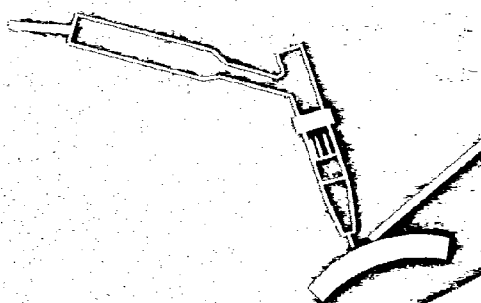
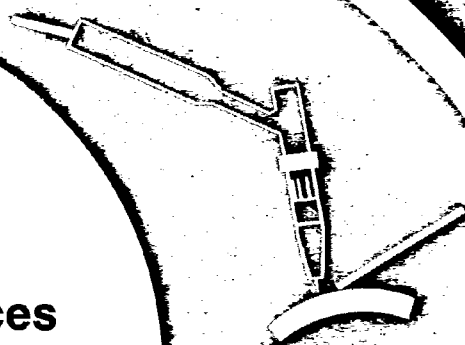


**Recommended Practices
for Gas Tungsten Arc
Welding of Titanium
Pipe and Tubing**



American Welding Society

Keywords—Titanium pipe, gas
tungsten arc welding,
recommended practice

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Recommended Practices for Gas Tungsten Arc Welding of Titanium Pipe and Tubing

Superseding
ANSI/AWS D10.6-85

Prepared by
AWS Committee on Piping and Tubing

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

This standard summarizes information on the welding of titanium. It explains the special precautions necessary to shield the molten and hot metal from atmospheric contamination. Various methods of checking weld quality are also presented.



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Foreword

(This Foreword is not a part of ANSI/AWS D10.6-91, *Recommended Practices for Gas Tungsten Arc Welding of Titanium Pipe and Tubing*, but is included for information purposes only.)

Welding of titanium piping is done primarily with the Gas Tungsten Arc Welding process, though other welding methods are used to join other titanium product forms and components. Since this standard deals only with titanium piping and tubing, this document is confined to a discussion of gas tungsten arc welding.

The first version of D10.6 was published in 1959 as a Committee Report—*Gas Tungsten Arc Welding of Titanium Piping and Tubing*. This document was revised and updated in 1973 under the same title.

In 1985, the standard was rewritten as ANSI/AWS D10.6-85, *Recommended Practices for Gas Tungsten Arc Welding of Titanium Pipe and Tubing*. This version contained a large amount of added information on weld shielding and testing for weld quality.

The present document, ANSI/AWS D10.6-91, bears the same title and has been updated to cover the latest alloys and filler metals and to “fine tune” much of the information previously presented.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, Piping and Tubing Committee, American Welding Society, 550 N. W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

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Recommended Practices for Gas Tungsten Arc Welding of Titanium Piping and Tubing

1. Scope

This document summarizes information on the welding of titanium pipe.¹ The information has been collected from the welding literature and from various company shops and laboratories. The document is intended to serve as a welding guide.

2. Basic Information

In general, titanium pipe can be welded using GTAW techniques similar to those used for welding stainless steel pipe. However, the following paragraphs describe two fundamental differences that must be understood before satisfactory welds can be made.

2.1 Absorption. Titanium, at temperatures of 1200°F (650°C) and higher, will absorb hydrogen, oxygen, and nitrogen from the atmosphere. These elements, even in very small quantities, will cause embrittlement of titanium welds and heat-affected zones.

2.2 Reactions. Molten titanium reacts strongly with practically all materials, including refractories and

carbon. The reaction products become impurities, and they will impair the ductility and toughness of the welded pipe joint.

2.3 The above differences make it necessary that the weld and adjacent heated areas on the inside and the outside of the pipe be thoroughly shielded from the atmosphere while at welding temperatures. Equally important, the parts to be welded must be meticulously cleaned before welding.

3. Welding Process

Titanium pipe as described herein is readily welded by the gas tungsten arc welding (GTAW) process, both manually and automatically. For fundamentals of this process, see AWS C5.5, *Recommended Practices for Gas Tungsten Arc Welding*.

4. Power Sources

Direct current electrode negative (DCEN), usually supplied by constant-current generators or rectifiers, is used for the welding of titanium pipe. The power source should maintain the current within narrow limits and provide for close adjustment in the lower current ranges.

1. Where *pipe* is used in this document, it refers to both piping and tubing.

Table 1
Chemical Composition Requirements of Base Metal
(From ASTM B337)

Element	Composition, %					
	Grade 1	Grade 2	Grade 3	Grade 7	Grade 9	Grade 12
Nitrogen, max	0.03	0.03	0.05	0.03	0.02	0.03
Carbon, max	0.10	0.10	0.10	0.10	0.05	0.08
Hydrogen, max	0.015	0.015	0.015	0.015	0.013	0.015
Iron, max	0.20	0.30	0.30	0.30	0.25	0.30
Oxygen, max	0.18	0.25	0.35	0.25	0.12	0.25
Palladium	—	—	—	0.12 to 0.25	—	—
Aluminum	—	—	—	—	2.5 to 3.5	—
Molybdenum	—	—	—	—	—	0.2 to 0.4
Vanadium	—	—	—	—	2.0 to 3.0	—
Nickel	—	—	—	—	—	0.6 to 0.9
Residuals (each), max	0.1	0.1	0.1	0.1	0.1	0.05
Residuals (total), max	0.4	0.4	0.4	0.4	0.4	0.3
Titanium, (by difference)	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

Superimposed high-frequency (hf) current is strongly recommended for arc initiation to prevent contamination of the weld. A foot-pedal, or a hand-operated contactor which includes current control, is highly desirable.

Provision must be made for flow of shielding gas through the torch before arc initiation and after the arc is broken.

5. Tungsten Electrodes

Thoriated tungsten electrodes, designated EWTh-2 in the latest edition of AWS A5.12, *Specification for Tungsten Arc Welding Electrodes*, are preferred. Electrode tips should be ground to a point, then flattened

slightly. The exact shape and dimensions may vary for different applications or conditions.

6. Titanium Grades (Base Metal)

Six grades of titanium are commonly used for pipe and tubing. They are covered by ASTM B337 for pipe, B338 for tubing, and B363 for fittings. (See Tables 1 and 2 for the chemical and mechanical requirements for B337. Requirements for B338 and B363 are similar to those for B337). The microstructure of these grades is essentially single-phase alpha titanium. These grades are not hardenable by heat treatment. Certain other grades such as alpha-beta titanium alloys have been fabricated into pipe;

Table 2
Tensile Requirements of Base Metal
(From ASTM B337)

Tensile Strength			Yield Strength, 0.2% Offset Yield				Elongation in 2 in. or 50 mm, Min, %
min							
			Min		Max		
Grade	ksi	MPa	ksi	MPa	ksi	MPa	
1	35	240	25	170	45	310	24
2	50	345	40	275	65	450	20
3	65	450	55	380	80	550	18
7	50	345	40	275	65	450	20
9A	125	860	105	725	—	—	10
9B	90	620	70	485	—	—	15
12	70	483	50	345	—	—	18

Notes:

- Grade 9A properties are for cold-worked and stress-relieved material.
- Grade 9B properties are for annealed material.

Table 3
Chemical Composition Requirements for Titanium Filler Metals
Weight Percent ^{a, b}
(From ANSI/AWS A5.16)

AWS Classification	UNS ^c Number	Carbon	Oxygen	Hydrogen	Nitrogen	Aluminum	Vanadium	Iron	Other
ERTi-1	R50100	0.03	0.10	0.005	0.015	—	—	0.10	—
ERTi-2	R50120	0.03	0.10	0.008	0.020	—	—	0.20	—
ERTi-3	R50125	0.03	0.10–.15	0.008	0.020	—	—	0.20	—
ERTi-4	R50130	0.03	0.15–.25	0.008	0.020	—	—	0.30	—
ERTi-7	R52401	0.03	0.10	0.008	0.020	—	—	0.20	Pd 0.12–.25
ERTi-9	R56320	0.03	0.12	0.008	0.020	2.5–3.5	2.0–3.0	0.25	Yt 0.005
ERTi-9ELI	R56321	0.03	0.10	0.005	0.012	2.5–3.5	2.0–3.0	0.20	Yt 0.005
ERTi-12	R53400	0.03	0.25	0.008	0.020	—	—	0.030	Mo 0.2–0.4 Ni 0.6–0.9

a. Titanium constitutes the remainder of the composition.

b. Single values are maximum.

c. SAE/ASTM Unified Numbering Systems for Metals and Alloys.

however, they are not covered by this document. The manufacturers of these alloys should be consulted for welding recommendations.

7. Filler Metals

7.1 Filler Metal Classification. Bare welding rods and electrodes are commercially available for welding titanium pipe and should conform to AWS Classifications ERTi-1, ERTi-2, ERTi-3, ERTi-4, ERTi-7, ERTi-9, ERTi-9ELI, and ERTi-12 in the latest edition of ANSI/AWS A5.16, *Specification for Titanium and Titanium Alloy Bare Welding Rods and Electrodes*. The other welding rods listed in ANSI/AWS A5.16 do not apply to welding the base metals covered by this standard. See Table 3 for chemical composition requirements for filler metals.

7.2 Welding Rod Size. For manual welding, welding rod up to 1/16 in. (1.6 mm) diameter is suitable for welding pipe with wall thickness up to about 0.175 in. (4.4 mm). Above that thickness, 3/32 in. (2.4 mm), 1/8 in. (3.2 mm), or 5/32 in. (4.0 mm) welding rod may be used.

Welding rods are supplied in straight lengths or in coils without support. Welding wire is wound on spools for automatic gas tungsten arc welding (GTAW).

For automatic welding, wire diameters of 0.035 in. (0.8 mm), 0.045 in. (1.1 mm), and 1/16 in. (1.6 mm) are available.

7.3 Filler Metal Application. Generally, titanium filler metal is selected to match the composition of the base metal. However, a corrosive environment or high-

temperature service may dictate the use of nonmatching filler metals. ERTi-1, ERTi-2, ERTi-3, and ERTi-4 filler metals are referred to as commercially pure titanium, with the level of impurities increasing slightly from ERTi-1 to ERTi-4. While any of these alloys may be used with B337 or B338 Grades 1, 2, and 3, service conditions should be considered. Normally, ERTi-7 would be used with base metal Grade 7, ERTi-9 with Grade 9, and ERTi-12 with Grade 12, if corrosive environment or high-temperature-strength requirements did not dictate other filler metals. Refer to the Appendix of the latest edition of ANSI/AWS A5.16.

8. Joint Design

Square-groove butt joints are used on piping with walls up to 0.093 in. (2.4 mm) thick and a single-V-groove (75 degree groove angle) on walls from 0.093 in. (2.4 mm) to 0.375 in. (9.5 mm) thick. U-grooves are used for wall thicknesses over 0.375 in. (9.5 mm). The various joint designs are shown in Figure 1.

9. Joint Preparation

Joints may best be prepared by sawing, machining, or milling. Such operations should not overheat the metal, and should be done with care to ensure accurate fit. Hand grinding can be employed if done with caution to avoid over-heating. Clean grinding wheels should be used, and they should be dressed frequently. Carbide rotary files are also useful. Soft or rubber-bonded wheels should not be used. Abrasive particles embedded in ground surfaces should be removed by filing or machining. Clamps and fixtures should be kept clean to minimize contamination by grease and dirt in the joint area.

10. Pickling and Cleaning

10.1 Pickling Procedure. Scale formed on the pipe at temperatures up to 1100°F (600°C) can be removed by pickling in the following solution:

Nitric acid—30–40%

Hydrofluoric acid—4–5%

Water—balance

Temperature—room temperature

Time—2–20 min. (depending on scale thickness)

CAUTION: Chemical solutions require extreme care in mixing and use.

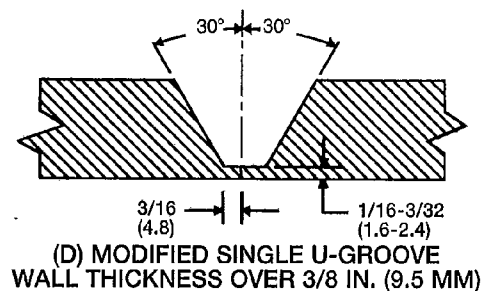
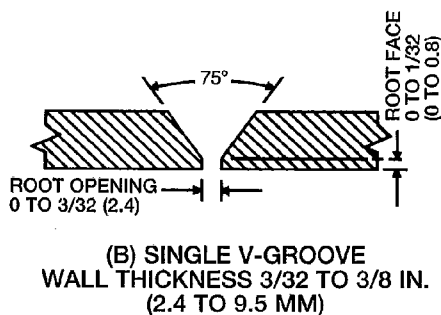
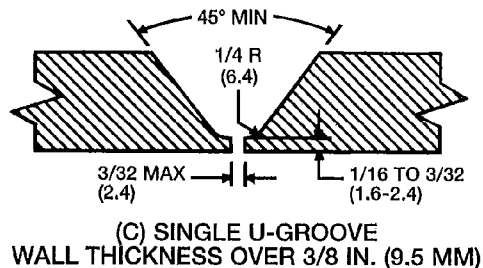
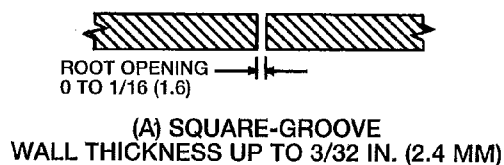
Always add acids to cold water while stirring.

Never allow hydrofluoric acid to contact the skin.

The nitric acid concentration should be maintained above 20% to minimize hydrogen absorption and consequent embrittlement. After pickling, the pipe should be rinsed in hot water or alcohol and dried. (Note: Solutions described above contain hazardous chemicals. Strict precautions are necessary in their use and disposal.) Scale

formed at temperatures above 1100°F (600°C) is thicker and more refractory than that formed at lower temperatures. It may require molten salt baths or mechanical means for removal. These treatments should be followed by pickling as described above.

10.2 Other Cleaning Procedures. Pipe received from primary fabricators is usually scale-free and requires only simple degreasing or abrasive cleaning to prepare it for welding. Degreasing may be accomplished by an alkaline wash, a solvent wash, or both. The alkaline wash may be a dilute solution of sodium hydroxide; the solvent wash may be acetone, alcohol, or methyl ethyl ketone. Abrasive cleaning should be used with care. Any adhering particles should be removed by filing or other mechanical means. Light power brushing with a stainless steel brush is acceptable; however, the brush should be clean and used only for titanium.



NOTE: ALL DIMENSIONS ARE IN INCHES (MILLIMETERS)

Figure 1—Titanium Pipe Joint Design

If an air-driven tool is used, degreasing is often necessary because such tools may exhaust air which has been contaminated with lubricants.

11. Fitting and Tacking

11.1 Accuracy. Accurate fitting is essential. Poor fit not only allows the molten metal to drop through but also makes purging more difficult by increasing the possibility of contamination from air.

11.2 Clamping. For girth welds in pipe, a clamping device similar to that shown in Figure 2 is suggested. This unit incorporates a split copper ring to hold the pipe in proper alignment. Where possible, clamping devices should be designed to make tack welding unnecessary.

11.3 Tack Welding. When tack welds are used, they should be welded under the same conditions (including back purging) as the final weld. Tack welds should be tapered or feathered to aid proper fusion of the root bead. If a tack weld contains a crack, it should be removed, shielding improved, and another tack weld made before proceeding.

12. Preweld Cleaning

12.1 Joints. Thorough cleaning of joints and filler metal immediately before welding is imperative. Mechanical cleaning may be required to remove oxides. All oil or grease residue on the pipe should be removed by an alcohol, acetone, or methyl ethyl ketone wash. Chlorinated solvents should never be used for cleaning, because their residues may lead to cracking in the weld and heat-affected zone. Once the weld joint has been cleaned, it should be kept entirely free of contamination, including fingerprints, until welding begins. Wrapping the joint in clean, dry, cloth or paper, and handling the parts with white gloves are good practices.

12.2 Filler Metal. Welding rod should be clean and bright. To insure cleanliness, the rod should be wiped immediately before use with a clean cloth saturated with a nonchlorinated solvent such as acetone or methyl ethyl ketone, then thoroughly dried with a clean, lint-free cloth. Welding rod once removed from its container should not be returned to the container without being cleaned again. The container should be properly marked.

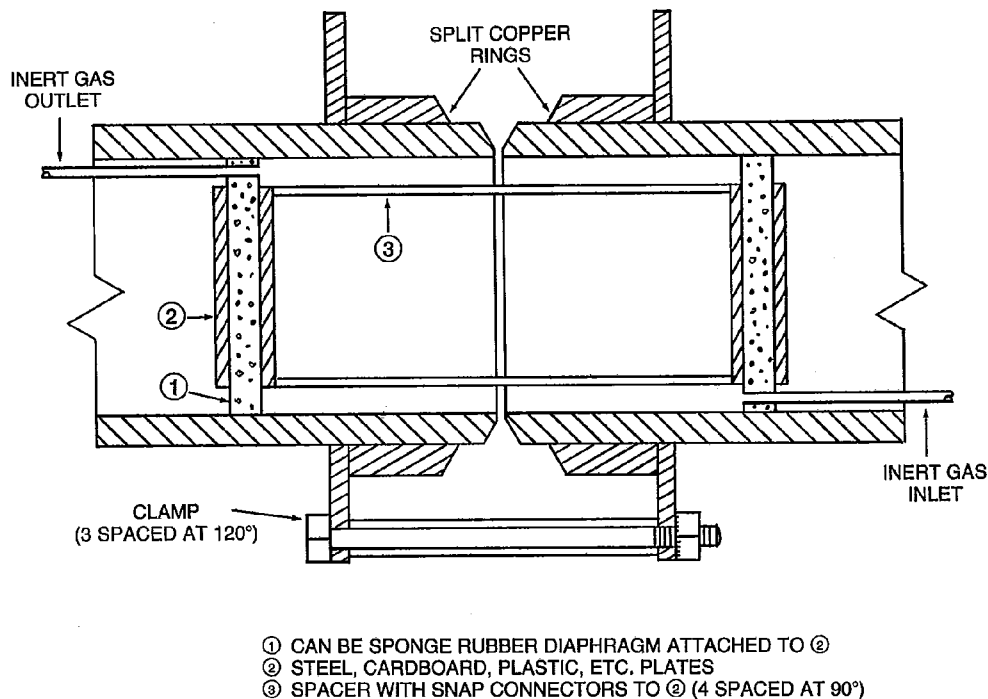


Figure 2—Gas Purging and Assembly Clamping Device

13. Gas Shielding

13.1 Gas Used. Only argon or helium of high purity (99.995% min) should be used. Mixtures of argon and helium are also used (typically 70% argon, 30% helium). The dew point of these gases should be -75°F (-59°C) or lower. Argon is the most commonly used shielding gas, as well as the trailing shielding gas. Argon provides greater arc stability than helium, and it is a more effective shield because of its higher density. Argon is also more readily available and less costly than helium. Helium may be selected where increased penetration is desired for heavy wall pipe. The gas flow should be high enough to shield the weld, but not so high as to cause turbulence. Flowmeters are usually used for all gas shielding.

13.2 Gas Distribution. Manifolds, station valves, regulators, flowmeters, hoses, tubing, torches, and other associated equipment must be clean, leak-free, and free of moisture. The hose used for the shielding gas should be clean, nonporous, and flexible, made of vinyl or other suitable plastic. Rubber hose should not be used because it absorbs air. The adequacy of the shielding gas can be verified using the test described in 13.6.

13.3 Trailing Shields. Trailing shields are used to protect the weld and heat-affected zones until they cool below 1000°F (540°C). Shields for circumferential pipe welds (where the pipe is rotated) can be separate from the torch and may be designed to fit snugly part-way around the pipe, as shown in Figure 3. The inert gas is released through a diffuser which streamlines the flow of gas over the weld and provides a soft, uniform distribution. Gas turbulence must be avoided, as it can cause contamination by air. Shields for circumferential welds where the pipe is fixed may be attached to the torch. One

torch trailing shield is illustrated in Figure 4. Variations of this shielding device may be adapted to fabrication conditions.

13.4 Gas Nozzles. Nozzle diameters depend upon the weld size; however, the largest practical diameter should be used. Nozzles can be standard or preferably gas lens types. The shielding gas flow rate should be proportional to the nozzle size to avoid turbulence from excessive velocity.

13.5 Root Shielding. Argon gas should be used to shield the inside diameter of the weld joint during welding operations. A simple and effective method of confining the gas under the weld is shown in Figure 2. This is practical when dams can readily be removed after the weld is completed.

When rigid dams cannot be removed after welding, a satisfactory dam can be made with water dissolvable paper stuffed in the ID of the pipe on each side of the weld joint. After the joint is completed, the dam can be dissolved with water being forced through the pipe.

When use of dams is impractical, the entire pipe should be filled with gas. A convenient means of confining the gas is to seal the ends of the pipe with plastic film and masking tape. Table 4 shows the purging requirements for various diameters of pipe. For further information refer to ANSI/AWS D10.11, *Recommended Practices for Root Pass Welding of Pipe Without Backing*.

13.6 Torch Shielding Gas and Purge Test. The effectiveness of the torch shielding gas and the back purge may be tested by a puddle test using 1/16 in. (1.6 mm) thick titanium sheet that has been properly cleaned. The sheet is placed over the joint after the pipe is purged, as shown in Figure 5.

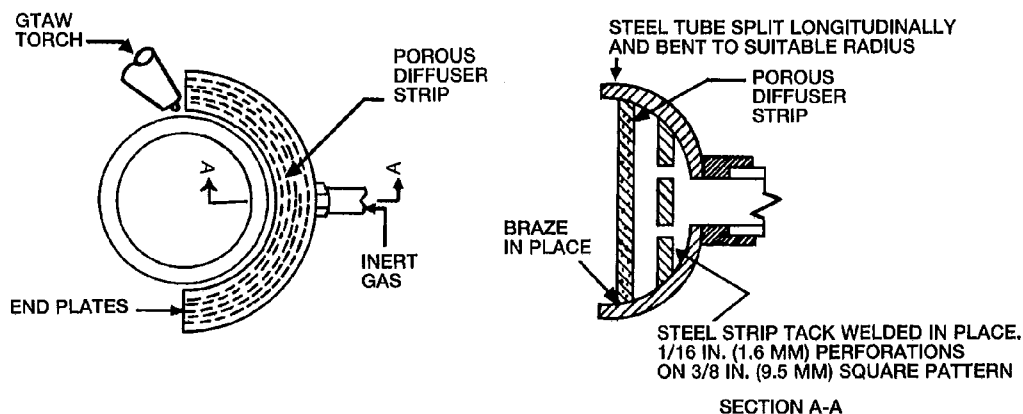


Figure 3—Trailing Shield for Circumferential Welds When the Pipe is Rotated

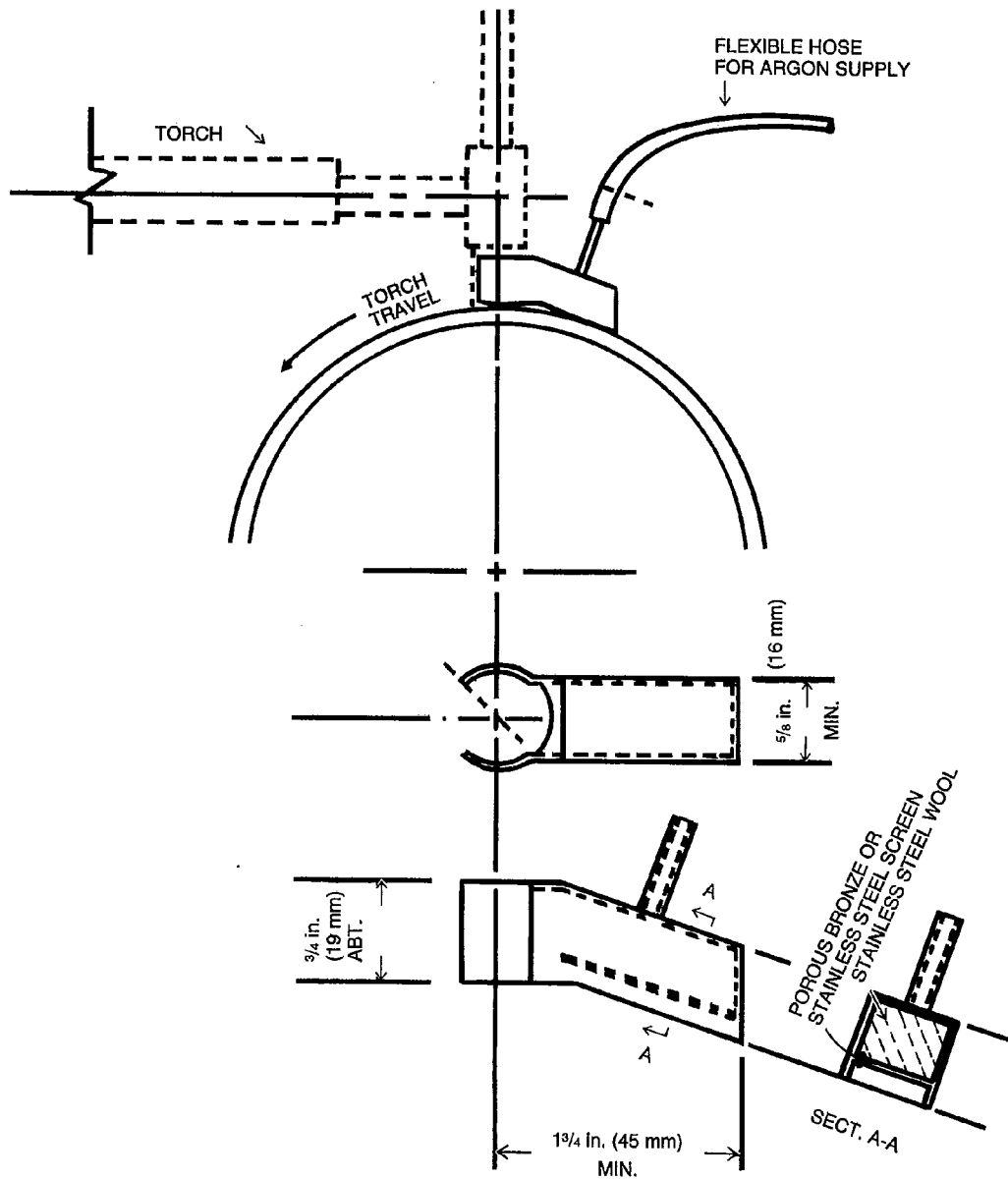


Figure 4—Torch Trailing Shield

Table 4
Time of Preweld Purge Prior to Welding
(Fox Six Volumes Displacement)

Pipe, id		Time of Purge Per foot (305 mm) length
in.	mm.	
under 2	51	24s
3	76	55s
4	102	1 min 30s
5	127	2 min 30s
6	152	3 min 30s

Notes: These values are based on a gas flow of 20 cfh (9 L/min). Other rates of gas flow will require other purging times. After the Time of Purge shown, flow rates may be reduced to maintain positive pressure. See AWS D10.11 for other sizes and flow rates.

A puddle is melted on the sheet over the open joint. Both sides of the sheet are examined for oxidation. Both sides of the sheet should be silver in color. If the back side of the sheet shows oxidation, the purge is ineffective. Possible venting of the purge gas at some other location should be checked. If oxidation is found on the front of the sheet, the torch shielding gas is inadequate. The gas flow, tightness of connections, and purity of the gas should be checked.

13.7 Chamber Welding. Chamber welding methods afford excellent protection from air contamination and can be used advantageously for certain operations such as welding small tube or pipe assemblies. Chambers are commercially available, or may be fabricated to suit.

14. Welding Procedures and Techniques

14.1 Welding Conditions. Current and voltage settings are dependent upon the size of pipe to be welded, joint design, shielding setup (a trailing shield should be

used), size of tungsten electrode, filler metal, welding speed, and gas flow rates. All of these factors are inter-related. For example, if the welding speed is reduced, the amperage should be reduced; or if a trailing shield is not used, lower speeds and lower amperages should be employed. A survey of various company practices shows a considerable variation in procedures.

14.2 Typical Welding Settings. Table 5 lists typical welding conditions. Other combinations may also give good results. For this reason, sample welds should be made and tested to verify the welding procedure before starting production welding.

14.3 Technique. Good techniques for welding other metals and alloys by the gas tungsten arc process also apply to the welding of titanium pipe. The details emphasized in the following paragraphs are particularly important.

14.3.1 Electrode Practices. The electrode is usually extended from 5/32 to 1/4 in. (4.0 to 6.0 mm) beyond the nozzle. For deeper V-grooves and in corners, this may be increased to as much as 1 in. (25 mm). However, care should be exercised to limit this extension to the shortest possible distance to ensure adequate gas shielding. Arc length should be as short as possible. Care should be used to avoid tungsten contamination caused when the electrode touches the molten pool. When this occurs, the contaminated weld area should be ground out, followed by thorough cleaning. The electrode end should be reground before rewelding.

14.3.2 Starting and Stopping the Arc. Shielding at the start and stop of a pipe weld is very important. Preferably, the arc should be initiated with high-frequency power. Weld starting and stopping tabs should be used when possible.

Table 5
Typical Conditions for Manual Gas Tungsten
Arc Welding of Titanium Pipe

Wall Thickness, in. (mm)	No. of Beads	Welding Rod Diam., in. (mm)	Tungsten Diam., in. (mm)	Amperes dcen	Argon Shielding Gas Flow,* cfh (L/min)	Gas Nozzle Size, in. (mm)	Weld Type
Up to 3/32 (2.4)	1	1/16 (1.6)	1/16 (1.6)	80-120	12-15 (6-7)	1/2-5/8 (13-16)	square groove
3/32-3/16 (2.4-4.8)	1, 2	1/16-3/32-1/8 (1.6-2.4-3.2)	1/16-3/32 (1.6-2.4)	120-210	15-20 (7-9)	5/8-3/4 (16-19)	single-v groove
1/4 (6.4)	1, 2, 3	3/32-1/8-5/32 (2.4-3.2-4.0)	3/32-1/8 (2.4-3.2)	140-225	15-20 (7-9)	3/4-1.0 (19-25)	single-v groove

*Trailing shield gas flow and backing gas flow rates will vary widely, depending upon specific conditions.

In order to avoid absorption of atmospheric gases by the titanium, the weld metal and the filler metal must be kept under the inert gas until both are below 1000°F (540°C). It is important that the welder use postweld gas flow control to accomplish this. Amperage control by either a foot pedal or automatic downslope control should be used to avoid crater cracking.

14.3.3 Welding Travel Speeds. The welding speed affects the gas shielding flow rate requirements. For example, as speeds are increased, gas shielding area

and gas flow rate should be increased. Sample welds should be made under varying conditions to determine the acceptable combinations of speed and gas shielding.

14.3.4 Filler Metal Practice. If the hot end of the filler metal is removed from the gas shield prior to cooling and then reused, it will contribute to weld contamination. Welding rod should be added by a technique that will keep the hot end within the torch gas blanket. If the rod tip becomes contaminated, it should be cut off before reusing.

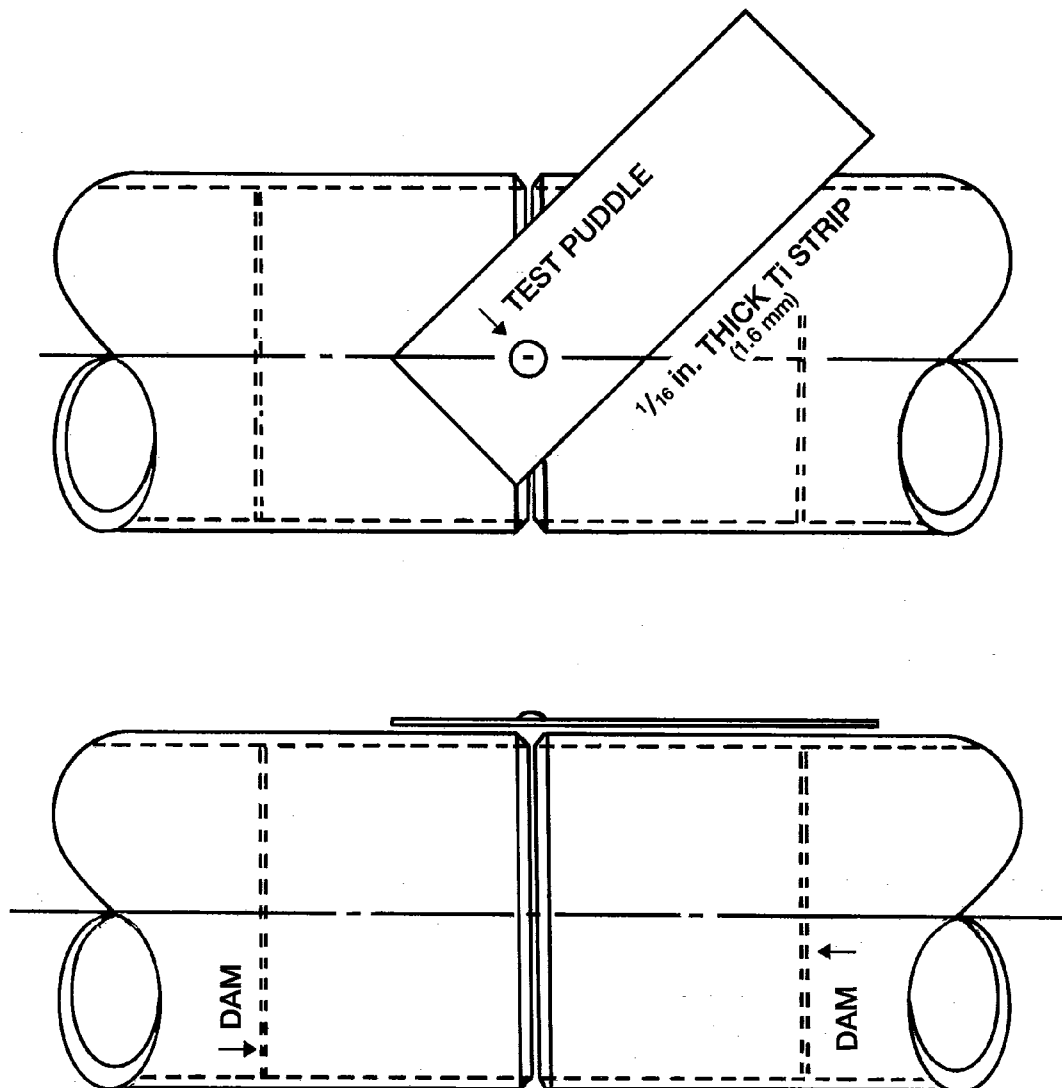


Figure 5—Puddle Test for Torch Shielding Gas and Back Purge

14.3.5 Root Pass Technique. Because of the low thermal conductivity of titanium, it is desirable to use the keyhole technique for the root bead. This technique is described in ANSI/AWS D10.11, *Recommended Practices for Root Pass Welding of Pipe Without Backing*.

14.3.6 Weld Passes and Repairs. If the surface appearance of a bead is bright and silvery, cleaning is not needed. However, straw or very light blue surface oxides may be removed by light brushing with stainless steel wire brushes. If dark colors show or if gray or yellow powder appears, the contaminated bead should be removed mechanically and rewelded. Interpass temperatures should be kept below 350°F (175°C); this minimizes the area which has to be kept under the shielding gas blanket. Rewelding over contaminated weld beads may improve the appearance, but the weld metal will be contaminated and will require removal (see section 16).

15. Preheat and Postweld Heat Treatment

15.1 Preheat. Preheat is neither necessary nor recommended. Interpass temperature should not exceed 350°F (175°C).

15.2 Postweld Heat Treatment (PWHT). Postweld heat treatment is seldom necessary or recommended. However, where there is concern with residual stress (for example, where stress corrosion is anticipated), PWHT may be performed by heating titanium pipe to 1000°F (540°C) for 30 minutes to 1 hour to relieve peak stresses. This PWHT is sometimes accomplished in furnaces without protective atmospheres. (Where a protective atmosphere is required, only an inert gas or vacuum may be used.) PWHT will not restore ductility lost through weld contamination. Components to be heat treated shall be clean prior to heating. Discoloration resulting from heat treatment is not usually detrimental, but it may be removed as described in section 10.

16. Weld Quality Tests

Because titanium welds are very sensitive to contamination and consequent embrittlement, weld quality tests are important to ensure that satisfactory welds are being produced. A number of tests that may be useful are discussed below.

For a more complete coverage of mechanical testing, refer to AWS B4.0, *Standard Methods for Mechanical Testing of Welds*. For a review of nondestructive testing, refer to AWS B1.10, *Guide for the Nondestructive Inspection of Welds*, which covers visual, radiographic, liquid penetrant, ultrasonic, and other methods that may be used on production welds or test welds.

Table 6
Bend Diameters for Testing Specimens

Specimen Thickness Range T	Bend Diameters			
	Grade 1 & 2	Grade 3	Grade 7	Grade 12
Under 0.07 in (1.8 mm)	3T	4T	3T	5T
0.07–0.19 in. (1.8–4.8 mm)	4T	5T	4T	6T
0.19 in. (4.8 mm) and over*	5T	6T	5T	7T

* Suggested values (may be those agreed upon between the supplier and purchaser).

16.1 Bend Testing. Contamination by carbon, oxygen, hydrogen, and nitrogen directly affects the bend ductility of the weld joint. A convenient method of ascertaining whether a welding procedure is adequate is to test for bend ductility. One method is to make a test pipe weld following the welding procedure, and prepare transverse bend specimens. If the welding procedure is satisfactory, face- and root-bend specimens can be bent at room temperature through an angle of 180 degrees without cracking. The bend should be made on a diameter equal to that shown in Table 6 for applicable grade and thickness.

16.2 Hardness Testing. The hardness of a well-shielded titanium weld should not be appreciably greater than the hardness of the base pipe or the filler metal. An increase of not over 30 Brinell (5 Rockwell B) hardness points indicates a satisfactory joint as long as the hardness does not exceed 240 BHN or 100 RB. Any larger increase indicates excessive contamination (an estimate of the hardness increase may be made using a portable hardness tester of the type commonly used on aluminum.)

16.3 Radiographic Examination. Welds made in titanium easily meet the most stringent radiographic requirements; however, the effects of contamination are not normally evident on radiographs.

16.4 Color. The appearance of welds indicates, to some extent, the degree of contamination that has occurred and can serve as a field test (see Table 7).

16.5 Other Tests. Tensile tests and impact tests, following standard methods, may be used to determine strength of pipe joints. Liquid-penetrant testing is useful in determining cracks. However, dye-penetrant solutions containing chlorinated hydrocarbons should not be used. Chemical analysis and microscopic examination are also useful.

Table 7
Significance of Weld Color and Remedies Indicated

Color of Titanium	Significance	Shielding	Remedy
Silver	Generally a good weld	Good	
Straw to very light blue	Acceptable weld	Fair	Discoloration should be removed with stainless steel brush before next pass.
Blue or purple	Poor weld	Poor	Remove weld bead and adjacent metal completely; improve shielding before welding.
Gray or yellow	Very poor weld	Extremely poor	Remove weld bead and heat-affected zone completely. Examine shielding equipment for leaks, gas supply, etc. Make test welds before rewelding.

17. Safety and Health

This standard does not attempt to give detailed coverage to all welding safety and health hazards. However, pertinent information can be found in the following documents.

- (1) ANSI/ASC Z49.1, *Safety in Welding and Cutting*.
- (2) AWS Welding Handbook, 8th Edition, Volume 1, Chapter 16.

(3) NFPA No. 70, *National Electrical Code*.

(4) *Code of Federal Regulations (CFR)*, Title 29, Chapter XVII, Part 1910.

(5) Manufacturers safety manuals and instructions on all equipment and materials used.

These documents should be referred to and complied with as required.

AWS Piping and Tubing Documents

Designation	Title
AWS D10.4	Austenitic Chromium-Nickel Stainless Steel Piping and Tubing, Recommended Practices for Welding
AWS D10.6	Titanium Piping and Tubing, Recommended Practices for Gas Tungsten Arc Welding
AWS D10.7	Aluminum and Aluminum Alloy Pipe, Recommended Practices for Gas Shielded Arc Welding
AWS D10.8	Chromium-Molybdenum Steel Piping and Tubing, Recommended Practices for Welding
AWS D10.9	Qualification of Welding Procedures and Welders for Piping and Tubing, Specification for
AWS D10.10	Local Heating of Welds in Piping and Tubing, Recommended Practices for
AWS D10.11	Root Pass Welding of Pipe Without Backing, Recommended Practices for
AWS D10.12	Low Carbon Steel Pipe, Recommended Practices and Procedures for Welding