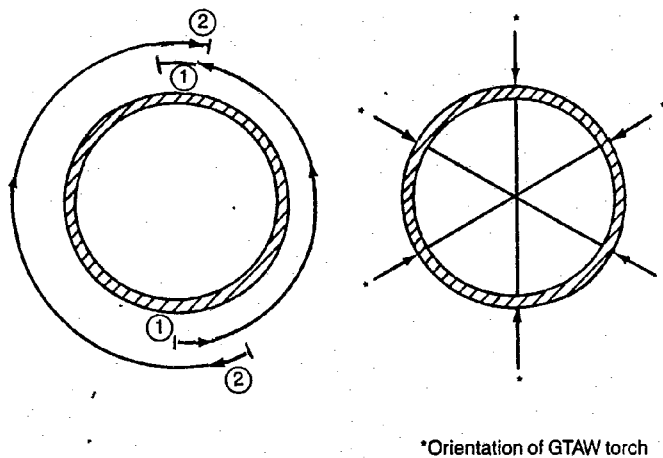


Errata Sheet

D10.7-86, Recommended Practices for Gas Shielded Arc Welding of
Aluminum and Aluminum Alloy Pipe

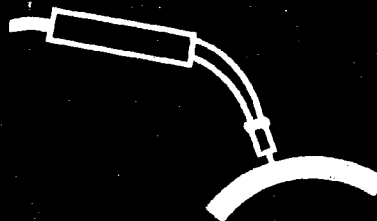
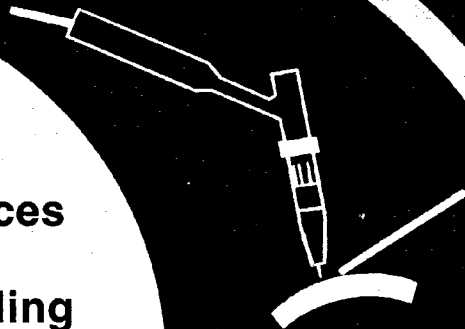
Page 21 — (Figure 5, left-hand sketch) Torch direction arrows
should be pointing in the opposite direction as
follows:



1. Weld vertically upward.
2. Overlap ends of first bead 1 in. (25 mm) minimum.
3. Maintain torch direction toward pipe center.
4. Alternate sides of pipe for successive passes.

Fig. 5—Gas tungsten arc welding torch directions, horizontal fixed position

**Recommended Practices
for
Gas Shielded Arc Welding
of
Aluminum and
Aluminum Alloy Pipe**



AMERICAN WELDING SOCIETY

Keywords—Aluminum Pipe, Recommended practice,
Gas tungsten arc welding, Gas metal arc welding

ANSI/AWS D10.7-86
An American National Standard

Approved by
American National Standards Institute

**Recommended
Practices
for
Gas Shielded Arc Welding
of
Aluminum and
Aluminum Alloy Pipe**

Superseding D10.7-60

Prepared by
AWS Committee on Piping and Tubing

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors
August 20, 1985

Abstract

This document presents information concerning those properties of aluminum which affect its weldability and which cause specific problems in the fabrication of aluminum pipe. Recommendations are made for solving these problems and suggested procedures are presented for welding aluminum pipe joints with the Gas Tungsten Arc and Gas Metal Arc Welding Processes.

AMERICAN WELDING SOCIETY
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Foreword

The purpose of these recommended practices is to facilitate the selection and specification of welding processes and procedures for aluminum and aluminum alloy pipe. These recommended practices are intended to provide information which may be used to minimize or avoid difficulties in the welding of such pipe.

These recommended practices have been prepared by the Subcommittee on Aluminum Piping of the AWS Committee on Piping and Tubing. It is important to recognize that this publication does not present the only possible conditions for welding aluminum pipe. The data given are presented merely as initial guides to operating conditions.

The first version of this document, AWS D10.7-60, was written to present the advances made in Aluminum Pipe welding during and subsequent to WWII. The present document supercedes D10.7-60 and updates the material to reflect the present state of the art.

The Subcommittee will welcome comments on these recommended practices, as well as any additional information on the use of the included processes that could be incorporated in a subsequent revision.

Communications should be addressed to the Secretary, AWS Committee on Piping and Tubing, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

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Recommended Practices for Gas Shielded Arc Welding of Aluminum and Aluminum Alloy Pipe*

1. History of Aluminum Pipe Welding

For many years, pipe was generally joined with threaded fittings. Improved welding techniques gradually caused a trend toward welded joints. Today, welded piping systems are specified in a wide variety of industries, including power, refrigeration, chemical, petroleum, industrial gas and air, and food processing.

Oxyfuel gas welding with oxyhydrogen or oxyacetylene was initially used for aluminum pipe. This process required the use of fluxes which had to be removed subsequent to welding, since they were a corrosion hazard to the pipe in the presence of moisture. Furthermore, welding, other than in the flat position, was very difficult. Both factors imposed a severe limitation on welded aluminum piping systems.

The development of the gas tungsten arc welding process (GTAW) during World War II provided a practical solution to the problems associated with oxyfuel gas welding aluminum pipe. The corrosion hazard resulting from the flux was eliminated by the inert gas shield and all-position welding techniques were developed. Subsequently, the gas metal arc welding process (GMAW) was developed and provided a substantial reduction in pipe welding time for applications where this process is suitable.

2. Aluminum Pipe Alloys and Their Characteristics

Aluminum alloys have many characteristics which make them useful construction materials. Many of these properties, such as corrosion resistance, strength, light weight, protection of purity and color of the product transported, fracture toughness at cryogenic temperatures, and ease of fabrication are valuable in piping systems.

Many aluminum alloys are made in pipe form. The choice of the pipe alloy for a particular installation is made on the basis of the materials to be contained, the external exposure environment, and the service temperatures. For nominal chemical compositions, see Appendix A. Alloy 3003-H112, a nonheat-treatable alloy containing manganese, provides adequate strength for many applications, together with high resistance to corrosion. Alloy 6063-T6, a heat treated aluminum-magnesium-silicide alloy, provides higher strength

and equivalent corrosion resistance. Alloy 6061-T6 is similar in characteristics to 6063-T6, but it has higher strength. In most environments, its resistance to corrosion is equivalent to that of the 3003 and 6063 alloys. Alloys 5086 and 5083, nonheat-treatable aluminum-magnesium-manganese alloys, provide superior as-welded strength and high fracture toughness at ambient and cryogenic temperatures.

It should be noted that the heat associated with welding reduces both tensile strength and design allowable values for most aluminum alloys. For example, for 6061-T6 these values are reduced about one third.

Pipe in other alloys can be furnished for applications where high purity aluminum is required, where the design calls for higher strength, or where special corrosion resisting characteristics are desired. Alloys such as 1060, 5254, or 5652 may be used for high purity requirements. The 5254 and 5652 alloys are specially controlled purity versions of alloys 5154 and 5052. They belong to an important group of alloys which have magnesium as their principal alloying element, usually with some manganese or chromium.

Other alloys in this group are 5083, 5086, 5454, and 5456. These alloys are all nonheat-treatable but have excellent as-welded strength and ductility. They generally exhibit high resistance to corrosion; however, maximum service temperature requirements must be carefully investigated, since long time exposure to elevated temperature can adversely affect their corrosion resistance. Alloys 5052 and 5454 are recommended when sustained service temperatures are above 150° F (66° C). Alloys 5083 and 5086 are used in marine applications. Alloy 5083 is favored for cryogenic applications.

Clad versions of the standard alloys are sometimes used for resistance to corrosion under special conditions. In the clad products, an integral coating (usually 10 percent of the pipe wall thickness) of an alloy selected is used to provide cathodic protection to the core alloy. The presence of the cladding does not normally affect weldability. Combinations of alloys can be welded in most cases, and welding procedures should be based on core alloys. Table 1 gives information on filler metals for various base metal alloy combinations.

*The term pipe in this document is intended to include tube where appropriate.

2/RECOMMENDED PRACTICES FOR GAS SHIELDED ARC WELDING

Table 1
Guide to choice of filler metal for welding aluminum pipe

Base metal alloy designation	356.0 443.0	6061 6063 6101 6351	5454	514.0 5154 5254 ^a	5086	5083	5052 5652 ^a	3004	1100 3003 Alc 3003	1060 1350
1060, 1350	ER 4043 ^f	ER 4043 ^{b,f}	ER 5654 ^b	ER 5654 ^b	ER 5356 ^b	ER 5356 ^b	ER 5654 ^b	ER 5654 ^b	ER 1100 ^c	ER 1100 ^c
1100, 3003, Alc 3003	ER 4043 ^f	ER 4043 ^{b,f}	ER 5654 ^b	ER 5654 ^b	ER 5356 ^b	ER 5356 ^b	ER 5654 ^b	ER 5654 ^b	ER 1100 ^c	
3004	ER 4043 ^f	ER 5654 ^{b,c}	ER 5654 ^b	ER 5654 ^b	ER 5356 ^b	ER 5356 ^b	ER 5654 ^b	ER 5654 ^b		
5052, 5652 ^a	ER 4043 ^{b,f}	ER 5654 ^b	ER 5554 ^b	ER 5654 ^b	ER 5356 ^b	ER 5356 ^b	ER 5554 ^{a,b}			
5083	ER 5356 ^{b,c}	ER 5356 ^b	ER 5356 ^b	ER 5356 ^b	ER 5356 ^e	ER 5183 ^e				
5086	ER 5356 ^{b,c}	ER 5356 ^b	ER 5356 ^b	ER 5356 ^b	ER 5356 ^e					
514.0, 5154, 5254 ^a	ER 4043 ^{b,f}	ER 5654 ^b	ER 5654 ^b	ER 5654 ^{a,b}						
5454	ER 4043 ^{b,f}	ER 5554 ^b	ER 5554 ^b							
6061, 6063, 6101, 6351	ER 4043 ^{b,f}	ER 5654 ^b								
356.0, 443.0	ER 4043 ^{d,f}									

Notes:

- Recommendations in this Table apply to the gas shielded arc welding processes. For oxyacetylene gas welding, only ER1100, ER4043, and ER4047 filler metals are ordinarily used.
- Filler metals are listed in AWS Specification A5.10.
- Filler metals ER5356, ER5183, ER5556, and ER5654 are not recommended for sustained elevated temperature service [over 150° F (65° C)]. ER5554 is suitable for elevated temperature service.
- Local corrosion attack may occur in the weld region in certain electrolytes, due to solution potential variations. These variations can result from compositional differences between the filler and base metals or from heat related metallurgical effects.

- Base metal alloys 5254 and 5652 are used for hydrogen peroxide service. ER5654 filler metal is used for welding both alloys for service below 150° F (65° C).
- ER5183, ER5356, ER5554, ER5556, and ER5654 may be used. In some cases they provide (1) improved color match after an anodizing treatment, (2) highest weld ductility, and (3) higher weld strength. ER5554 is suitable for elevated temperature service.
- ER4043 or ER4047 may be used.
- Filler metal with the same analysis as the base metal can be used.
- ER5183, ER5356, or ER5556 may be used.
- ER4047 may be used.

3. Welding Characteristics of Aluminum

The important characteristics of aluminum which affect its weldability are

- (1) Refractory nature of aluminum oxide
- (2) Lack of color change as the metal approaches the welding temperature
- (3) High heat conductivity
- (4) High coefficient of thermal expansion

3.1 Aluminum Oxide. Aluminum and oxygen have a strong affinity for each other, and aluminum oxide instantaneously begins to form on aluminum surfaces exposed to air. This oxide film is thin, transparent, tenacious, refractory, and has a melting temperature much higher than aluminum. An excessively thick oxide film can cause welding difficulties and affect weld quality. The normal oxide film is removed progressively or ruptured by the welding arc, and additional oxide must be prevented from forming on the molten metal surfaces under the arc if fusion is to occur.

A flux is not required in gas tungsten arc welding (GTAW) or in gas metal arc welding (GMAW). The electric arc in both processes penetrates and breaks up the aluminum oxide film, which is not an electrical conductor. A regulated flow of inert gas (either argon or helium, or a combination of both) around the arc area prevents reformation of oxide without contaminating the metal and permits the welder to deposit filler metal with a high degree of control. Gas purging of the pipe or gas shielding of the weld root is not normally necessary for aluminum pipe welds.

3.2 No Color Change There is no visible color change in aluminum as it is heated from room temperature to welding temperature. Therefore, the welder must pay careful attention to the area being heated to control the flow of metal when visible melting begins.

3.3 High Heat Conductivity. Since aluminum is an excellent heat conductor, a different welding technique is required from that for steel, which has lower heat conductivity.

Welding currents and welding speeds are generally higher for aluminum. Stringer beads are generally used, although the final pass is sometimes welded with a weaving technique with GTAW.

3.4 High Coefficient of Expansion. Aluminum expands about twice as much as steel for a given increase in temperature. This can be an advantage where the joint is loosely fitted in preparation for welding, since the joint will tend to close as the temperature rises. It can also be a disadvantage when joints are tightly fitted because expansion forces can increase the metal thickness at the joint. Measurements have shown that up to about $\frac{1}{8}$ in. (3 mm) shrinkage will occur when butt joints are welded in Schedule 40 pipe in sizes

through 12 in. (305 mm). The gas metal arc welding process with its concentrated heat and its lower heat input generally causes less shrinkage than does the gas tungsten arc welding process.

3.5 Weldability of Aluminum Alloys. Aluminum is alloyed with small amounts of other metals to develop specific characteristics such as high strength. To the welder, aluminum and its weldable alloys appear much alike while being welded. However, the alloys differ in their ability to resist solidification cracking. During solidification, the contraction strains which occur may be sufficient to cause cracking unless proper procedures and filler metals are used. The cracks may occur either in the weld metal or in the heat-affected zone of the base metal.

Commercially pure aluminum and the lower strength alloys (for example, 1100 and 3003) are not generally susceptible to cracking. However, the higher strength alloys such as 6061 or 6063 tend to be susceptible to hot cracking, especially if filler metal of the same composition as the base metal is used. For this reason, 6061 and 6063 alloys are welded with filler metals having enough silicon or magnesium, for example 4043 or 5356, to produce a crack resistant composition in the weld. It should be noted that the recommended filler metals given for pipe in Table 1 are in some cases different from those recommended for welding other structures. Because pipe is often exposed to particularly corrosive environments, filler metal alloys have been selected to give best corrosion resistance. When filler metals differing in composition from the base metal are used to eliminate solidification cracking (as in the case of 6061 or 6063 alloy), the weld metal should consist of about 70 percent added filler metal diluted with not more than 30 percent base metal. This may require beveling the joint, increasing the root opening, or limiting the amount of base metal melted.

4. Welding Processes and Equipment

4.1 Alternating Current Gas Tungsten Arc Welding (GTAW). A gas tungsten arc method commonly used for aluminum pipe welding uses alternating current (ac), a tungsten electrode, and argon gas. The arc provides good cleaning and excellent oxide film dispersion with this method. With some power supplies, high frequency is necessary to aid arc initiation during reversal of current, thus stabilizing the arc. This process gives a clean, bright weld pool which is clearly visible and easily controlled.

The welding technique is not difficult for an experienced GTAW welder. Interpass cleaning is unnecessary. Although pure tungsten electrodes may be used, either thoriated or zirconiated tungsten electrodes are preferred for alternating

4/RECOMMENDED PRACTICES FOR GAS SHIELDED ARC WELDING

current GTAW. They have higher current capacity than pure tungsten electrodes of equal size.

4.2 Direct Current Electrode Negative (DCEN). Another gas tungsten arc method uses direct current electrode negative, a tungsten electrode, and helium shielding gas. With this method, and the use of smaller electrodes of 2 percent thoriated tungsten, a more concentrated arc is obtained. This results in deeper joint penetration than with ac welding. The weld pool does not appear as fluid as with an ac arc. This method requires more skill by the welder, more thorough precleaning of the joint, and interpass cleaning, since there is no arc cleaning action by DCEN welding.

4.3 Gas Metal Arc Welding (GMAW). Gas metal arc welding uses direct current electrode positive (DCEP). Motor or engine driven generators or transformer-rectifier machines may be used and may be either constant current (drooping) or constant voltage type. Constant speed wire feeders are most commonly used. With constant current (drooping) power sources the wire feeder control requires a scratch or slow-speed starting feature. With true constant current power sources, i.e., having a vertical volt-ampere characteristic curve, voltage feedback from the arc is necessary to control electrode speed.

4.4 Automatic Welding. Equipment has been developed for both machine and automatic gas shielded welding of aluminum pipe. The design and operation of this type of equipment permit controlled use of the characteristic high speed of gas metal arc welding in the joining of pipe in the horizontal fixed position. Equipment of this type has been successfully used on a number of pipe line jobs in the field. Constant voltage, constant current, and pulsed current power sources have proved successful.

Automatic equipment has also been developed for gas tungsten arc welding of aluminum pipe.

5. Welding Materials

5.1 Gas Nozzles – GTAW. Water-cooled metal nozzles are generally preferred over ceramic nozzles, particularly when higher welding currents are used. The ceramic nozzles are not as durable at higher temperatures and are more easily broken. However, the smaller ceramic nozzles may be preferred for welding certain joints, such as 45 degree intersectional welds where the clearances are small. Small diameter, extra long ceramic nozzles, or coated metal nozzles, are often used to avoid short circuiting of the nozzle when welding such joints. Nozzle sizes are shown in Tables 2 through 10.

5.2 Tungsten Electrodes. As discussed previously, pure tungsten, thoriated tungsten, or zirconiated tungsten electrodes are used for ac gas tungsten arc welding. Two percent

thoriated tungsten electrodes are used for dc gas tungsten arc welding. Electrode sizes are listed in Tables 2 through 10.

5.3 Filler Metals. Filler metal selection can be made from Table 1 for the various pipe alloys and combinations of alloys.

5.4 Inert Gas. Argon is the preferred gas for most gas shielded arc welding. Although a mixture of helium and argon is sometimes employed for gas metal arc welding, the advantages of using such a mixture do not extend to pipe welding. Helium is necessary for DCEN welding with the GTAW process. Otherwise, all inert gas pipe welding is done with argon. Welding grade gases are required.

6. Welding Preparation

The ends of the aluminum pipe are generally prepared for welding by machining. Oxyfuel gas cutting of the edge, as is done in steel, is not possible, but plasma arc cutting can be used for beveling. Pipe can be ordered with standard welding bevels, as shown in Fig. 1, or with the preparation for a U-groove, shown in Fig. 2, on special order. The U-groove preparation is recommended for manual gas tungsten arc welding using alternate current.

Pipe ends must be thoroughly cleaned prior to assembly to remove all foreign substances that could cause porosity or weld inclusions. Solvents or other cleaning materials must not be used after the joint has been assembled.

Joint edges can be wiped with solvent-soaked rags to remove surface oil, grease, and dirt. This should be sufficient cleaning for most joints. Suitable solvent must be nonflammable, nontoxic, and stable in the presence of an arc. The provisions of the latest edition of American National Standard Z49.1, *Safety in Welding and Cutting*¹ must be followed. Particular reference is made to paragraph 5.5.4, "Cleaning Compounds," in that standard.

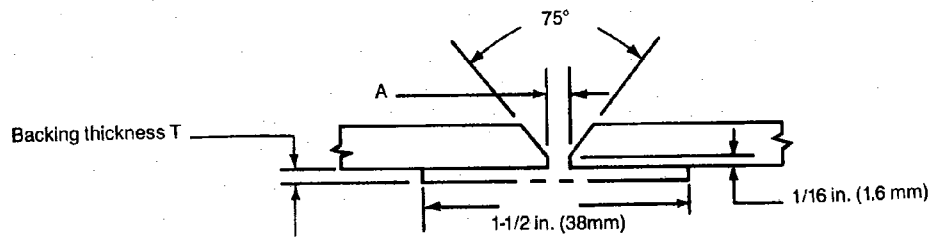
Solvent cleaning is most effective on smooth surfaces. If solvent wiping will not remove imbedded dirt, files, chisels, wire brushes, or metal scrapers should be used. These should be clean and free from oil. When using grinding wheels, make certain special high-speed wheels for aluminum are used. Wire brushing can be used to remove heavy oxide coatings.

7. Welding Conditions

7.1 Machine Settings and Other Variables. When ac gas tungsten arc welding, the size of tungsten electrode used should be small enough to cause the end to form a hemi-

1. Published by the American Welding Society. See Appendix C.

Table 2
Gas tungsten arc welding
Alternating current in the horizontal rolled position



Edge preparation

A = 0 for no backing ring or removable backing ring
 A = 1/4 in. (6.4 mm) max for integral backing ring

Nominal pipe size		Wall thickness		Welding rod dia.		Current ac	T		No. of passes ^a
in.	mm	in.	mm	in.	mm	amp	in.	mm	A = 0
1	25	0.133	3.38	3/32	2.4	100-115	0.072	1.83	1-2
1-1/4	32	0.140	3.55	1/8	3.2	110-135	0.072	1.83	1-2
1-1/2	38	0.145	3.68	1/8	3.2	115-140	0.072	1.83	1-2
2	50	0.154	3.91	1/8	3.2	125-150	0.093	2.36	1-2
2-1/2	64	0.203	5.16	1/8	3.2	140-180	0.093	2.36	2
3	76	0.216	5.49	1/8-5/32	3.2-4.0	150-190	0.093	2.36	2
3-1/2	89	0.226	5.74	1/8-5/32	3.2-4.0	160-200	0.093	2.36	2
4	102	0.237	6.02	1/8-3/16	3.2-4.8	170-210	0.125	3.18	2
5	127	0.258	6.55	5/32-3/16	4.0-4.8	190-230	0.125	3.18	2
6	152	0.280	7.11	5/32-3/16	4.0-4.8	210-250	0.187	4.75	2
8	203	0.322	8.18	5/32-3/16	4.0-4.8	220-260	0.187	4.75	2-3
10	254	0.365	9.27	5/32-3/16	4.0-4.8	240-280	0.187	4.75	2-3
12	305	0.406	10.31	5/32-3/16	4.0-4.8	250-290	0.187	4.75	2-3

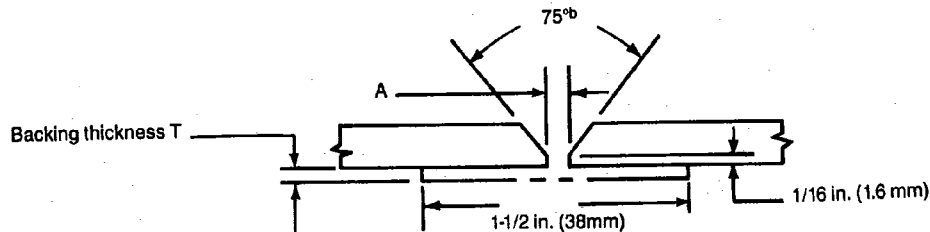
Notes:

1. Tungsten electrode diameter is 1/8 in. (3.2 mm) for 1 to 3-1/2 in. (25 to 89 mm) pipe size and 3/16 in. (4.8 mm) for 4 to 12 in. (102 to 305 mm) pipe size.
2. Gas nozzle orifice diameter is 7/16 in. (11.1 mm) for 1 to 2-1/2 in. (25 to 50 mm) pipe size and 1/2 in. (12.7 mm) for 2-1/2 to 12 in. (64 to 305 mm) pipe size.
3. Argon flow rate is 25 to 40 cfm (12 to 19 l/m).

a. More passes are required when A = 1/4 in. (6.4 mm)

6/RECOMMENDED PRACTICES FOR GAS SHIELDED ARC WELDING

Table 3
Gas tungsten arc welding
Alternating current in the horizontal fixed position



Edge preparation

A = 0 for no backing ring or removable backing ring
 A = 1/4 in. (6.4 mm) max for integral backing ring

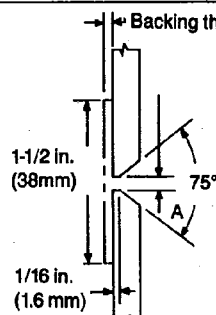
Nominal pipe size		Wall thickness		Welding rod dia.		Current ac	Argon flow		T		No. of passes ^a
in.	mm	in.	mm	in.	mm	amp	cfh	l/m	in.	mm	A = 0
1	25	0.133	3.38	3/32	2.4	90-110	30-80	14-38	0.072	1.83	1-2
1-1/4	32	0.140	3.55	1/8	3.2	100-120	30-80	14-38	0.072	1.83	1-2
1-1/2	38	0.145	3.68	1/8	3.2	110-130	30-80	14-38	0.072	1.83	1-2
2	50	0.154	3.91	1/8	3.2	120-140	30-80	14-38	0.093	2.36	1-2
2-1/2	64	0.203	5.16	1/8	3.2	130-150	30-80	14-38	0.093	2.36	2
3	76	0.216	5.49	1/8	3.2	145-165	30-80	14-38	0.093	2.36	2
3-1/2	89	0.226	5.74			150-170	30-80	14-38	0.093	2.36	2
4	102	0.237	6.02	1/8-3/16	3.2-4.8	160-180	35-80	17-38	0.125	3.18	2
5	127	0.258	6.55	5/32-3/16	4.0-4.8	180-190	35-80	17-38	0.125	3.18	2
6	152	0.280	7.11	5/32-3/16	4.0-4.8	195-205	50-80	24-38	0.187	4.75	2
8	203	0.322	8.18	5/32-3/16	4.0-4.8	210-220	50-80	24-38	0.187	4.75	2-3
10	254	0.365	9.27	5/32-3/16	4.0-4.8	230-240	50-80	24-38	0.187	4.75	2-3
12	305	0.406	10.31	5/32-3/16	4.0-4.8	245-255	50-80	24-38	0.187	4.75	2-3

Notes:

1. Tungsten electrode diameter is 1/8 in. (3.2 mm) for 1 to 3-1/2 in. (25 to 89 mm) pipe size, and 3/16 in. (4.8 mm) for 4 to 12 in. (102 to 305 mm) pipe size.
2. Gas nozzle orifice diameter is 1/2 in. (12.7 mm).

- a. Greater number of passes for bottom 90 degree of pipe circumference and when A = 1/4 in. (6.4 mm).
- b. 110° angle required on bottom 90° of pipe can be applied to full 360°.

Table 4
Gas tungsten arc welding
Alternating current in the vertical position



Edge preparation

A = 0 for no backing ring or removable backing ring

A = 1/4 in. (6.4 mm) max for integral backing ring

Nominal pipe size		Wall thickness		Welding rod dia.		Current ac	Argon flow		T		No. of passes ^a
in.	mm	in.	mm	in.	mm	amp	cfh	l/m	in.	mm	A = 0
1	25	0.133	3.38	3/32	2.4	95-115	25-50	12-24	0.072	1.83	1-2
1-1/4	32	0.140	3.55	1/8		105-125	25-50	12-24	0.072	1.83	1-2
1-1/2	38	0.145	3.68	1/8		115-135	25-50	12-24	0.072	1.83	1-2
2	50	0.154	3.91	1/8	3.2	125-145	30-60	14-28	0.093	2.36	2-3
2-1/2	64	0.203	5.16	1/8		135-155	30-60	14-28	0.093	2.36	3-5
3	76	0.216	5.49	1/8		150-170	40-60	19-28	0.093	2.36	3-5
3-1/2	89	0.226	5.74	1/8		155-175	40-60	19-28	0.093	2.36	3-5
4	102	0.237	6.02	1/8-5/32	3.2-4.0	165-185	40-60	19-28	0.125	3.18	3-5
5	127	0.258	6.55	5/32-3/16	4.0-4.8	185-205	50-60	24-28	0.125	3.18	3-5
6	152	0.280	7.11	5/32-3/16	4.0-4.8	200-220	50-60	24-28	0.187	4.75	3-5
8	203	0.322	8.18	5/32-3/16	4.0-4.8	215-235	60-80	28-38	0.187	4.75	5-8
10	254	0.365	9.27	5/32-3/16	4.0-4.8	235-255	60-80	28-38	0.187	4.75	5-8
12	305	0.406	10.31	5/32-3/16	4.0-4.8	250-270	70-80	33-28	0.187	4.75	6-8

Notes:

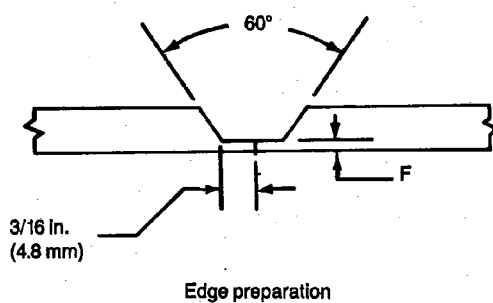
1. Tungsten electrode diameter is 1/8 in. (3.2 mm) for 1 to 3-1/2 in. (25 to 89 mm) pipe size, and 3/16 in. (4.8 mm) for 4 to 12 in. (102 to 305 mm) pipe size.

2. Gas nozzle orifice diameter is 7/16 in. (11.1 mm) for 1 to 2-1/2 in. (25 to 64 mm) pipe size and 1/2 in. (12.7 mm) for 3 to 12 in. (76 to 305 mm) pipe size.

a. More passes are required when A = 1/4 in. (6.4 mm).

8/RECOMMENDED PRACTICES FOR GAS SHIELDED ARC WELDING

Table 5
Gas tungsten arc welding
Alternating current in the horizontal rolled position

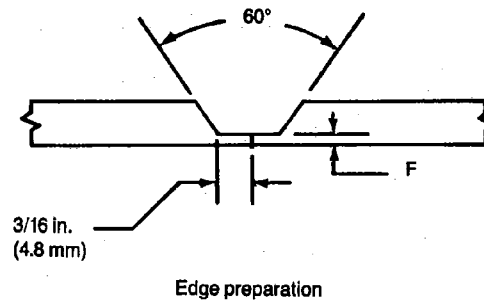


Nominal pipe size		Wall thickness		Welding rod dia.		Current ac	Argon flow		F		No. of passes
in.	mm	in.	mm	in.	mm	amp	cfh	l/m	in.	mm	
1	25	0.133	3.38	3/32	2.4	80-100	25-40	12-19	1/16	1.6	1-2
1-1/4	32	0.140	3.55	3/32	2.4	90-110	25-40	12-19	1/16	1.6	1-2
1-1/2	38	0.145	3.68	3/32	2.4	100-120	25-40	12-19	1/16	1.6	1-2
2	50	0.154	3.91	3/32	2.4	110-130	25-40	12-19	1/16	1.6	3-4
2-1/2	64	0.203	5.16	1/8	3.2	120-140	30-40	14-19	3/32	2.4	3-4
3	76	0.216	5.49	1/8	3.2	135-155	30-40	14-19	3/32	2.4	3-4
3-1/2	89	0.226	5.74	1/8	3.2	140-160	30-40	14-19	3/32	2.4	3-4
4	102	0.237	6.02	1/8	3.2	150-170	30-40	14-19	3/32	2.4	3-4
5	127	0.258	6.55	5/32	4.0	170-190	30-40	14-19	3/32	2.4	3-4
6	152	0.280	7.11	5/32	4.0	185-205	35-40	17-19	3/32	2.4	3-5
8	203	0.322	8.18	5/32-3/16	4.0-4.8	200-220	35-40	17-19	3/32	2.4	3-5
10	254	0.365	9.27	5/32-3/16	4.0-4.8	220-240	35-40	17-19	3/32	2.4	3-5
12	305	0.406	10.31	5/32-3/16	4.0-4.8	235-255	35-40	17-19	3/32	2.4	3-5

Notes:

1. Tungsten electrode diameter is 1/8 in. (3.2 mm) for 1 to 3-1/2 in. (25 to 89 mm) pipe size, and 3/16 in. (4.8 mm) for 4 to 12 in. (102 to 305 mm) pipe size.
2. Gas nozzle orifice diameter is 7/16 in. (11.1 mm) for 1 to 2-1/2 in. (25 to 64 mm) pipe size and 1/2 in. (12.7 mm) for 3 to 12 in. (76 to 305 mm) pipe size.

Table 6
Gas tungsten arc welding
Alternating current in the horizontal fixed position



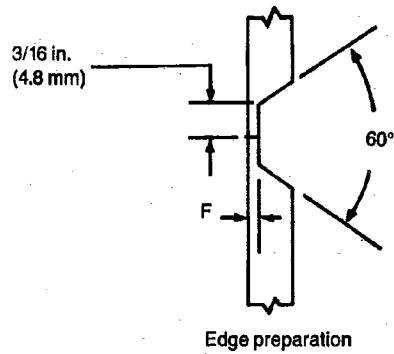
Nominal pipe size		Wall thickness		Welding rod dia.		Current ac	Argon flow		F	
in.	mm	in.	mm	in.	mm	amp	cfh.	l/m	in.	mm
1	25	0.133	3.38	3/32	2.4	80-100	30-80	14-38	1/16	1.6
1-1/4	32	0.140	3.55	3/32	2.4	90-110	30-80	14-38	1/16	1.6
1-1/2	38	0.145	3.68	3/32	2.4	100-120	30-80	14-38	1/16	1.6
2	50	0.154	3.91	3/32	2.4	110-130	30-80	14-38	1/16	1.6
2-1/2	64	0.203	5.16	1/8	3.2	120-140	30-80	14-38	1/16	1.6
3	76	0.216	5.49	1/8	3.2	135-155	30-80	14-38	3/32	2.4
3-1/2	89	0.226	5.74	1/8	3.2	140-160	30-80	14-38	3/32	2.4
4	102	0.237	6.02	1/8-5/32	3.2-4.0	150-170	35-80	17-38	3/32	2.4
5	127	0.258	6.55	1/8-5/32	3.2-4.0	170-190	35-80	17-38	3/32	2.4
6	152	0.280	7.11	1/8-5/32	3.2-4.0	185-205	50-80	24-38	3/32	2.4
8	203	0.322	8.18	5/32-3/16	4.0-4.8	200-220	50-80	24-38	3/32	2.4
10	254	0.365	9.27	5/32-3/16	4.0-4.8	220-240	50-80	24-38	3/32	2.4
12	305	0.406	10.31	5/32-3/16	4.0-4.8	235-255	50-80	24-38	3/32	2.4

Notes:

1. Tungsten electrode diameter is 1/8 in. (3.2 mm) for 1 to 3-1/2 in. (25 to 89 mm) pipe size and 3/16 in. (4.8 mm) for 4 to 12 in. (102 to 305 mm) pipe size.
2. Gas nozzle orifice diameter is 1/2 in. (12.7 mm).
3. Number of passes is 3 to 6 for 1 to 12 in. (25 to 305 mm) pipe size.

10/RECOMMENDED PRACTICES FOR GAS SHIELDED ARC WELDING

Table 7
Gas tungsten arc welding
Alternating current in the vertical position

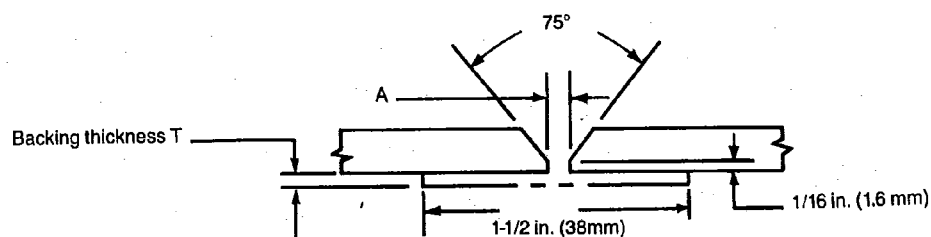


Nominal pipe size		Wall thickness		Welding rod dia.		Current ac	Argon flow		F		No. of passes
in.	mm	in.	mm	in.	mm	amp	cfh	l/m	in.	mm	
1	25	0.133	3.38	3/32	2.4	80-100	25-50	12-24	1/16	1.6	3-4
1-1/4	32	0.140	3.55	1/8	3.2	90-110	25-50	12-24	1/16	1.6	3-4
1-1/2	38	0.145	3.68	1/8	3.2	100-120	25-50	12-24	1/16	1.6	3-4
2	50	0.154	3.91	1/8	3.2	110-130	30-60	14-28	1/16	1.6	4-5
2-1/2	64	0.203	5.16	1/8	3.2	120-140	30-60	14-28	1/16	1.6	4-5
3	76	0.216	5.49	1/8	3.2	135-155	40-60	19-28	3/32	2.4	4-5
3-1/2	89	0.226	5.74	1/8	3.2	140-160	40-60	19-28	3/32	2.4	4-5
4	102	0.237	6.02	1/8	3.2	150-170	40-60	19-28	3/32	2.4	4-5
5	127	0.258	6.55	5/32-3/16	4.0-4.8	170-190	50-60	24-28	3/32	2.4	4-5
6	152	0.280	7.11	5/32-3/16	4.0-4.8	185-205	50-60	24-28	3/32	2.4	5-6
8	203	0.322	8.18	5/32-3/16	4.0-4.8	200-220	60-80	28-38	3/32	2.4	5-6
10	254	0.365	9.27	5/32-3/16	4.0-4.8	220-240	60-80	28-38	3/32	2.4	5-6
12	305	0.406	10.31	5/32-3/16	4.0-4.8	230-250	70-80	33-38	3/32	2.4	5-6

Notes:

1. Tungsten electrode diameter is 1/8 in. (3.2 mm) for 1 to 3-1/2 in. (25 to 89 mm) pipe size and 3/16 in. (4.8 mm) for 4 to 12 in. (102 to 305 mm) pipe size.
2. Gas nozzle orifice diameter is 1/2 in. (12.7 mm).

Table 8
Gas tungsten arc welding, electrode negative
Direct current in the horizontal rolled position



Edge preparation

A = 0 for no backing ring or removable backing ring

A = 1/4 in. (6.4 mm) max for integral backing ring

Nominal pipe size		Wall thickness		Current dcen	T		No. of passes ^a
in.	mm	in.	mm	amp	in.	mm	A = 0
1	25	0.133	3.38	40-50	0.072	1.83	1
1-1/4	32	0.140	3.55	40-50	0.072	1.83	1
1-1/2	38	0.145	3.68	50-60	0.072	1.83	1
2	50	0.154	3.91	50-60	0.093	2.36	1
2-1/2	64	0.203	5.16	60-90	0.093	2.36	1-2
3	76	0.216	5.49	60-90	0.093	2.36	1-2
3-1/2	89	0.226	5.74	80-105	0.093	2.36	1-2
4	102	0.237	6.02	80-105	0.125	3.18	1-2
5	127	0.258	6.55	80-105	0.125	3.18	1-2
6	152	0.280	7.11	80-105	0.187	4.75	2-3
8	203	0.322	8.18	90-120	0.187	4.75	2-3
10	254	0.365	9.27	90-120	0.187	4.75	2-4
12	305	0.406	10.31	90-120	0.187	4.75	2-4

Notes:

1. Tungsten (2% thorium) electrode diameter is 1/16 in. (1.6 mm).

2. Gas nozzle orifice diameter is 7/32 in. (5.6 mm).

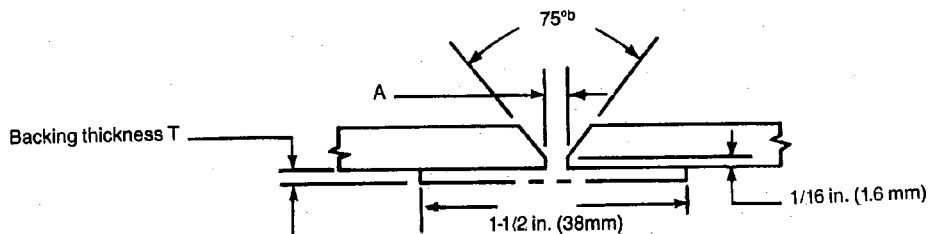
3. Welding rod diameter is 1/8 in. (3.2 mm).

4. Helium flow rate is 40 to 60 cfm (19-28 l/m).

a. More passes are required when A = 1/4 in. (6.4 mm)

12/RECOMMENDED PRACTICES FOR GAS SHIELDED ARC WELDING

Table 9
Gas tungsten arc welding, electrode negative
Direct current in the horizontal fixed position



Edge preparation

A = 0 for no backing ring or removable backing ring

A = 1/4 in. (6.4 mm) max for integral backing ring

Nominal pipe size		Wall thickness		Current dcen	T		No. of passes ^a
in.	mm	in.	mm	amp	in.	mm	A = 0
1	25	0.133	3.38	40-50	0.072	1.83	1-2
1-1/4	32	0.140	3.55	40-50	0.072	1.83	1-2
1-1/2	38	0.145	3.68	50-60	0.072	1.83	1-2
2	50	0.154	3.91	50-60	0.093	2.36	1-2
2-1/2	64	0.203	5.16	60-90	0.093	2.36	2-3
3	76	0.216	5.49	60-90	0.093	2.36	2-3
3-1/2	89	0.226	5.74	70-105	0.093	2.36	2-4
4	102	0.237	6.02	70-105	0.125	3.18	2-4
5	127	0.258	6.55	70-105	0.125	3.18	2-4
6	152	0.280	7.11	70-120	0.187	4.75	2-6
8	203	0.322	8.18	70-120	0.187	4.75	2-6
10	254	0.365	9.27	70-120	0.187	4.75	2-8
12	305	0.406	10.31	70-120	0.187	4.75	2-8

Notes:

1. Tungsten (2% thorium) electrode diameter is 1/16 in. (1.6 mm).

2. Gas nozzle orifice diameter is 7/32 in. (5.6 mm).

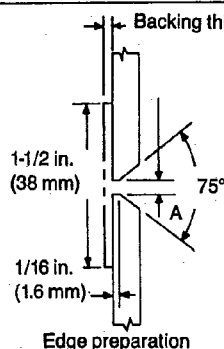
3. Welding rod diameter is 1/8 in. (3.2 mm).

4. Helium flow rate is 40 to 60 cfm (19-28 l/m).

a. Greater number of passes for bottom 90 degrees of pipe circumference and when A = 1/4 in. (6.4 mm)

b. 110 degree angle required on bottom 90 degrees of pipe—can be applied to full 360 degrees.

Table 10
Gas tungsten arc welding, electrode negative
Direct current in the vertical position



A = 0 for no backing ring or removable backing ring
 A = 1/4 in. (6.4 mm) max for permanent backing ring

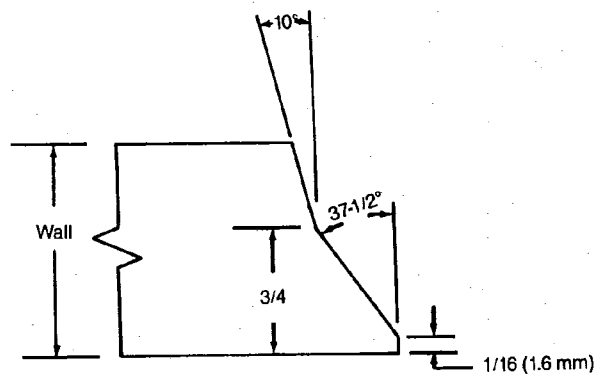
Nominal pipe size		Wall thickness		Current dcen	T		No. of passes ^a
in.	mm	in.	mm	amp	in.	mm	A = 0
1	25	0.133	3.38	40-50	0.072	1.83	1
1-1/4	32	0.140	3.55	40-50	0.072	1.83	1
1-1/2	38	0.145	3.68	50-60	0.072	1.83	1
2	50	0.154	3.91	50-60	0.093	2.36	1-2
2-1/2	64	0.203	5.16	60-90	0.093	2.36	1-2
3	76	0.216	5.49	60-90	0.093	2.36	1-2
3-1/2	89	0.226	5.74	80-105	0.093	2.36	1-2
4	102	0.237	6.02	80-105	0.125	3.18	2-3
5	127	0.258	6.55	80-105	0.125	3.18	2-3
6	152	0.280	7.11	80-105	0.187	4.75	2-3
8	203	0.322	8.18	100-130	0.187	4.75	2-3
10	254	0.365	9.27	100-130	0.187	4.75	3
12	305	0.406	10.31	100-130	0.187	4.75	3

Notes:

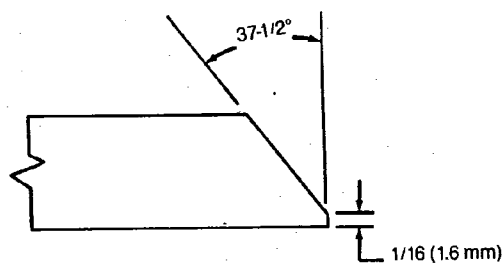
1. Tungsten (2% thorium) electrode diameter is 1/16 in. (1.6 mm).
2. Gas nozzle orifice diameter is 7/32 in. (5.6 mm).
3. Welding rod diameter is 1/8 in. (3.2 mm).
4. Helium flow rate is 40 to 60 cfm (19-28 l/m).

a. More passes are required when A = 1/4 in. (6.4 mm)

14/RECOMMENDED PRACTICES FOR GAS SHIELDED ARC WELDING



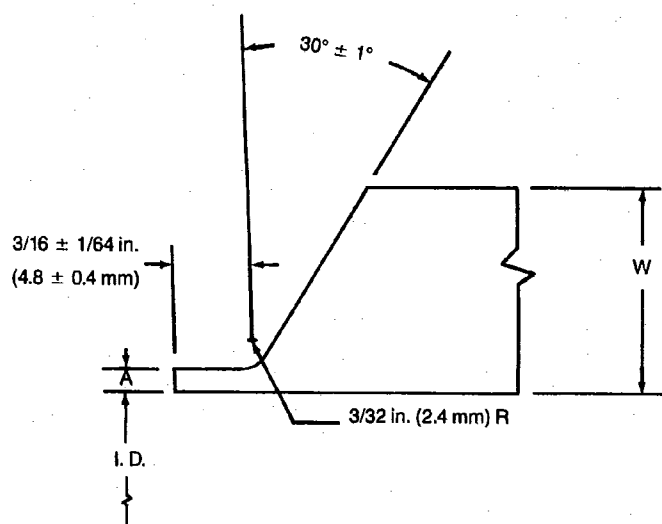
(a) Compound bevel—for wall thickness over 3/4 in. (19 mm)



(b) Straight bevel—for wall thickness 3/4 in. (19 mm) and less

Note: All dimensions except angles are in inches (mm).

Fig. 1—Standard V-groove bevels



Pipe size		A		W, max	
in.	mm	in.	mm	in.	mm
1/8 through 2-1/2	3.2 through 64	1/16 ± 1/64	1.6 ± 0.4	0.276	7.01
3 through 12	76 through 305	3/32 ± 1/64	2.4 ± 0.4	0.500	12.7

Fig. 2—Pipe end preparation for U-groove recommended for manual ac gas tungsten arc welding

16/RECOMMENDED PRACTICES FOR GAS SHIELDED ARC WELDING

sphere at the required welding current, but not so small that it overheats, causing the end to become unstable and fall from the electrode. It is also necessary to select the proper current setting for the thicknesses of base metal. Tables 2 through 10 show several of the factors which should be controlled, including tungsten electrode diameter, gas nozzle orifice, welding current, gas flow rate, filler rod diameter, and number of welding passes. These values can be varied, depending upon the actual weldment. However, they provide a good starting point to consistently provide welds of good quality.

7.2 Edge Preparation. Complete root penetration must be obtained by the root pass² of a pipe weld. This can be facilitated by a combination of proper edge preparation and welding technique. Complete root penetration can be obtained in welds in the horizontal rolled position with a $\frac{1}{16}$ in. (1.6 mm) root face and V-groove angles of 75 to 90 degrees.

When welding in the horizontal fixed position without backing, the U-groove should be used (see Figs. 2 and 3). A U-groove decreases the joint's heat conducting capacity and permits complete root penetration and fusion with a smaller weld pool. This smaller weld pool is more easily held in the overhead position by surface tension and the inert gas flow. When welding in the horizontal fixed position with backing, a V-groove may be used, provided that the bottom 90 degree quadrant of the joint is beveled to form a groove angle of 110 degrees.

Tables 2 through 10 show the variables which apply to gas tungsten arc and gas metal arc welding of schedule 40 pipe in the various positions. Table 11 indicates typical welding conditions for gas metal arc welding in the horizontal rolled position. The use of edge preparations other than those shown may require changes in the welding position. The use of edge preparations other than those shown may require changes in the welding conditions listed.

8. Weld Backing

Either permanent or removable backing may be used in the fabrication of pipe welds. Integral backings generally are not recommended for fluid flow because of the possibility of crevice corrosion; however, they commonly are used for electrical bus or structural applications.

8.1 Permanent Backings. Permanent backings should be of an alloy in the same Material No. Grouping³ as the pipe

2. Further information on root pass welding is available in ANSI/AWS D10.11, Recommended Practices for Root Pass Welding.

3. Material No. Groupings are listed in Table C2 of AWS B2.1-84, *Standard for Welding Procedure and Performance Qualification*.

being welded. They should be free of any projection into the joint (for root opening control), since the oxides on the faying surfaces will not break up, and incomplete root fusion will result. Flat or grooved aluminum backings are preferred and can be tack welded in place to maintain the root opening.

8.1.1 Spacing. Spacing between flat, permanent backings and the pipe I.D. is important. If a tight fit exists, the root opening should be adequate to permit a root pass to be made along each side as illustrated in Fig. 4(A). This would require a wider root opening than the $\frac{1}{4}$ in. (6.4 mm) maximum permitted in Tables 2 through 4 and 8 through 11.

8.1.2 Single Root Pass. If a single root pass is made with a tight fit between pipe and backing, either of the following problems can occur:

(a) A narrow root opening may cause bridging of the root and minimal fusion to the backing as shown in Fig. 4(B). A root opening of $\frac{3}{16}$ to $\frac{1}{4}$ in. (4.8 to 6.4 mm) should allow room for thorough arc cleaning and complete fusion to the backing.

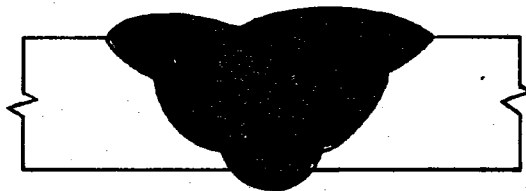
(b) A wider root opening may result in root undercut as shown in Fig. 4(C). The condition can be improved by providing for a space between the backing and the uneven tube surface as shown in Figs. 4(D) and 4(E).

8.2 Removable Backings. A removable backing can be a grooved and segmented collapsible unit or a tapered unit allowing a controlled root reinforcement, as shown in Fig. 4(E). The root opening should be a maximum of $\frac{1}{16}$ in. (1.6 mm) to avoid direct impingement of the arc upon the backing material. Non-magnetic stainless steel or "hard coat" anodized aluminum are commonly used backing materials. Grooved ceramic backings can also be employed. These are broken upon completion of the weld and flushed from the pipe.

9. Welding Technique

9.1 Gas Tungsten Arc Welding (Manual Welding). The sound welding of any joint requires proper edge preparation, cleanliness, and a good fit. Tungsten electrodes contaminated with aluminum shall not be used. The prepared edges should be cleaned to remove all traces of foreign material before the joint is assembled. After the joint has been properly aligned, it should be tack welded at three or more locations. The tack welds should have complete root penetration and be rather flat and should not exceed 1 in. (25 mm) in length. Three such welds equally spaced around the joint will usually suffice to maintain alignment.

When making a weld in the horizontal rolled position, either with or without backing, the first pass should be applied at about the 1 o'clock position as the pipe moves clockwise because vertical welding on aluminum should always be done in the upward direction. This provides a



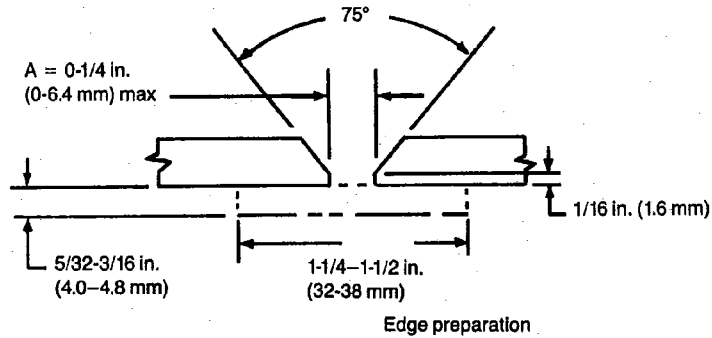
Advantages

1. Smooth, complete root penetration.
2. No concave root surfaces (suck-back).
3. No backing required.
4. Good for *all* fixed pipe positions.
5. Preheating not required.

Fig. 3—Finished weld in U-groove showing weld beads. Advantages are given of the U-groove with dimensions shown in Fig. 2 and techniques shown in Fig. 5.

18/RECOMMENDED PRACTICES FOR GAS SHIELDED ARC WELDING

Table 11
Gas metal arc welding
in horizontal rolled position



Nominal pipe size		Wall thickness		Electrode diameter		Current dc	Argon flow		No. of passes ^a
in.	mm	in.	mm	in.	mm	amp	cfh	l/m	A = 0
4	102	0.237	6.02	3/64	1.2	190-210	45	21	2
5	127	0.258	6.55	3/64	1.2	205-225	45	21	2
6	152	0.280	7.11	3/64	1.2	215-235	45	21	2
8	203	0.322	8.18	1/16	1.6	215-235	50	24	3
10	254	0.365	9.27	1/16	1.6	215-235	50	24	3
12	305	0.406	10.31	1/16	1.6	240-260	50	24	3

Note: Root opening = 0 for no backing ring or removable backing ring and 1/4 in. (6.4 mm) for permanent backing ring.

a. More passes required when A = 1/4 in. (6.4 mm).

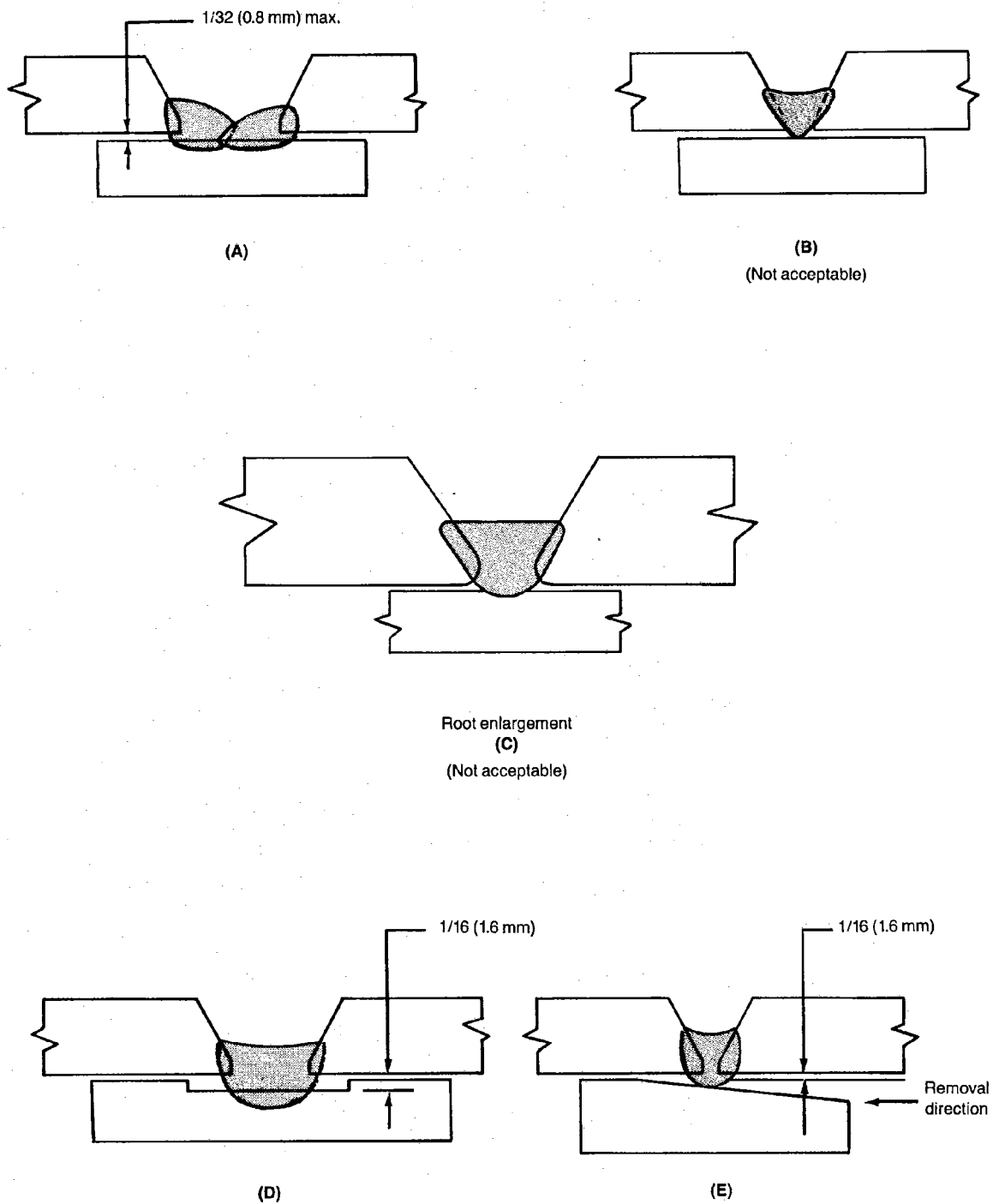


Fig. 4—Possible backing arrangements for use with V-groove welds

20/RECOMMENDED PRACTICES FOR GAS SHIELDED ARC WELDING

better opportunity to obtain complete root penetration and improved weld quality. The starts and stops of subsequent passes should be staggered. When completing the weld, the end should be tapered for about 1½ in. (38 mm) to avoid shrinkage craters. Stringer beads are used, except for the last or cover pass which can be weaved to suit. With direct current, electrode negative however, only stringer beads should be used.

When welding with the pipe in the vertical position, only stringer beads should be used.

When welding pipe in the horizontal fixed position, the root pass should be started near the bottom center; the weld should progress across the bottom, up one side, and across top center. The root pass is welded on the remaining circumference in a similar manner with the second bead overlapping the ends of the first bead (see Fig. 5).

The tungsten electrode should be pointed toward the center line of the pipe or tube (i.e., for butt joints, the electrode axis should be perpendicular to the pipe surface). The arc should be maintained at a controllable length, usually about ⅜ in. (4.8 mm) to ¼ in. (6.4 mm), or just long enough to prevent contamination of the electrode when the welding rod is added. The inert gas should be adjusted to flow at a rate which will provide good shielding.

The welding rod should be used in such a manner that it does not interfere with the stability of the arc. For ac welding, the best way to accomplish this is to direct the welding rod nearly tangent to the pipe at the location of the arc, and periodically insert the tip of the rod into the leading edge of the pool. The end of the rod must always remain within the gas shield. For dcen welding, the welding rod is added to the pool continuously. Smooth, uniform forward motion of the arc will cause best results; short, jerky movements will promote inclusions, rough appearance, and incomplete root penetration.

9.2 Gas Metal Arc Welding. Semi-automatic gas metal arc welding is generally limited to the horizontal rolled position. The pipe ends should be properly prepared for this process as shown in Table 11. The pipe ends and the backing ring should be thoroughly cleaned to remove all traces of foreign material. The backing ring and edges should be properly aligned and fitted, and three or more tack welds made to maintain alignment and root opening. Usually, the root opening is ⅛ to ¼ in. (3.2 to 6.4 mm) depending on wall thickness. Tack welds should be small, have complete penetration, and be up to 1 in. (25 mm) in length. Three equally spaced tacks will maintain alignment.

Welding should begin at the top center while the pipe is rotating at a uniform speed. The arc should be established in the groove, and it can be started ahead of the start of welding which will permit the weld bead to cover the arc strikes. A leading torch angle of 10 or 15 degrees is used.

The first pass should be a stringer bead, taking care to obtain complete fusion to the backing.

When terminating any weld bead, the arc should be manipulated to reduce the depth of fusion and weld pool size, thereby decreasing the final shrinkage area. This can usually be accomplished by rapidly increasing the speed of welding for the final 1 to 2 in. (25 to 50 mm) of the weld length.

The current settings shown in Table 11 will provide a good starting point for welding the various sizes of pipes. These values can be modified, depending upon the welder's experience. It should be noted that the arc voltage has an important influence on the smooth deposition of filler metal. It may not always be possible to measure arc voltage, but there will be ample evidence of its influence. Spatter which accompanies welding usually is caused by low voltage, and the voltage should be increased to correct this condition. The voltage setting will also influence the size of the weld bead, since a high voltage will form a wider bead than will a lower voltage.

10. Heat Treatment

10.1 Preheating. Preheating is generally not recommended for aluminum pipe. However, if preheat is required because of very low ambient temperatures or base metal thickness, the temperature should not exceed 200° F (93° C) for the 5000 series alloys containing 3 percent or more magnesium, or 350° F (176° C) for other alloys. Time at temperature should be held to a minimum to minimize impairment of base metal properties. Local over-heating should be avoided. The use of crayons or other temperature indicators is recommended because aluminum does not change color at temperatures below its melting point.

10.2 Postweld Heat Treatment. Postweld heat treatment of aluminum piping systems is seldom practical, or recommended.

11. Code Requirements—Welding Qualifications and Design

Several national standards and specifications contain requirements which apply to the welding of aluminum. An example is the ASME Boiler and Pressure Vessel Code, of which Section II and Section VIII, Divisions 1 and 2 include requirements for the material, design, and fabrication of aluminum vessels. Section IX, Welding Qualifications, includes a section on nonferrous materials, among which are

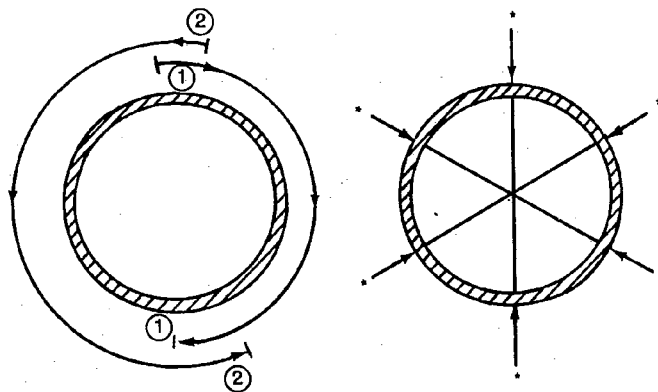
the standard aluminum pipe alloys. Some of the nonstandard aluminum alloys are also covered, and certain ASME code cases provide requirements for the design and fabrication of vessels and qualifications for welds in aluminum alloys that are not covered by Section VIII or Section IX.

Other standards applying to aluminum alloys include: (1) AWS B2.1, *Standard for Welding Procedure and Performance Qualification*, (2) ANSI B31.3, *Petroleum Refinery Piping*, (3) ANSI B31.5, *Refrigeration Piping*, (4) ANSI B31.1, *Power Piping*, (5) API 620, Appendix Q, *LNG Storage Tanks*, and (6) AWS D1.2, *Structural Welding Code-Aluminum*.

12. Safe Practices

The potential hazards of arc welding are fumes and gases, electric shock, infrared and ultraviolet radiation, burns, fire, explosion and, at times, noise. These hazards are described in detail in Chapter 10, Volume 5, Seventh Edition of the *Welding Handbook* and the latest edition of ANSI/ASC Z49.1, *Safety in Welding and Cutting* published by the American Welding Society.

Other sources of information, including a Supplementary Reading List, are available in Appendix C.



*Orientation of GTAW torch

1. Weld vertically upward.
2. Overlap ends of first bead 1 in. (25 mm) minimum.
3. Maintain torch direction toward pipe center.
4. Alternate sides of pipe for successive passes.

Fig. 5—Gas tungsten arc welding torch directions, horizontal fixed position

Appendix A

**Nominal composition of aluminum alloys—percent of alloying elements—
aluminum and normal impurities constitute remainder**

Alloy								
Wrought alloys	Silicon	Copper	Manganese	Magnesium	Chromium	Zinc	Titanium	Aluminum and others
1060								99.60 min.
1100 ^a		0.12						99.00 min.
1350								99.50 min.
3003		0.12	1.2					Rem.
3004			1.2	1.0				Rem.
4043 ^a	5.2							Rem.
4047 ^{a,b}	12.0							Rem.
4145 ^{a,c}	10.0	4.0						Rem.
5050				1.4				Rem.
5052				2.5	0.25			Rem.
5083			0.7	4.45	0.15			Rem.
5086			0.45	4.0	0.15			Rem.
5154				3.5	0.25			Rem.
5183 ^a			0.8	4.75	0.15			Rem.
5254				3.5	0.25			Rem.
5356 ^a			0.12	5.0	0.12			Rem.
5454			0.8	2.7	0.12			Rem.
5456			0.8	5.1	0.12			Rem.
5554 ^a			0.8	2.7	0.12		0.12	Rem.
5556 ^a			0.8	5.1	0.12		0.12	Rem.
5652				2.5	0.25			Rem.
5654 ^a				3.5	0.25		0.10	Rem.
6061	0.6	0.27		1.0	0.20			Rem.
6063	0.40		0.7					Rem.
6101	0.50			0.6				Rem.
6351	1.0		0.6	0.6				Rem.
7072						1.0		Rem.
Cast alloys								
356.0	7.0		0.30					Rem.
443.0	5.2							Rem.
514.0			4.0			1.8		Rem.

a. Beryllium 0.0008% max for welding electrode and rod only.

b. Alternate designation is 718.

c. Alternate designation is 716.

Appendix B

Pipe diameters, wall thicknesses, and weights

Nominal pipe size	Schedule number	Outside diameter,*		Inside diameter,*		Wall thickness,*		Weight*	
		in.	mm	in.	mm	in.	mm	lbs/ft	kg/m
1/8	40	0.405	10.3	0.269	6.83	0.068	1.73	0.085	0.126
	80	0.405	10.3	0.215	5.46	0.095	2.41	0.109	0.162
1/4	40	0.540	13.7	0.364	9.24	0.088	2.23	0.147	0.219
	80	0.540	13.7	0.392	7.67	0.119	3.02	0.185	0.275
3/8	40	0.675	17.1	0.493	12.52	0.091	2.31	0.196	0.292
	80	0.675	17.1	0.423	10.74	0.126	3.20	0.256	0.381
1/2	5	0.840	21.3	0.710	18.03	0.065	1.65	0.185	0.275
	10	0.840	21.3	0.674	17.12	0.083	2.11	0.232	0.345
	40	0.840	21.3	0.622	15.80	0.109	2.77	0.294	0.473
	80	0.840	21.3	0.545	13.84	0.147	3.73	0.376	0.559
	160	0.840	21.3	0.466	11.84	0.187	4.75	0.451	0.671
3/4	5	1.050	26.7	0.920	23.37	0.065	1.65	0.237	0.353
	10	1.050	26.7	0.884	22.45	0.083	2.11	0.297	0.442
	40	1.050	26.7	0.824	20.93	0.113	2.87	0.391	0.582
	80	1.050	26.7	0.742	18.85	0.154	3.91	0.510	0.759
	160	1.050	26.7	0.614	15.60	0.218	5.54	0.670	0.997
1	5	1.315	33.4	1.185	30.10	0.065	1.65	0.300	0.446
	10	1.315	33.4	1.097	27.86	0.109	2.77	0.486	0.723
	40	1.315	33.4	1.049	26.64	0.133	3.38	0.581	0.865
	80	1.315	33.4	0.957	24.31	0.179	4.55	0.751	1.118
	160	1.315	33.4	0.815	20.70	0.250	6.35	0.984	1.464
1-1/4	5	1.660	42.2	1.530	38.86	0.065	1.65	0.383	0.570
	10	1.660	42.2	1.442	36.63	0.109	2.77	0.625	0.930
	40	1.660	42.2	1.380	35.05	0.140	3.56	0.786	1.170
	80	1.660	42.2	1.278	32.46	0.191	4.85	1.037	1.543
	160	1.660	42.2	1.160	29.46	0.250	6.35	1.302	1.938
1-1/2	5	1.900	48.3	1.770	44.96	0.065	1.65	0.441	0.656
	10	1.900	48.3	1.682	42.72	0.109	2.77	0.721	1.073
	40	1.900	48.3	1.610	40.89	0.145	3.68	0.940	1.399
	80	1.900	48.3	1.500	38.10	0.200	5.08	1.256	1.869
	160	1.900	48.3	1.338	33.98	0.281	7.14	1.681	2.502
2	5	2.375	60.3	2.245	57.02	0.065	1.65	0.555	0.826
	10	2.375	60.3	2.157	54.79	0.109	2.77	0.913	1.359
	40	2.375	60.3	2.067	52.50	0.154	3.91	1.264	1.881
	80	2.375	60.3	1.939	49.25	0.218	5.54	1.737	2.585
	160	2.375	60.3	1.689	42.90	0.343	8.71	2.575	3.832

*All weights and dimensions are nominal.

(Continued)

26/APPENDIX

Pipe diameters, wall thicknesses, and weights (Continued)

Nominal pipe size	Schedule number	Outside diameter,*		Inside diameter,*		Wall thickness,*		Weight*	
		in.	mm	in.	mm	in.	mm	lbs/ft	kg/m
2-1/2	5	2.875	73.0	2.709	68.81	0.083	2.10	0.856	1.274
	10	2.875	73.0	2.635	66.93	0.120	3.05	1.221	1.817
	40	2.875	73.0	2.469	62.71	0.203	5.16	2.004	2.982
	80	2.875	73.0	2.323	59.00	0.276	7.01	2.650	3.944
	160	2.875	73.0	2.125	53.97	0.375	9.52	3.464	5.155
3	5	3.500	88.9	3.334	84.68	0.083	2.10	1.043	1.552
	10	3.500	88.9	3.260	82.80	0.120	3.05	1.498	2.229
	40	3.500	88.9	3.068	77.93	0.216	5.49	2.621	3.900
	80	3.500	88.9	2.900	73.66	0.300	7.62	3.547	5.278
	160	3.500	88.9	2.626	66.70	0.437	11.10	4.945	7.359
3-1/2	5	4.000	102	3.834	97.38	0.083	2.10	1.201	1.787
	10	4.000	102	3.760	95.50	0.120	3.05	1.722	2.563
	40	4.000	102	3.548	90.12	0.226	5.74	3.151	4.689
	80	4.000	102	3.364	85.45	0.318	8.08	4.326	6.438
4	5	4.500	114	4.334	110.08	0.083	2.10	1.354	2.015
	10	4.500	114	4.260	108.20	0.120	3.05	1.942	2.890
	40	4.500	114	4.026	102.26	0.237	6.02	3.733	5.555
	80	4.500	114	3.826	97.18	0.337	8.56	5.183	7.713
	120	4.500	114	3.626	92.10	0.437	11.10	6.560	9.762
	160	4.500	114	3.438	87.32	0.531	13.49	7.786	11.587
5	5	5.563	141	5.345	135.76	0.109	2.77	2.196	3.268
	10	5.563	141	5.295	134.49	0.134	3.40	2.688	4.000
	40	5.563	141	5.047	128.19	0.258	6.55	5.057	7.526
	80	5.563	141	4.813	122.25	0.375	9.52	7.188	10.697
	120	5.563	141	4.563	115.90	0.500	12.70	9.353	13.919
	160	5.563	141	4.313	109.55	0.625	15.87	11.400	16.965
6	5	6.625	168	6.407	162.74	0.109	2.77	2.624	3.905
	10	6.625	168	6.357	161.47	0.134	3.40	3.213	4.781
	40	6.625	168	6.065	154.05	0.280	7.11	6.564	9.768
	80	6.625	168	5.761	146.33	0.432	10.97	9.884	14.709
	120	6.625	168	5.501	139.72	0.562	14.27	12.59	18.736
	160	6.625	168	5.189	131.80	0.718	18.24	15.67	23.320
8	5	8.625	219	8.407	213.54	0.109	2.77	3.429	5.103
	10	8.625	219	8.329	211.56	0.148	3.76	4.635	6.898
	20	8.625	219	8.125	206.37	0.250	6.35	7.735	11.511
	30	8.625	219	8.071	205.00	0.277	7.04	8.543	12.713
	40	8.625	219	7.981	202.72	0.322	8.18	9.873	14.693
	60	8.625	219	7.813	198.45	0.406	10.31	12.33	18.349
	80	8.625	219	7.625	193.67	0.500	12.70	15.01	22.338
	100	8.625	219	7.439	188.95	0.593	15.06	17.60	26.192
	120	8.625	219	7.189	182.60	0.718	18.24	20.97	31.207
	140	8.625	219	7.001	177.82	0.812	20.62	23.44	34.883
	160	8.625	219	6.813	173.05	0.906	23.01	25.84	38.455

*All weights and dimensions are nominal.

(Continued)

Pipe diameters, wall thicknesses, and weights (Continued)

Nominal pipe size		Outside diameter,*		Inside diameter,*		Wall thickness,*		Weight*	
in.	Schedule number	in.	mm	in.	mm	in.	mm	lbs/ft	kg/m
10	5	10.750	273	10.482	266.24	0.134	3.40	5.256	7.822
	10	10.750	273	10.420	264.67	0.165	4.19	6.453	9.603
	20	10.750	273	10.250	260.35	0.250	6.35	9.698	14.432
	30	10.750	273	10.136	257.45	0.307	7.80	11.84	17.620
	40	10.750	273	10.020	254.51	0.365	9.27	14.00	20.835
	60	10.750	273	9.750	247.65	0.500	12.70	118.93	28.171
	80	10.750	273	9.564	242.93	0.593	15.06	22.25	33.112
	100	10.750	273	9.314	236.58	0.718	18.24	26.61	39.601
12	5	12.750	324	12.420	315.47	0.165	4.19	7.673	11.419
	10	12.750	324	12.390	314.71	0.180	4.57	8.361	12.443
	20	12.750	324	12.250	311.15	0.250	6.35	11.55	17.188
	30	12.750	324	12.090	307.09	0.330	8.38	15.14	22.531
	40	12.750	324	11.938	303.22	0.406	10.31	18.52	27.561
	60	12.750	324	11.626	295.30	0.562	14.27	25.3	37.651
	80	12.750	324	11.376	288.95	0.687	17.45	30.62	45.568

*All weights and dimensions are nominal.

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 51B-1977, 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 Nostrand Reinhold Co., 1981.
- (5) Dalziel, Charles F., Effects of Electric Current on Man, *ASME 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

Appendix D

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 D10.8, Chromium-Molybdenum Steel Piping and Tubing, Recommended Practices for Welding |
| 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 D10.12, Plain Carbon Steel Pipe, Recommended Practices and Procedures for Welding |