains (3.24 g) of sulfur per 100 standard cu ft (2.8 m³). At higher sulfur levels, severe sulfur attack may occur at service temperatures. Table A1 recommends the specific grades of high nickel filler materials on the basis of service temperature.

Joints exposed to furnace gases or products containing more than 50 grains (3.24 g) of sulfur per 100 stan-

dard cu ft (2.8 m³) should be welded with high carbon electrodes matching the chemistry of the base metal (such as E310HC-40 for HK-40).

A2.13 Special Considerations for Repair Welding. In addition to the eight recommendations proposed for welding new castings, the following six additional points should be considered when welding used or aged castings:

(1) The base metal temperature during joint preparation, cleaning, and welding should be minimized by:

(a) Narrow beads with maximum travel speed and minimum weaving should be deposited.

(b) Interpass temperature should be limited by cooling between passes to 350° F (175° C) for new material; 250° F (120° C) for repairing new material; 250° F (120° C) for solution annealed used material; 150° F (65° C) for used material that has not been solution annealed.

(2) Alignment and holding assemblies should be designed to minimize restraint.

(3) The bead should be peened while it is still hot to reduce shrinkage stresses. Sufficient force should be used to give the weld bead a shot blast appearance. Multi-needle scaling tools have been used successfully for this application.

(4) Welding on the HAZ of a previous weld should be avoided, since it has the poorest ductility regardless of heat treatment and service exposure.

(5) If new and used components are part of the repair, welds should be minimized between two used components.

A2.14 Buttering. Aged HK-40 with marginal ductility can at times be welded by buttering the groove face prior to attempting a butt weld. This operation consists of two steps. One or more layers of ductile weld metal are made under minimum restraint conditions and are inspected after remachining the groove face. Thus, when attempting the more highly restrained butt joint, sufficient duc-

Table A1
Filler Metal Selection Guide

Welding Process	Service Temperature Range, F (C)		
	Below 1100° (315)	1100°-1600° (315-471)	1600° and above (471)
Shielded metal arc (AWS A5.11)	(ENiCrFe-3)	(ENiCrFe-2)	(ENiCrMo-3)
Gas shielded arc ^a (AWS A5.14)	(ERNiCr-3)	(ERNiCr-3)	(ERNiCrMo-3) ^b

a. Gas tungsten arc (GTAW) and gas metal arc (GMAW).

b. Root pass only ERNiCr-3 or ERNiCrMo-3. Complete weld ERNiCrMo-3.

tile buttering is available adjacent to the groove weld to absorb part of the plastic deformation associated with weld solidification and cooling.

When joining aged HK-40 to more ductile materials such as new or solution annealed HK-40, it is only necessary to butter the aged component. While many welds have been successfully completed employing the buttering technique, very low ductility components cannot be salvaged by this method. In such cases, solution annealing, discussed earlier in this Appendix, appears to be desirable.

A2.15 Training and Inspection. Only items peculiar to the welding of high carbon austenitic castings are discussed, and the important differences between these and standard wrought materials are highlighted. The major differences are due both to the less ductile nature of these castings and to the impossibility of evaluating and inspecting the weldments by some of the standard tools such as hardness testers and ultrasonics.

A2.16 Welder Training. Even the most qualified welder should be given some additional training prior to welding cast austenitic components. First of all, the welder must become thoroughly familiar with the high carbon stainless or high nickel filler metals. When using high nickel filler metal and any type of wrought base metal, he can be certified by conventional ASME bend tests or radiography.

Due to lack of ductility, bend tests are not possible when using the cast base metals and radiography may not reveal small cracks. Thus, the welder must use conventional Type E310 or Inconel filler metal and wrought alloy for his initial test. For the second training phase, the welder should use cast tubing with production type joints and accessibility restrictions. The soundness of this weld can be evaluated by a combination of visual, penetrant (PT) and radiographic (RT) inspection, and by metallographic examination.

For butt joints requiring open root GTAW, the welder should be given sufficient practice and training until he can deposit consistently sound welds with complete and uniform penetration. The adequacy of his work can be inspected visually and by PT.

Due to the high degree of skill and the critical nature of the work, it is suggested that the welder be provided with a practice pipe on which he completes at least half of a root pass immediately prior to his production weld. The welding of the practice pipe should be repeated prior to every shift to check the welder and the equipment.

During all training phases and when working on the practice pipes, emphasis should be placed upon the special requirements associated with the welding of castings. These have been discussed earlier and include:

- (1) Minimum heat input

- (2) Low welding currents
- (3) High travel speed
- (4) Narrow stringer beads
- (5) Multiple bead techniques
- (6) Low interpass temperatures
- (7) Proper crater filling
- (8) Smooth surface finish

At the same time, the welder should become familiar with the proper use of the peening tool, or train with another worker as a welding and peening team.

A2.17 Weld Inspection. In addition to the usual final inspection, a preweld and in-process inspection program is of prime importance. A complete quality control program should include:

- (1) Visual and penetrant (PT) inspection of finished bevels and all areas within 1/2 in. (13 mm) of the planned joint.
- (2) Review of welder training, qualification, and practice pipes.
- (3) PT inspection of root bead.
- (4) Check that low interpass temperatures and adequate peening are employed.
- (5) Removal of surface irregularities and undercut to prevent stress concentrations.
- (6) Radiography (RT) of final welds on a 100 percent or spot basis, as required. If this is not possible due to joint location or lack of adequate equipment, the use of in-process PT inspection should be considered.

A2.18 Summary. It is not possible to prepare one document that details all conditions and all requirements that may be encountered in welding high carbon stainless steel during the fabrication of new components or during maintenance activities. However, the foregoing discussion should provide some guidelines in establishing sound procedures for welding new and used HK-40 or similar alloy castings.

The specific requirements associated with each fabrication and with each component call for detailed procedures containing the necessary planning, testing, training, and inspection phases. To accomplish its mission, the final procedure should not only be technically sound, but should also be understood by the welder.

References for Appendix A

1. Voelker, C. H., and Zeis, L. A., How to repair HK-40 furnace tubes, *Hydrocarbon Processing*, 51(4), pp. 121-124, April 1972.
2. Ebert, H. W., Solution annealing in the field, *Welding Journal*, Vol 53(2), pp. 88-93, February 1974.
3. Ebert, H. W., Fabrication of HK-40 in the field, *Welding Journal*, Vol. 55(11), pp. 939-945, November 1976.

Appendix B

Document List

The following is a complete list of the standards prepared by the AWS Committee on Piping and Tubing.

AWS D10.4	Austenitic Chromium-Nickel Stainless Steel Piping and Tubing, Recommended Practices for Welding	AWS D10.9	Qualification of Welding Procedures and Welders for Piping and Tubing, Specification for
AWS D10.6	Titanium Piping and Tubing, Recommended Practices for Gas Tungsten Arc Welding	AWS D10.10	Piping and Tubing, Local Heat Treatment of Welds in
AWS D10.7	Aluminum and Aluminum Alloy Pipe, Recommended Practices for Gas Shielded Arc Welding	AWS D10.11	Root Pass Welding, Recommended Practices for
AWS D10.8	Chromium-Molybdenum Steel Piping and Tubing, Recommended Practices for Welding	AWS D10.12	Plain Carbon Steel Pipe, Recommended Practices and Procedures for Welding

Appendix C

Safety and Health

There are many factors involved in welding and allied processes which may have adverse effects on the safety and health of those individuals who work in, or who spend time in, areas where welding and allied operations are being performed.

Individuals and organizations using the processes described in this document should familiarize themselves with the safety and health aspects of the work to be done.

A series of essays on the subjects of "Fumes and Gases", "Noise", "Chromium and Nickel in Welding Fume", "Electrical Hazards", "Radiation", "Fire Protection", and "Burn Protection", has appeared in the *Welding Journal* (August through December 1982).

Supplementary Reading List

(1) ANSI/NFPA 51-B1977, *Cutting and Welding Processes*, Quincy, MA: National Fire Protection Association.

(2) *Arc Welding and Cutting Noise*, Miami: American Welding Society, 1979.

(3) Balchin, N. C., *Health and Safety in Welding and Allied Processes*, 3rd Ed., England: The Welding Institute, 1983.

(4) Compressed Gas Association, Inc., *Handbook of Compressed Gases*, 2nd Ed., New York: Von Nontrand Reinhold Co., 1981.

(5) Dalziel, Charles F., *Effects of Electric Current on Man*, ASEE Journal, 1973, June 18-23.

(6) *Effects of Welding on Health*, I, II, III, and IV, Miami: American Welding Society, 1979, 1981, 1983.

(7) *Fumes and Gases in the Welding Environment*, Miami: American Welding Society, 1979.

(8) *Safe Handling of Compressed Gases in Containers*, P-1, New York: Compressed Gas Association, 1974.

(9) *The Facts About Fume*, England: The Welding Institute, 1976.

(10) *The Welding Environment*, Miami: American Welding Society, 1973.

(11) *Ultraviolet Reflectance of Paint*, Miami: American Welding Society, 1976.

(12) *Welding Fume Control with Mechanical Ventilation*, 2nd Ed., San Francisco: Fireman's Fund Insurance Companies, 1981.

Further detailed information may be found in the publications of the following organizations:

(1) American Welding Society (AWS)
550 NW LeJeune Road
P.O. Box 351040
Miami, Florida 33135

(2) Occupational Safety and Health Administration (OSHA), all publications available from:
Superintendent of Documents
U.S. Printing Office
Washington, DC 20402

(3) American Conference of Governmental Industrial Hygienist (ACGIH)
6500 Glenway Avenue
Building D-5
Cincinnati, Ohio 45211

(4) National Institute for Occupational Safety and Health (NIOSH)
4676 Columbia Parkway
Cincinnati, Ohio 45226

(5) National Fire Protection Association (NFPA)
Batterymarch Park
Quincy, Massachusetts 02269