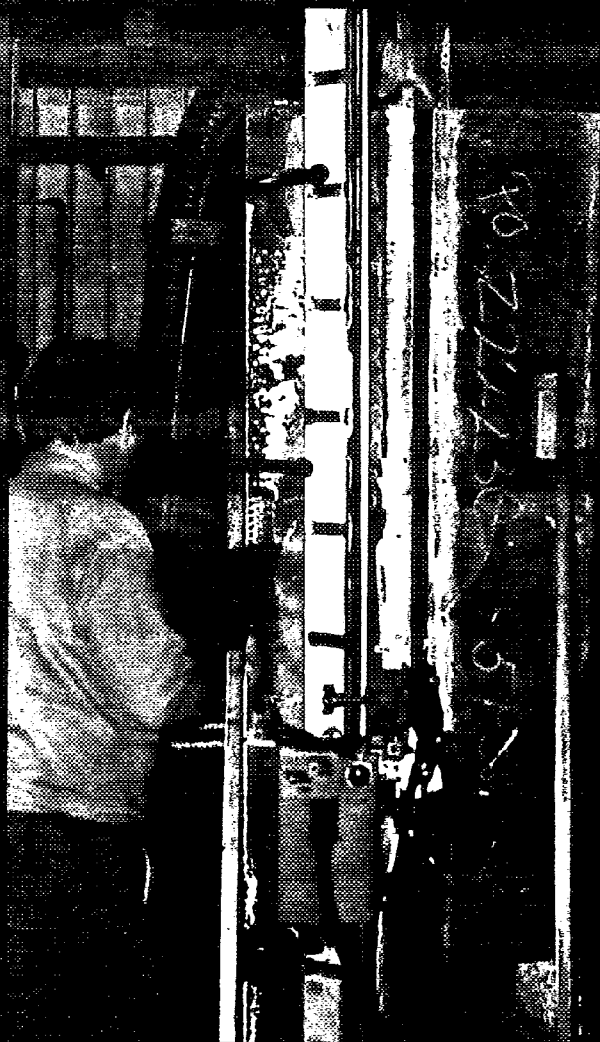




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March 8, 1989

Recommended Practices for Electrogas Welding

Superseding AWS C5.7-81

Prepared by
AWS Committee on Arc Welding and Cutting

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Technical Council

Abstract

Electrogas Welding (EGW) is a specialized application of the gas metal arc welding (GMAW) or the flux cored arc welding (FCAW) processes for vertical position welding. The electrode deposits filler metal in the cavity formed by shoes that bridge the groove between the plates being welded. The electrode may be solid or flux cored, and additional shielding may or may not be obtained from an externally supplied gas or gas mixture. The weld is usually completed in a single pass.

Fundamentals of the process, including the various methods of welding, are presented. A discussion of equipment, consumables, applications, and metallurgical advantages and limitations is given. The selection of process variables and operating conditions and typical EGW procedures is then presented. Inspection of welds, and training and qualification of welding procedures and operators are described. Finally, a trouble shooting guide, safety considerations, and a supplementary reading list are presented.



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Foreword

(This Foreword is not a part of ANSI/AWS C5.7-89, *Recommended Practices for Electrogas Welding*, but is included for information purposes only.)

Electrogas welding (EGW) was introduced as a practical fabricating process in 1961. In the past several years, advances have been made so that electrogas welding is now accepted as an efficient and practical method in some metal joining applications. EGW applications should continue to expand as fabricators become more familiar with the fundamentals, techniques, and advantages of this welding process. The increased usage and interest in EGW has prompted the American Welding Society to sponsor this *Recommended Practices for Electrogas Welding*.

Sufficient data have been recently gathered and organized to yield an authoritative source of sound technical practices for electrogas welding. Accordingly, the AWS Arc Welding and Cutting Committee has prepared these recommended practices as compiled by the Subcommittee on Electrogas Welding. These recommended practices are based on a survey of electrogas welding as used in the metal fabricating and construction industry.

The description of electrogas welding and its features is presented here as clearly and concisely as possible. The Committee has developed these guidelines in the hope that they will lead to further development of the electrogas welding process and thus, to higher quality and performance standards.

Comments on this publication are most welcome. They should be addressed to the Secretary, AWS Arc Welding and Cutting Committee, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

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Recommended Practices for Electrogas Welding

1. Scope

This guide establishes standard practices for electrogas welding low carbon and structural steels. Aluminum and stainless steel are excluded because of a lack of general commercial use of electrogas welding for these materials.

2. Introduction

Electroslag welding was the first single-pass vertical welding process available; and there was an immediate demand for equipment that would enable the process to be applied to thinner workpieces than is generally possible with the electroslag process. Until the electrogas process became available in 1961,¹ almost all vertical joints were welded with the manual shielded metal arc or semiautomatic gas metal arc welding process. Laboratory evaluation using a flux cored electrode with auxiliary gas shielding and an adaption of an electroslag machine determined that a plate as thin as 1/2 in. (12.7 mm) could be welded in the vertical position at high speeds by the single-pass electrogas technique. Electrogas welding (EGW) has enjoyed steady growth in the United States in the past decade. This growth has occurred because the process has high deposition rates, high efficiency, weld metal soundness, a simple joint preparation, and other advantages.

Some of the advantages associated with EGW have resulted in considerable cost savings, particularly in joining thicker materials. Savings have been achieved when joint members can be joined in the vertical position and where thick base metal can be

joined with a continuous vertical weld. EGW is often less expensive than the more conventional joining methods such as submerged arc welding (SAW) and flux cored arc welding (FCAW) in thicker base metals. Even in some applications involving thinner base metals, EGW has resulted in cost savings because of its efficiency, simple joint preparation, etc.

There are two primary variations of the EGW process commonly used in the United States. In the first method, a solid electrode is fed into the joint. In the second method, a flux cored electrode is used. These methods of EGW for plain carbon, structural, and pressure vessel quality steels will be discussed in more detail later in these recommended practices. Although EGW has been used to join aluminum and some grades of stainless steels, those applications are not discussed in this document.

3. Definitions

The definitions listed below are terms used in this guide which may be unfamiliar to the reader. Refer to ANSI/AWS A3.0, *Standard Welding Terms and Definitions* for a complete list of terms used in this document.

backing. A material or device placed against the back side of the joint, or at both sides of a weld in electrogas welding, to support and retain molten weld metal. The material may be partially fused or remain unfused during welding and may be either metal or nonmetal.

backing shoe. A nonconsumable backing device used in electrogas welding.

1. See Supplementary Reading List, item number 6.

consumable guide—EGW. An EGW process variation in which filler metal is supplied by an electrode and its guiding member.

consumable guide. A guide that is consumed along with the electrode during welding.

cycle period. Total time for the electrode to complete transverse swing from one extreme to the other and back, including dwell time at both extremes.

dwell. Time of electrode pause at its extreme transverse positions.

electrode extension. The length of unmelted electrode extending beyond the end of the guide.

electrogas welding (EGW). An arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the work. Molding shoe(s) are used to confine the molten weld metal for vertical position welding. The electrode may be either flux cored or solid. Shielding may or may not be obtained from an externally supplied gas or gas mixture.

electrogas welding electrode. A filler metal component of the welding circuit through which current is conducted from the electrode guiding member to the molten weld pool.

form factor. The ratio of the maximum width [root opening plus depth of fusion (sidewall penetration)] to the maximum depth of the molten metal.

guide. A conductive supporting member through which the solid or flux cored electrode passes. It is usually tubular in form, although other shapes may be used.

inboard shoe. The backing shoe that is closer to the main portion of the welding machine, see Figures 1 and 2.

moulding shoe. A nonstandard term for **backing shoe**.

moving shoe. The backing shoe that is required to slide along the joint in a controlled intermittent or continuous motion by the welding equipment.

nonconsumable guide. A guide that is not con-

sumed during welding, usually a copper alloy, and may be water-cooled.

oscillation distance. The horizontal distance in one direction over which an oscillating electrode traverses.

oscillation speed. Oscillation distance divided by oscillation time.

oscillation time. Time necessary to complete the oscillation distance.

outboard shoe. The backing shoe that is on the side of the plate farthest from the main portion of the welding machine, see Figures 1 and 2.

retaining shoe. A nonstandard term for **backing shoe**.

runoff weld tab. Additional material that extends beyond the end of the joint, on which the weld is terminated.

starting weld tab. Additional material that extends beyond the beginning of the joint, on which the weld is started.

strongback. A u-shaped bracket, used to hold the workpieces in alignment, which allows clearance for the backing shoe.

sump. A nonstandard term for **starting weld tab**.

stationary shoe. A backing shoe that remains in a fixed position during welding, see Figure 1.

4. Fundamentals

4.1 Process Description. Electrogas welding is similar to both the gas metal arc welding (GMAW) process and the flux cored arc welding (FCAW) process, but uses backing shoes to confine the molten weld metal for vertical position welding. Additional shielding may or may not be obtained from an externally supplied gas or mixture.

A joint with a square-groove or single-V-groove joint geometry is positioned so that the weld axis, or length of weld, is vertical. Electrogas welding is a machine welding process and once started, it normally continues to completion and welding is usually done in one pass. The nature of the melting and

solidification during welding results in high quality weld metal. There is little or no angular distortion of the workpieces with a single-pass weld.

4.2 Principles of Operation. The consumable electrode, solid or flux cored, is fed downward into a

cavity formed by the base metals to be welded and the backing shoes. A starting weld tab is usually used at the beginning of the weld to allow the process to reach stabilization before the molten weld metal reaches the workpieces. An arc is initiated between the electrode and the starting tab.

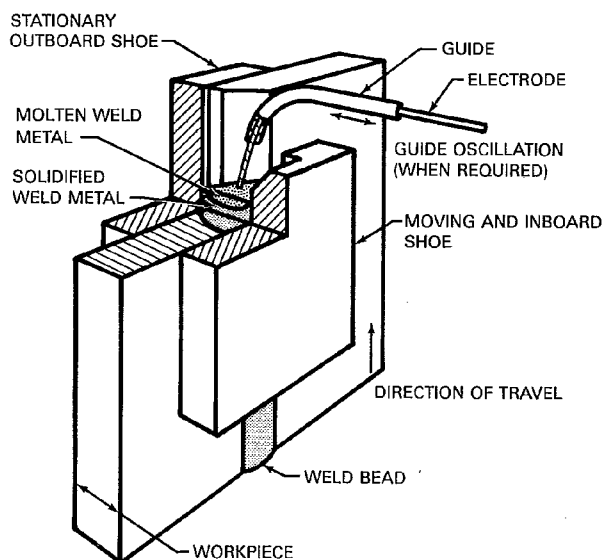


Figure 1 — Schematic Diagram of EGW Process Using a Moving Shoe and a Stationary Shoe

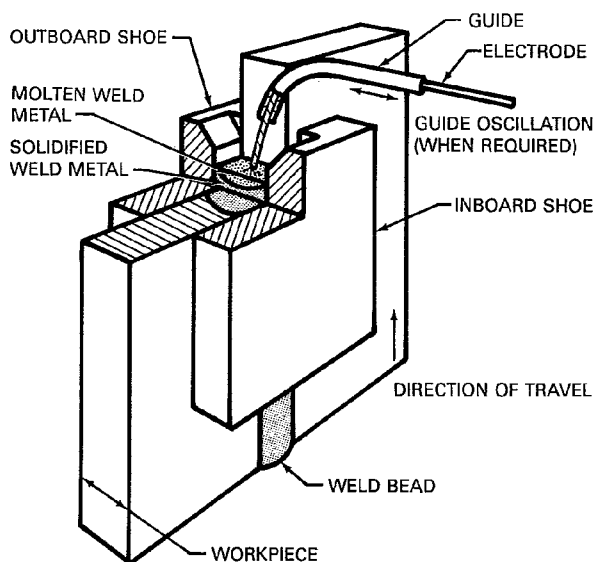


Figure 2 — Schematic Diagram of EGW Process Using Two Moving Shoes

Heat from the arc melts the base metal groove faces and the continuously fed electrode. Melted electrode and base metal collect in a pool beneath the arc and solidify to form the weld metal. The electrode may be oscillated horizontally through the joint for uniform distribution of heat and weld metal. As the cavity fills, one or both shoes may move upward. Although the weld axis is vertical, the process is actually flat with vertical travel.

4.3 Electrode Variations

4.3.1 Solid Electrode. Figure 3 shows a schematic view of electrogas welding using a solid electrode. One electrode is normally fed into the joint. The electrode is fed through a nonconsumable guide. Horizontal oscillation of the electrode may be performed to weld thicker workpieces. Gas shielding, normally carbon dioxide (CO_2) or an argon-carbon dioxide (Ar-CO_2) mixture, is provided in the cavity above the weld pool.

Water-cooled copper shoes are normally used on each side of the joint to retain the molten weld metal. The shoes are usually attached to the welding machine and move vertically as the machine moves. Vertical movement of the welding machine should be consistent with the deposition rate. Vertical movement may be automatic or controlled by the welding operator.

Electrogas welding with solid electrode can be used to weld base metals ranging in thickness from approximately 3/8 in. (9.5 mm) to 4 in. (100 mm).

Base metal thicknesses from 1/2 in. (13 mm) to 3 in. (76 mm) are most commonly welded. Electrode diameters most commonly used are 1/16, 5/64, 3/32, and 1/8 in. (1.6, 2.0, 2.4, and 3.2 mm).

4.3.2 Flux Cored Electrode. Figure 4 shows a schematic view of electrogas welding using a flux cored electrode. The principles of operation and characteristics are identical with the solid electrode variation, except that with flux cored electrodes, a thin layer of slag forms between the weld metal and copper shoes to provide a smooth weld face.

Electrogas welding with a flux cored electrode may be performed using an external gas shield or a self-shielding electrode. The self-shielded electrode operates at a higher current level and deposition rate.

Electrode sizes commonly used range from 1/16 in. to 1/8 in. (1.6 mm to 3.2 mm). The wire (electrode) feeder must be able to handle the electrode diameter chosen — which means, in the case of smaller diameters, it must feed at speeds necessary to deposit filler metal at desired rates.

4.4 Consumable Guide Variations. The consumable guide method of EGW can be used and is similar to consumable guide electroslog welding. This variation of EGW is primarily used for short weldments in shipbuilding and structural steel fabrication. Consumable guide EGW is very similar to the previously described conventional process, but the equipment is simpler (see Figures 5 and 6). The

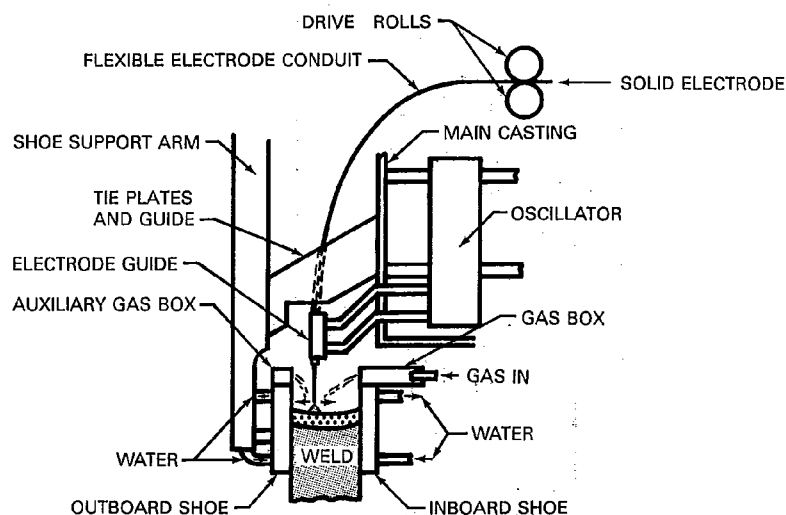


Figure 3 — Electrogas Welding with Solid Electrode Using Moving Shoes

principle difference is that none of the equipment moves vertically during consumable guide welding. As in conventional EGW, the electrode is fed into the arc, but is fed through a hollow consumable guide which extends the complete length of the joint. As the weld progresses vertically, the guide tube and the electrode melt and are consumed in the weld.

The consumable guide provides approximately five to ten percent of the filler metal, with the balance supplied from the electrode. Arc initiation is begun in the same general fashion as in the conventional process.

A collar or clamp device, usually made of copper, holds the guide tube in consumable guide welding. The consumable guide is selected so that its chemical composition is compatible with the base metal. Guide tubes are usually 1/2 or 5/8 in. O.D. (13 to 16 mm) and 1/8 to 3/16 in. I.D. (3.2 to 4.8 mm). Guide tubes are available in various lengths and for some applications may be welded together to accommodate longer joints. Oscillation with a single consumable guide tube over 3 ft (.91 m) becomes increasingly more difficult as weld length increases. If the required amount of oscillation cannot be properly controlled, additional electrodes may be added and the oscillation deleted or minimized.

The shoes are usually separate from the wire feed drive, guide, and controls in this method of EGW. The shoes may be held in place with wedges placed between the shoes, and strong backs welded to the workpiece. On short welds, shoes may be the same length as the joint. Several sets of shoes may be required for longer joints.

Consumable guide tubes may sometimes be used for complex shaped joints. The guides are pre-formed to suit the required shape.

5. Equipment

The basic mechanical equipment for electrogas welding consists of a direct current power supply, shoes for retaining molten metal, an electrode guide, a device for feeding the electrode, a mechanism for oscillating the electrode guide, and the equipment needed for supplying shielding gas when used. In a typical electrogas welding system, the essential components (with the exception of the welding power source) are incorporated in an assembly that moves vertically as welding progresses.

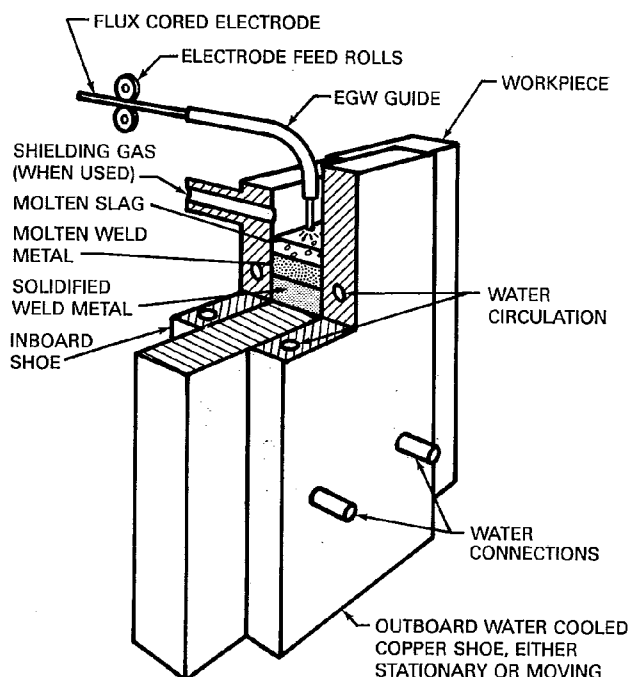


Figure 4 — Electrogas Welding with Flux Cored Electrode

5.1 Welding Power Source. Direct current electrode positive (reverse polarity) is normally used for EGW, with the power source being either constant voltage or constant current. The power source should be rugged and capable of delivering the required current without interruption during the welding of a joint that may be many feet (meters) in

length. Power sources used for electrogas welding usually have capacities of 750 to 1000 amperes at 30 to 55 volts and 100 percent duty cycle. Direct current is more frequently supplied by transformer-rectifier power sources, although motor-driven and engine-driven generators are also used.

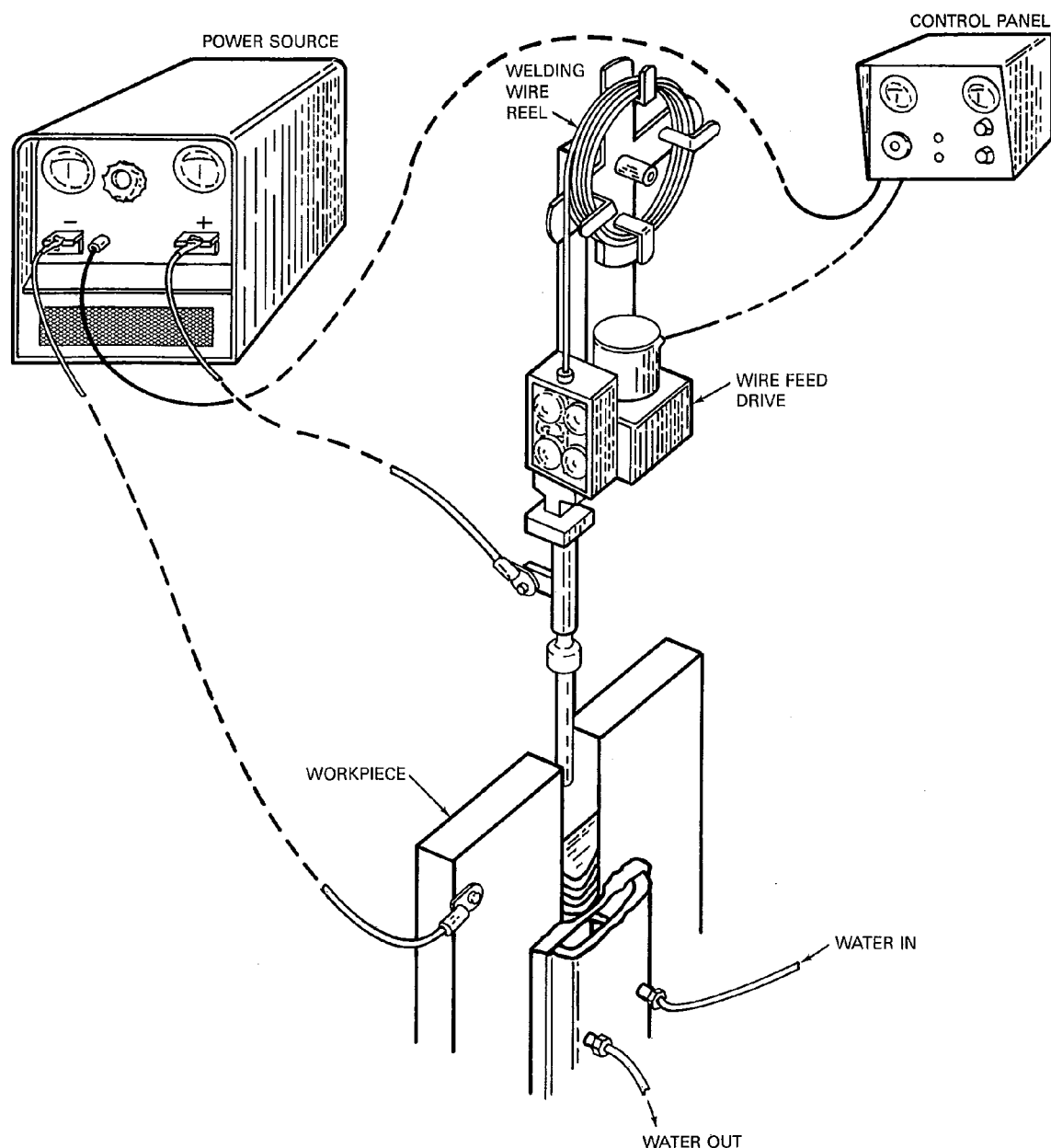


Figure 5 — Consumable Guide EGW Equipment

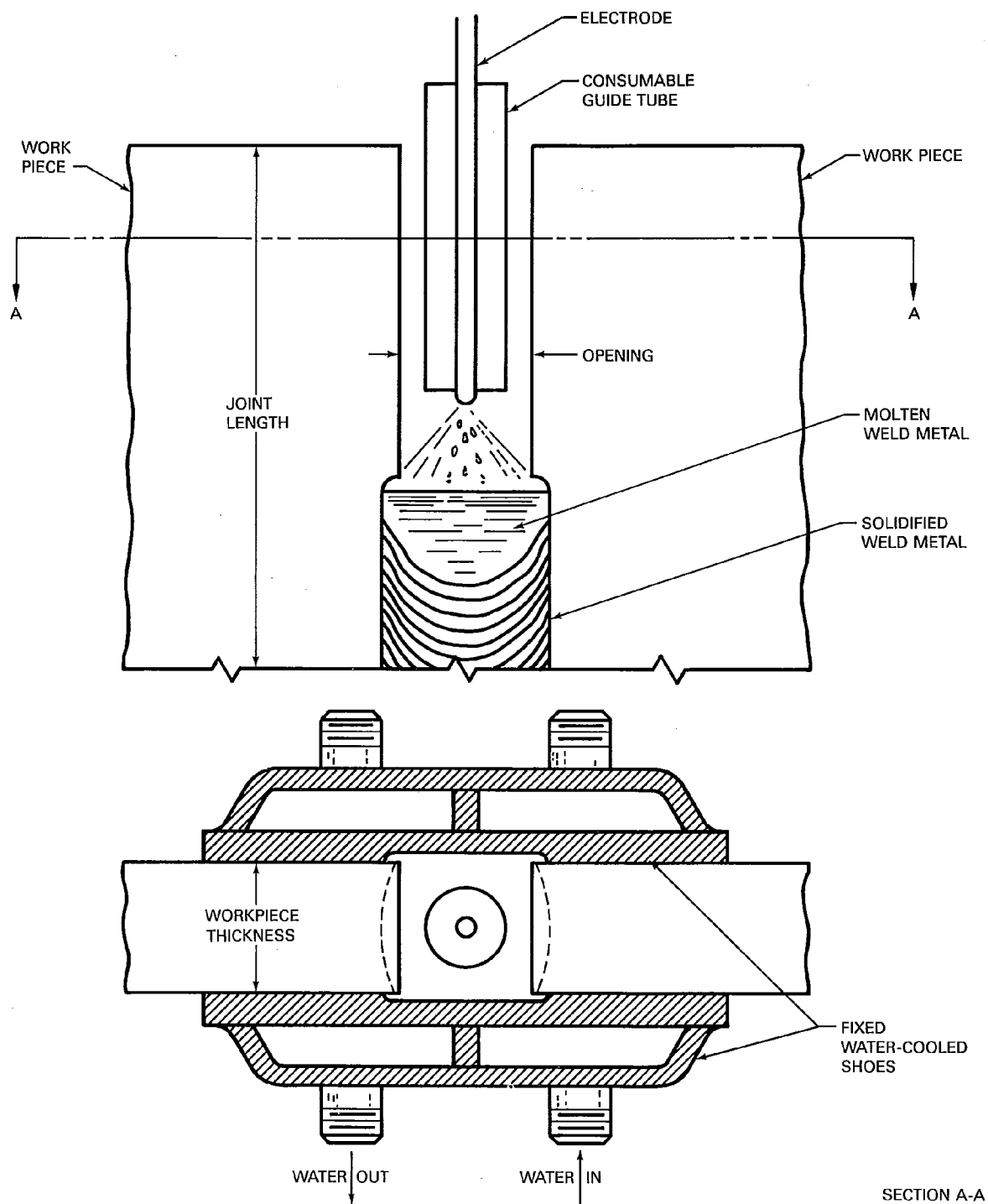


Figure 6 — Schematic Diagram of Consumable Guide EGW Process.

5.2 Wire (Electrode) Feeder. The wire (electrode) feeder is of the push type, such as used with automatic gas metal arc or flux cored arc welding. The wire feeder is normally mounted as an integral part of the vertical-moving welding machine. Wire feed speeds may vary up to 545 in./min (230 mm/s) with a 1/8 in. (3.2 mm) electrode.

The wire feed system may include a wire straightener that tends to eliminate the cast and helix set in the electrode and thus minimize wire (electrode) wander at the joint. Since the electrode extension in electrogas welding is relatively long, 1-1/2 in. (38 mm) or more, a straight length of electrode projecting from the guide is necessary to assure positive arc location in the joint.

5.3 Electrode Guide Oscillators. With base metals 1-1/4 in. to 4 in. (32 mm to 100 mm) thick, it is necessary to move the arc back and forth between the shoes and over the molten weld pool to achieve uniform filler metal deposition and ensure fusion to both groove faces. Horizontal oscillation of the arc is usually not needed for joints in a base metal less than 1-1/4 in. (32 mm) thick, but is sometimes used with thinner base metals to minimize depth of fusion and to improve weld properties. This horizontal motion is accomplished by a system that oscillates the electrode guide and provides adjustable dwell times. In one commercial machine, the speed is 18 in./min (8 mm/s), with the dwell time adjustable from 0 to 4 seconds.

5.4 Electrode Guide. Electrode guides in many respects are similar to the welding guns used with gas metal arc welding or with flux cored arc welding. The guide may have a shielding gas outlet to deliver gas around the protruding electrode (usually supplementary to the shielding gas supplied by ports in the shoes), and it may be water cooled. The electrode guide (or at least part of it, in the case of a curved guide) rides inside the root opening directly above the molten weld pool. It must be narrow enough to be contained in the root opening with clearance to permit horizontal oscillation between the two shoes. For this reason, the width of an electrode guide is often limited to 3/8 in. (9.5 mm), so as to accommodate the 11/16 in. (18 mm) minimum root opening customarily used.

5.5 Backing Shoes (Dams). Backing shoes are pressed against each side of the root opening between the workpieces to retain the molten weld metal. One or both shoes may move upward as welding progresses. In some weldments, a steel bar

is used as a welded backing in place of the outboard shoe. Ceramic backing shoes may also be used on some applications. Backing shoes are usually water-cooled; moving shoes must be water cooled. The shoes are usually grooved to develop the desired weld reinforcement. The shoes may or may not contain gas ports for impinging shielding gas directly onto the molten weld pool. When gas ports are not used in the shoes, a "gas box" arrangement may be mounted on the shoes so as to surround the electrode and the welding arc. Gas ports in the shoes and gas boxes are not required when using self-shielded flux cored electrodes.

5.6 Controls. With the exception of the vertical travel control, EGW controls are primarily adaptations of the devices used with gas metal arc and flux cored arc welding. Vertical travel controls, either electrical, optical, or manual, maintain a given electrode extension with the top of the movable shoe a specific distance above the molten weld pool.

On equipment using a self-shielded flux cored electrode, starting procedures must be carefully controlled to minimize porosity in the starting weld tab area. Welds are usually started at lower wire feed speeds and voltages. These lower settings must be maintained while the arc stabilizes and the starting area is heated. After a preset time, the equipment should automatically change the feed speed and voltage to the desired welding speed and voltage. Automatic rather than manual changing helps to minimize starting porosity.

6. Electrodes and Shielding Gas

6.1 Electrodes. Either flux cored or solid electrodes may be used with the electrogas welding process. The welding wire supply must be adequate to complete the entire weldment in a single pass.

Flux cored EGW electrodes contain a lower percentage of slag forming compounds than typical electrodes used in the flux cored arc welding process (FCAW). These electrodes allow a thin slag layer to form between the shoes and the weld to provide a smooth weld surface. Flux cored electrodes are supplied in sizes from 1/16 to 1/8 in. (1.6 to 3.2 mm). Only flux cored electrodes specifically designed for EGW should be used (see 6.3).

Solid electrodes are generally identical to those used for gas metal arc welding. They are supplied in sizes from 0.030 to 1/8 in. (0.8 to 3.2 mm).

Both flux cored and solid electrodes are available in various chemical compositions designed to intro-

duce the necessary alloying elements to achieve strength, impact properties, or appropriate combinations of these in the weld metal, depending upon the particular requirement. To obtain desired strength and impact properties in the weld metal comparable to those of the base metal, additional alloying elements such as manganese, silicon, and nickel are incorporated in the electrodes. These properties are normally obtained in the as-welded condition.

6.2 Shielding. Self-shielded flux cored electrodes for EGW contain core materials that shield the molten weld metal from oxygen and nitrogen. Other flux cored electrodes require a shielding gas (normally carbon dioxide). Recommended gas flow rates range from 30 to 140 CFH (14 to 66 L/min). A mixture of argon and carbon dioxide is normally used for welding steel with solid electrodes and may be used with flux cored electrodes. Recommended gas flow rates range from 40 to 140 CFH (19 to 66 L/min). Gas flow rates are dependent upon the equipment design, and manufacturer recommendations should be followed.

6.3 AWS Specification for Electrode Filler Metal.

Flux cored electrodes are classified in ANSI/AWS A5.26, *Specification for Consumables Used for Electrode Gas Welding of Carbon and High Strength Low Alloy Steels*, on the basis of whether a shielding gas is required, and on the chemical composition and as-welded mechanical properties of the weld metal (see Tables 1 and 3). The solid electrodes are classified on the basis of their chemical composition and on the as-welded mechanical properties of the weld metal (see Tables 2 and 3). Note in Table 3 that two levels of strength have been established and each level stipulates the types of steel base metal permissible. This takes into account the high dilution rate and single-pass nature of electrode gas welding. For each level of strength, electrode classifications are provided that define three levels of minimum toughness as determined by the Charpy V-notch impact test. Mechanical properties shown in Table 3 are obtained with a standard welding procedure using typical electrode gas welding conditions.

Table 1
Chemical Composition for Weld Metal from Flux Cored Electrodes, Weight Percent^{a,b}

AWS ^{c,d} Classifi- cation	Shielding Gas	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	V
EGXXT1	None	-	1.50	0.03	0.03	0.50	0.30	0.20	0.35	-	0.08
EGXXT2	CO ₂	-	2.00	0.03	0.04	0.90	0.30	0.20	0.35	-	0.08
EGXXT3	CO ₂	0.10	1.0 to 1.8	0.03	0.03	0.50	0.7 to 1.1	-	0.30	-	-
EGXXT4	Ar-CO ₂ or CO ₂	0.12	1.00 to 2.00	0.02	0.03	0.15 to 0.50	1.50 to 2.00	0.20	0.40 to 0.65	-	0.05
EGXXT5	CO ₂	0.12	0.50 to 1.30	0.03	0.03	0.30 to 0.80	0.40 to 0.80	0.45 to 0.70	-	0.30 to 0.75	-
EGXXTG	Not specified—No chemical composition requirements										

a. Single values shown are maximum percentages.

b. The sample for chemical composition for the flux cored electrodes should be taken from an undiluted ingot made in a water-cooled copper mold using the typical electrode gas welding conditions shown in Fig. 4 of A5.26-78, except for EGXXT1, which should be taken from a welded joint using steel plates as per 2.2 of A5.26-78, base metals for Test Plates.

c. May be used with and without consumable guide tubes. Consumable guide tubes, when used, should conform to AISI specifications for 1008 to 1020 carbon steel tubing.

d. The letters XX in this table refer to either the 6Z, 60, 62 or 7Z, 70, 72 mechanical property designations of Table 3.

Table 2
Chemical Composition for Solid Electrodes, Weight Percent

Classification												
Carbon Steel Classes	C	Mn	P	S	Si	Ni^a	Cr^a	Mo^a	V^a	Ti	Zr	Al
EGXXS-1	0.07 to 0.19	0.90 to 1.40	0.025	0.035	0.30 to 0.50	-	-	-	-	-	-	-
EGXXS-2	0.06	0.90 to 1.40	0.025	0.035	0.40 to 0.70	-	-	-	-	0.05 to 0.15	0.02 to 0.12	0.05 to 0.15
EGXXS-3	0.06 to 0.15	0.90 to 1.40	0.025	0.035	0.45 to 0.70	-	-	-	-	-	-	-
EGXXS-5	0.07 to 0.19	0.90 to 1.40	0.025	0.035	0.30 to 0.60	-	-	-	-	-	-	0.50 to 0.90
EGXXS-6	0.07 to 0.15	1.40 to 1.85	0.025	0.035	0.80 to 1.15	-	-	-	-	-	-	-
Special Classes^b												
EGXXS-1B	0.07 to 0.12	1.60 to 2.10	0.025	0.035	0.50 to 0.80	0.15	-	0.40 to 0.60	-	-	-	-
EGXXS-GB	No chemical composition requirements											

Note: Single values shown are maximums. The letters XX in this table refer to either the 6Z, 60, 62 or 7Z, 70, or 72 mechanical property designations of Table 3.

a. For carbon steel classes, these elements may be present but are not intentionally added.

b. Alloy additions made for purposes of deoxidation and usability improvement. Not included to improve mechanical properties.

7. Applications

7.1 Base Metals. Among the many alloys that have been electrogas welded on a production basis in the United States, the largest from a weight standpoint have been in the low carbon, structural, and pressure vessel quality steels as follows:

- (1) Low carbon steels: AISI-1018, 1020
- (2) Structural steels: ASTM-A36, A131, A242, A283, A441, A572, A573, A588
- (3) Pressure vessel steels: ASTM-A285, A515, A516, A537.

In addition to the above steels, EGW has been used to join aluminum and some grades of stainless steels

(4) Electro gas welding of steels that are quenched and tempered or normalized may not be permitted by some standards (e.g., ANSI/AWS D1.1, *Structural Welding Code—Steel*).

7.2 Joint Design. The most commonly used joint is a butt joint with a square-groove joint geometry and approximately 7/8 in. (22 mm) root opening. This joint is normally used with two moving shoes [see Figure 7(A)]. The next most commonly used design is a butt joint with a V-groove joint geometry, which is commonly used with one moving and one stationary shoe [see Figure 7(B)]. This joint usually has a root opening of 5/32 in. (4 mm) and a face opening of 7/8 in. (22 mm). The moving shoe is

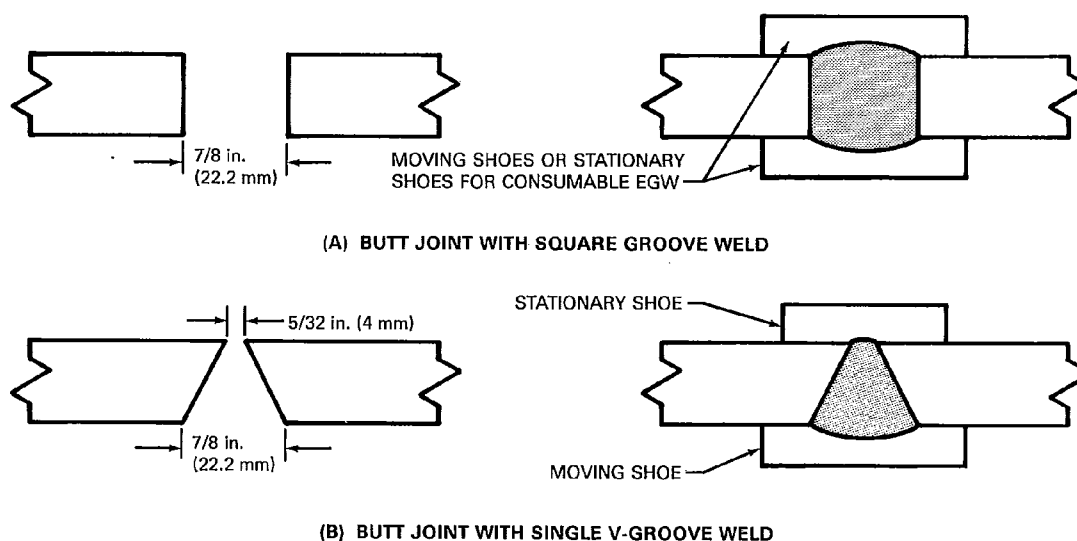


Figure 7 — Typical EGW Joint Designs

Table 3
As-welded Mechanical Property Requirements for Weld Metal

AWS Classification ^a	Tensile Strength ksi	Yield Strength at 0.2% Offset min, ksi	Elongation in 2 in., Min, Percent	Charpy V-notch Impact Strength, min ^b
(When using ASTM A36 plate) ^c				
EG6ZXXX} EG60XXX} EG62XXX}	60 to 80	36	24	{ Not required (20 ft · lb at 0° F ^d (20 ft · lb at -20° F ^d
(When using ASTM structural steels, A242, A441, A572 Grade 50, or A588) ^c				
EG7ZXXX} EG70XXX} EG72XXX}	70 to 95	50	22	Not required (20 ft · lb at 0° F ^d (20 ft · lb at -20° F ^d

a. The letters XXX in this table refer to classifications T1, T2, T3, S-1, S-2, S-3, and so forth. Shielding gas for flux cored electrodes is as noted in Table 1. Shielding gas is CO₂ for solid electrodes. Other gases may be used if agreed upon between supplier and purchaser.

b. For the five specimens tested, the lowest value obtained, together with the highest value obtained, may be disregarded for this test. Two of the three remaining values may be greater than the specified 20 ft · lb energy level.

c. Restriction of base metals for tensile/yield strengths listed is necessary due to inherent characteristics of the electrogas process.

d. Note that if a specific electrode meets the requirements of a given classification, this classification also meets the requirements of all lower numbered classifications in the series. For instance, an electrode meeting the requirements of the EG62 classification, also meets the requirements of EG6Z. This applies to the EG7X series also.

SI Equivalents							
ksi	MPa	in.	mm	ft · lb	J	°F	°C
36	250	2	50	20	27	0	-18
50	350					-20	-29
60	420						
70	490						
80	550						
95	650						

used to contain the weld metal at the weld face, and the stationary shoe is used to contain the weld metal at the root. The joint designs illustrated in Figure 7 should not be taken as restrictions, but only as a reflection of currently used types.

Any joint design that gives complete fusion should be considered and tested by the fabricator (see Figure 8). Many successful welds have been made in T-joints, double-V-grooves with welded backing bars, and some in multipass joints. The welding engineer, once familiar with the electrogas process, should experiment with any joint that he believes will work and qualify the process accordingly.

7.3 Assembly and Alignment

7.3.1 Misalignment. Workpiece surface misalignment must be limited to 1/8 in. (3.2 mm) on both front and back surfaces. Grinding may be required to stay within this tolerance. Greater misalignment creates a variety of problems, including leakage of weld metal, irregular bead shape, incomplete fusion, undercut, and loss of shielding with attendant porosity. In addition, when using a steel backing bar, excessive misalignment can result in excessive fusion through a backing bar.

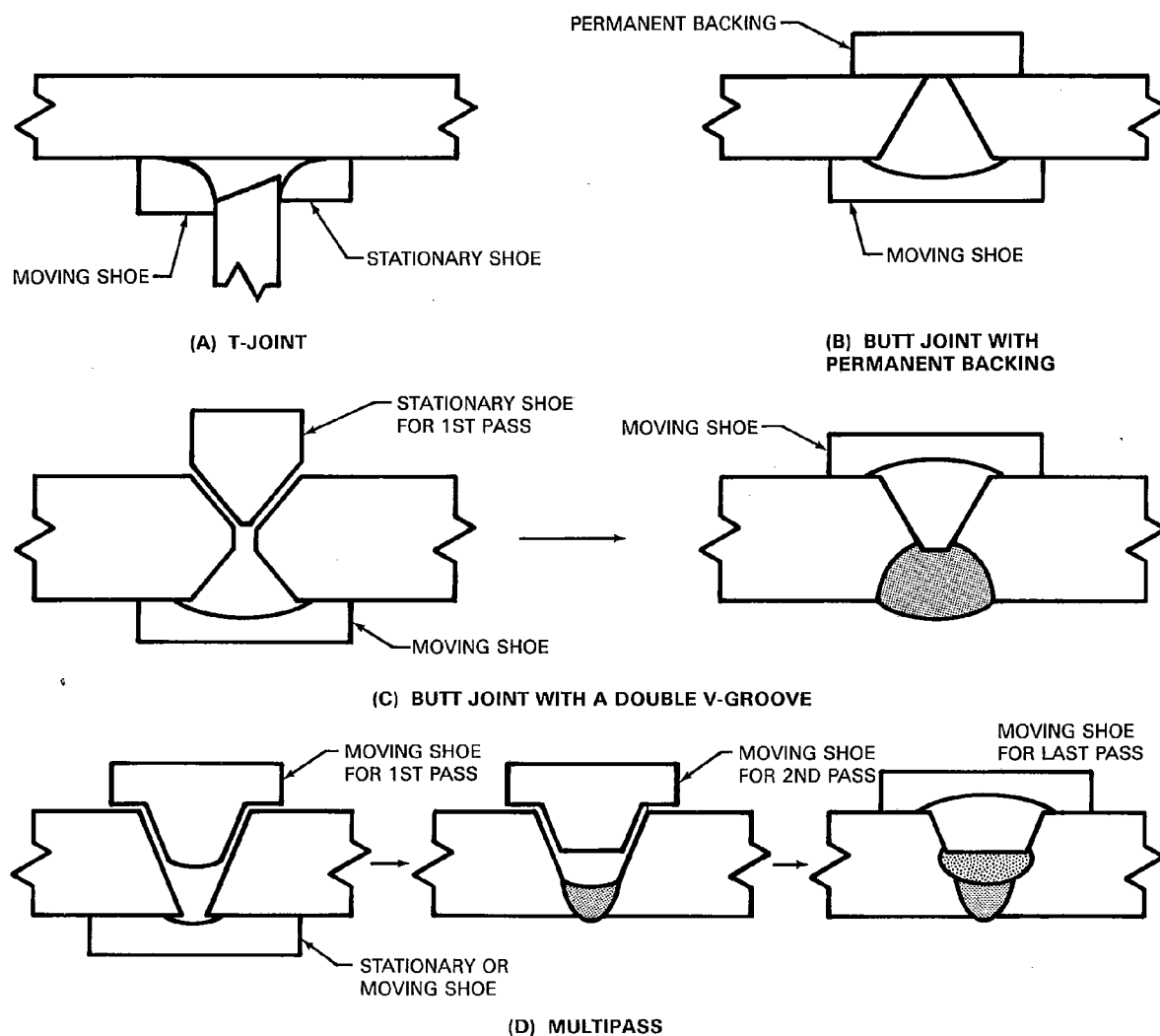


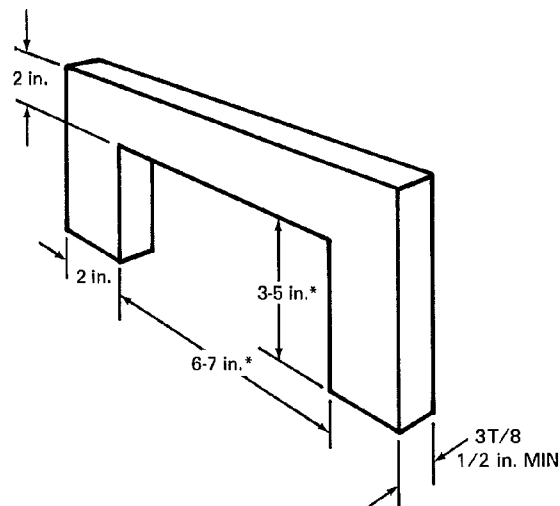
Figure 8 — Alternate EGW Joint Designs

7.3.2 Strongbacks. Suitable clamps or brackets, or both, are required to hold the workpieces in alignment during welding. U-shaped brackets, designed to allow clearance for the outboard moving shoe or outboard stationary backing, as shown in Figure 9, are commonly used. The brackets must hold the workpieces in alignment, but not be rigid enough to cause cracking. Generally, smaller brack-

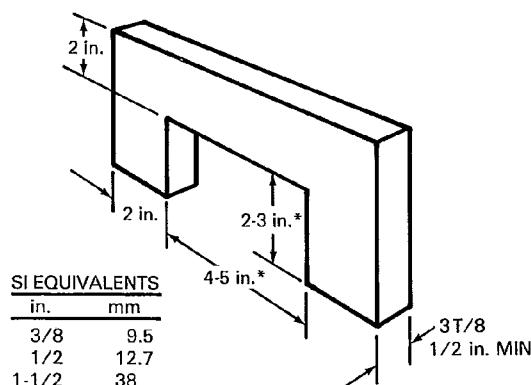
ets can be used for stationary shoe applications than are needed for clearance of a moving shoe.

7.3.3 Starting Weld Tab (Sump). A starting tab permits striking the arc below the actual joint so any starting defects can be easily removed.

The starting tab must be deep enough to allow the process to stabilize before the weld pool rises into the joint. Some EGW equipment starts at a reduced voltage and current and slower travel speed, then



(A) FOR MOVING SHOE



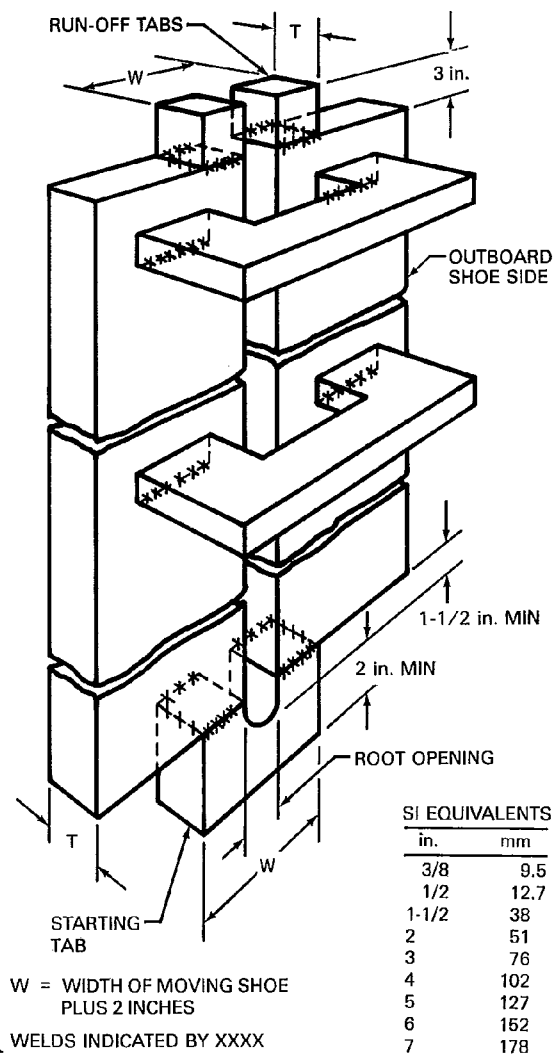
(B) FOR STATIONARY SHOE

SI EQUIVALENTS

in.	mm
3/8	9.5
1/2	12.7
1-1/2	38
2	51
3	76
4	102
5	127
6	152
7	178

*ACTUAL DIMENSIONS TO FIT DAM OR SHOE

T = BASE METAL THICKNESS



W = WIDTH OF MOVING SHOE PLUS 2 INCHES

— WELDS INDICATED BY XXXX

SI EQUIVALENTS

in.	mm
3/8	9.5
1/2	12.7
1-1/2	38
2	51
3	76
4	102
5	127
6	152
7	178

Figure 9 — Typical Brackets Used for EGW Joint Assembly

Figure 10 — Typical Arrangement of Starting, Run off Tabs, and Brackets for EGW Joint Assemblies

switches to normal welding conditions after a preset time. This technique allows the weld pool to stabilize in the starting tab area before the weld rises into the joint. The starting tab is cut off after welding.

The starting tab thickness and groove shape must be the same as those of the workpieces. The starting tab is attached to the workpieces, as shown in Figure 10. The top of the starting tab, where it fits against the bottom of the workpieces, should be clean and dry. Continuous seal welds should be ground flush where the shoes fit. Insufficient seal weld strength or thickness of material beneath the groove in the starting tab, can result in weld metal leakage, which would delay the start of upward travel.

7.3.4 Run off Weld Tabs. Run off tabs are required because the rapid cooling of the large weld pool at the end of the weld creates a shrinkage crater with a tendency for trapped slag or gas. Typical run off tabs are shown in Figure 10. Stationary backing shoes must reach to the top of the run off tab. The weld should be made into the run off area, finishing 1 in. to 2 in. (25 to 51 mm) above the top of the workpiece depending on base metal thickness. The run off tabs should be removed after the work is completed.

7.4 Typical Applications. Most applications of electrogas welding have been on base metals used for tank fabrication, shipbuilding, structural member fabrication, and pressure vessel manufacture. Any joint that must be or may be welded in a vertical position may be an application that can significantly reduce cost. EGW is essentially appropriate for workpieces ranging in thickness from 3/8 in. to 4 in. (10 mm to 100 mm) where the weld joint can be made in the vertical position and the joint is accessible to the equipment. Figures 11 through 15 illustrate some typical EGW applications.

8. Metallurgical Advantages and Limitations

8.1 Electrogas Welding Thermal Cycle. The thermal cycle of EGW closely approximates that of a large submerged arc weld. The macrostructure of electrogas welds shows significant grain enlargement (large grains) with a marked tendency to columnar growth. The heat-affected zone is wider than in conventional arc welding, but narrower than that of an electroslog weld comparable in size.

A detailed description of the metallurgical effects of weld thermal cycles may be found in the *AWS Welding Handbook*, Vol. 1, 8th Ed. In summary, the protracted thermal cycle associated with electrogas welding makes it practically impossible for hard phases to form in the weld or heat-affected zone of carbon and low alloy steels. This point can best be illustrated by sectioning an electrogas weld and measuring the hardness at various points in the weld and heat-affected zone. If the hardness is measured by the Knoop microhardness method, the general distribution of hardnesses may be plotted for each zone as shown in Figure 16. The data reflect a gradual change in hardness from the weld through the heat-affected zone to the unaffected base metal. This gradual change in hardness is typical of the electrogas process in low carbon steel and low alloy plate materials.

In contrast to the hardness survey for the electrogas weld, a similar survey is shown in Figure 17 for a multipass shielded metal arc weld (vertical up). The important point of this figure is the sharp increase in hardness in the heat-affected zone near the weld interface. In some cases, this hardness can approach the maximum quench hardness of the base metal. This hardness pattern in the heat-affected zone is typical for all commonly used multipass welding processes, such as shielded metal arc welding (SMAW), submerged arc welding (SAW), flux cored arc welding (FCAW), gas metal arc welding (GMAW), etc. The protracted thermal cycle of electrogas welding does allow considerably more time for grain growth to occur. Consequently, much coarser grains are obtained in the heat-affected zone of an electrogas weld. This is a disadvantage of EGW, since coarse grains are usually associated with low notch impact values. This problem is discussed further in the sections on macrostructure and mechanical properties.

8.2 Weld Macrostructure. The macrostructure of electrogas welds is determined mainly by the chemical composition and welding conditions. For carbon and low alloy steels, the primary structure that exists when the width of the weld pool is equal to or greater than its depth will be such that the dendrites have an upward direction. This condition is desirable for most applications, since it results in the best overall joint properties and is least sensitive to weld cracking. If, however, the primary dendrites grow perpendicular to the welding direction, all impurities, segregates, and low melting point constituents will concentrate in the center of the weld due to segregation during weld metal solidification. This

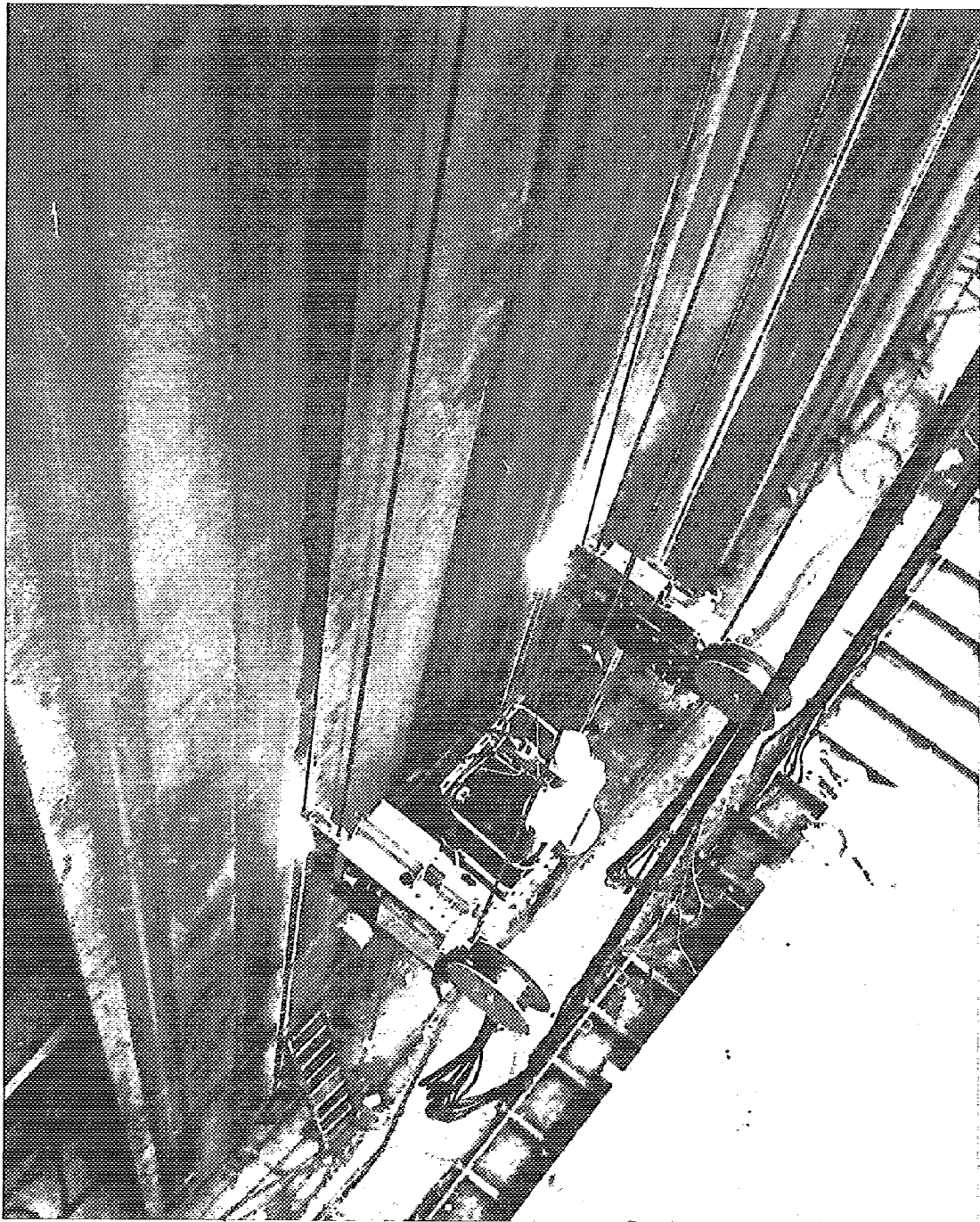


Figure 11 — Electrogas Welding of a Ship Hull Using Two Machines Controlled by One Operator

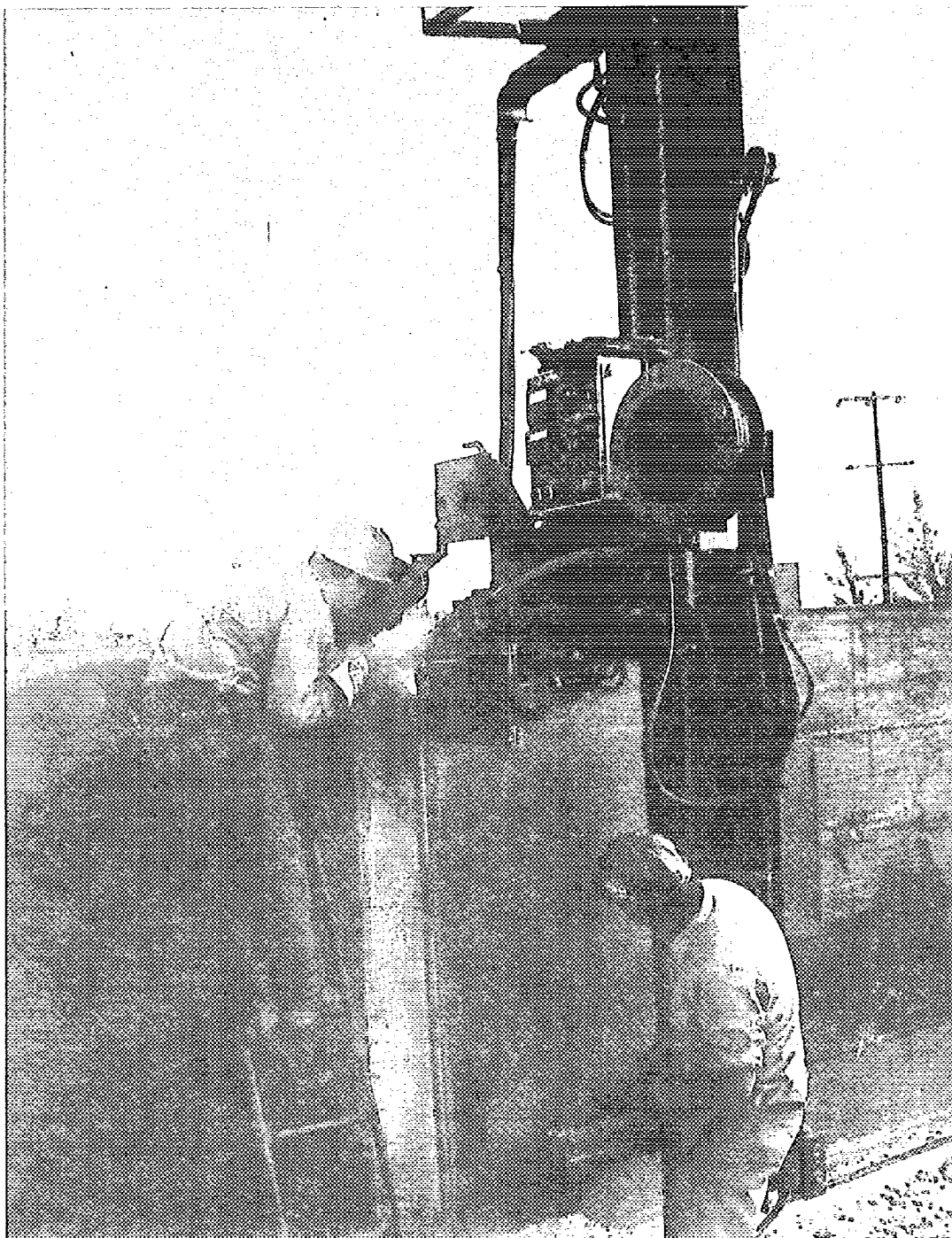


Figure 12 — Field Electrogas Welding of a Storage Tank

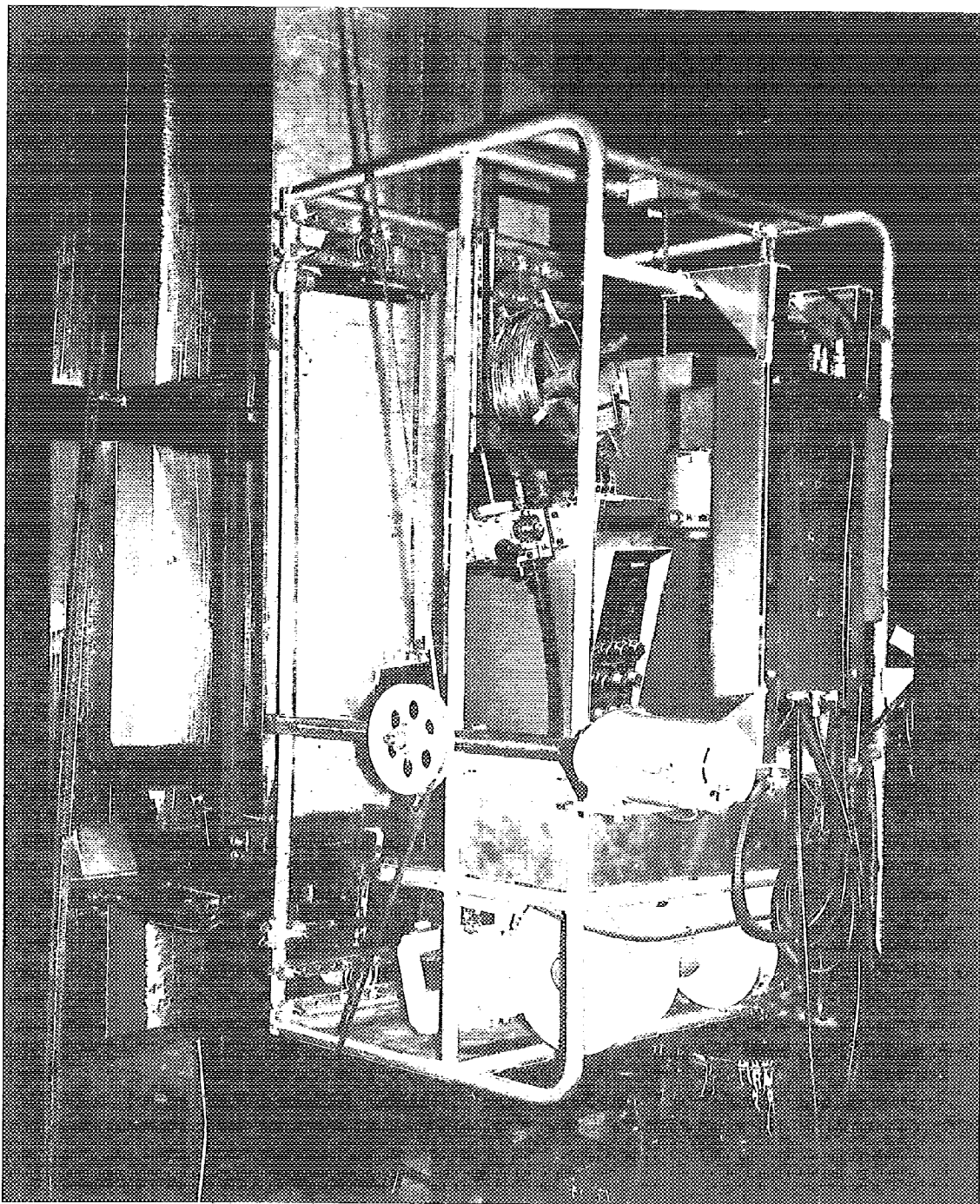


Figure 13 — A Portable EGW Unit Housed in a Special Elevator Cage

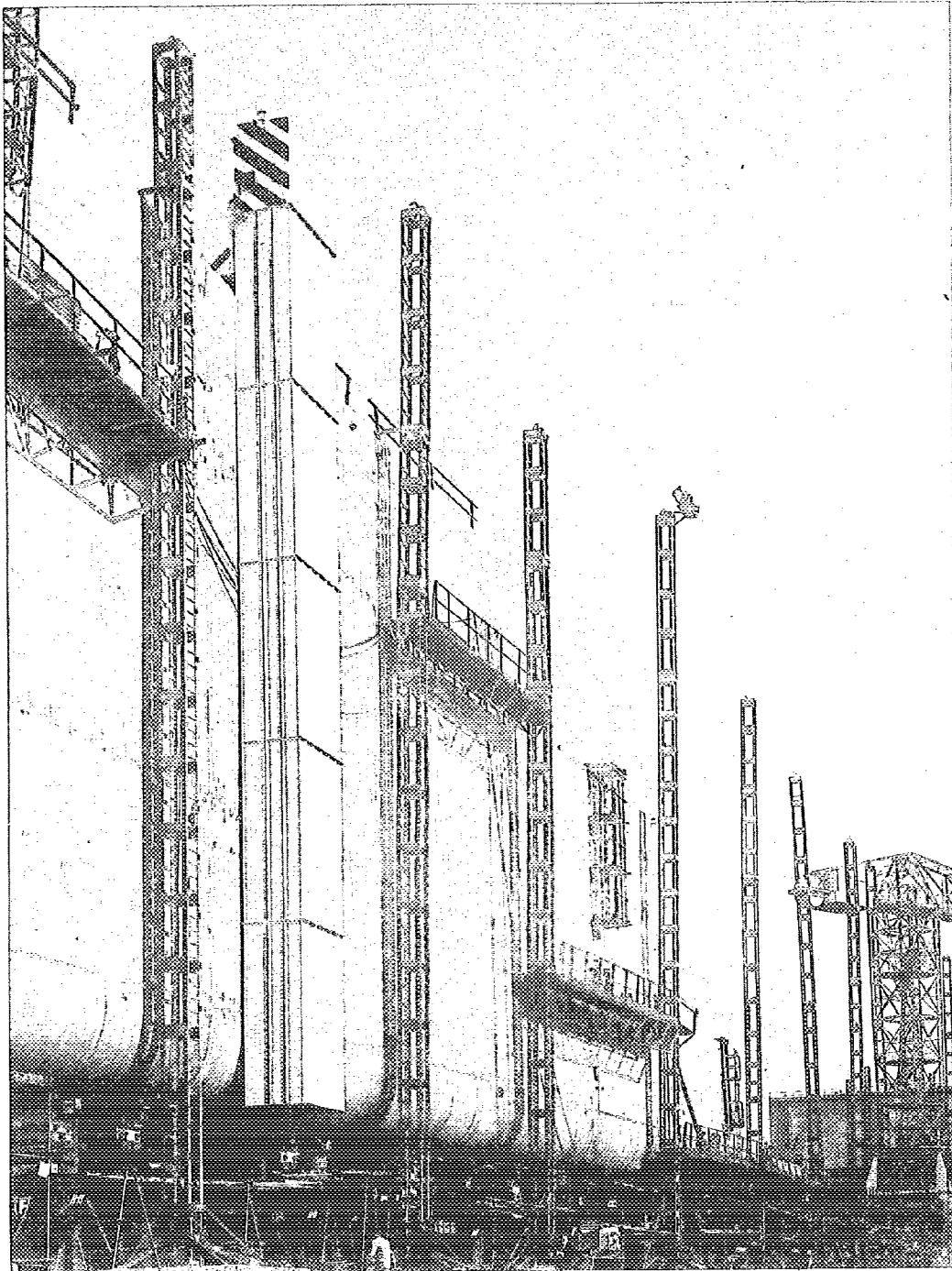


Figure 14 — A Self-Contained EGW Unit Used in Ship Building

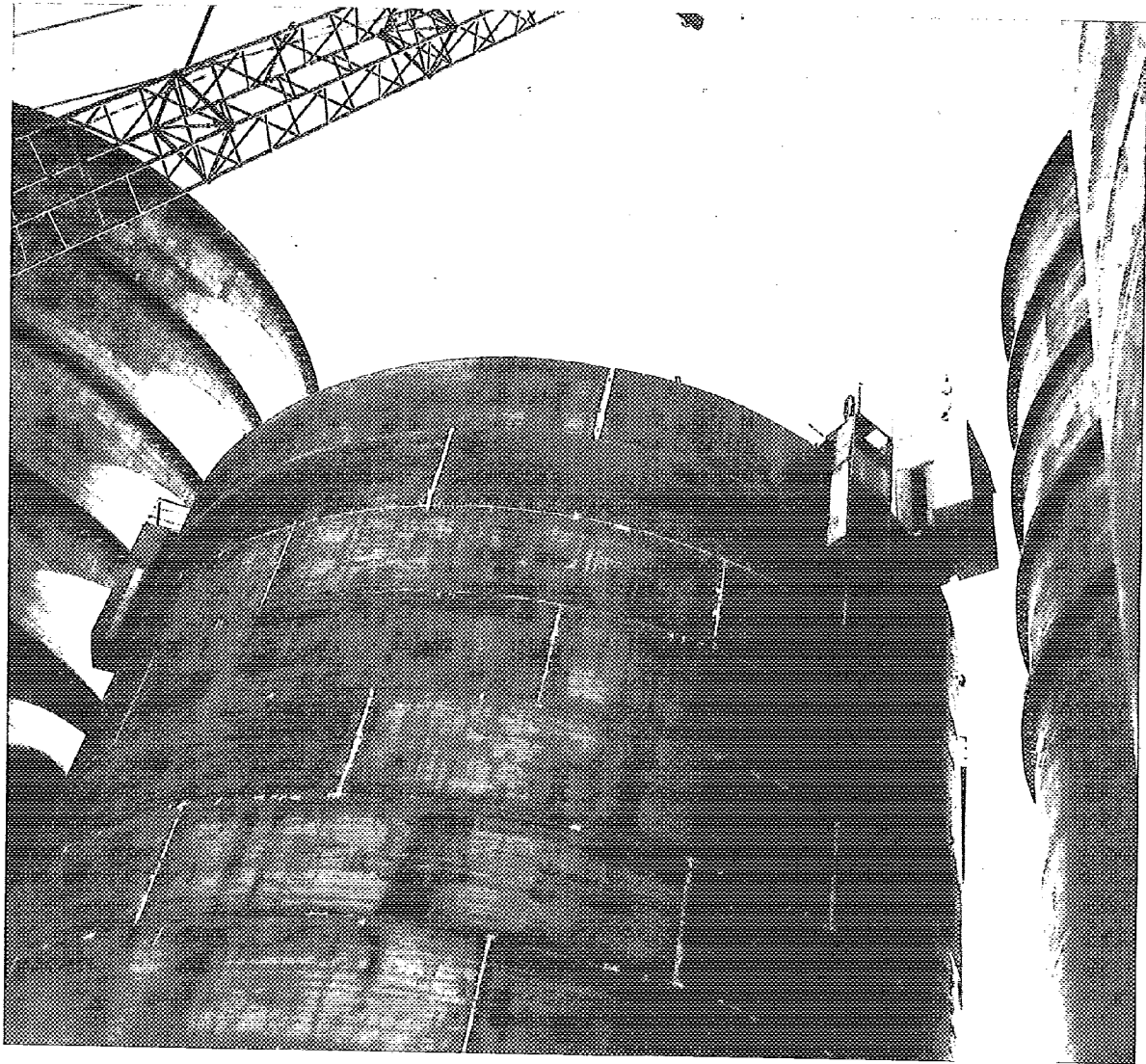


Figure 15 — Electrogas Welding of Vertical Joints for Surge Tanks

occurs when the weld pool is deep and narrow. This condition increases the tendency for weld cracking, which usually occurs at high temperatures in conjunction with, or immediately after, solidification.

The weld metal structure resulting from electrogas welding consists of large dendritic grains; the resultant heat-affected zone is wide with considerable grain coarsening near the weld interface. Large dendritic grains generally reduce notch impact values and raise the transition temperature. Properly made electrogas welds in the as-welded condition generally meet the minimum impact properties called for by most code requirements. For low temperature applications, it may be difficult to meet notch toughness requirements with electrogas welds without postweld heat treatment to refine the grain.

8.3 Preheat. Preheating of the base metal is usually unnecessary when electrogas welding steels in the low and medium carbon ranges. A large amount of the heat generated in electrogas welding is carried away into the workpieces. The heat carried away serves to preheat the base metal, due to the relatively slow moving weld pool.

Although the heat of welding is sufficient in most applications, preheat requirements must be determined by the user on the basis of the specific conditions of each application. Preheat is most frequently required to prevent cracking when:

- (1) Welding high strength steels
- (2) High carbon or hardenable high alloy steels
- (3) Welding 3 to 4 in. (76 to 100 mm) base metal
- (4) Restraint of the base metal is high
- (5) Temperature of the base metal is below 32°F (0°C)

Preheating the start area of the weld is also used to improve edge wetting. Excessive preheat slows the weld freezing and cooling rate, which affects mechanical properties, increases the dilution, and raises the possibility of such problems as metal leakage.

Sometimes the weld must be restarted along the joint due to equipment failure, wire breakage, weld metal leakage, or some other process failure. Restarts should be avoided, if possible, due to the high incidence of weld defects associated with restarts. If restarts are necessary, preheating the restart area should be considered to improve fusion.

Preheating the restart area should also be considered for electrogas welds using equipment that has two moving shoes. In this case, an insert or wedge is jammed into the joint immediately after the weld is stopped. The insert will prevent squeezing the head

assembly between the workpieces as they contract. Preheating the restart area helps to control the shrinkage forces from the contracting workpieces and may be required to expand the joint enough to remove the insert.

8.4 Postweld Heat Treatment. Most applications of electrogas welding, particularly the welding of field-erected structures, require no postweld heat treatments. Stress-relief heat treatment of electrogas weldments typically results in a slight drop in tensile strength and a slight improvement in weld and heat-affected zone notch impact properties. In weldments requiring optimum notch impact properties, a postweld heat treatment such as normalizing may be required. Quenched and tempered steels require postweld heat treatment to restore the original properties of the base metal.

8.5 Residual Stresses and Distortion. Since solidification of an electrogas weld begins at the shoes, the weld faces are under compressive residual stresses, and the center of the weld is in tension. This unique residual stress pattern is just the reverse of the residual stresses that are likely to occur with multipass welding processes.

Angular distortion in the horizontal plane is virtually nonexistent in single-pass electrogas welds. This is due to the symmetry of most electrogas groove designs in the workpiece thickness direction, which results in uniform weld shrinkage transverse to the weld axis and the workpiece thickness direction. As welding progresses up the joint, the joint members are drawn together by the weld shrinkage. Therefore, the opening at the top of the joint should be approximately 3/32 to 1/8 in. (2.4 to 3.2 mm) more than at the bottom to allow for this shrinkage. Factors influencing shrinkage allowance include base metal type and thickness, joint length, and weight of the joint members being joined.

Angular distortion can occur for the multiple-pass applications of electrogas welding and is usually compensated for by a preweld adjustment of the joint member alignment. Experience will determine the proper amount of preweld adjustment for each application.

8.6 Mechanical Properties. By its nature, electrogas welding is a high dilution (up to thirty-five percent base metal) process. Therefore, weld metal chemical composition and mechanical properties can vary substantially with different types of steel and even with different heats of the same steel.

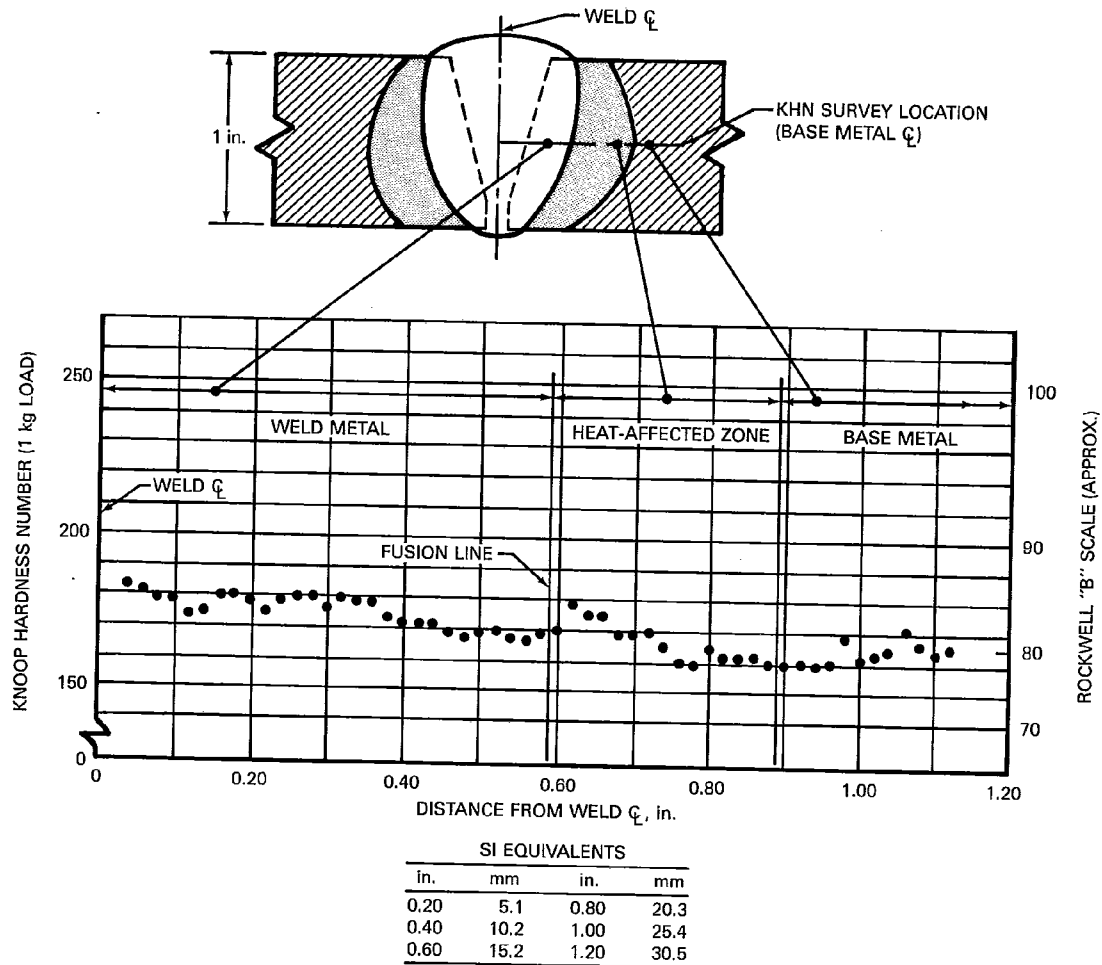


Figure 16 — Knoop Microhardness Survey Across Electrogas Weld in an A283 Grade C Base Metal

Mechanical properties also vary with cooling rate, procedures, joint design, and type of backing. Electrogas electrodes are designed to accommodate as much variation as practical.

When used with specified procedures, the properties in Tables 4, 5, and 6 were obtained. Because there are many variables, however; the properties that will be obtained in an actual application cannot be guaranteed. Mechanical properties to be expected in production must be determined by the user by actual testing to job requirements. Typical weld metal mechanical properties are listed in Table 4 for flux cored electrogas welds in various carbon and structural steels and in Table 5 for welds in pressure vessel quality (PVQ) steels.

One problem encountered in electrogas welding

has been low notch toughness properties of the weld and heat-affected zone in the as-welded condition. By using suitably alloyed electrodes and controlled welding conditions, the notch toughness properties of the weld metal can be made equal to or better than the base metal for most structural and PVQ steels. In most cases, controlled welding conditions have resulted in heat-affected zone notch toughness values that are well within the limits established by the codes for structural and PVQ steels in the as-welded condition. In some cases, for structural steels with low heat-affected zone notch toughness values, it has been found that the unaffected base metal values have been as low or lower. This is shown in Table 6.

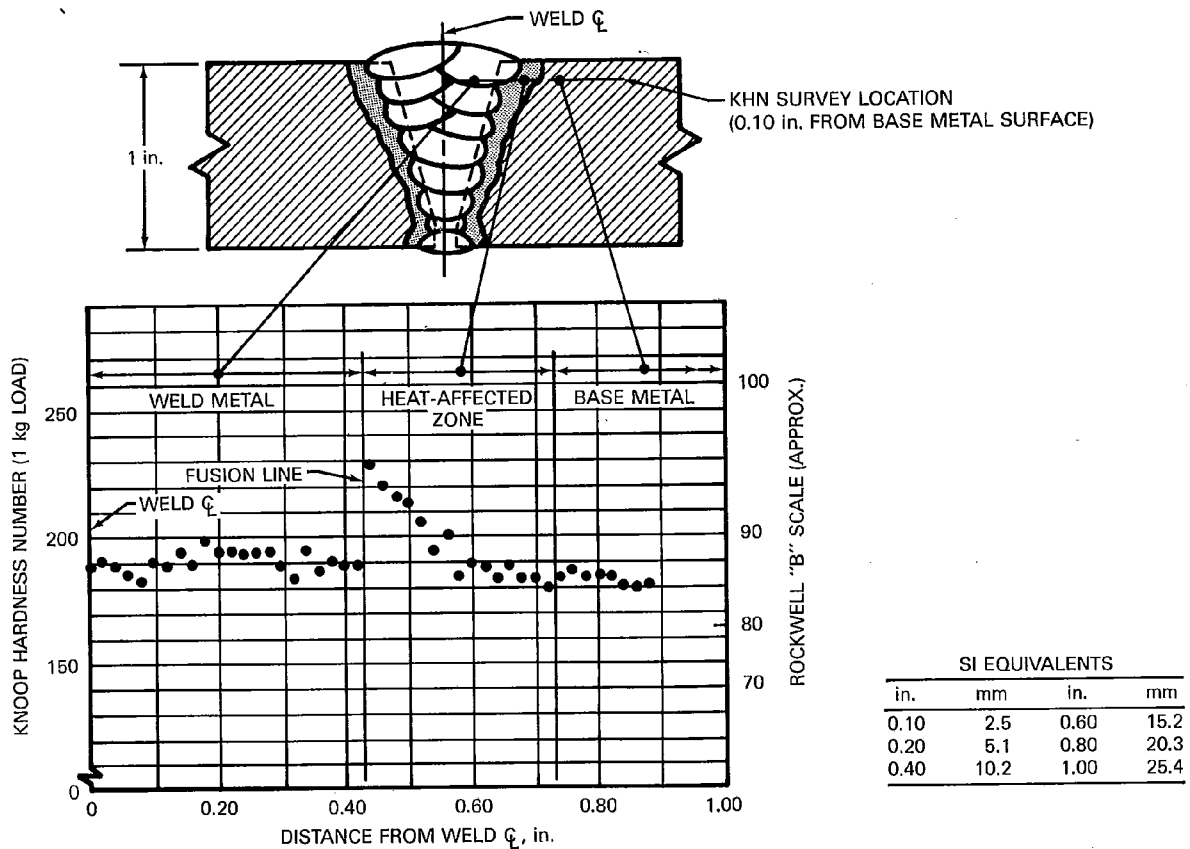


Figure 17 — Knoop Microhardness Survey Across Shielded Metal Arc Weld (vertical up) in an A283 Grade C Base Metal

The electrogas process should be used with caution and thorough testing for applications specified to have low temperature notch toughness properties (i.e., quenched and tempered, low alloy, special low temperature, and normalized steels). The electrogas process may degrade the heat-affected zone toughness to the extent that use of the process should only be considered when the weldment will be given a quench-and-temper or a normalizing heat treatment after welding. Electro gas welding of steels that are quenched and tempered or normalized is not permitted by the ANSI/AWS D1.1, *Structural Welding Code—Steel*.

9. Selection of Process Variables and Other Welding Conditions.

Process variables for electro gas welding include current, electrode feed speed, voltage, electrode extension, electrode oscillation, and root opening. The proper selection of these variables affects the operation and economics of the process and the resultant weld quality. The effects of each variable must be fully understood, since they differ significantly from gas metal arc and flux cored arc welding. As an example, the weld axis is perpendicular to the electrode axis in conventional arc welding pro-

Table 4
Typical As-Welded Mechanical Properties of Structural Steels Welded
with Flux Cored Electrodes

Materials (ASTM)	Thickness		Electrode Class (A5.26)	Gas ^a	Yield Strength		Ultimate Tensile Strength		Elongation in 2 in., (51 mm) Percent	Test Temp.,		Charpy V-notch Impact Strength ^b			
	in.	mm			ksi	MPa	ksi	MPa		°F	°C	WMCL		BM-HAZ	
C1020	1/2	12	EG72T1	-	71.8	495	80.1	552	28	-20	-29	32	43	-	-
C1020	1	25	EG72T1	-	63.6	439	78.5	541	27	-20	-29	24	33	-	-
A36	1	25	EG72T1	-	65.2	450	78.9	544	27	-20	-29	30	41	-	-
A36	1	25	EG72T4	CO ₂	69.5	479	91.8	633	26	-22	-30	26	35	-	-
A36	3	76	EG72T4	CO ₂	67.0	462	89.0	614	26	-22	-30	23	31	-	-
A36	3	76	EG72T4	Ar80/CO ₂	-	-	87.2	601	23	0	-18	36-	49-	-	-
												42	57		
A131-C	1-1/2	38	EG72T3	CO ₂	-	-	71.1	490	30	-30	-34	33	45	22	30
A441	3/4	19	EG72T1	-	73.6	507	82.4	569	23	-20	-29	30	41	-	-
A441	1	25	EG72T1	-	66.2	456	80.5	555	23	-20	-29	27	36	-	-
A441 He	2	51	EG72T1	-	64.7	446	80.6	556	24	-20	-29	22	30	-	-
A441	2	51	EG72T4	CO ₂	68.4	472	92.4	637	24	0	-18	22	30	-	-
A572-50	1	25	EG72T4	Ar80/CO ₂	-	-	-	-	+14	-10	45	61	25	34	-
A572-50	1-1/2	38	EG72T1	-	56.7	392	77.0	591	23	0	-18	10	14	-	-
A588	3	76	EG72T4	CO ₂	-	-	95.4	658	23	0	-18	41	56	-	-

a. Ar80/CO₂ is 80% argon and 20% CO₂.

b. Test specimen notch location is as follows: WMCL, weldmetal centerline; BM-HAZ, heat-affected zone of parent metal.

Table 5
Typical As-Welded Mechanical Properties in Pressure Vessel Steels Welded
with Flux Cored Electrodes

Materials (ASTM)	Thickness		Electrode Class (A5.26)	Gas ^a	Yield Strength		Ultimate Tensile Strength		Elongation in 2 in., (51 mm) Percent	Test Temp.,		Notch Toughness Charpy V-notch Impact Strength ^b			
	in.	mm			ksi	MPa	ksi	MPa		°F	°C	WMCL		BM-HAZ	
A203	1-5/8	41	EG72T4	Ar80/CO ₂	53.0	365	71.5	493	32	-40	-40	21	23	42-82	57-111
A516	1	25	EG72T1	-	57.7	398	74.3	512	26	-20	-29	21	28	-	-
A516	1-1/2	38	EG72T4	Ar80/CO ₂	78.0	538	89.5	610	29	-20	-29	30	41	28-67	33-91
A537-1	3/4	19	EG72T1	-	69.6	480	85.6	590	24	-4	-20	32	43	-	-
A537-1	1	25	EG72T4	CO ₂	62.3	430	83.0	572	29	-20	-29	25	34	29	39
A537-1	1-1/8	29	EG72T4	Ar80/CO ₂	74.0	510	100.0	690	26	-22	-30	34	46	-	-
A633	1	25	EG72T1	-	73.5	507	87.8	605	25	0	-18	46	62	-	-

a. Ar80/CO₂ is 80% argon and 20% CO₂.

b. Test specimen notch location is as follows: WMCL, weld metal centerline; BM-HAZ, heat-affected zone of base metal.

cesses (GMAW and FCAW). The weld pool surface is normally parallel to the plate surface. Joint penetration and depth of fusion are generally increased by increasing the welding current and decreasing the voltage. However, in electrogas welding, the weld axis is parallel to the electrode wire and the weld pool surface is perpendicular to the plate surface. Increasing the welding current or decreasing

the voltage in electrogas welding has the effect of creating a deeper and narrower molten weld pool, which will reduce the depth of fusion.

9.1 Welding Voltage. The welding voltage is the major variable affecting weld width and base metal melting in electrogas welding. Increasing the voltage increases the depth of fusion at the groove face

Table 6
As-Welded Notch Toughness Properties of Electrode Gas Weld in 1 in. (25 mm)
Thick A283 Steel

	Charpy V-Notch* ft · lb (J)		
	+70°F (21°C)	+20°F (-7°C)	0°F (-18°C)
Unaffected plate	25, 18, 9 (33.9, 24.4, 12.2)	5, 5, 6 (6.8, 6.8, 8.1)	4, 3, 5 (5.4, 4.1, 6.8)
Heat-affected zone	35, 28, 12 (47.4, 37.9, 16.3)	5, 5, 5 (6.8, 6.8, 6.8)	6, 6, 5 (8.1, 8.1, 6.8)
Center of weld	35, 32, 18 (47.4, 43.4, 24.4)	22, 23, 11 (29.8, 31.2, 14.9)	12, 10, 8 (16.3, 13.6, 10.8)

*Notch perpendicular to the plate surface.

and width of the weld as shown in Figure 18. Welding voltages of 30 to 55 volts are used, with voltage increasing as the workpiece thickness and the deposition rate increase. Excessively high voltage may produce unstable operation, due to the arc being diverted to the groove faces above the weld pool.

9.2 Welding Current—Electrode Feed Speed. Welding current and electrode feed speed are directly proportional for a given electrode extension. Increasing the electrode feed speed increases the deposition rate and welding current.

For a given set of conditions, increasing the current decreases the depth of fusion and width of the weld, as shown in Figure 19. Low current levels are usually associated with slow travel speeds and wide welds. As the current level is increased, the electrode feed speed, deposition rate, and rate of joint fill (travel speed) increase. Excessive welding current may cause a severe reduction in weld width and depth of fusion. Excessive welding current may also produce centerline weld cracking associated with a low form factor (see 9.3). Welding currents of 400 to 800 amperes for a 3/32 in. (2.4 mm) diameter and 500 to 1000 amperes for 1/8 in. (3.2 mm) diameter electrode are commonly used. *ALL* welding leads must be large enough to carry high currents for the long arc times typical of this type of welding.

9.3 Form Factor. The resistance of the weld to centerline cracking is greatly influenced by the manner in which it solidifies. Heat is removed from the molten weld metal by the base metal and backing shoes. Solidification begins at these cooler areas and progresses toward the center of the weld. Since filler metal is continuously added, there is a pro-

gressive solidification from the bottom of the joint, and there is always molten weld metal above the solidifying weld metal. The result of the solidification pattern is shown by the sketch of a vertical section of an electrode gas weld in Figure 20.

The weld pool solidification pattern can be expressed by the term *form factor*. The form factor is the ratio of the maximum pool width (root opening plus depth of fusion) to its maximum depth. The maximum depth is measured on a polished and etched vertical cross section by drawing a line perpendicular to the grain boundary lines, starting at the weld interface on one side of the joint and ending at the weld interface on the other side. (See dashed line in Figure 20).

The form factor is measured on a vertical section of the electrode gas weld, usually taken at the base metal centerline. Welds having a high (1.5) form factor (wide width and shallow depth) have maximum resistance to centerline cracking. Welds having a low (0.5) form factor (narrow width and deep molten weld pool) tend to have low resistance to centerline cracking. Thus, the form factor is a calculated number that describes the shape of the weld metal solidification pattern. However, form factor alone does not control cracking. The chemical composition of the base metal (especially carbon content), the use of incorrect filler metals, and joint restraint may also contribute to centerline cracking.

The shape of the weld pool and resultant form factor are controlled by the welding variables. In general, increasing the voltage increases the form factor, while increasing the current has the tendency to decrease the form factor. Since the welding conditions are usually specified in a welding proce-

ture, the form factor is rarely measured or recorded.

9.4 Electrode Extension. When using a constant potential power supply, increasing the electrode extension at a constant electrode feed speed will result in a reduced arc voltage and a lower welding current. The resultant weld will tend to become narrow, as shown in Figure 21.

Increasing the electrode extension while keeping the current constant (by increasing feed speed) will

increase the deposition rate and have more tendency to decrease the depth of fusion and weld width.

In externally gas shielded electrogas welding, an electrode extension of about 1-1/2 in. (38 mm) is used. For most self-shielded flux cored electrogas welding, an electrode extension of 2 to 3 in. (51 to 76 mm) is used.

9.5 Electrode Oscillation. Base metals up to 1-1/4 in. (32 mm) thick are commonly welded with a

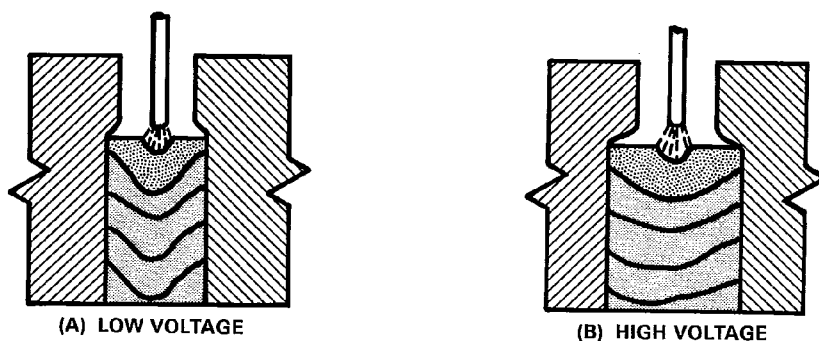


Figure 18 — Effect of Welding Voltage on the Shape of the Weld Pool

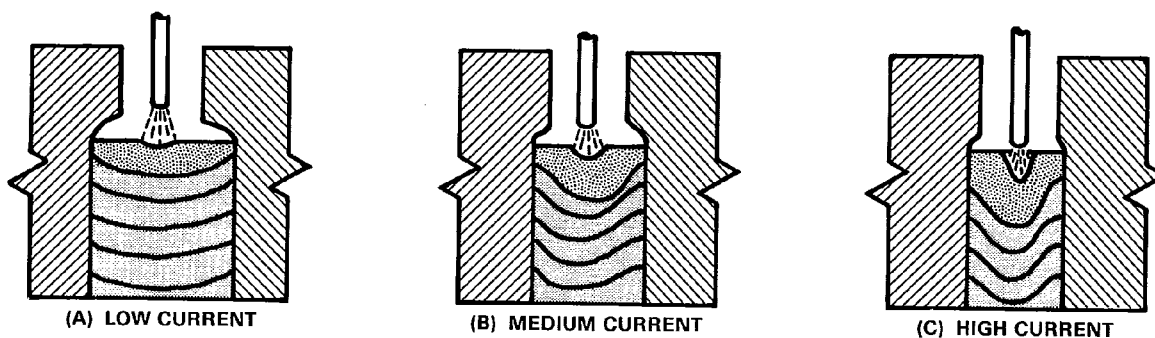


Figure 19 — Effect of Welding Current on the Shape of the Weld Pool

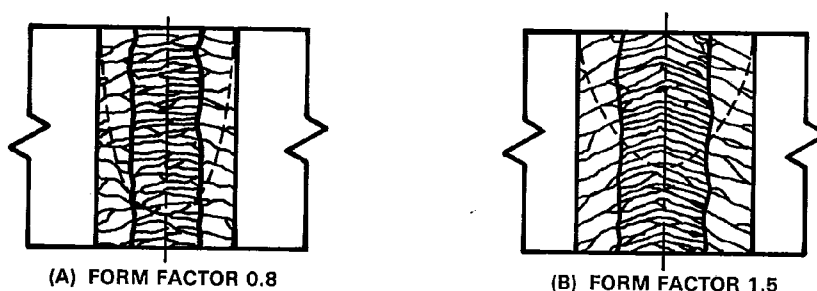


Figure 20 — Weld Macrostructure of a Vertical Section of an Electrode Gas Weld

stationary electrode. Thicker base metals, up to 1-1/2 in. (38 mm), have been welded with a stationary electrode, but high voltages and special techniques are required to prevent incomplete fusion at the weld toes (lack of edge fusion). Oscillation of the electrode is thus generally required when welding workpieces thicker than 1-1/4 in. (32 mm), but workpieces as thin as 1 in. (25 mm) have been welded with oscillation.

Horizontal oscillation is controlled so that the arc stops at a distance of approximately 3/8 in. (9.5 mm) from each shoe. Oscillation speed is commonly 20 to 100 in./min (0.51 mm to 2.54 m/min). It is necessary to use a dwell period at each end of the oscillation travel to obtain complete fusion at the weld toes. The dwell time may vary from 1/2 to 3 seconds.

9.6 Joint Opening. A minimum joint opening is needed to give sufficient clearance for the electrode guide, which is usually placed inside the joint. Increasing the joint opening increases the weld width. Excessive joint openings will consume extra amounts of filler materials, which may reduce the economic savings of the process. Excessive joint openings may also cause incomplete fusion at the weld toes if the voltage is not increased. Joint openings for the butt joints with a square groove joint geometry are generally 11/16 in. (18 mm) to 1-1/4 in. (32 mm). Joint openings for the butt joint with a single V-groove joint geometry are generally 11/16 to 1-1/4 in. (18 to 32 mm) at the face and 5/32 to 3/8 in. (4.0 to 9.5 mm) at the root.

9.7 Work Lead. The work lead is usually con-

nected to the starting sump, but it can be split and attached to each side of joint at the bottom. Although this circuiting has proved adequate in most applications, severe arc blow can cause excessive starting porosity, lack of fusion on one side of the joint, or both. The final work lead location must be determined by the user on the basis of the specific conditions of each application.

9.8 EGW Procedures. Tables 7 through 10 give examples of commonly used settings for electrogas welds made with various AWS electrode classifications. Different settings may be required for specific applications.

10. Inspection of Welds and Rework

Because of the nature of the EGW process, the weld defects that may occur do not always resemble those of a multipass arc weld. Weld metal defects that may be encountered in the electrogas process are discussed in section 13, Trouble Shooting Guide.

Conventional nondestructive examination can be used to determine the soundness of the EGW joint.

Nondestructive Examination techniques normally used with EGW include:

- (1) VT—Visual
- (2) RT—Radiography (isotope or x-ray)
- (3) MT—Magnetic particle
- (4) PT—Liquid penetrant
- (5) UT—Ultrasonic (the large grain size may require special techniques)

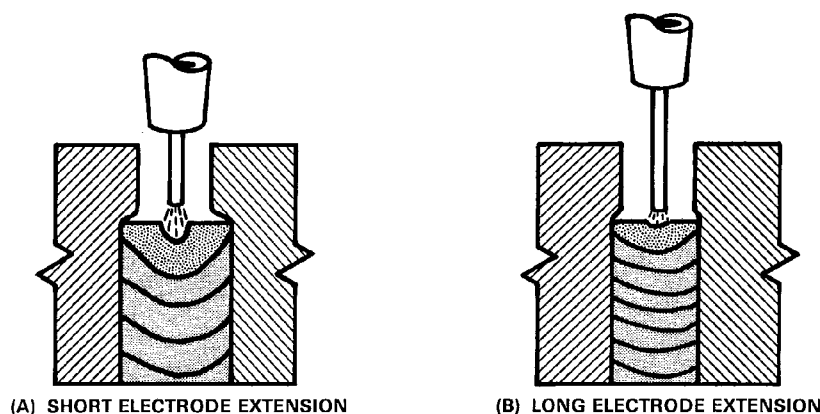
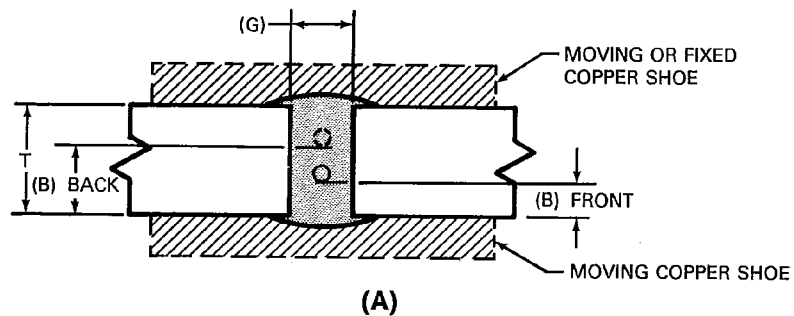


Figure 21 — Effect of Electrode Extension (with CP power supply) on the Shape of the Weld Pool

Table 7
Commonly Used Settings for Electrogas Welds with AWS Class EG72T1 Electrode with Moving Shoe(s)



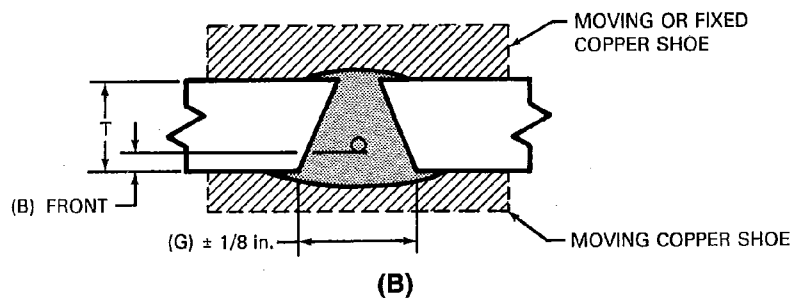
Base metal thickness (T), in. (mm)	3/4 (19 mm)	1 (25mm)	1-1/4 (32 mm)	1-1/2 (38 mm)
Current, amperes (approx.)	$\left\{ \begin{array}{c} 625-675 \\ (40-42) \end{array} \right\}$			
Voltage, volts (DCEP)				
Wire feed speed, in/min (mm/sec)	$\left\{ \begin{array}{c} 350 \\ (148) \end{array} \right\}$			
Travel speed, in/min (approx.) (mm/sec)	4.1 (1.7)	3.4 (1.4)	2.6 (1.1)	1.7 (0.7)
Electrode type	$\left\{ \begin{array}{c} EG72T1 \\ 0.120 (3.0) \\ 3 \pm 1/8 (76 \pm 3.2) \end{array} \right\}$			
Electrode size, in. (mm)				
Electrode extension, in. (mm)				
Electrode location ¹ (B) in., front (mm)	1/4	5/16 (8.0)	3/8 (9.5)	1/4 (6.4)
(B) in., back (mm)	6.4			1 (25)
Electrode drag angle ²	[8°]			
Oscillation distance, in. (mm)	No oscillation	No oscillation	No oscillation	3/4 19
Cycle period, sec				5
Dwell, sec				2 front; 2 back
Traverse time, sec				0.5
Root opening (G), in. (mm)	$\left\{ \begin{array}{c} 3/4 + 1/8 - 0 \\ (19 + 3.2 - 0) \end{array} \right\}$			
Start sequence "on," ³ sec	2	5	8	10

1. Electrode location is measured from the open face of the joint to the near side of the electrode tip after establishing 3 in. (76 mm) electrode extension. Location should be set carefully and monitored during welding.

2. See Table 13 (11d).

3. The starting circuit should deliver 150 in/min (64 min/s) wire feed speed at 29 arc volts. These conditions should be maintained for the number of seconds shown in the Table.

Table 7 (continued)



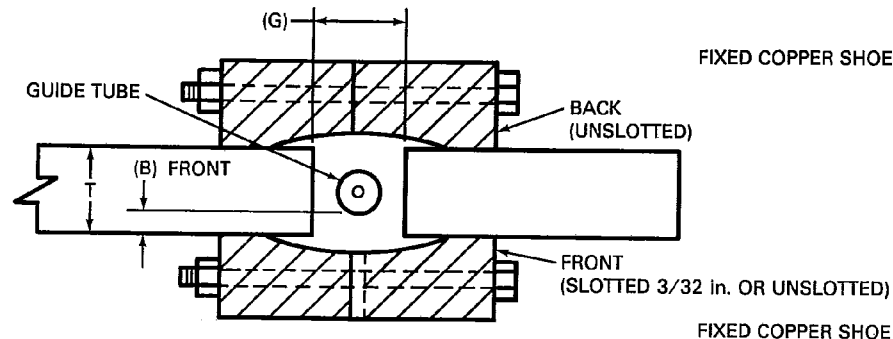
(B)				
Base metal thickness (T), in. (mm)	1/2 (12.7)	5/8 (15.8)	3/4 (19)	1 (25)
Current, amperes (approx.)	450-500	475-525	525-575	525-575
Voltage, volts (DCEP)	35-37	36-38	37-39	37-39
Wire feed speed, in/min (mm/sec)	300 (127)	340 (144)	380 (161)	380 (161)
Travel speed, in/min (approx.) (mm/sec)	6.0 (2.5)	3.2 (1.4)	2.7 (1.1)	2.2 (0.9)
Electrode type	EG72T1 3/32 (2.4) $2 \pm 1/8$ (51 ± 3.2)			
Electrode size, in. (mm)				
Electrode extension, in. (mm)				
Electrode location ¹ (B) in., front (mm)	1/8 (3.2)	3/16 (4.8)	1/4 (6.4)	5/16 (8.0)
Electrode drag angle ²	8°	8°	8°	8°
Root opening G (in) + 1/8 - 0 (mm) 3.2 - 0	1/2 (12.7)	5/8 (15.9)	3/4 (19)	3/4 (19)
Start sequence "on," sec	2	3	4	6

1. Electrode location is measured from the open face of the joint to the near side of the electrode tip after establishing 3 in. (76 mm) electrode extension. Location should be set carefully and monitored during welding. The guide tip should be 2 in. (51 mm) above the top of the shoe. The top of the molten weld pool will then be 1 in. (25 mm) below the top of the shoe.

2. See Table 13 (11d).

3. The starting circuit should deliver 150 in/min (64 min/s) wire feed speed at 29 arc volts. These conditions should be maintained for the number of seconds shown in the Table.

Table 8
Commonly Used Settings for Electrogas Welds with AWS Class EG72T1 Electrode with Consumable Guide Tube



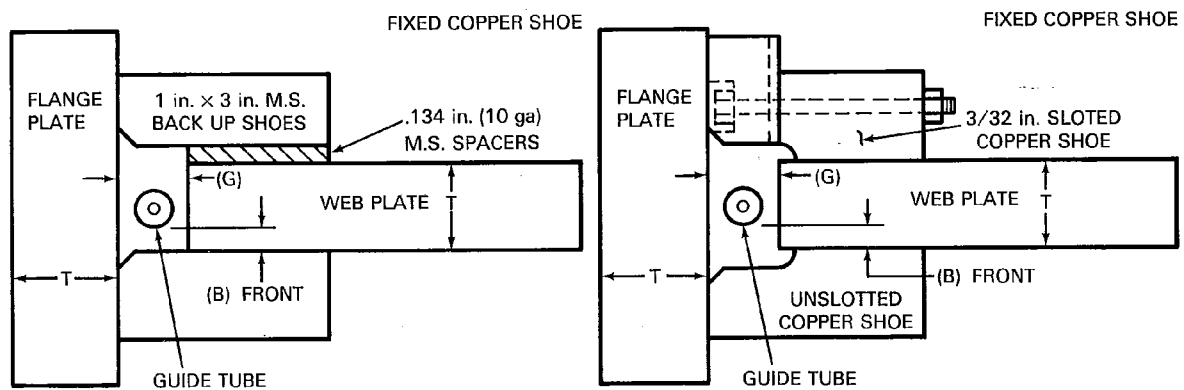
(A)				
Base metal thickness (T), in. (mm)	3/4 (19)	1 (25)	1-1/4 (32)	1-1/2 (38)
Current, amperes (approx.)	650-750	675-775	700-800	725-825
Voltage, volts (DCEP)	35-38	38-40	40-42	42-44
Wire feed speed, in/min (mm/sec)	200 (85)	230 (97)	265 (112)	300 (127)
Travel speed, in/min (approx.) (mm/sec)	3 (1.3)	2.5 (1.1)	2 (0.85)	2 (0.85)
Electrode type	{EG72T1}			
Electrode size, in. (mm)	{0.120 (3.0)}			
Guide tube	{1/2" (12.7) O.D. X 5/32" (4.0) I.D. C1008/C1020}			
Guide tube location ¹ (B)in., front (mm)	1/8 (3.2)	1/4 (6.4)	3/8 (9.5)	1/2 (12.7)
(B)in., back	-			
Oscillation distance, in.	No oscillation			
Cycle period, sec.	7/8 + 1/8 - 0 (22 + 3.2 - 0)			
Root opening (G), in.	-			
Start time "on," ² sec	3	3	3	3
Crater time "on," ³ sec	6	10	15	20

1. Guide tube location is measured from the open face of the joint to the near side of the guide tube. Location should be set carefully and guide tube should be checked at top and bottom of joint before shoes are attached.

2. The starting circuit should deliver 100 in/min (42 mm/s) wire feed speed at 35 arc volts. The conditions should be maintained for the number of seconds shown in the table.

3. The crater circuit should deliver 100 in/min (42 mm/s) wire feed speed at 35 arc volts. The conditions should be maintained for the number of seconds shown in the table.

Table 8 (continued)



(B)

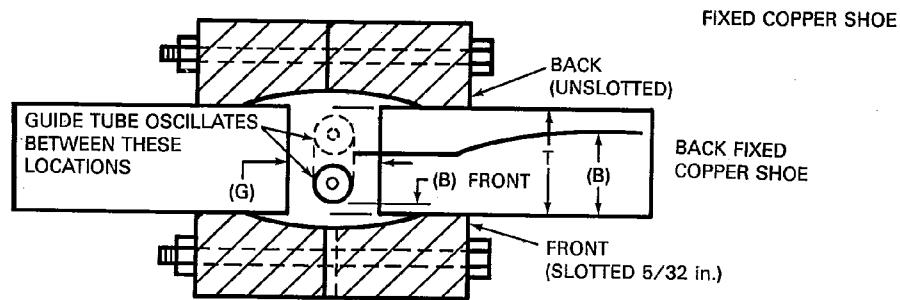
Base metal thickness (T), in. (mm)	3/4 (19)	1 (25)	1-1/4 (32)	1-1/2 (38)
Current, amperes (approx.)	650-750	675-775	700-800	725-825
Voltage, volts (DCEP)	35-38	38-40	40-42	42-44
Wire feed speed, in/min (mm/sec)	200 (85)	230 (97)	265 (112)	300 (127)
Travel speed, in/min (approx.) (mm/sec)	2 (0.8)	2 (0.8)	2 (0.8)	2 (0.8)
Electrode type	EG72T1			
Electrode size, in. (mm)	0.120 (3.0)			
Guide tube	{1/2" (12.7) O.D. X 5/32" (4.0) I.D. C1008/C1020}			
Guide tube location ¹ (B)in., front (mm)	1/8 (6.4)	1/4 (6.4)	3/8 (9.5)	1/2 (12.7)
(B)in., back	-	-	-	-
Oscillation distance, in.	No oscillation			
Cycle period, sec.				
Root opening (G), in.	7/8 + 1/8 - 0 (25 + 3.2 - 0)			
Start time "on," ² sec	3	3	3	3
Crater time "on," ³ sec	6	10	15	20

1. Guide tube location is measured from the open face of the joint to the near side of the guide tube. Location should be set carefully and guide tube should be checked at top and bottom of joint before shoes are attached.

2. The starting circuit should deliver 100 in/min (42 mm/s) wire feed speed at 35 arc volts. The conditions should be maintained for the number of seconds shown in the table.

3. The crater circuit should deliver 100 in/min (42 mm/s) wire feed speed at 35 arc volts. The conditions should be maintained for the number of seconds shown in the table.

Table 8 (continued)



(C)

Base metal thickness (T), in.	2 (51)	3 (76)	4 (102)
Current, amperes (approx.)	775-875	800-900	800-900
Voltage, volts (DCEP)	42-44	43-45	45-47
Wire feed speed, in./min (mm/sec)	350 (148)	400 (169)	400 (169)
Travel speed, in./min (approx.) (mm/sec)	1.4 (0.59)	1.2 (0.46)	0.8 (0.34)
Electrode type	EG72T1		
Electrode size, in. (mm)	0.120 (3.0)		
Guide tube	{1/2" (12.7) O.D. X 5/32" (4.0) I.D. C1008/C1020}		
Guide tube location ¹ (B)in., front (mm)	1/4 (6.4)	1/4 (6.4)	1/4 (6.4)
(B)in., back	1 1/4 (32)	2 1/4 (57)	3 1/4 (83)
Oscillation distance, in.	1	2	3
Cycle period, sec.	8.0	12	18
Dwell, sec.	2-3	2-3	3-4
Traverse time, sec.	1.5	3.5	5.5
Root opening (G), in. (mm)	1 + 1/8 - 0 (25 + 3.2 - 0)		
Start time "on," ² sec	3	3	3
Crater time "on," ³ sec	20	30	40

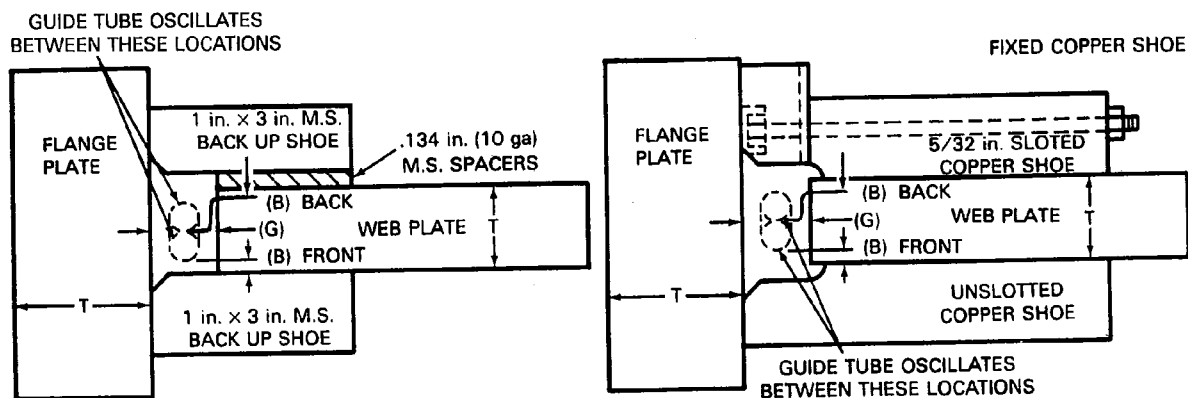
1. On 2 in. (51 mm) through 4 in. (102 mm) plate the guide tube oscillates between the locations shown and along the center line of the gap. The locations are 1/4 in. (6.4 mm) in from the surface of the plate to the edge of the guide tube.

The oscillation should be set before putting on the copper shoes so that guide tube locations can be checked at the top and at the bottom of the joint. The locations can be set by adjusting the stops on the oscillator.

2. The starting circuit should deliver 100 in./min (42 mm/s) wire feed speed at 35 arc volts. The conditions should be maintained for the number of seconds shown in the table.

3. The crater circuit should deliver 100 in./min (42 mm/s) wire feed speed at 35 arc volts. The conditions should be maintained for the number of seconds shown in the table.

Table 8 (continued)



(D)

Base metal thickness (T), in. (mm)	2 (51)	3 (76)	4 (102)
Current, amperes (approx.)	775-875	800-900	800-900
Voltage, volts (DCEP)	42-44	43-45	45-47
Wire feed speed, in./min (mm/sec)	350 (148)	400 (169)	400 (169)
Travel speed, in./min (approx.) (mm/sec)	1.4 (0.59)	1.1 (0.46)	0.8 (0.34)
Electrode type	← { EG72T1 } →		
Electrode size, in. (mm)	0.120 (3.0)		
Guide tube	{ 1/2" (12.7) O.D. X 5/32" (4.0) I.D. C1008/C1020 }		
Guide tube location ¹ (B)in., front (mm)	1/4 (6.4)	1/4 (6.4)	1/4 (6.4)
(B)in., back (mm)	1 1/4 (32)	2 1/4 (57)	3 1/4 (83)
Oscillation distance, in. (mm)	1 (25)	2 (51)	3 (76)
Cycle period, sec.	8.0	12.0	18.0
Dwell, sec.	2-3	2-3	3-4
Traverse time, sec.	1.5	3.5	5.5
Root opening (G), in. (mm)	← { 1 + 1/8 - 0 (25 + 3.2 - 0) } →		
Start time "on," ² sec	3	3	3
Crater time "on," ³ sec	20	30	40

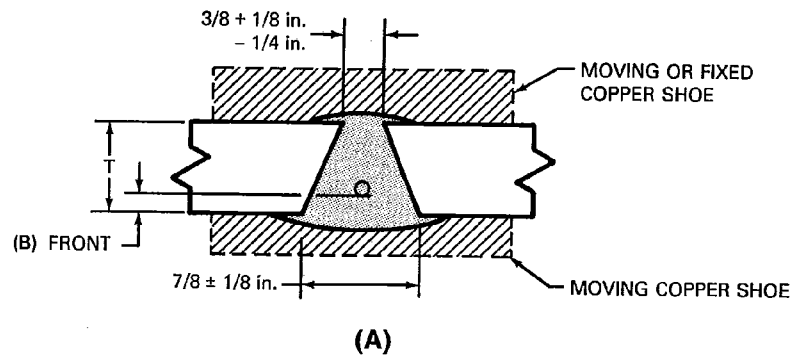
1. On 2 in. (51 mm) through 4 in. (76 mm) plate the guide tube oscillates between the locations shown and along the center line of the gap. The locations are 1/4 in. (6.4 mm) from the surface of the plate to the edge of the guide tube.

The oscillation should be set before putting on the copper shoes so that guide tube locations can be checked at the top and at the bottom of the joint. The locations can be set by adjusting the stops on the oscillator.

2. The starting circuit should deliver 100 in./min (42 mm/s) wire feed speed at 35 arc volts. The conditions should be maintained for the number of seconds shown in the table.

3. The crater circuit should deliver 100 in./min (42 mm/s) wire feed speed at 35 arc volts. The conditions should be maintained for the number of seconds shown in the table.

Table 9
Commonly Used Settings for Electrogas Welds with AWS Class EG72T4 Electrode with Moving Shoe(s)

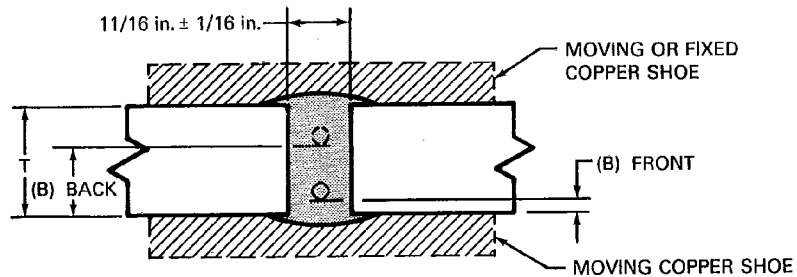


Base metal thickness (T), in. (mm)	3/4 (19)	1 (25)	1-1/4 (32)
Current, amperes	650-700	700-750	700-750
Voltage, volts (DCEP)	42-44	44-46	46-48
Travel speed, in./min (mm/sec)	6.7-9.0 (2.8-3.8)	4.3-5.8 (1.8-2.4)	3.6-4.8 (1.5-2.0)
Electrode type	{ EG72T4 1/8 (3.2) 2 ± 1/8 (51 ± 3.2) }		
Electrode size, in. (mm)			
Electrode extension, in. (mm)			
Electrode location ¹ (B) in., front (mm)	5/16 (7.9)	7/16 (11.1)	5/8 (16)
(B) in., back	—	—	—
Electrode drag angle ²	0°	0°	0°
Oscillation distance, in.	No Oscillation		
Cycle period, sec.			
Dwell, sec			
Traverse time, sec			
Gas - CO ₂ , CFH (L/min)	40-60 (18.9-28.3)	40-60 (18.9-28.3)	40-60 (18.9-28.3)

1. Electrode location is measured from the open face of the joint to the rear side of the electrode tip after establishing 2 in. (51 mm) electrode extension. Location should be set carefully and monitored during welding. The guide tip should be 1 in. (25 mm) above the top of the shoe. The top of the molten weld pool will then be 1 in. (25 mm) below the top of the shoe.

2. See Table 13 (11d).

Table 9 (continued)



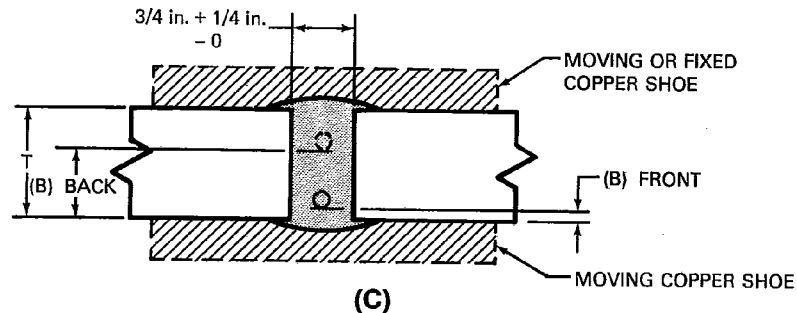
(B)

Base metal thickness (T), in. (mm)	1/2 (12.7)	3/4 (19)	1 (25)	2 (51)
Current, amperes			700-750	
Voltage, volts (DCEP)	42-44	46-48	40-41	42-43
Travel speed, in./min (mm/sec)	3.4-4.6 (1.4-1.9)	2.6-3.5 (1.1-1.5)	1.9-2.5 (0.8-1.0)	1.4-1.9 (0.6-0.8)
Electrode type	← EG72T4 1/8 (3.2) 2 ± 1/8 (51 ± 3.2) →			
Electrode size, in. (mm)				
Electrode extension, in. (mm)				
Electrode location ¹ (B) in., front (mm)	3/16 (4.8)	5/16 (7.9)	1/8 (3.2)	1/8 (3.2)
(B) in., back	—	—	3/4 (19)	1-3/4 (44)
Electrode drag angle ²	0°	0°	0°	0°
Oscillation distance, in.			5/8	1-5/8
Cycle period, sec.	No Oscillation	No Oscillation	5	5
Dwell, sec			2.0 front	2.0 back
Traverse time, sec			1	1
Gas - CO ₂ , CFH (L/min)	40-60 (18.9-28.3)	40-60 (18.9-28.3)	40-60 (18.9-28.3)	40-60 (18.9-28.3)

1. Electrode location is measured from the open face of the joint to the near side of the electrode tip after establishing 2 in. (51 mm) electrode extension. Location should be set carefully and monitored during welding. The guide tip should be 1 in. (25 mm) above the top of the shoe. The top of the molten weld pool will then be 1 in. (25 mm) below the top of the shoe.

2. See Table 13 (11d).

Table 9 (continued)



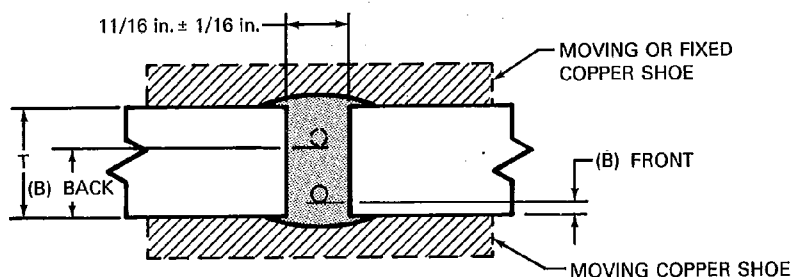
Base metal thickness (T), in. (mm)	1 (25)	1-1/4 (32)	1-1/2 (38)
Current, amperes	305-335	335-375	355-395
Voltage, volts (DCEP)	35-39	36-40	37-41
Wire feed speed, in/min (mm/sec)	325 (138)	350 (148)	375 (158)
Travel speed, in/min (mm/sec)	1.35-1.50 (0.57-0.63)	1.0-1.1 (0.42-0.46)	0.80-0.90 (0.34-0.38)
Electrode type	← EG72T4 1/16 (1.6) 1-1/2 ± 1/8 (38 ± 3.2) →		
Electrode size, in. (mm)			
Electrode extension, in. (mm)			
Electrode location ¹ (B) in., front (mm)	15/32 (11.9)	11/32 (8.7)	11/32 (8.7)
(B) in., back	—	19/32 (15)	1-3/32 (28)
Electrode drag angle ²	0°	0°	0°
Oscillation distance, in. (mm)		1/4 (6.4)	1/2 (12.7)
Cycle period, sec.	No	2.02	2.06
Dwell, sec	Oscillation	1 front, 1 back .01	1 front, 1 back .03
Traverse time, sec			
Gas - Ar80/CO ₂ , CFH (L/min)	130 (61)	130 (61)	130 (61)

1. Electrode location is measured from the open face of the joint to the near side of the electrode tip after establishing 2 in. (51 mm) electrode extension. Location should be set carefully and monitored during welding. The guide tip should be 5/8 in. (16 mm) above the top of the shoe. The top of the molten weld pool will then be 7/8 in. (22 mm) below the top of the shoe.

2. See Table 13 (11d).

3. AR80/CO₂ is 80% argon and 20% CO₂.

Table 10
Commonly Used Settings for Electrogas Welds with AWS Class EG70S-1 Electrode and
Moving Shoe(s)



Base metal thickness (T), in. (mm)	1 (25)	1-1/2 (38)	2 (51)
Current, amperes	315-370	315-370	315-370
Voltage, volts (DCEP)	32-35	32-35	32-35
Wire feed speed, in./min (mm/sec)	350 (148)	350 (148)	350 (148)
Travel speed, in./min (mm/sec)	1.20-1.33 (0.51-0.56)	0.8-0.88 (0.34- 0.37)	0.6-0.67 (0.25- 0.28)
Electrode type	← EG70S-1 1/16 (1.6) 1-1/2 ± 1/8 (38 ± 3.2) →		
Electrode size, in. (mm)			
Electrode extension, in. (mm)			
Electrode location ¹ (B) in., front (mm)	15/32 (11.9)	7/32 (5.5)	7/32 (5.5)
(B) in., back	—	1-7/32 (31)	1-23/32 (44)
Electrode drag angle ²	0°	0°	0°
Oscillation distance, in.		1 (25)	1/2 (38)
Cycle period, sec.	No	2.12	4.18
Dwell, sec	Oscillation	1 front, 1 back	2 front, 2 back
Traverse time, sec		.06	.09
Gas - Ar80/CO ₂ , CFH (L/min)	130 (61)	130 (61)	130 (61)

1. Electrode location is measured from the open face of the joint to the near side of the electrode tip after establishing 1-1/2 in. (38 mm) electrode extension. Location should be set carefully and monitored during welding. The guide tip should be 5/8 in. (16 mm) above the top of the shoe. The top of the molten weld pool will then be 7/8 in. (22 mm) below the top of the shoe.

2. See Table 13 (11d).

3. AR80/CO₂ is 80% argon and 20% CO₂.

All NDE should be performed in accordance with qualified procedures by qualified technicians. See ANSI/AWS B1.10-86, *Guide for the Nondestructive Inspection of Welds*.

10.1 Methods of Inspection. The inspection method used will depend not only upon the requirements of the code or standard specification pertinent to the weldment, but also the owner's or purchaser's contract specifications.

Every joint should have thorough visual examination (VT), which would reveal incomplete fusion, underfill, and, in some cases, cracks. When the starting and runoff tabs are removed, defects such as cracking and porosity can be seen. However, for internal defects (such as porosity, inclusions, cracking, and, in rare instances, subsurface incomplete fusion), radiography (RT), and ultrasonic (UT) examination are the most effective means of non-destructive testing.

Magnetic particle (MT) examination can also be used for detecting cracks and incomplete fusion, but it is limited to the surface and immediate sub-surface.

10.2 Acceptance. Most welding acceptance criteria are established by the customer or some regulatory agency or both. EGW applications are almost always welded to various standard requirements. Some standards presently permitting use of the EGW process (sometimes with additional restrictions) are listed below:

(1) AWS D1.1, *Structural Welding Code-Steel*, American Welding Society, 550 NW LeJeune Road, P.O. Box 351040, Miami, Florida 33135

(2) *ASME Boiler and Pressure Vessel Code*, Sections I, III, VIII and IX, American Society of Mechanical Engineers, 345 E. 47th Street, New York, New York 10017

(3) API Standards 620 and 650, American Petroleum Institute, 2101 L St., N.W., Washington, DC 20037

(4) CSA Standards W59, Canadian Standards Association, 178 Rexdale Blvd. Rexdale, Ontario CANADA M9W1R3

(5) *ABS Rules for Building and Classing Steel Vessels*, 1980, Chap.30, American Bureau of Shipping, 65 Broadway, New York, New York 10006

(6) *Lloyds Register of Shipping Rules and Regulations for Classification of Ships*, Part 3, Chapter 10; Part 2, Chapter 11; Lloyds Register of Shipping, 17 Battery Place, New York, New York 10004

Occasionally, customer requirements will supplement or alter these requirements.

10.3 Quality Control. A written procedure that identifies the essential variables to be used in EGW should be prepared. This procedure should be reviewed to determine its adequacy on the basis of comparison with applicable standard requirements.

Only an approved welding procedure (see Tables 11 and 12) should be issued to the welding foreman or welding operator, together with any additional instructions considered necessary.

A check-off list should be used by the welding operator to assure that the equipment is properly set up and that all of the required operating adjustments are made (see Tables 13 and 14).

Proper quality control procedures should be used

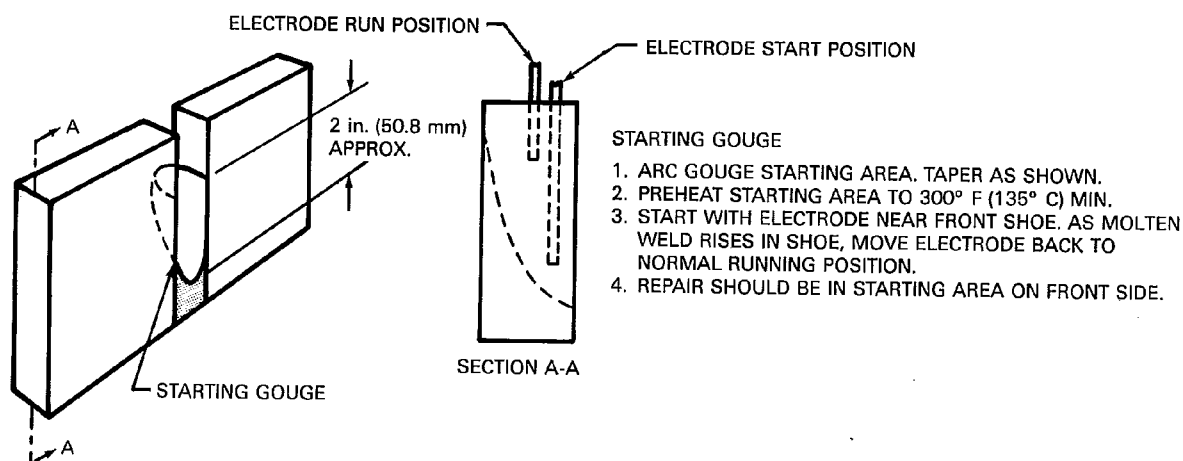


Figure 22 — Typical EGW Restart Procedure

to provide assurance that the proper filler metal is being used and that the qualified welding procedure is being followed.

10.4 Rework. In general, repairs of defective joints can be minimized by a good preventive maintenance program on the equipment by using well qualified and properly trained welding operators and by implementing a sound welding procedure.

A defect such as underfill can often be repaired by rewelding with the SMAW process without gouging or grinding. Defects such as lack of fusion (at the joint surface), overlap, copper pickup on weld face, and metal spillage are visible defects that can be repaired by gouging or grinding to sound metal and rewelding with the SMAW process. Defects such as porosity, cracking, and lack of fusion (internal) are

usually detected by radiographic or ultrasonic testing and can be repaired by gouging to sound metal and rewelding with the SMAW or GMAW process. See Figure 23, in section 13, Troubleshooting Guide for graphic examples of defects.

Economic considerations should dictate whether EGW or some other process will be used for repair. Generally, repairs will be made with the SMAW process using electrodes appropriate for the base metal and a qualified welding procedure.

Restarting of electrogas welds should be avoided if possible. Sometimes the weld must be restarted in a partially completed electrogas weld. Where such restarts are made, some repairs in the restarting area are necessary. The size and accessibility of these repair areas can be controlled by preheating to about 300°F (135°C) min. One method of prepar-

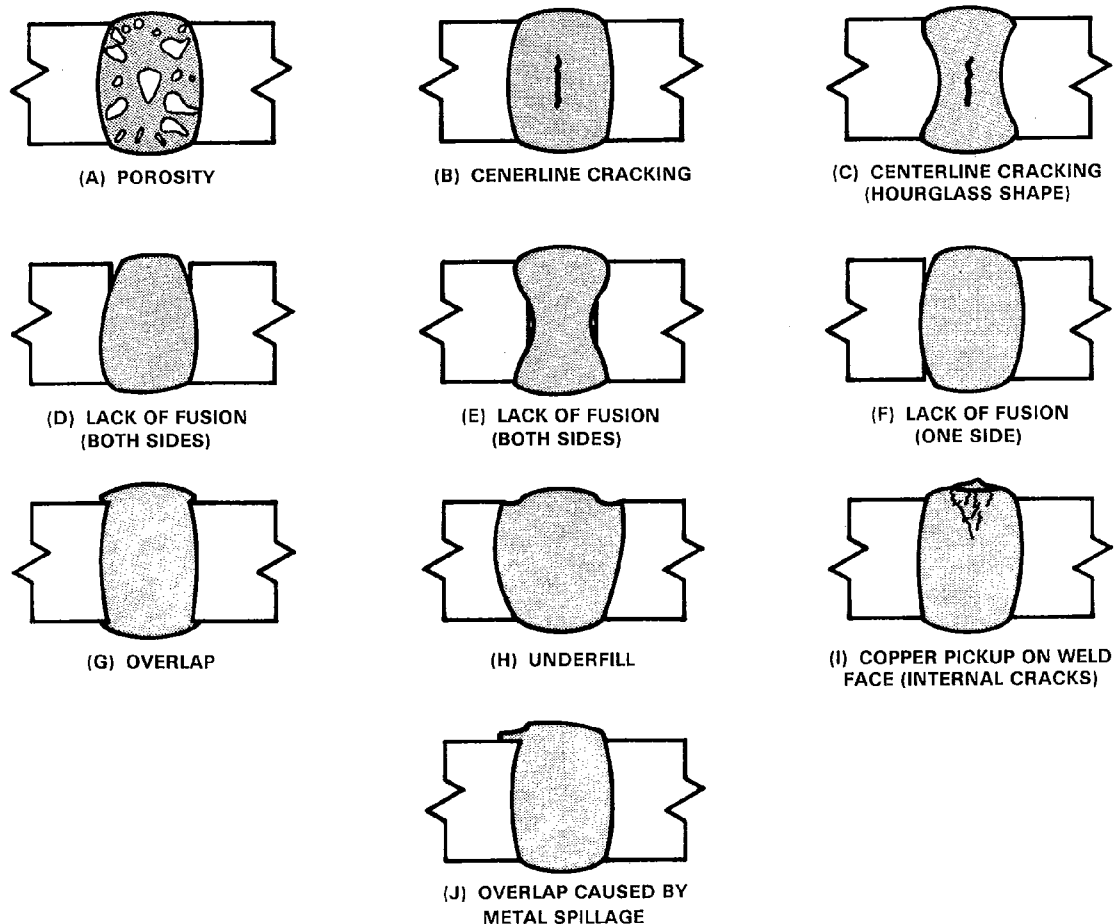


Figure 23 — Weld Defects in EG Welds Caused by Improper Technique or Defective Equipment, or Both

Table 11
Typical EGW Procedure Specification with Moving Shoe(s)¹

Welding Process: Welding shall be done by the electrogas welding (EGW) process, using one electrode wire. (If two [2] electrodes are used, the electrode spacing should be specified.)

Base Metal: The base metal shall conform to the specification for _____.

Base Metal Thickness: This procedure will cover the welding of the base metal from _____ inches (_____ mm) thick to _____ inches (_____ mm) thick.

Filler Metal: The electrode shall conform to AWS Specification A5.26 for classification EG _____. The diameter of the electrode shall be _____ inches (_____ mm).

Shielding Gas: Electrode is used with/without externally supplied shield gas.

Shielding gas, if used: Composition _____
Flow Rate _____

Position: Welding shall be done in the vertical position.

Shoes: The welding shall be done using a water-cooled copper inboard shoe. The outboard shoe shall be _____.

Preheating: None required by this procedure specification. However, no welding shall be performed when the temperature of the base metal at the point of welding is below 32°F (0°C).

Postweld Heat Treatment: None required by this procedure specification.

Base Metal Preparation: The edges or surfaces of the parts to be joined shall be prepared by _____ and shall be cleaned of oil, grease, moisture, scale, rust, or other foreign material. The surfaces upon which the copper shoes must slide shall be flat and smooth.

Welding Current: The welding current shall be direct current, electrode positive (reverse polarity).

Welding Technique: The welding shall be done in a single pass, vertical up. Starting and run-off tabs shall be used.

An electrode extension of _____ inches (_____ mm) shall be maintained during welding. The welding power supply shall have a _____ characteristic.

Welding Conditions: All welding shall be performed using the conditions given below:

Plate thickness (in.[mm]) _____
Root opening (in.[mm]) _____
Welding current² (amps) _____
Electrode WFS³ (in/min[mm/s]) _____
Welding voltage (volts) _____

Oscillation:

Distance (in.[mm]) _____
Period (sec) _____
Dwell (sec) _____
Traverse time (sec) _____

Travel Speed: Speed of vertical travel is a function of deposition rate and need not be specified.

Procedure Qualification: Procedure Qualification tests have been made in accordance with _____.

Joint Design: The joint design shall be as detailed below:

1. A typical EGW Procedure Specification should include but not be limited to the items included herein.
2. On some equipment, electrode wire feed speed (WFS) is the controlling variable, and welding current need not be specified.
3. On some equipment, electrode feed space may not be proportional to welding current and may not need to be specified.

ing the plate for a restart using an arc gouged start area is shown in Figure 22. The restart area should be closely inspected for defects. Generally, repairs will be made with the SMAW process.

11. Training

Properly trained operators are vital to the successful application of the EGW process. The nature

Table 12
Typical EGW Procedure Specification¹ Using Consumable Guide tubes and Fixed Copper Shoes.

Welding Process: Welding shall be done by the electrogas welding (EGW) process, using a consumable guide tube.

Base Metal: The base metal shall conform to the specification for _____

Base Metal Thickness: This procedure will cover the welding of the base metal from _____ in. (_____ mm) thick to _____ in. (_____ mm) thick.

Filler Metal: The electrode shall conform to AWS Specification A5.26 for classification EG _____. The diameter of the electrode shall be _____ in. (_____ mm).

Shielding Gas: Electrode is used with/without externally supplied shield gas.
 Shielding gas, if used: Composition _____
 Flow rate _____

Shoes: The fixed copper shoes shall be water cooled/air cooled and shall be one piece/stacked.

Preheating: None required by this procedure specification. However, no welding shall be performed when the temperature of the base metal at the point of welding is below 32°F (0°C). Start area of weldment may be preheated to _____°F (_____°C) to improve fusion at start of weld, especially on heavier plates.

Postweld Heat Treatment: None required by this procedure specification.

Base Metal Preparation: The edges or surfaces of the parts to be joined shall be prepared by _____ and shall be cleaned of oil, grease, moisture, scale, rust, or other foreign material. The surfaces against which the copper shoes must fit shall be flat and smooth.

Welding Current: The welding current shall be direct current, electrode positive (reverse polarity).

Welding Technique: The welding shall be done in a single pass, vertical up. Starting and run-off tabs shall be used. The welding power supply shall have a _____ characteristic.

Welding Conditions: All welding shall be performed using the conditions given below:

Plate thickness [in.(mm)] _____
 Root opening [in.(mm)] _____
 Electrode WFS² [in/min(mm/s)] _____
 Welding current³ (amps) _____
 Welding voltage (volts) _____

Oscillation:

Distance [in.(mm)] _____
 Period (sec) _____
 Dwell (sec) _____
 Traverse time (sec.) _____

Travel Speed: Speed of vertical travel is a function of deposition rate and need not be specified.

Procedure Qualification: Procedure Qualification tests have been made in accordance with _____

Joint Design: The joint design shall be as detailed below:

1. A typical EGW Procedure Specification should include but not be limited to the items included herein.
2. On some equipment, electrode feed speed may not be proportional to welding current and may not need to be specified.
3. On most equipment, electrode wire feed speed (WFS) is the controlling variable, and welding current need not be specified.

of the process generally involves base metals greater than 3/4 in. (19 mm) thick, which are costly to fabricate and repair. EGW is generally a single-pass or, in some cases, a multiple-pass welding process, and the operator should have sufficient knowledge to set up and properly operate the equipment. EGW is unlike manual and semiautomatic processes where welding can be temporarily stopped or delayed and easily

restarted. EGW should be continuous from beginning to end. Restarts in EG welds are susceptible to weld defects which may require extensive repairs. Depending upon the type of application and setup, at least some portion of welding must be completed before the welding operator can visually inspect, evaluate, and take any necessary corrective action. There are some applications where the entire weld is

made before visual inspection can be performed. For these reasons, an electrogas operator should be well trained if all of the benefits of the process are to be gained. The operator should be a conscientious and alert individual who has been sufficiently trained to deal with the peculiar problems associated with this process.

11.1 Process Variables. Training should begin with some type of off-the-job instruction. Instructions should include pictures, slides, chalk board, films, or other graphical aids as necessary for the operator to understand the basics of the electrogas process and the variables that will be encountered. Questions should be encouraged, and the following items should be discussed in detail:

- (1) A brief and concise explanation of the process.
- (2) The importance of each control variable, why they are important, and what could happen if variables are not controlled. This interrelationship should be explained in detail.
- (3) Evaluating the weld and taking corrective action; troubleshooting and problem solving.
- (4) Description of the equipment to be used. Equipment manuals are helpful and may be provided for this discussion.
- (5) Review and thorough explanation of pertinent welding procedures and specifications.
- (6) Safety.

11.2 Equipment Familiarization. No training can be complete without instructing the operator at the welding station. Instructions should cover all the operating functions of the equipment (knobs, buttons, switches, etc.) and how to care for the equipment.

The operator should be shown how to spot potential problems and how to solve them. Items such as kinked wire, worn feed rolls, and loose or broken conductors are examples of problems that can be expected to cause a weld stoppage.

Finally, the operator should be shown how to make an acceptable weld.

12. Qualifications

12.1 Process and Equipment. The electrogas process has been generally proven by its successful use on the many applications covered in 7.4. However, each user has to establish according to the governing stan-

dards, the proper equipment, the correct welding procedure, and properly trained welding operators.

For new equipment or new applications, it is recommended that instructions and assistance be obtained from the equipment manufacturer.

(1) The equipment should have been proven by application, and it is recommended that trial applications be made to qualify the equipment and help to train the welding operator.

(2) An operator check list should be developed for the application. (See the recommended check list in Tables 13 and 14.)

Table 13
Typical Electrogas Check List with Moving Shoe(s)

Electrogas welding is designed to continuously weld the entire joint, usually in a single pass. Before starting to weld, it is vital that the operator check all elements of the operation.

CHECK EACH ITEM AS JOB PROGRESSES

1. Check workpiece preparation. Make sure that the weld edge and adjacent surface have been prepared properly along entire length.
2. Fit starting tab at bottom of joint and run-off tabs at top. Minimum distance from starting surface in the tab to bottom edge of joint shall be 1-1/2 in. (38 mm).
3. Fit seam per procedure. Maintain required tolerance.
4. Attach and tighten ground cables.
5. Make sure the machine is properly fitted to the joint.
6. Check vertical rise. Make sure there are no obstructions that would prevent or stop the rise of the machine and that equipment leads are of adequate length.
7. Check quantity of electrode wire and gas (if used). Make sure there is enough to finish the weld.
8. Check water and gas connections. Make sure both are in operating condition.
9. Check the face of the shoe(s). Make sure there are no worn or irregular areas that would cause a "hang up" during welding.
10. Check wire guide tip. Do not start with a worn tip; it could cause a shutdown or, at best, poor welding conditions.
11. Check head and electrode line-up. Line up the head and electrode control. Specific line-up settings and tolerances are listed in each welding procedure.
- 11a. Electrode angle to joint is always 90°.

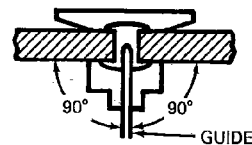
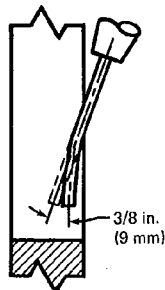


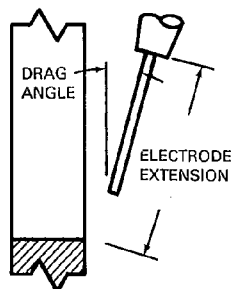
Table 13 (Continued)

11b. Adjust the wire straightener so that the electrode is straight or has a maximum underbend of 3/8 in. (9 mm).



11c. Adjust electrode extension. Do *not* change the electrode extension when making other adjustments.

11d. Adjust drag angle.



11e. Set the electrode location by measuring from the front face of the plate after the electrode is in the seam. Note: the electrode location changes as the guide tip wears. Replace the guide tip when it becomes worn or the end is fused or deformed.

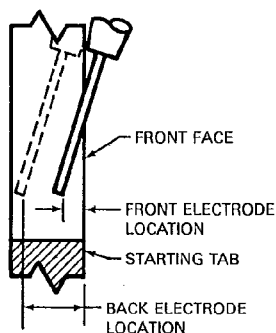
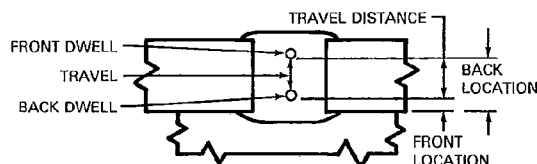


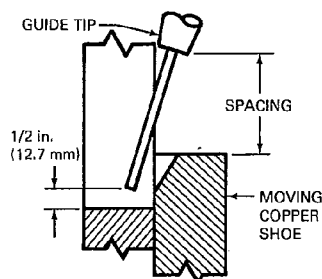
Table 13 (Continued)

11f. Set sufficient spacing between the guide tip and top of the movable shoe.

When oscillation of the electrode in the joint is required, set the front location (for the electrode), oscillation distance, oscillation time, and dwell time(s) as specified.



11g. Set 1/2 in. (13 mm) spacing between the end of the electrode and the starting tab.



12. Check moving shoe(s). Clamp with the correct operating pressure.

13. Apply glass tape or putty to any opening between the shoe face and work caused by the weld reinforcement groove in the shoe. A run-out may occur at start-up if this is not done.

14. Set water and gas flow rates.

15. Have a few tools (e.g., pliers, screwdriver, and open end wrench) handy.

16. Check operation of ventilating equipment if used.

17. Have eye shield ready.

18. Set start-up volts and amperes.

19. Energize contactor.

20. Recheck and adjust welding conditions.

21. Turn on oscillator, if used.

12.2 Welding Procedure. Current standards are available for procedure qualification such as ANSI/AWS D1.1-88, *Structural Welding Code—Steel*, Section 5; ASME, Section IX; ABS, Chapter 30; and API 650 (refer to ASME), and others. Tests should be conducted to prove conformance to the applicable standard(s).

12.3 Welding Operator. All EGW welding operators should be qualified to the applicable standard. Welders and welding operators having previous gas

Table 14
Typical Electrode Gas Checklist for Welding
with Consumable Guide Tubes and
Fixed Copper Shoes

Electrode gas welding is designed to continuously weld the entire joint, usually in a single pass. Before starting to weld, it is vital that the operator check all elements of the operation.

CHECK EACH ITEM AS JOB PROGRESSES

1. Check workpiece preparation. Make sure that the weld edges and adjacent surfaces have been prepared properly along entire length.
2. Fit starting tab at bottom of joint and run-off tabs at top. Minimum distance from starting surface in the tab to bottom edge of joint shall be 1-1/2 in. (38 mm).
3. Fit seam per procedure. Maintain required tolerance.
4. Attach and tighten ground cables.
5. Align guide tube properly in joint.
6. Check starting stickout (see procedure). After starting the weld, stickout is no longer a controllable parameter.
7. Check quantity of electrode wire and gas (is used). Make sure there is enough to finish the weld.
8. Check water and gas connections. Make sure both are in operating condition. Check water flow rate.
9. Check the face of the shoe(s). Make sure there are no worn or irregular areas that would cause poor fitup, resulting in the puddle leaking out between the shoe and plate.
10. Set oscillator locations and dwell times (if applicable) as shown below.
11. Attach shoes securely to plate.
12. Apply glass tape or putty to any opening between the shoe face and work caused by the weld reinforcement groove in the shoe. A run-out may occur at start-up if this is not done.
13. Set water and gas flow rates.
14. Have a few tools (e.g., pliers, screwdriver and open-end wrench) handy.
15. Check operation of ventilating equipment, if used.
16. Have eye shield ready.
17. Set start-up volts and amperes.
18. Energize contactor.
19. Recheck and adjust welding conditions.
20. Turn on oscillator, if used.

metal arc or flux cored arc welding experience are readily trained as electrode gas welding operators. Proper operations require only light physical work but do demand close attention.

The initial welding operator is often qualified by having welded a successful procedure test. Once the equipment and procedures have been proven, new operators can be trained by existing operators. Some standards permit qualification of the welding operator when the first 36 in. (91 mm) of the welder's initial production work meets radiographic soundness requirements.

13. Troubleshooting Guide

This troubleshooting guide lists weld defects which may be caused by improper technique or defective equipment. A pictorial representation of weld cross sections with defects is shown in Figure 23. References to Figure 23 in this Troubleshooting Guide may or may not be representative of the visual appearance the operator would see on the face of the weld.

13.1 Porosity at the start of a weld may be caused by the following:

- (1) Improper starting procedures: low electrode feed speed, high voltage, short electrode extension, insufficient start sequence time
- (2) Contaminants in starting tab or between starting tab and workpieces
- (3) Condensation on shoes or between shoes and workpieces
- (4) Excessive chilling: Preheat in start area may be needed on 2 to 4 in. (51 to 100 mm) workpiece when temperature is under 50°F (10°C) or when using large copper starting tabs
- (5) Starting tab too shallow
- (6) Arc location too close to shoes
- (7) Water leakage in starting tab
- (8) Poor shoe or starting tab fit
- (9) Insufficient gas coverage or contaminated gas, if auxiliary gas required
- (10) Arc blow caused by improper location of work lead

13.2 Porosity in the weld may be caused by the following (see Figure 23A):

- (1) May follow from severe starting porosity that extends into weld
- (2) Excessive voltage
- (3) Low electrode feed speed
- (4) Electrode extension too short
- (5) A "cold" weld (low electrode feed speed and voltage) (often accompanied by roll-over on weld faces)
- (6) Contaminants in weld area
- (7) Loose fit of shoe allows air to bleed into weld
- (8) Insufficient gas coverage or contaminated gas, if auxiliary gas required
- (9) Water leakage from shoe
- (10) Arc blow caused by improper location of work lead

13.3 Porosity at weld termination may be caused by the following:

- (1) Run-off tabs or stationary shoe too short
- (2) Slag leaking due to improperly attached run-off tabs
- (3) Arc blow caused by improper location of work lead

13.4 Centerline weld cracking may be caused by the following [see Figures 23 (B) and (C)]:

- (1) Failure to follow procedure
 - (a) Electrode feed speed too high (excessive current)
 - (b) Voltage too low
 - (c) Excessive dwell time
 - (d) Root opening too narrow
- (2) Quench rate too fast:
 - (a) Large shoes or excess cooling water
 - (b) Low workpiece temperature; preheat of start area may be needed on 2 to 4 in. (51 to 100 mm) workpiece, when temperature is under 50°F (10°C)
 - (c) Excessive plate restraint

13.5 Incomplete fusion at weld toes may be caused by the following [see Figures 23 (D) and (E)]:

- (1) Cold weld (low voltage or slow electrode feed speed and low voltage)
- (2) Excessive electrode feed speed causing fast travel speed
- (3) Narrow root opening causing fast travel speed
- (4) Oscillation speed too fast
- (5) Too much slag on top of molten weld pool
 - (a) Shoe groove dimensions too narrow or shallow
 - (b) Equipment and shoe design not permitting slag spatter to leave weld pool
 - (c) Weld pool depth too far below top of shoe, preventing slag spatter from leaving the pool

13.6 Incomplete fusion to one groove face may be caused by the following [see Figure 23 (F)]:

- (1) Arc location off center
- (2) Electrode angled toward one groove face
- (3) Arc blow caused by improper location of work lead

13.7 Overlap of bead edges on the face of the workpiece and poor fusion of weld toes may be caused by the following [see Figure 23 (G)]:

- (1) On front face
 - (a) Arc location too far back: adjust wire

straightener, drag angle, or guide location; check guide tip for wear

- (b) Bevel angle too large
- (c) Cold weld (low voltage or low electrode feed and voltage)
- (2) On back face
 - (a) Arc location too far forward: adjust wire straightener, drag angle, or guide location; check guide tip for wear
 - (b) Cold weld (low voltage or low electrode feed and voltage)
- (3) On both faces
 - (a) Cold weld (low voltage or low electrode feed and voltage)
 - (b) Groove in copper shoe(s) too wide
 - (c) Excessive quenching from shoe(s) (improper shoe design or excessive water flow)
 - (d) Excessive travel speed
 - (e) Joint opening too narrow
 - (f) Arc blow
 - (g) Incorrect oscillation cycle

13.8 Underfill may be caused by the following [see Figure 23 (H)]:

- (1) Excessive melting of workpiece beyond shoe

NOTE: this condition is an appearance deficiency and is usually not considered a defect.
- (2) Groove in shoe too narrow

13.9 Melt-through in starting tab may be caused by the following:

- (1) Insufficient starting tab bottom thickness
- (2) Poorly fitted shoes
- (3) Metal leaking through the shoe groove preventing start of travel (plug shoe groove at weld starting tab)

13.10 Copper pickup on weld face(s) may be caused by the following [see Figure 23 (I)]:

- (1) Arcing on shoe(s)
- (2) Melting of shoes due to poor shoe cooling

13.11 Metal spillage (overlap) from the front or back may be caused by the following [see Figure 23 (J)]:

- (1) Poor fit-up
- (2) Workpiece surface irregularities

13.12 Wire (electrode) wander while welding may be caused by the following

- (1) Worn guide tip
- (2) Improper wire straightener setting

13.13 Arcing to groove faces may be caused by the following

- (1) Joint opening too narrow
- (2) Voltage too high
- (3) Oscillation distance too large in beveled joint
- (4) Wire (electrode) wandering

13.14 Hourglass nugget shape on 3 to 4 in. (76 to 100 mm) workpieces may be caused by the following [see Figures 23 (C) and (E)]:

- (1) Oscillation dwell too long
- (2) Oscillation travel too fast

14. Safety Recommendations

Use of the EGW process is safe, provided proper procedures are followed and precautions taken. If these procedures and precautions are followed, EGW can be done safely with minimal health risk.

FUMES AND GASES can be dangerous to your health. Keep your head out of the fumes. Use enough ventilation, exhaust at the work, or both, to keep fumes and gases from your breathing zone and the general area.

ARC RAYS can injure the eyes.

INFRARED (HEAT) RADIATION can cause burns.

ULTRAVIOLET RADIATION can cause skin injury similar to sunburn.

ELECTRIC SHOCK can kill. Do not touch live electrical parts.

READ AND UNDERSTAND the manufacturer's instructions and your employers safety practices.

Before using the EGW process, acquaint yourself and those for whom you are responsible with the proper procedure and precautions. The primary source for these is contained in ANSI/ASC Z49.1, *Safety in Welding and Cutting*.² For Federal safety regulations established by the U.S. Labor Department's Occupational Safety and Health Administration, see the latest edition of OSHA Standards, Code of Federal Regulations, Title 29, Part 1910.

14.1 Radiant Energy. EGW may produce radiant energy (radiation) harmful to health. You should acquaint yourself with the effects of this radiant energy. Radiant energy from EGW will be nonion-

izing (such as ultraviolet, visible light, or infrared). Radiation can produce a variety of effects such as skin burns and eye damage, depending on the radiant energy's wavelength and intensity, if excessive exposure occurs.

The intensity and wavelengths of nonionizing radiant energy produced depend on many factors such as welding parameters, electrode and base metal composition, fluxes, and any coating or plating on the base material. The total radiant energy produced by the EGW process can be higher than that produced by the SMAW process, because of the significantly lower welding fume and the more exposed arc. Generally, the highest ultraviolet radiant energy intensities are produced when using an argon shielding gas and when welding on aluminum.

Protection from possible harmful effects caused by nonionizing radiant energy from welding include the following measures:

(1) Do not look at welding arcs except through welding filter plates which meet the requirements of ANSI Z87.1, *Practice for Occupational and Educational Eye and Face Protection*. The choice of filter shade may be made on the basis of visual acuity and may, therefore, vary widely from one individual to another, particularly under different current densities, workpiece materials, and electrode types. As a rule of thumb, start with a shade that is too dark to see the weld zone. Then go to a lighter shade which gives sufficient view of the weld zone without going below the minimum. Minimum values apply where the actual arc is clearly seen. Experience has shown that lighter filters may be used when the arc is hidden by the workpiece, the guide, or the shoes.

The following chart suggests* filter glass shades for EGW as a guide:

Operation	Arc Current	Minimum Protective Shade	Suggested Shade No. (Comfort)
EGW ferrous material	160-250	10	12
	250 & above	10	14
EGW nonferrous material	160-250	10	12
	250 & above	11	14
Spectacles or goggles		2	2

* See ANSI Z49.1-88, Table 1 for more information.

2. See Appendix A.

(2) Protect exposed skin with adequate gloves and clothing as specified in ANSI/ASC Z49.1.

(3) Beware of reflections from welding arcs, and protect all persons from intense reflections.

(4) Avoid exposing passersby to welding operations by use of screens, curtains, or adequate distance from aisles, walkways, etc.

(5) Safety glasses with UV protective side shields have been shown to provide some beneficial protection from ultraviolet radiation produced by welding arcs.

14.2 Burn Protection. Molten metal, sparks, slag, and hot work surfaces are produced by the EGW process. These can cause burns if precautionary measures are not used.

Workers should wear protective clothing made of fire resistant material. Leather or wool clothing that is dark in color (to reduce reflection, which could cause ultraviolet burns to the face and neck underneath the helmet) is recommended. The greater intensity of ultra-violet radiation may cause rapid disintegration of cotton clothing, unless protective chemicals are used to treat the cotton. Do not wear pants with cuffs or open pockets or other places on clothing that can catch and retain molten metal or sparks. Wear high top shoes or leather leggings and fire resistance gloves. Pant legs should be worn over the outside of high top boots. Use helmets or hand shields that provide protection for the face, neck and ears, and wear a head covering to protect the head. In addition, appropriate eye protection should be used. Keep clothing free of grease and oil. Do not carry combustible materials in pockets. If any combustible substance has been spilled on clothing, change to clean fire resistant clothing before working with open arcs. When required, use aprons, cape-sleeves, leggings, and shoulder covers and bibs designed for welding service.

Other personnel in the work area should be protected by the use of noncombustible screens or by the use of appropriate protection as described in the previous paragraph. Before leaving a work area, mark hot work pieces to alert other persons of this hazard. (Note: Burns can be caused by touching hot equipment such as electrode guides, tips and shoes. Therefore, insulated gloves should be worn when these items are handled unless an adequate cooling period has been allowed before touching.)

14.3 Electrical Hazards. Electric shock can kill. However, it can be avoided. Do not touch live electrical parts. Read and understand the manufacturer's instructions and recommended safe

practices. Faulty installation, improper grounding, and incorrect operation and maintenance of electrical equipment are all sources of danger.

Ground all electrical equipment and the workpiece. The work lead is not a ground lead. It is used only to complete the welding circuit. A separate connection is required to ground the workpiece. Do not mistake the work lead for a ground connection. Accessory equipment, such as wire feeders, travel mechanism, oscillators, etc., should be grounded. If they are not grounded, insulation breakdown might cause these units to become electrically "hot" with respect to ground.

Use the correct cable size, since sustained overloading will cause cable failure and result in possible electric shock or fire hazard. Make sure all electrical connections are tight, clean and dry. Poor connections can overheat and even melt. Further, they can produce dangerous arcs and sparks. Do not allow water, grease or dirt to accumulate on plugs, sockets or electrical units. Moisture can conduct electricity. To prevent shock, keep the work area, equipment, and clothing dry at all times. Wear dry gloves, rubber soled shoes, or stand on a dry board or insulated platform.

Do not attempt to repair or disconnect electrical equipment under load. Disconnecting under load produces arcing of the contacts and may cause burns or shocks, or both. The welding power contactor should be turned off except when welding is actually in progress or at service check for open circuit voltage (when electrode cannot feed). The main power switch should be turned off before opening the control cabinet. The primary power for the welding power source should be turned off and any shielding gas supply should be shut off at the supply source when leaving the work or stopping the work for any appreciable time, or when moving the machine.

Keep cables and connectors in good condition. Improper or worn electrical connections may set up conditions that could cause electrical shock or short circuits. Do not use worn, damaged or bare cables. Avoid open circuit voltage and line voltage.

When several welders are working with arcs of different polarities, or when a number of alternating current machines are being used, the open circuit voltages can be additive. The added voltages increase the severity of the shock hazard.

In case of electric shock, turn off the power. If the rescuer must resort to pulling the victim from the live contact, use nonconducting materials. If the victim is not breathing, administer cardiopulmonary resuscitation (CPR) as soon as contact with the

electrical source is broken. Call a physician and continue CPR until breathing has been restored, or until a physician has arrived. Treat electrical burns as thermal burns; that is, apply clean, cold (iced) compresses. Prevent contamination and cover with a clean, dry dressing. Call a physician.

14.4 Fumes and Gases. Electrode welding produces fumes and gases which may be harmful to health. Fumes are solid particles which originate from welding consumables, the base metal, and any coatings present on the base metal. Gases are produced during the welding process or may be produced by the effects of process radiation on the surrounding environment. You—the reader—should acquaint yourself with the effects of these fumes and gases. The amount and composition of these fumes and gases depend upon the composition of the filler metal and base material, current level, arc length, and other factors.

The possible effects of over-exposure range from irritation of eyes, skin, and respiratory system to more severe complications. Effects may occur immediately or at some later time. Fumes can cause symptoms such as nausea, headaches, dizziness, and metal fume fever. The possibility of more serious effects exists when especially toxic materials are involved. In confined spaces the gases might displace breathing air and cause asphyxiation.

Keep your head out of the fumes. Use enough ventilation, exhaust at the arc, or both, to keep fumes and gases from your breathing zone and general area. Adequate ventilation should be provided, especially when welding with self-shielded flux cored electrodes. If chlorinated solvents have been used to degrease or clean the workpiece, a check should be made to ensure that the solvent has been removed before welding. In some cases, natural ventilation may be questionable. Air sampling should be used to determine if corrective measures should be applied.

14.5 Noise and Hearing Protection. Exposure to ex-

cessive noise can cause a loss of hearing. The loss of hearing can be either full or partial, and temporary or permanent. In electrode welding, noise may result from the welding process, the power source, or other equipment. Excessive noise most often results from other operations taking place near the EGW equipment such as grinding and chipping.

Excessive noise adversely affects hearing capability. This adverse effect in hearing capability may be a temporary threshold shift from which the ears may recover if removed from the noise source. However, if a person is exposed to this same noise level for a longer time, then the loss of hearing may become permanent. The time required to develop permanent hearing loss depends upon factors such as individual susceptibility, noise level, and exposure duration.

A direct method to protect against excessive noise is to reduce the intensity of the source. Another method is to shield the source, but this has limitations. The acoustical characteristics of a room will also affect the level of noise. When engineering control methods fail to reduce the noise, personal protective devices such as ear muffs or ear plugs may be employed. Generally, these devices are only accepted when engineering controls are not fully effective.

The permissible noise exposure limits can be found in CFR Title 29, Chapter XVII, Part 1910. Additional information may be found in *Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*.

A recommended method for measuring noise emitted by arc welding processes may be found in ANSI/AWS F6.1-78, *Method for Sound Level Measurement of Manual Arc Welding and Cutting Processes*.

14.6 Safety and Health Information Sources. For additional sources of safety and health information, refer to the Safety and Health references in the back of this document.

Safety and Health References

(1) American Conference of Government Industrial Hygienists (ACGIH). *Threshold Limit Values for Chemical Substances and Physical Agents in the Working Environment* available from American Conference of Government Industrial Hygienists, 6500 Glenway Ave., Cincinnati, Ohio 45211.

(2) American National Standards Institute (ANSI). ANSI Z87.1, *Practice for occupational and educational eye and face protection* available from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

(3) ———. ANSI Z244.1, *Safety requirements for the lockout/tagout of energy sources*.

(4) ———. ANSI Z49.1, *Safety in welding and cutting*.

(5) ———. OSHA Standards, *Code for federal regulations, Title 29, Part 1910*. Available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

(6) American Welding Society (AWS). *Fumes and*

gases in the welding environment. Available from the American Welding Society, 550 N.W. LeJeune Rd., P.O. Box 351040, Miami, Florida 33135.

(7) ———. ANSI/AWS F6.1-78, *Method for sound level measurement of manual arc welding and cutting processes*.

(8) Hinrichs, J. F. "Project committee on radiation—summary report." *Welding Journal*. January 1978.

(9) Another excellent source of safety and health information in easy to understand form is a series of fact sheets that have been collected and are available from the American Welding Society, 550 N.W. LeJeune Rd., P.O. Box 351040, Miami, Florida 33135. The titles are listed below: Fumes and Gases, Radiation, Noise, Chromium and Nickel in Welding Fume, Electrical Hazards, Fire Prevention, Burn Protection, Mechanical Hazards, Tripping and Falling, Falling Objects, Confined Spaces.

Supplementary Reading List

- (1) American Society for Metals. *Metals handbook*. Vol. 6, 9th Ed., Metals Park, Ohio: American Society for Metals. 719-728.
- (2) American Welding Society. *Welding handbook*, Vol. 2, 7th Ed. Miami, Florida: American Welding Society. (1978) pp 225-260.
- (3) Arnold, P. C., and Bertossa, D. C. "Multiple-pass automatic vertical welding. *Welding Journal*. 45 (8): 1966, 651-660.
- (4) Campbell, H. C. Electroslag, electrogas, and related welding processes. Bulletin No. 154. New York: Welding Research Council.
- (5) Eichhorn, F. Pyrasch, D. "Welding of HSLA [high strength low alloy] steels with a high speed electrogas welding process. Weldfair '86. Welding for Profit, Vol. 1, Paper 4, pp 25-47. (Proceedings, 34th National Conference, Adelaide, 2-7 Nov. 1986.) Milson's Point, Australia: Australian Welding Institute, 1986.
- (6) ———. "Welding of HSLA [high strength low alloy] steels with a high speed electrogas welding process." *Australian Welding Journal*. (31) 3: Spring 1986, pp.39-43.
- (7) Eichhorn, F. and Rummel, J. "High speed electroslag and electrogas welding of low alloy steel materials with metal powder additions (Elektro-schlacke- und Elektrogasschnellschweißen . . .)" DVS Berichte No. 68. (Proceedings, International Conference, Vertical Welding, Aachen, 9-10 April 1981.) Dusseldorf, W. Germany: Deutscher Verband fur Schweisstechnik: 1981, pp 12-18.
- (8) Franz, R. J. and Wooding, W. H. "Automatic vertical welding and its industrial applications." *Welding Journal*. 42 (6): 1963 pp.489-494.
- (9) Griensven, H. van. "Application of electroslag and electrogas welding in shipbuilding. DVS Berichte No. 68. (Proceedings, International Conference, Vertical Welding, Aachen, 9-10 Apr. 1981.) Dusseldorf, W. Germany: Deutscher Verband fur Schweisstechnik, 1981, pp. 50-53.
- (10) Irving, R. R. "Vertical welding goes into orbit." *Iron Age*. 26 October 1972, p. 50.
- (11) Loosen, B. "Electrogas welding—applications and progress." *Welding Design and Fabrication*. 51 (9): September 1978, pp. 94-97.
- (12) Norcross, J. E. "Electroslag/electrogas welding in the free world." *Welding Journal*. 44(3): 1965, pp. 177-186.
- (13) ———. "Properties of electroslag and electrogas welds." *Welding Journal*. 44 (3): 1965, pp. 135-s-140-s.
- (14) Normando, N. J., Wilcox, D. V., and Ashton, R. F. "Electrogas vertical welding of aluminum." *Welding Journal*. 52(7): 1973, pp 440-448.
- (15) Schoumaker, H. R. P. "Electrogas [welding] process—25 years of industrial use." *Welding Review*. 5(2) May 1986: pp.126-127, 130, 133. 26 ref.
- (16) Schwartz, N. B. "New way to look at welded joints." *Iron Age*. 20 August 1970, pp. 54-55.
- (17) Warner, B. "Welding offshore drillings rigs." *American Machinist*. 14 October 1974.