F-1607-E

Linde ELECTRIC WELDING INSTRUCTIONS

How to do TIG (Heliarc) Welding

UNION CARBIDE WELDING PRODUCTS

CONTENTS

I. INTRODUCTION

HELIARC inert gas shielded arc welding was originally developed for welding corrosion-resistant and other difficult-to-weld metals. Over a period of years, however, its application has expanded to include welding and surfacing operations on practically all commercial metals. The purpose of this booklet is to explain briefly the theory of operation behind HELIARC welding, and to describe the basic techniques employed in applying this process to a variety of the more commonly welded commercial metals.

Description

HELIARC welding is a gas-arc welding process which uses an inert gas to protect the weld zone from the atmosphere. The necessary heat for welding is provided by a very intense electric arc which is struck between a virtually non-consumable tungsten electrode and the metal workpiece (see Figure 1). HELIARC welding differs from metal arc welding in that the electrode is not melted and used as a filler metal. On joints where filler metal is required, a welding rod is fed into the weld zone and melted with the base metal as in oxy-acetylene welding.

In any type of welding, the best obtainable weld is one which has the same chemical, metallurgical, and physical properties as the base metal itself. To obtain such conditions, the molten weld puddle must be protected from the atmosphere during the welding operation; otherwise, atmospheric oxygen and nitrogen will combine readily with the molten weld metal and result in a weak, porous weld. In HELIARC welding, the weld zone is shielded from the atmosphere by an inert gas which is fed through

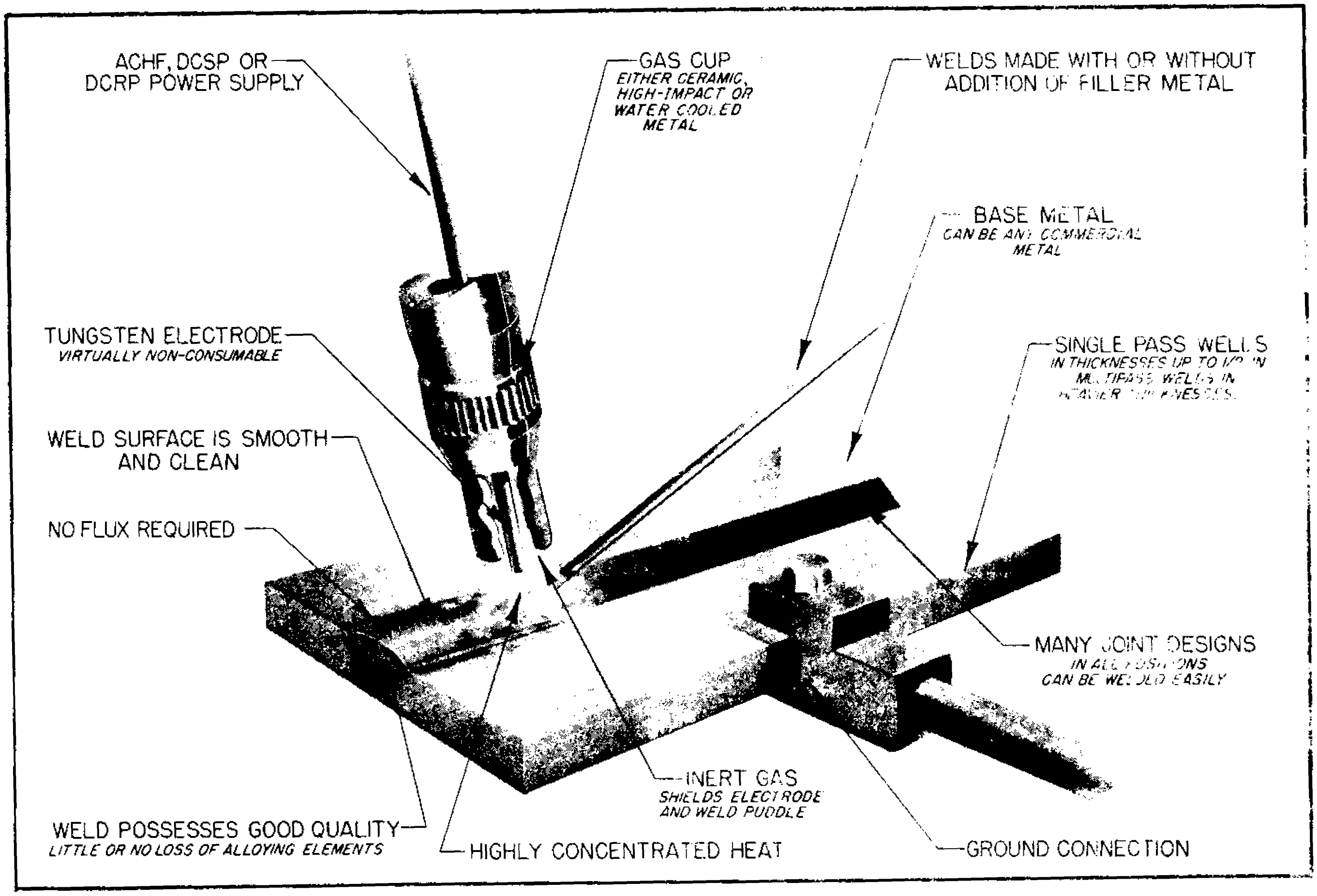


FIG. 1 – Essentials of the TIG Welding Process

the welding torch. Either argon or helium may be used. Argon is recommended because of its general suitability for a wide variety of metals, and for the considerably lower flow rates required. The latter advantage is especially important for reducing welding costs. The welding operation with argon is also easier because heat input to the weld puddle is affected less by variations in arc length.

Advantages

HELIARC welds, because of this 100% protection from the atmosphere, are stronger, more ductile, and more corrosion-resistant than welds made with ordinary metal arc welding processes. In addition, the fact that no flux is required makes welding applicable to a wider variety of joint types. Corrosion due to flux entrapment cannot occur, and expensive post-welding cleaning operations are eliminated. The entire welding action takes place without spatter, sparks, or fumes. Fusion welds can be made in nearly all metals used industrially. These include aluminum alloys, stainless steel, magnesium alloys, nickel and nickel-base alloys, copper, silicon-copper, copper-nickel, brasses, silver, phosphor bronze, plain carbon and low-alloy steels, cast iron, and others. The process is also widely used for welding various combinations of dissimilar metals, and for applying hard-facing and surfacing materials to steel.

II. FUNDAMENTALS OF TIG WELDING

The power supply for HELIARC welding may be either a.c. or d.c. However, certain distinctive weld characteristics obtained with each type often make one or the other better suited to a specific application. Table I below, provides a handy guide to the type of current you should use for a given job. An explanation of the effects produced by the two types of current, together with the reason for high-frequency stabilization of alternating current, follows:

TABLE I
CURRENT SELECTION FOR "HELIARC" WELDING

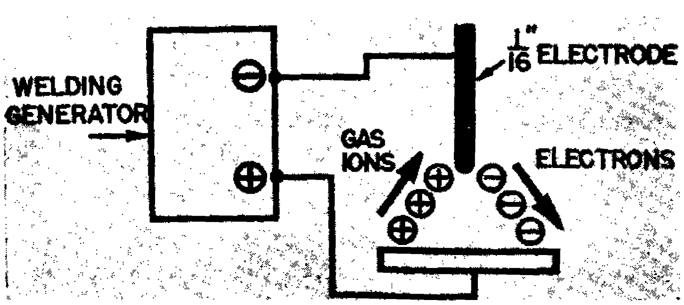
MATERIAL	ALTERNATING CURRENT* With High-Frequency Stabilization	DIRECT CURRENT STRAIGHT Polarity	DIRECT CURRENT REVERSE Polarity
Magnesium up to 1/8 in. thick	1	N.R.	2
Magnesium above 3/16 in. thick	1	N.R.	N.R.
Magnesium Castings	1	N.R.	2
Aluminum up to 3/32 in. thick	1	N.R.	2
Aluminum over 3/32 in. thick	1	N.R.	N.R.
Aluminum Castings	1	N.R.	N.R.
Stainless Steel	2	1	N.R.
Brass Alloys	2	1	N.R.
Silicon Copper	N.R.	1	N.R.
Silver	2	1	N.R.
HASTELLOY Alloys	2	1	N.R.
Silver Cladding	1	N.R.	N.R.
Hard-Facing	1	1	N.R.
Cast Iron	2	1	N.R.
Low Carbon Steel, 0.015 to 0.030 in.	2**	1	N.R.
Low Carbon Steel, 0.030 to 0.125 in.	N.R.	1	N.R.
High Carbon Steel, 0.015 to 0.030 in.	2	1	N.R.
High Carbon Steel, 0.030 in. and up	2	1	N.R.
Deoxidized Copper***	N.R.	1	N.R.

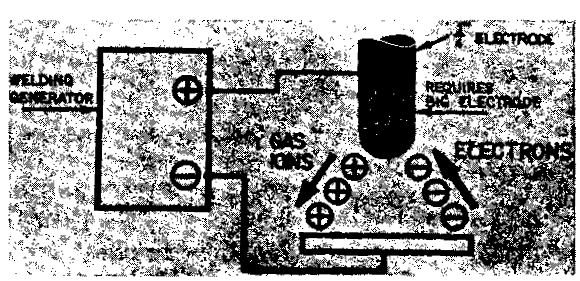
KEY: 1. Excellent operation.
2. Good operation.
N.R. Not recommended.

**Where a.c. is recommended as a second choice, use about 25% higher current than is recommended for DCSP.*
***Do not use a.c. on tightly jigged part.*
****Use brazing flux or silicon bronze flux for 1/4-in. and thicker.*

A. Direct Current Welding

In direct current welding, the welding current circuit may be hooked up as either "straight-polarity" or "reverse-polarity." The machine connection for direct current straight-polarity (DCSP) welding is electrode negative and work positive. In other words, the electrons flow from the electrode to the plate or workpiece, as shown in Figure 2. For direct current reverse-polarity welding (DCRP), the connections are just the opposite; electrons flow from the plate to the electrode, as shown in Figure 3.





In straight-polarity welding, the electrons hitting the plate at high velocity exert a considerable heating effect on the plate. In reverse-polarity welding, just the opposite occurs; the electrode acquires this extra heat which then tends to melt off the end of the electrode. Thus, for any given welding current, DCRP requires a larger diameter electrode than DCSP does. For example, a 1/16-in. diameter pure tungsten electrode can handle 125 amperes of welding current under straight-polarity conditions. If the polarity were reversed, however, this amount of current would melt off the electrode and contaminate the weld metal. Hence, a 1/4-in. diameter pure tungsten electrode is required to handle 125 amperes DCRP satisfactorily and safely.

These opposite heating effects influence not only the welding action but also the shape of the weld obtained. DCSP welding will produce a narrow, deep weld; DCRP welding, because of the larger electrode diameter and lower currents generally employed, gives a wide, relatively shallow weld. Figure 4 below illustrates the difference.

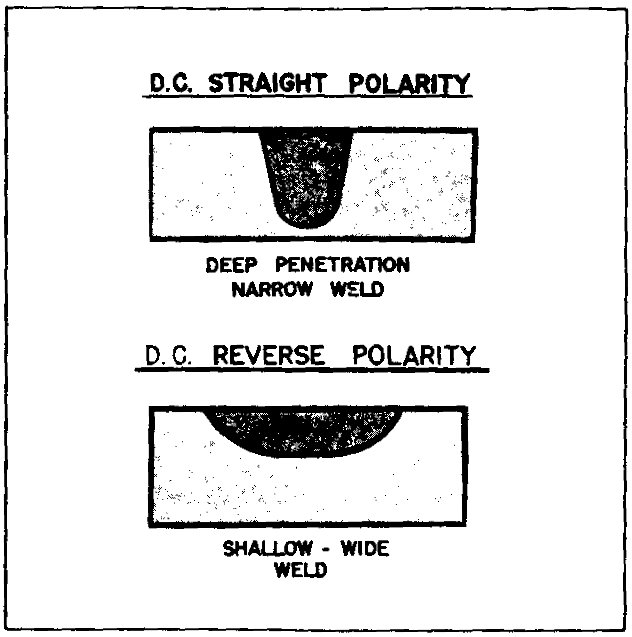


FIG. 4 – Effect of Polarity on Weld Shape

One other effect of DCRP welding should be considered here - namely the so-called plate cleaning effect which seems to occur. Although the exact reason for this surface cleaning action is not known, it seems probable that either the electrons leaving the plate or the gas ions striking the plate tend to break up the surface oxides, scale, and dirt usually present.

B. Alternating Current Welding

THEORETICALLY, straight a.c. welding is a combination of DCSP and DCRP welding. This can be best explained by showing the three current waves visually. As shown in Fig. 5, half of each complete a.c. cycle is DCSP; the other half is DCRP.

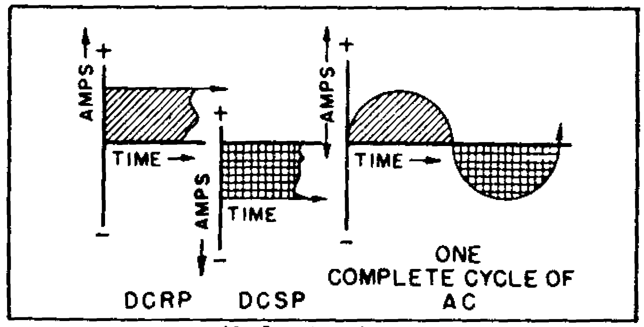


FIG. 5 – A.C. Wave

ACTUALLY, however, moisture, oxides, scale, etc. on the surface of the plate tend to prevent (partially or completely) the flow of current in the reverse-polarity direction. This is called rectification. For example, if no current at all flowed in the reverse-polarity direction, the current wave would look something like this:

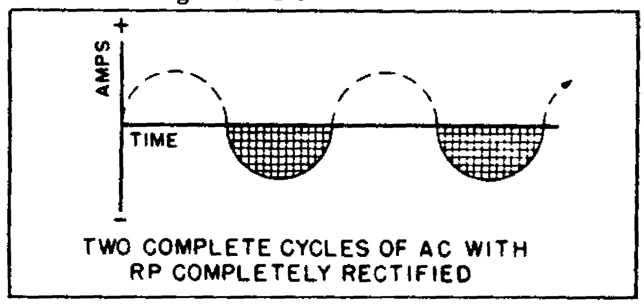


FIG. 6 – Rectified A.C. Wave

To prevent what is shown above from occurring, it is common practice to introduce into the welding current a high-voltage, high-frequency, low-power additional current. This high-frequency current jumps the gap between the electrode and the workpiece, and pierces the oxide film, thereby forming a path for the welding current to follow. Superimposing this high-voltage, high-frequency current on the welding current gives you the following advantages:

1. The arc may be started without touching the electrode to the workpiece.
2. Better arc stability is obtained.
3. A longer arc is possible. This is particularly useful in surfacing and hard-facing operations.
4. Welding electrodes have longer life.
5. The use of wider current ranges for a specific diameter electrode is possible.

A typical weld contour produced with high-frequency stabilized a.c. is shown below, together with both DCSP and DCRP welds for comparison.

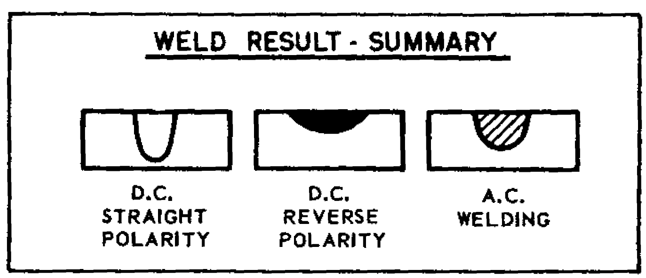


FIG. 7 – Comparison of Weld Contours

III. PREPARATION FOR WELDING

A. Joint Design

The principal basic types of joints used in HELIARC welding are the butt, lap, corner, edge, and tee. Almost any HELIARC weld you make will be one or a combination of two or more of these basic types. Selection of the proper design for a particular application will depend primarily on the following factors:

(a) Physical properties desired in the weld.
(b) Cost of preparing the joint and making the weld.
(c) Type of metal being welded.
(d) Size, shape, and appearance of the assembly to be welded.

Filler metal in the form of welding rod need not be used if proper reinforcement and complete fusion of the edges can be obtained without it. The joint designs described below are but a few of the many that can be successfully HELIARC welded. They do represent those most frequently used. Innumerable variations of these types can be used to fulfill special job requirements.

No matter what type of joint is used, proper cleaning of the workpieces prior to welding is essential if welds of good appearance and physical properties are to be obtained. On small assemblies, manual cleaning with a wire brush, steel wool, or a chemical solvent is usually sufficient. For large assemblies, or for cleaning on a production basis, vapor degreasing or tank cleaning may be more economical. In any case, be sure to remove completely all oxide, scale, oil, grease, dirt, rust, and other foreign matter from the work surfaces.

Proper precautions should be taken when using certain chemical solvents for cleaning purposes. The fumes from some chlorinated solvents (three examples are carbon tetrachloride, trichlorethylene, and tetrachlorethylene) break down in the heat of an electric arc and form a toxic gas. Avoid welding where such fumes are present. Furthermore, these solvents vaporize easily and prolonged inhalation of the vapor can be dangerous. Proper ventilating equipment should be provided to remove fumes and vapor from the work area.

1. BUTT JOINTS

The square-edge butt joint is the easiest to prepare, and can be welded with or without filler metal depending on the thickness of the pieces being welded. Joint fitup for a square-edge butt should always be true enough to assure 100 per cent penetration with good fusion. When welding light-gauge material without adding filler metal, extreme care should be taken to avoid low spots and burn-through. The heavier thicknesses will generally require filler metal to provide adequate reinforcement.

FIG. 8 – Square Edge Butt Joint

The single-vee butt joint is used where complete penetration is required on material thicknesses ranging between 3/8 and 1-inch. Filler rod must be used to fill in the "vee." The included angle of the "vee" should be approximately 60 degrees; the nose will measure from 1/8-to 1/4-inch depending on the composition and thickness of the pieces being welded.

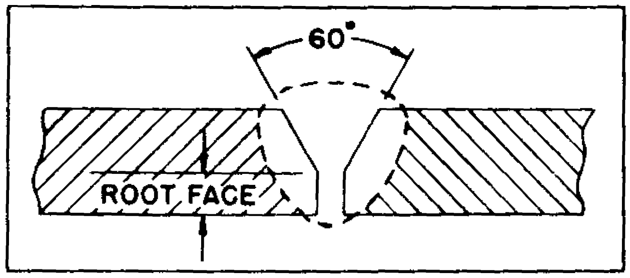


FIG. 9 – Single-Vee Butt Joint

This flange-type butt joint should be used in place of the square edge butt joint where some reinforcement is desired. This joint is practical only on relatively thin material (0.065 to 0.085 inches).

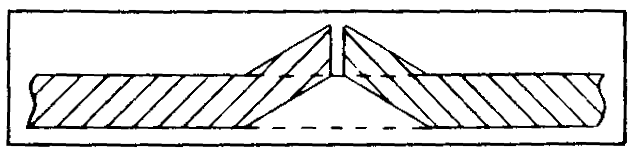


FIG. 10 – Flange Joint

A double-vee butt joint is generally used on stock thicker than 1/2 inch, where the design of the assembly being welded permits access to the back of the joint for a second pass. With this type of joint, proper welding techniques will assure a good sound weld with 100 per cent fusion.

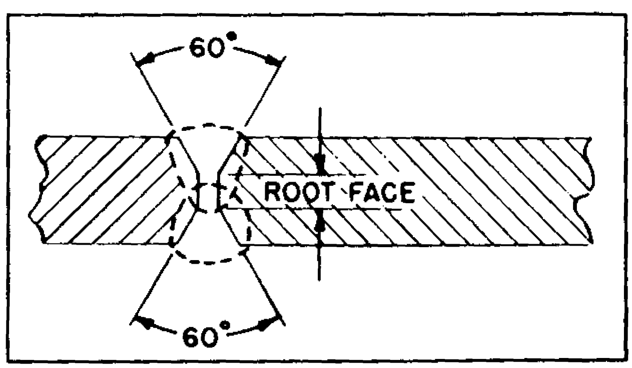


FIG. 11 – Double-Vee Butt Joint

2. LAP JOINT

A lap joint has the advantage of eliminating entirely the necessity for edge preparation. The only requirement for making a good lap weld is that the plates be in close contact along the entire length of the joint to be welded. On material 1/4-inch thick or less, lap joints can be made with or without filler rod. When no filler metal is used, care must be taken to avoid low spots or burn-through. The lap type joint is not usually recommended on material thicker than 1/4 inch except for rough fitup. When so used, filler rod must always be added to assure good fusion and buildup. The number of passes required will depend on the thickness of the pieces being joined.

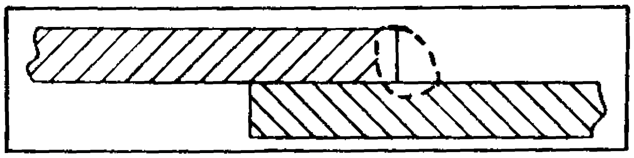


FIG. 12 – Lap Joint

3. CORNER JOINTS

Corner joints are frequently used in the fabrication of pans, boxes, and all types of containers as well as for other heavier purposes. Type A shown below is used on material thicknesses up to 1/8 inch. No filler metal is required, as the amount of base metal fused is sufficient to assure a sound, high-strength weld. Type B, as shown, is used on heavier material that requires filler rod to provide adequate reinforcement. Type C is used on very heavy material where 100 per cent penetration is impossible without the beveled edge preparation. The nose should be thick enough to prevent burn-through on the first pass. The number of passes required will depend on the size of the vee and thickness of the members being welded. On all corner joints, be sure the pieces are in good contact along the entire seam.

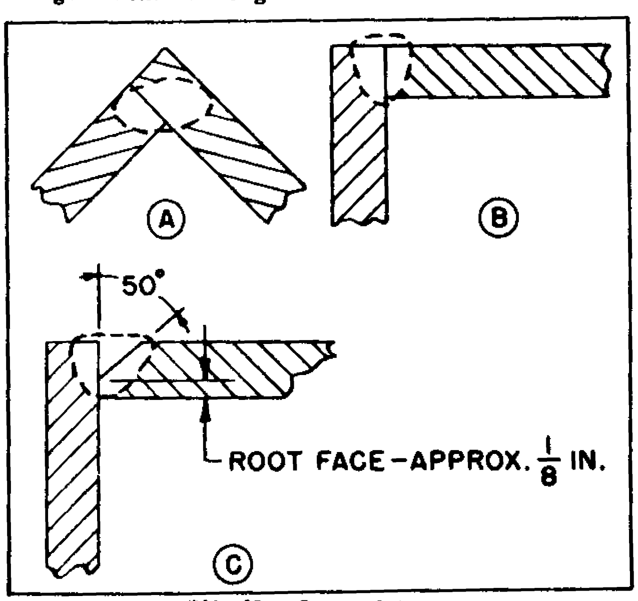


FIG. 13 – Corner Joints

4. TEE JOINT

All tee joints require the addition of filler rod to provide the necessary buildup. The number of passes on each side of the joint will depend upon the thickness of the material and the size of the weld desired. When 100 per cent penetration is required (as shown in the sketch), be sure that welding current values are adequate for the thickness of the web material.

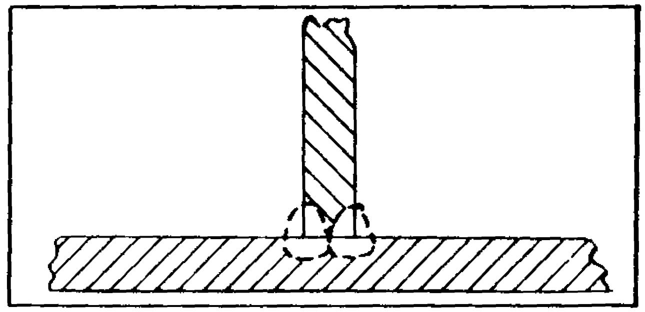


FIG. 14 – Tee Joint

5. EDGE JOINT

Edge joints such as the one shown below are used solely on light-gauge material and require no filler rod addition. Preparation is simple, and the joint economical to weld. This type should not be used, however, where direct tension or bending stresses will be applied to the finished joint, as it may fail at the root under relatively low stress loads.

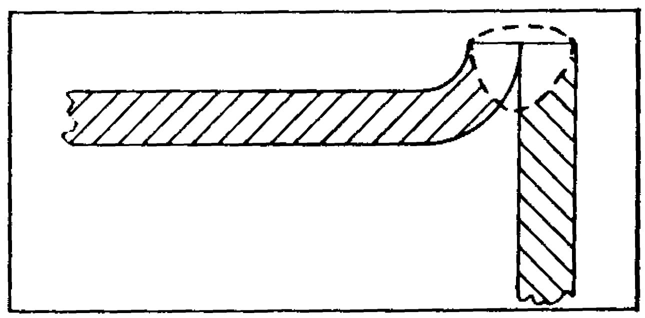


FIG. 15 – Edge Joint

B. Weld Backup

On many HELIARC welding applications, the joint should be backed up. This is done for several reasons. On light-gauge material, backing is usually used to protect the underside of the weld from atmospheric contamination resulting in possible weld porosity or poor surface appearance. In addition to these functions, weld backup prevents the weld puddle from dropping through by drawing away from the workpiece some of the heat generated by the intense arc and can also physically support the weld puddle. A HELIARC weld can be backed up by (1) metal backup bars, (2) introducing an inert gas atmosphere on the weld underside, or (3) a combination of the first two methods, or (4) use of flux backing, painted on the weld underside as a water- or alcohol-mixed slurry or with glass tape.

Flat metal backup bars are generally used on joints like the flange type shown in Fig. 16, where the bar does not actually touch the weld zone. If the bar comes in contact with the underside of the weld, non-uniform penetration may be obtained and the weld underside may be rough and uneven.

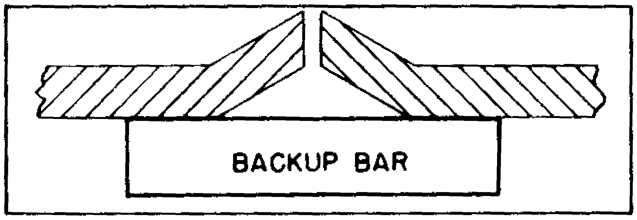


FIGURE 16

A type of backup bar more commonly used is that shown below in Fig. 17, where the surface is cut or machined out directly below the joint. On square edge butt joints, for example, where fitup is not too accurate and filler rod is required, a bar of this sort will protect the bottom of the weld from excessive contamination by the atmosphere, as well as draw heat away from the weld zone.

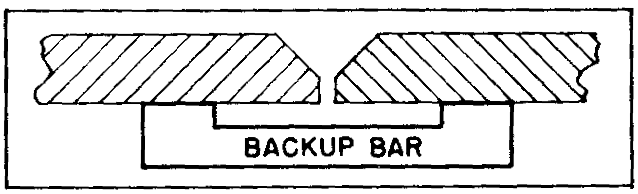


FIGURE 17

On applications where the final weld composition must conform to extremely rigid specifications, extra care must be taken to exclude all atmospheric oxygen from the weld underside. This is accomplished by introducing an atmosphere of gas into the relief groove of a backing bar similar to that shown above. Nitrogen may be used for the stainless steels. Argon should be used for aluminum, magnesium, and other metals that oxidize readily or react with nitrogen at high temperatures. Where no explosion hazard exists (as would in the welding of closed containers etc.), hydrogen may be used on all but the most readily oxidized metals. Where design of the assembly being welded prohibits the use of a backing bar, three or four hydrogen flames impinging on the weld underside may be used to exclude the atmosphere. Information on how to set up a system utilizing a gaseous atmosphere for backup purposes is available from Linde Air Products Company on request.

C. Apparatus Check

Before starting to weld, the entire welding setup should be thoroughly checked. It is extremely important to use the proper size electrode, gas cup, etc., and that all components of the setup are functioning properly to realize the full advantages of HELIARC welding.

1. Check all connections in the argon supply line for tightness. Be sure that good seals are obtained between the torch body, the cap, and the gas cup, as any air leakage into the argon stream will contaminate both the weld and the electrode. Be sure any gaskets required are in good condition and firmly in place. After welding, the electrode should have a clean silvery appearance upon cooling. A dirty and rough electrode surface usually signifies air leakage in the torch or argon supply system.
2. Check the welding current and argon flow settings. They should be preset to the approximate values recommended for the material being welded, as given in Section V of this booklet.
3. Select the proper gas cup and electrode size.
4. Check the rate of water flow through the torch. Flow rates lower than those recommended decrease torch efficiency and may result in damage to the torch, particularly if the torch is being used at or near its maximum capacity. Safe flow requirements for each HELIARC torch depend on the design and current capacity.
5. Check the ground connection to be sure it is securely clamped to the workpiece. The workpiece should be cleaned at the point of contact, preferably by grinding, to assure good contact.

IV. HANDLING THE TORCH

A. Starting an Arc

There is nothing difficult or technical about starting an arc in the proper manner. We recommend the particular procedure outlined briefly below, to ensure maximum protection of the workpiece from the atmosphere at the start of welding operations.

In a.c. welding, the electrode does not have to touch the workpiece to start the arc. The superimposed high-frequency current jumps the gap between the welding electrode and the work thus establishing a path for the welding current to follow. To strike an arc, first turn on the power supply and hold the torch in a horizontal position about 2 inches above the workpiece or starting block, as shown in Figure 18 below. Then quickly swing the end of the torch down toward the workpiece, so that the end of the electrode is about 1/8 inch above the plate. The arc will then strike. This downward motion should be made rapidly to provide the maximum amount of gas protection to the weld zone. Figure 19 shows the torch position at the time the arc strikes.

In d.c. welding, the same motion is used for striking an arc. However, in this case, the electrode must touch the workpiece in order for the arc to start. As soon as the arc is struck, withdraw the electrode approximately 1/8-inch above the workpiece to avoid contaminating the electrode in the molten puddle. High frequency is sometimes used to start a d.c. arc. This eliminates the need for touching the workpiece. The high frequency is automatically turned off by means of a current relay when the arc is started.

The arc can be struck on the workpiece itself or on a heavy piece of copper or scrap steel, and then carried to the starting point of the weld. Do not use a carbon block for starting the arc, as the electrode becomes contaminated causing the arc to wander (see Section B below). When starting to weld with a hot electrode, the action must be very rapid as the arc tends to strike before the torch is in proper welding position.

To stop an arc, merely snap the electrode quickly back up to the horizontal position. This motion must be made rapidly so the arc will not mar or damage the weld surface or workpiece.

B. Arc Wandering

With the torch held stationary, the points at which an arc leaves the electrode and impinges upon the workpiece may often shift and waver without apparent reason. This is known as "arc wandering," and is generally attributed to one of the following causes: (1) low electrode current density, (2) carbon contamination of the electrode, (3) magnetic effects, and (4) air drafts. The first two causes are distinguished by a very rapid movement of the arc from side to side, generally resulting in a zig-zag weld pattern. The third cause, magnetic effects, usually displace the arc to one side or the other along the entire length of the weld. The fourth causes varying amounts of arc wandering, depending upon the amount of air draft present.

When current density of the electrode is at a sufficiently high level (see torch instruction booklet for recommended amperages for various diameter electrodes), the entire end of the electrode will be in a molten state and completely covered by the arc. When too low a current density is used, only a small area of the electrode becomes molten resulting in an unstable arc which has poor directional characteristics and is difficult for the operator to control. Too high a current density results in excessive melting of the end of the electrode.

Although we clearly advise against striking an arc with a carbon pencil or on a carbon block, it is quite often done and is a primary cause of arc wandering. When the carbon touches the molten tungsten, tungsten carbide is formed. This has a lower melting point than pure tungsten, and forms a large

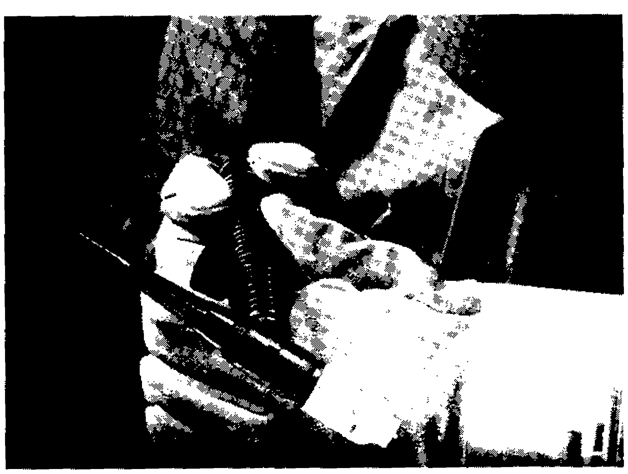


FIG. 18 – Torch Position for the Starting Swing

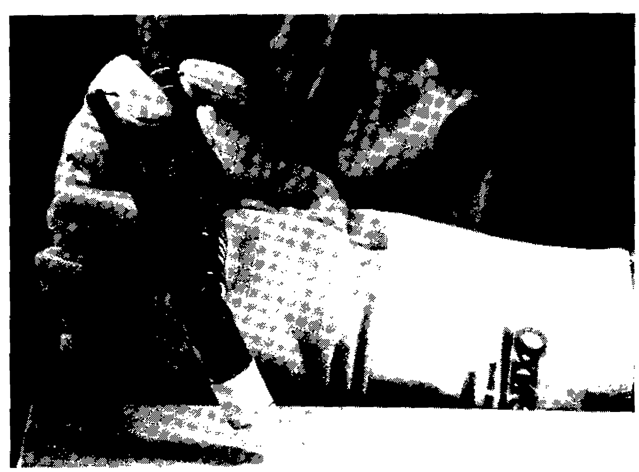


FIG. 19 – End of Swing to Draw an Arc

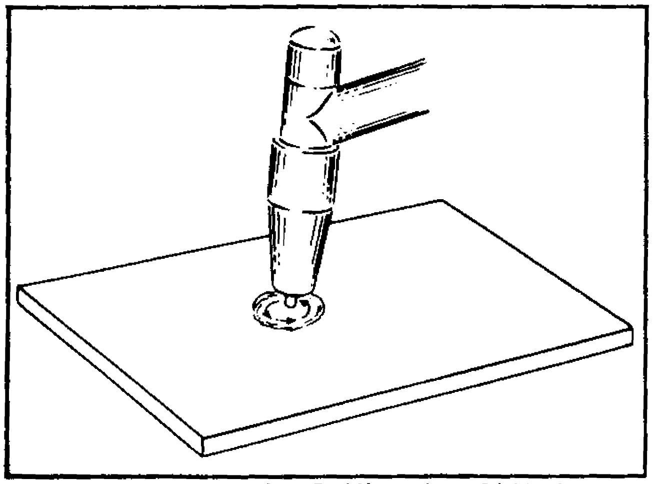


FIG. 20 – Forming a Molten Puddle with a HELIARC Torch

molten ball on the end of the electrode. This in effect reduces the current density at the electrode end, and arc wandering then occurs. The electrode can also be contaminated by touching it to the work piece or filler rod. When electrode contamination occurs in any form, it is best to clean the electrode by grinding, break off the contaminated end, or use a new electrode.

Magnetic effects are not generally encountered, and are too complex to be discussed fully. The most common magnetic action on an arc, however, results from the magnetic field set up by the current flowing through the workpiece. This magnetic field may tend to attract or repel (depending on its polarity) the arc from the normal path. One method of remedying this condition is to alter the position of the ground connection on the workpiece until the effects are no longer noticed. Often the hold-down jaws of the welding fixture may have to be changed to a non-magnetic material such as bronze, copper or stainless steel.

C. Making a Butt Weld

After the arc has been struck, hold the torch at about a 75 degree angle to the surface of the workpiece. The starting point of the work is first preheated by moving the torch in small circles (see Figure 20) until a molten puddle is formed. The end of the electrode should be held approximately 1/8-inch above the workpiece. When the puddle becomes bright and fluid, move the torch slowly and steadily along the joint at a speed that will produce a bead of uniform width. No oscillating or other movement of the torch except for the steady forward motion is required.

When filler metal is required to provide adequate reinforcement, the welding rod is held at about 15 degrees to the work and about one inch away from the starting point. First preheat the starting point and develop the puddle as described above. When the

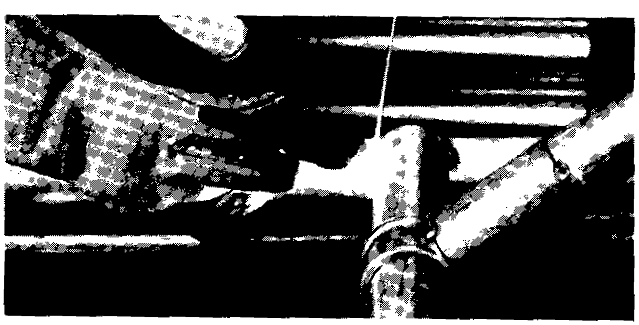


FIG. 21 – Position of Torch and Rod for Making a Butt Weld

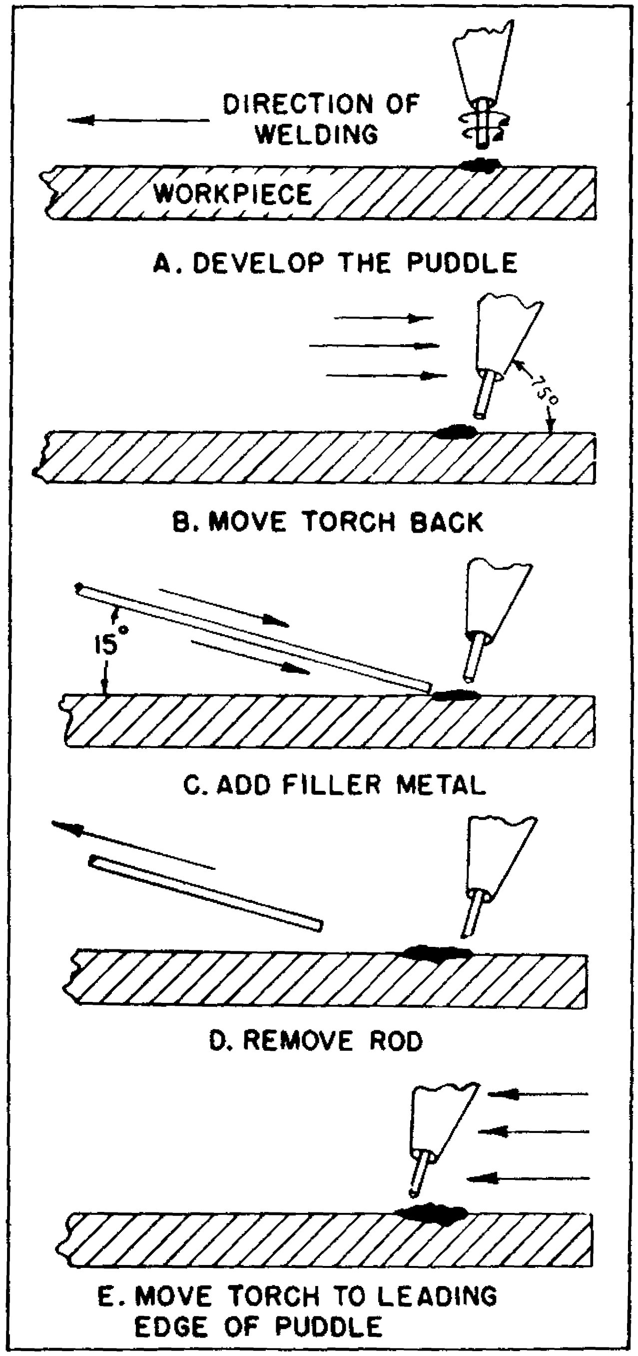


FIG. 22 – Addition of Filler Metal (Flat Position)

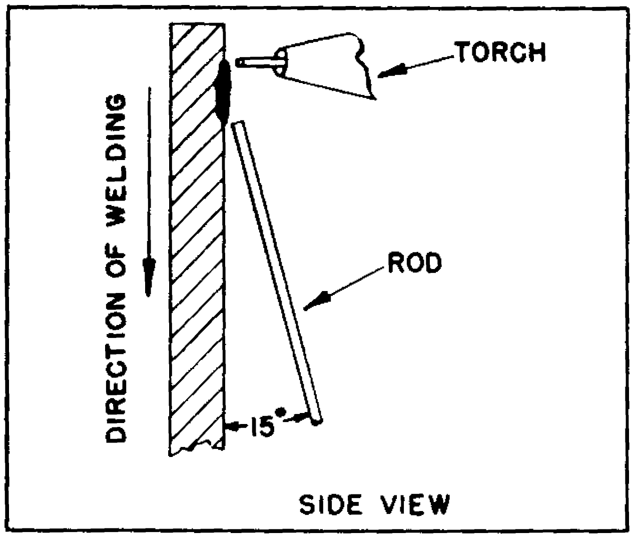


FIG. 23 – Addition of Filler Metal (Vertical Position)

puddle becomes bright and fluid, move the arc to the rear of the puddle and add filler metal by quickly touching the rod to the leading edge of the puddle. Remove the rod and bring the arc back up to the leading edge of the puddle. As soon as the puddle is again bright, repeat the same steps. This sequence is continued for the entire length of the seam. Figure 22 illustrates the steps graphically. The rate of forward speed and amount of filler metal added will depend on the desired width and height of the bead.

For making butt joints on a vertical surface, the torch is held perpendicular to the work. The weld is usually made from top to bottom. When filler rod is used, it is added from the bottom or leading edge of the puddle in the same manner as described above. Figure 23 above shows correct positioning of the rod and torch relative to the workpiece.

D. Making a Lap Weld

A lap weld or joint is started by first developing a puddle on the bottom sheet. When the puddle becomes bright and fluid, shorten the arc to about 1/16-inch. Oscillate the torch directly over the joint until the sheets are firmly joined. Once the weld is started, the oscillating movement is no

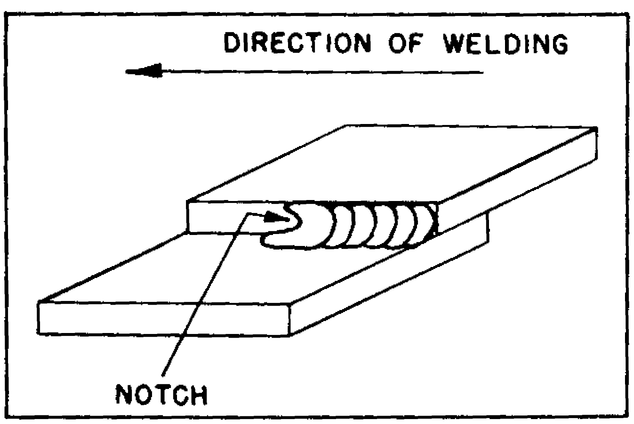


FIG. 24 – Lap Welding Technique

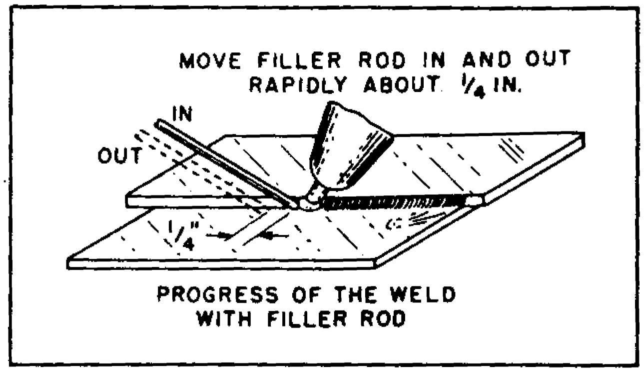


FIG. 25 – Progress of a Lap Weld with Filler Rod

longer necessary. Merely move the torch along the seam holding the end of the electrode just above the edge of the top sheet.

In lap welding, the puddle developed will be boomerang- or vee-shaped. The center of the puddle is called the "notch," and the speed at which this notch travels will determine how fast the torch can be moved ahead. Care must be taken that this notch (see Figure 24) is completely filled in for the entire length of the seam. Otherwise, it is impossible to get 100 per cent fusion and good penetration.

When filler metal is used, faster welding speeds are possible as the rod helps fill up the notch. Be sure to get complete fusion, however, and not merely lay in bits of filler rod on cold, unfused base metal. The rod should be alternately dipped into the puddle and withdrawn 1/4-inch or so, as illustrated in Figure 25. By carefully controlling the melting rate of the top edge, and by adding just the right amount of filler metal where needed, a good uniform bead of proper proportions can be obtained.

E. Making a Corner or Edge Joint

This is the easiest type of HELIARC weld to make. Develop a puddle at the starting point, and then move the torch straight along the joint. Regulate travel speed to produce a uniform looking bead. Too slow a welding speed will cause molten metal to roll off the edge. Irregular or too high speeds will produce a rough, uneven surface. No filler metal is required. The position of the welding torch is shown in Figure 26.

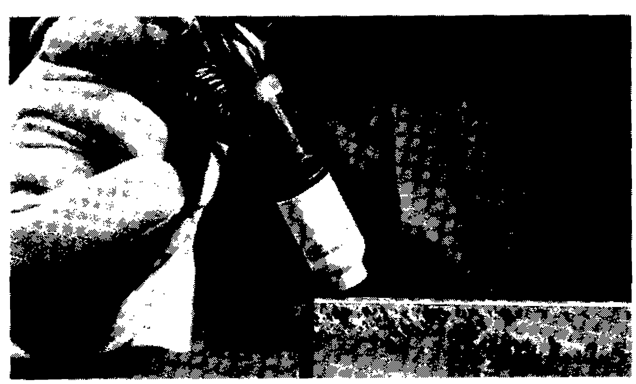


FIG. 26 – Welding on Edge Joint

F. Multipass Welding

Multipass welding will generally be necessary for welding material over 1/4-inch thick. The number of passes required will depend on the thickness of the material, and on the current carrying capacity of the equipment involved and the assembly being fabricated. The first pass should be a "root-weld" and provide complete fusion at the bottom of the joint. Subsequent passes can be made at higher currents due to the back up effect of the root weld. Care should be taken to prevent inclusions between weld layers. On heavy work, it is sometimes advantageous to carry all the beads along simultaneously in a staggered arrangement to utilize the residual heat of preceding passes.

V. WELDING DATA

A. Aluminum and Its Alloys

1. WROUGHT ALUMINUM ALLOYS -- CHEMICAL COMPOSITION LIMITS

Non Heat-Treatable Wrought Aluminum Alloys (Work Hardenable)						
Alloy	Nominal Composition			Recommended Rod		
	Mn	Mg	Cr	1st	2nd	3rd
1100	99.0% min. Al.			1100*	4043*	–
3003	1.2	–	–	1100*	4043*	–
3004	1.2	1.0	–	5556	5356*	4043*
5052	–	2.5	0.25	5556	5356*	5183
5652				5254*	5556	5356*
5083	0.8	4.5	0.10	5556	5183	5356*
5086	0.45	4.0	0.10	5556	5183	5356*
5154	–	3.5	0.25	5254*	5556	–
5254				5254*	5556	5356*
5454	0.8	2.8	0.10	5554	5556	5356*
5456	0.8	5.2	0.10	5556	5183	5356*

Heat-Treatable Wrought Aluminum Alloys (Solution Treat, Cold Work and/or Age)								
Alloy	Nominal Composition					Recommended Rod		
	Cu	Si	Mn	Mg	Cr	1st	2nd	3rd
2014	4.4	0.8	0.8	0.4	–	2319	4043*	716
2024	4.5	–	0.6	1.5	–	2319	4043*	716
2219	6.3	–	0.3	–	–	2319	4043*	716
6061	0.25	0.6	–	1.0	0.25	5556	5356*	4043*
6063	–	0.4	–	0.7	–	5556	5356*	4043*

* *These rods also have OXWELD rod numbers; see par. 2 below.*

2. WELDING RODS

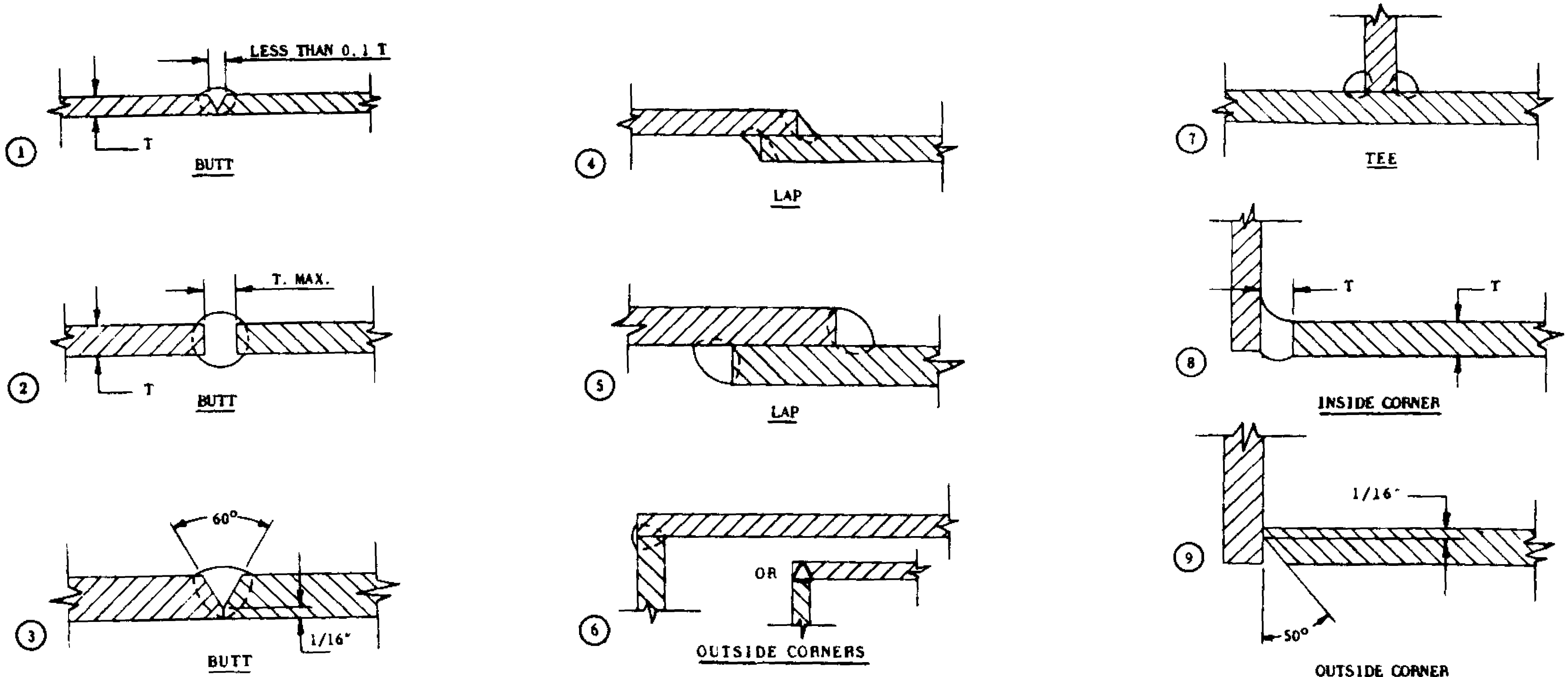
OXWELD 14 (1100) aluminum welding rod is used for welding commercially pure aluminum and aluminum-manganese alloys. It has approximately the same tensile strength as pure aluminum in the annealed state (about 12,000 psi).

OXWELD 23 (4043) aluminum welding rod is used for welding all but the pure aluminum manganese alloys. Do not use this rod on aluminum alloys such as Grades EC, 1060, 1100, and 3003 if high corrosion resistance is required. On strong aluminum alloys, the weld strength will vary with the alloy being welded, and the methods of heat-treating and quenching. However, sound welds made with this rod can be expected to reach tensile strengths between 25,000 and 30,000 psi.

OXWELD 64B (5254) aluminum rod and wire has been specially designed to produce porosity-free, high-strength welds in Types 5052, 5154, and 6061 aluminum base metals. The surface of the rod and wire has been specially treated to ensure absolute cleanliness in the weld metal. It is required for welding 5652 alloy.

OXWELD 67 (5356) aluminum rod and wire is designed to produce high quality SIGMA welds in Types 5052, 5154, 5356, 6061, 6063, 5083, and 5086 aluminum plate. Welds made with OXWELD 67 have a much greater resistance to hot-short cracking than those made with OXWELD 64B, particularly in low-magnesium alloys or between dissimilar metals. OXWELD 67 produces a more fluid weld puddle than OXWELD 64B, resulting in easier handling and superior weld quality.

3. WELDING CONDITIONS



TIG HAND-WELDING OF ALUMINUM

Thickness In.	Type of Weld	Type	WELDING CURRENT – AMPERES – Flat	Vertical	Overhead	* Electrode Diameter In.	** Welding Speed I.P.M.	WELDING ROD*** Size In.	GAS CUP OR NOZZLE SIZE – Ceramic (Lava) Cup (250 Amp. Max.)	High Impact (Alumina) Cup (300 Amp. Max.)	Metal Nozzle (Where available)	Gas Flow Argon C.F.H.	REMARKS
									Consult the torch instruction booklet for the maximum current ratings of the torch and for sizes and part numbers of available cups or nozzles.				
1/16	1,2 Butt	Alternating Current—High-Frequency Stabilized	60- 80	60- 80 Down	60- 80	1/16	12	None or 1/16	4,5,6	4,5,6	6	15	
	4,5 Lap		70- 90	55- 75 Up	60- 80	1/16	10	None or 1/16	4,5,6	4,5,6	6	15	
	6 Corner		60- 80	60- 80 Up	60- 80	1/16	12	None or 1/16	4,5,6	4,5,6	6	15	
	7 Fillets		70- 90	70- 90 Down	70- 90	1/16	10	None or 1/16	4,5,6	4,5,6	6	15	
1/8	1,2 Butt		125-145	115-135 Down	120-140	3/32	12	3/32 or 1/8	6,7	6,7	6,7	20	3/32" Rod—Overhead
	4,5 Lap		140-160	125-145 Up	130-160	3/32	10	None or 3/32	6,7	6,7	6,7	20	3/32" Rod—Overhead
	6 Corner		125-145	115-135 Up	130-150	3/32	12	None or 3/32	6,7	6,7	6,7	20	3/32" Rod—Vertical
	7 Fillets		140-160	115-135 Down	140-160	3/32	10	1/16 or 3/32	6,7	6,7	6,7	20	
3/16	1,2 Butt		190-220	190-220 Up or Down	180-210	1/8	11	1/8	7,8	7,8	6,8	20	
	4,5 Lap		210-240	190-220 Up	180-210	1/8	9	1/8	7,8	7,8	6,8	20	
	6 Corner		190-220	180-210 Up	180-210	1/8	11	1/8	7,8	7,8	6,8	20	
	7 Fillet		210-240	190-220 Up	180-210	1/8	9	1/8	7,8	7,8	6,8	20	
1/4	1,2 Butt		260-300	220-260 Up	210-250	3/16	10	1/8 or 3/16		8,10,12	8,10	25	1/8" Rod—Vertical and Overhead Two Passes
	4,5 Lap		290-340	220-260 Up	210-250	3/16	8	1/8 or 3/16		8,10,12	8,10	25	
	8 Corner		280-320	220-260 Up	210-250	3/16	10	1/8 or 3/16		8,10,12	8,10	25	
	7 Fillet		280-320	220-260 Up	210-250	3/16	8	1/8 or 3/16		8,10,12	8,10	25	1/8" Rod — Vertical
3/8	3 Butt		330-380	250-300	250-300	3/16 ,1/4	5	3/16 or 1/4			10	30	Two Passes
	5 Lap		330-380	250-300	250-300	3/16 ,1/4	5	3/16 or 1/4			10	30	Two Passes
	7 Tee Fillets		350-400	250-300	250-300	3/16 ,1/4	5	3/16 or 1/4			10	30	Two Passes
	9 Corner		330-380	250-300	250-300	3/16 ,1/4	5	3/16 or 1/4			10	30	Two Passes
1/2	3 Butt		400-450	290-350 Up	250-300	3/16 ,1/4	3	3/16 or 1/4			10	30	Two or Three Passes
	5 Lap		400-450	300-350 Up	275-325	3/16 ,1/4	3	3/16 or 1/4			10	30	Three Passes
	7 Tee Fillets		420-470	300-350 Up	275-325	3/16 ,1/4	3	3/16 or 1/4			10	30	Three Passes
	9 Corner		400-450	300-350 Up	275-325	3/16 ,1/4	3	3/16 or 1/4			10	30	Three Passes

*If two sizes are listed, the smaller is for vertical and overhead welding. Use a larger electrode or slightly lower welding current when balanced wave transformer is used.
**Welding speed for flat position.
***Select according to Par. 2, page 12.

Note: for aluminum heavier than ½ in., argon-helium mixtures provide greatly improved performance.

B. Stainless Steel

1. PRINCIPAL WELDABLE TYPES OF STAINLESS STEEL

AUSTENITIC - (Cr-Ni)

	%C	%Cr	%Ni	% Others	Rod to Use
Type 201	0.15 max.	17.0	4.0	Mn 6.5	OXWELD 60, or Type 304*
Type 202	0.15 max.	18.0	6.0	Mn 8.5	OXWELD 60, or Type 304*
Type 301	0.08-0.20	17.0	7.0	--	OXWELD 60, or Type 304*
Type 302	0.08-0.20	18.0	8.0	--	OXWELD 60, or Type 304*
Types 304,	0.08 max.	18.5	8.5	--	OXWELD 60, or Type 304*
304 ELC	0.03 max.	18.5	8.5	--	OXWELD 60
Type 308	0.08 max.	20.0	11.0	Mn. 2.00 max.	OXWELD 60, or OXWELD 308
Type 309	0.20 max.	24.0	13.0	--	OXWELD 309, or OXWELD 60
Type 310	0.25 max.	25.0	20.0	--	OXWELD 310, or OXWELD 60
Types 316,	0.10 max.	17.0	12.0	Mo 2.5	Types 316
317	0.10 max.	17.0	14.0	Mo 3.5	or 317
Type 318	0.10 max.	17.0	12.0	Mo 2.5, Cb 10xC	OXWELD 318
Type 321	0.10 max.	18.5	10.0	Ti 4 x C	OXWELD 60, or Type 321
Type 347	0.10 max.	18.5	10.0	Cb 10 x C	OXWELD 60

* *Type 309 rod should be used for giving high impact resistance at low temperatures - otherwise use rods listed.*

FERRITIC (Straight Cr)

	%C	%Cr	% Others	Rod to Use
Type 430	0.12 max.	14.0-18.0	--	Types 310†, 309, or 430
Type 446	0.35 max.	26.0	--	Types 310†, 309†, or 446

MARTENSITIC (Straight Cr)

	%C	%Cr	% Others	Rod to Use
Type 410	0.15 max.	12.0	--	Types 310†, 309†, 410, or 430
Type 501	0.10	5.0	--	Types 310†, 309†, or 502
Type 502	0.10 max.	5.0	--	Types 310†, 309†, or 502

† *These rods give ductile weld metal.*

2. SPECIAL PRECAUTIONS

AUSTENITIC TYPE (Cr-Ni)

1. Occasional hot tearing:
   Cause - Improper joint design, sequence of welding, or jigging.
   Correction - Use proper welding (DCSP) and sequence of welding. Change joint design.
2. Decreased ductility:
   Correction - Use lower current and/or multipass technique in which narrow stringer beads can be made at high speed and high current.
3. Decreased corrosion resistance near weld:
   Cause - Heat effect of welding causes carbide precipitation.
   Correction - Use Cb or Ti stabilized base metal (such as Type 347) and Cb stabilized rod; or heat treat entire assembly at 1900 deg. F. and cool rapidly after welding.

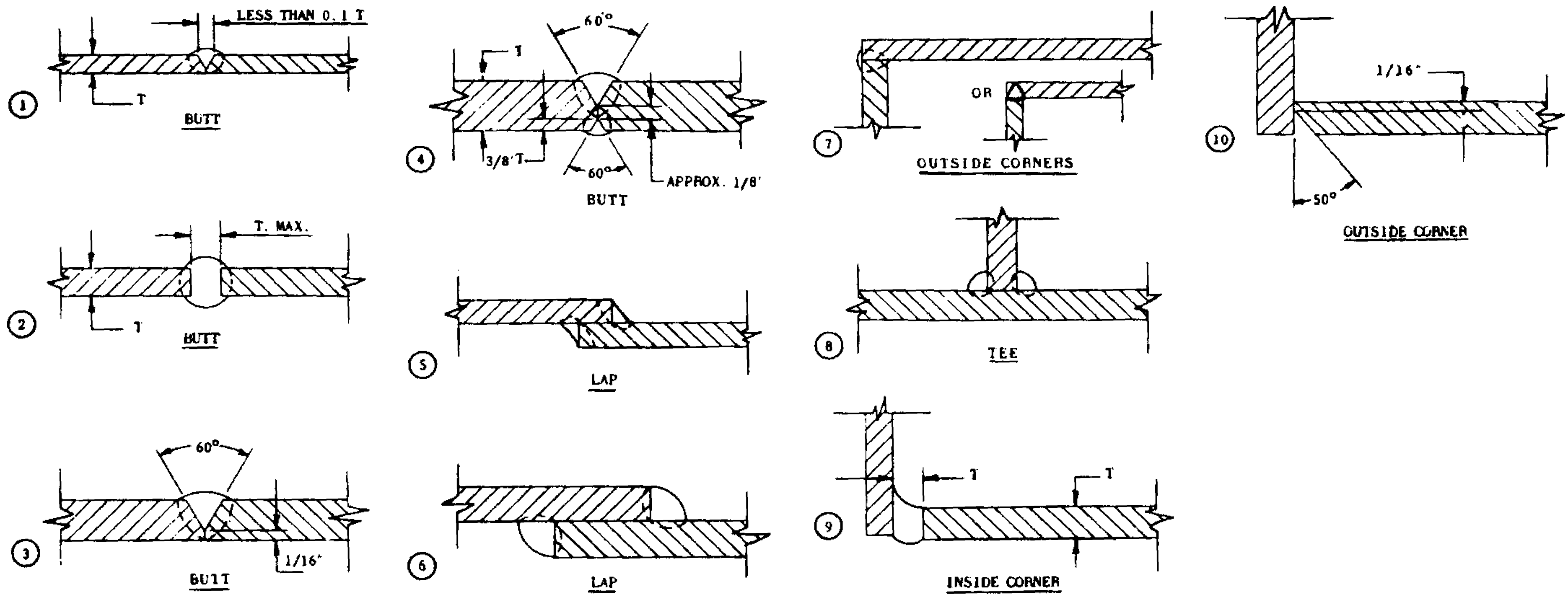
FERRITIC TYPE (Straight Cr, 14% and above)

1. Lower Cr grades may be air hardening. C and Cr contents must be balanced. Higher C requires higher Cr to maintain non-hardening structure.
2. Grain size increases with Cr content:
   Good combination of properties with 15-16% Cr - good impact resistance. No air hardening occurs when C is below 0.10%.
3. To increase toughness:
   Use Type 310 or 309 rod.
   Heat treatment followed by annealing.
4. To prevent possible cracking if C is high:
   Preheat to about 400 deg. F.

MARTENSITIC TYPE (Straight Cr)

1. Air hardening:
   Preheat to 400 to 500 deg. F. to avoid cracking. Follow by annealing to avoid excessive hardness and cracking. Follow recommendations of manufacturer.
   Use Type 310 or 309 rod to give ductile weld metal.

3. WELDING CONDITIONS



TIG HAND-WELDING OF STAINLESS STEEL*

Thickness In.	Type of Weld	WELDING CURRENT: Characteristics	WELDING CURRENT: AMPERES Flat	AMPERES Vertical	AMPERES Overhead	Electrode Diameter In.	** Welding Speed I.P.M.	WELDING ROD: Material Name No.	WELDING ROD: Size In.	GAS CUP OR NOZZLE SIZE: Ceramic (Lava) Cup (250 Amp. Max)	High Impact (Alumina) Cup (300 Amp. Max.)	Metal Nozzle (Where available)	Gas Flow Argon C.F.H.	REMARKS
										Consult the torch instruction booklet for the maximum current ratings of the torch and for sizes and part numbers of available cups or nozzles.				
1/16	1,2 Butt	Straight Polarity – Direct Current	80-100	70- 90 up	70-90	1/16	12	For welding rod to use, refer to "B-1," "Principal Weldable Types of Stainless Steel."	1/16	4,5,6	4,5,6	6	10	
	5,6 Lap		100-120	80-100 up	80-100	1/16	10		1/16	4,5,6	4,5,6	6	10	
	7 Corner		80-100	70- 90 up	70-90	1/16	12		1/16	4,5,6	4,5,6	6	10	
	8,9 Fillet		90-110	80-100 up	80-100	1/16	10		1/16	4,5,6	4,5,6	6	10	
3/32	1,2 Butt		100-120	90-110 up	90-110	1/16	12		1/16 or 3/32	4,5,6	4,5,6	6	10	
	5,6 Lap		110-130	100-120 up	100-120	1/16	10		1/16 or 3/32	4,5,6	4,5,6	6	10	
	7 Corner		100-120	90-110 up	90-110	1/16	12		1/16 or 3/32	4,5,6	4,5,6	6	10	
	8,9 Fillet		110-130	100-120 up	100-120	1/16	10		1/16 or 3/32	4,5,6	4,5,6	6	10	
1/8	1,2 Butt		120-140	110-130 up	105-125	1/16	12		3/32	4,5,6	4,5,6	6	10	
	5,6 Lap		130-150	120-140 up	120-140	1/16	10		3/32	4,5,6	4,5,6	6	10	
	7 Corner		120-140	110-130 up	115-135	1/16	12		3/32	4,5,6	4,5,6	6	10	
	8,9 Fillet		130-150	115-135 up	120-140	1/16	10		3/32	4,5,6	4,5,6	6	10	
3/16	1,2,Butt		200-250	150-200 up	150-200	3/32'	10		1/8	6,7,8	6,7,8	6,8	15	
	6 Lap		225-275	175-225 up	175-225	3/32 , 1/8	8		1/8	6,7,8	6,7,8	6,8	15	
	7 Corner		200-250	150-200 up	150-200	3/32	10		1/8	6,7,8	6,7,8	6,8	15	
	8,9 Fillet		225-275	175-225 up	175-225	3/32 , 1/8	8		1/8	6,7,8	6,7,8	6,8	15	
1/4	2,3 Butt		275-350	200-250 up	200-250	1/8	—		3/16			8	15	One or Two Passes
	6 Lap		300-375	225-275 up	225-275	1/8	—		3/16			8	15	One or Two Passes
	7 Corner		275-350	200-250 up	200-250	1/8	—		3/16			8	15	One Pass
	8,10 Fillet		300-375	225-275 up	225-275	1/8	—		3/16			8	15	
1/2	3,4 Butt		350-450	225-275 up	225-275	1/8 , 3/16	—		1/4			8	15	Two or Three Passes
	6 Lap		375-475	230-280 up	230-280	1/8 , 3/16	—		1/4			8	15	Three Passes
	8,10 Fillet		375-475	230-280 up	230-280	1/8 , 3/16	—		1/4			8	15	Three Passes

Conditions very similar for HASTELLOY B & C and other similar alloys.

****Welding speed for flat position.***

C. Magnesium Alloys

1. WELDABLE ALLOYS (See Dow Bulletin 141-94 "Joining Magnesium" for additional information.)

Alloy No. Dow & A.S.T.M.	Nominal Composition	Main Use	Tensile Strength (Annealed)	Melting Range Deg. F.	Properties	Welding Rod
HK31A	3.0 Th, 0.7 Zr.	Sheet, Plate, Castings	37,000 psi	1092-1204	Elevated temperature stability	EZ33A
AZ31B	3.0 Al, 1.0 Zn.	Sheet, plate, strip, shapes.	36,000 psi	990-1170	Formability and strength; general purpose alloy.	AZ92A or AZ61A

2. WELDING CONDITIONS

MANUAL WELDING OF MAGNESIUM (AZ31B & HK31A ALLOYS)
Using A.C.H.F.

Thickness in.	Type of Weld (1)	Welding Current Amperes* Flat Position		Welding Rod (2) Size, in.	Shielding Gas Flow		Remarks
		HK31A	AZ31B		Argon	Helium	
0.040	Butt	40	35	3/32, 1/8	10	25	Backup
0.040	Butt	30	25	3/32, 1/8	10	25	No backing
0.040	Fillet	40	35	3/32, 1/8	10	25	
0.064	Butt	55	50	3/32, 1/8	10	25	Backup
0.064	Butt & Corner	35	30	3/32, 1/8	10	25	No backing
0.064	Fillet	55	50	3/32, 1/8	10	25	
0.081	Butt	75	65	1/8	10	25	Backup
0.081	Butt, corner & edge	45	40	1/8	10	25	No backing
0.081	Fillet	75	65	1/8	10	25	
0.102	Butt	95	85	1/8	20	30	Backup
0.102	Butt, Corner & edge	70	60	1/8	20	30	No backing
0.102	Fillet	95	85	1/8	20	30	
0.128	Butt	110	100	1/8, 5/32	20	35	Backup
0.128	Butt, corner & edge	80	70	1/8, 5/32	20	35	No backup
0.128	Fillet	110	100	1/8, 5/32	20	35	
3/16	Butt	155	140	1/8, 5/32	20	35	1 pass
3/16	Butt	110	100	1/8, 5/32	20	35	2 passes
1/4	Butt	200	180	5/32, 3/16	25	50	1 pass
1/4	Butt	125	115	5/32	20	35	2 passes
3/8	Butt	270	250	5/32, 3/16	25	50	1 pass
3/8	Butt	160	140	5/32, 3/16	25	50	2 passes
1/2	Butt	330	310	3/16	25	50	2 passes
3/4	Butt	450	420	3/16, 1/4	35	75	2 passes

**Current values given for butt joint welding are with backing plate. Slightly lower values used for welding without a backing plate.*

3. PROCEDURES
   (a) Careful cleaning of the workpiece is always required since magnesium oxidizes readily. It is recommended that parts be degreased, hot-alkaline cleaned, and then immersed for approximately 3 minutes in a bath of the following composition: Chromic acid - 24 oz., Sodium Nitrate - 4 oz., and water to make one gallon.
   (b) A short arc length (1/16 in. or less), must be used to produce a bright, shiny weld. Longer arcs will leave the weld surface dark and cloudy looking.

(c) When using filler metal, hold the rod at a small angle (less than 10 deg.) to the plate, with the end of the rod touching the leading edge of the puddle. As the torch is moved along the joint, it melts off small pieces of the filler rod. No "dipping" motion of the rod is necessary.

(d) To minimize distortion and stress corrosion, magnesium welds should be stress relieved after welding as follows:

Alloy	Temp. - Deg. F.	Time - Min.
AZ31B-O	500	15
AZ31B-H24	300	60

HK31A is not stress corrosion sensitive and requires no thermal treatments after welding for this purpose. Straightening may be performed at 600°F (1 hr. maximum).

(e) Tensile Strength of magnesium welds is approximately 90 - 100% of the base metal strength for AZ31B alloy and 80-90% for HK31A alloy.

(f) Your metal supplier should be consulted if additional welding details are required.

D. Copper and Its Alloys

1. GENERAL

(a) The weldability of each copper-alloy group depends largely upon the alloying elements. For this reason, we do not attempt to give one set of welding conditions applicable to all groups. Each will be discussed separately.

(b) DCSP is generally used for welding most copper alloys. However, ACHF or DCRP is recommended for beryllium copper or for copper alloys less than 0.040-in. thick.

(c) Where flux is recommended, never use a flux containing fluorides. The intense heat of the arc will vaporize the fluorides which, if inhaled in appreciable quantities, will irritate the lungs.

(d) Always provide good ventilation when welding copper or any copper alloy. This is particularly important when welding beryllium copper or when using beryllium copper welding rod. The dusts, fumes, and mists of beryllium compounds in virtually every form are highly toxic. Because no safe maximum concentration has been established, extreme precautions should be taken to reduce the dusts, fumes, and mists to zero. An effective high-velocity ventilating system should be used regardless of the degree of contamination. The welding operator should also be protected with clothing, gloves, and a mask of an approved type.

2. ELECTROLYTIC COPPER

Due to the cuprous oxides contained in electrolytic copper, there is at present no known welding method that can produce sound, high-strength welds in this material. Electrolytic copper is sometimes welded when tensile strength requirements are only 19,000 psi or less, although porosity still occurs. Approximately the same welding conditions are used as those recommended for deoxidized copper below.

3. DEOXIDIZED COPPER

(a) Unlike electrolytic copper, this grade does not contain enough oxygen to cause oxide embrittlement or porosity if reasonable care is exercised during welding operations. Also, little change in electrical resistance occurs across the joint. Deoxidized copper is the type most widely used for fabrication by welding. The tensile strength of a good, sound weld is about 30,000 psi.

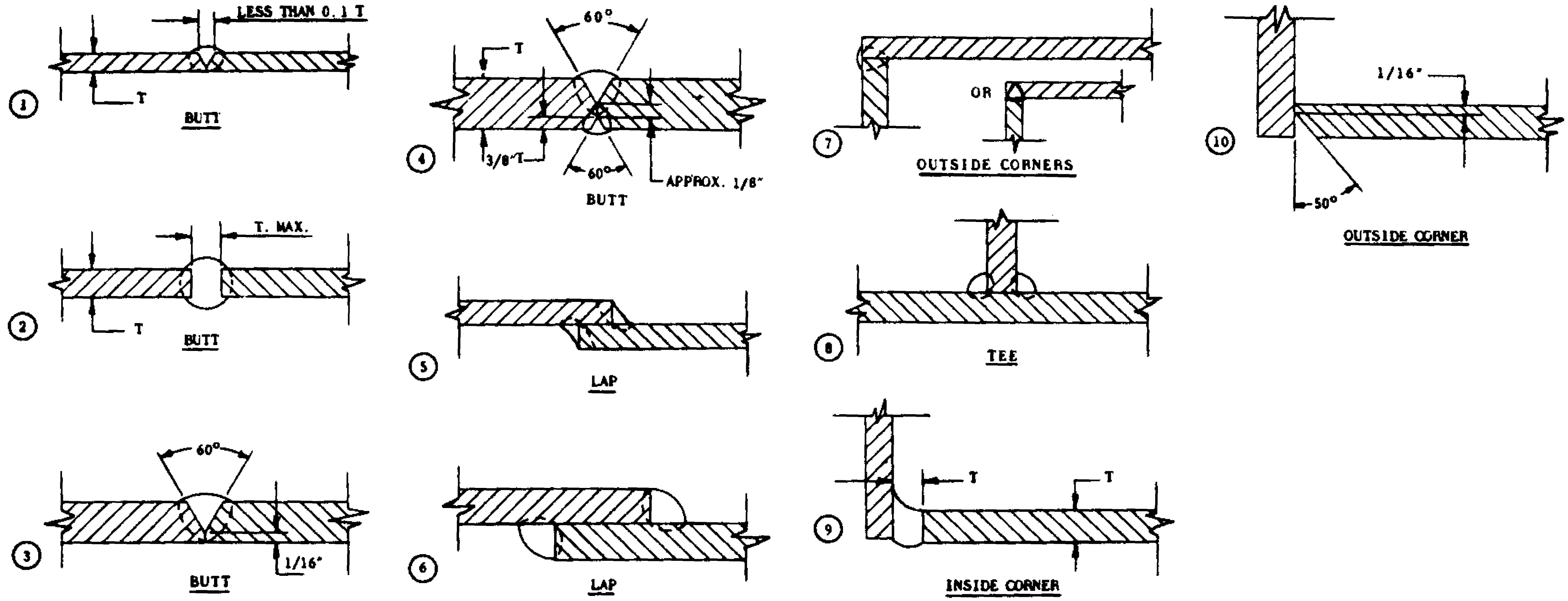
(b) Welding Technique: Workpieces thicker than 1/4-inch should be preheated to approximately 300-500 degrees F. prior to welding. A forehand welding technique will produce the best results. Flux is required for thick sections, and must be applied to both the area being welded and the rod.

(c) Welding Conditions - See Chart on Page 18.

4. COPPER-SILICON ALLOYS ("EVERDUR", "HERCULOY", ETC.)

(a) General: Excellent welds are made in these alloys without requiring flux. Plates up to 1/4-inch thick are generally prepared with a square edge. Forehand welding technique with DCSP is generally recommended for materials thicker than 0.05-in. On lighter material, ACHF should be used for best weld results. Where welding rod is required, OXWELD 26 Silicon-Bronze Rod is recommended.

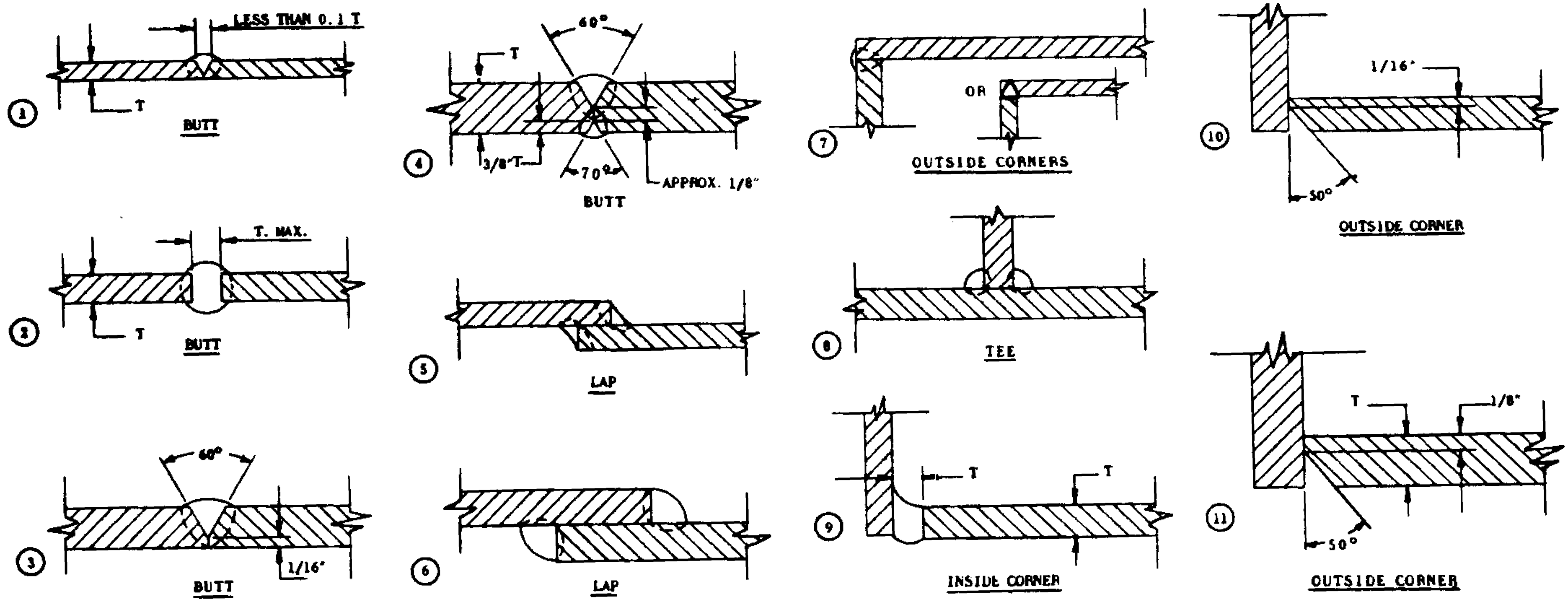
(b) Welding Conditions - See Chart on Page 19.



TIG HAND-WELDING OF DEOXIDIZED COPPER

Thickness In.	Type of Weld	WELDING CURRENT AMPS Type	WELDING CURRENT AMPS Flat	Electrode Diameter In.	Welding Speed I.P.M.	WELDING ROD* Size In.	GAS CUP OR NOZZLE SIZE: Ceramic (Lava) Cup (250 Amp. Max.)	GAS CUP OR NOZZLE SIZE: High Impact (Alumina) Cup (300 Amp. Max.)	GAS CUP OR NOZZLE SIZE: Metal Nozzle (Where available)	GAS FLOW Argon C.F.H.	GAS FLOW Helium C.F.H.	REMARKS
							Consult the torch instruction booklet for the maximum current ratings of the torch and for sizes and part numbers of available cups or nozzles.					
1/16	1,2 Butt	DIRECT CURRENT STRAIGHT POLARITY	110-140	1/16	12	1/16	4,5,6	4,5,6	6	15		One Pass
	5,6 Lap		130-150	1/16	10	1/16	4,5,6	4,5,6	6	15		One Pass
	7 Corner		110-140	1/16	12	1/16	4,5,6	4,5,6	6	15		One Pass
	8 Fillet		130-150	1/16	10	1/16	4,5,6	4,5,6	6	15		One Pass
1/8	1,2 Butt		175-225	3/32	11	3/32 or 1/8	6,7,8	6,7,8	6,8	15		One Pass
	6 Lap		200-250	3/32	9	3/32 or 1/8	6,7,8	6,7,8	6,8	15		One Pass
	7 Corner		175-225	3/32	11	3/32 or 1/8	6,7,8	6,7,8	6,8	15		One Pass
	8,9 Fillet		200-250	3/32	9	3/32 or 1/8	6,7,8	6,7,8	6,8	15		One Pass
3/16	1,2 Butt		190-225	1/8	10	1/8		8,10	8		30	One Pass; Preheat to 200°F.
	6 Lap		205-250	1/8	8	1/8		8,10	8		30	One Pass; Preheat to 200°F.
	7 Corner		190-225	1/8	10	1/8		8,10	8		30	One Pass; Preheat to 200°F.
	8,10 Fillet		205-250	1/8	8	1/8		8,10	8		30	One Pass; Preheat to 200°F.
1/4	3 Butt		225-260	1/8	9	1/8		8,10	8		30	One Pass; Preheat to 300°F.
	6 Lap		250-280	1/8	7	1/8		8,10	8		30	One Pass; Preheat to 300°F.
	7 Corner		225-260	1/8	9	1/8		8,10	8		30	One Pass; Preheat to 300°F.
	8,10 Fillet		250-280	1/8	7	1/8		8,10	8		30	One Pass; Preheat to 300°F.
3/8	3 Butt		280-320	3/16		3/16			8		40	Two Passes; Preheat to 500°F.
	6 Lap		300-340	3/16		3/16			8		40	Three Passes; Preheat to 500°F.
	7 Corner		280-320	3/16		3/16			8		40	Two Passes; Preheat to 500°F.
	8,10 Fillet		300-340	3/16		3/16			8		40	Three Passes; Preheat to 500°F.
1/2	4 Butt		375-525	3/16 , 1/4		1/4			8,10		40	Three Passes; Preheat to 500°F.

*OXWELD 63. (copper)



TIG HAND-WELDING OF SILICON BRONZE

Thickness In.	Type of Weld	WELDING CURRENT Type	AMPERES Flat	AMPERES Vertical	AMPERES Overhead	Electrode Diameter In.	* Welding Speed I.P.M.	WELDING ROD Material No. ⊕	WELDING ROD Size In.	GAS CUP OR NOZZLE SIZE: Ceramic (Lava) Cup (250 Amp. Max.)	High Impact (Alumina) Cup (300 Amp. Max.)	Metal Nozzle (Where available)	Gas Flow Argon C.F.H.	REMARKS
										Consult the torch instruction booklet for the maximum current ratings of the torch and for sizes and part numbers of available cups or nozzles.				
1/16	1,2 Butt	DIRECT CURRENT STRAIGHT POLARITY	100-120	90-110 Up	90-110	1/16	12	Everdur	1/16	4,5,6	4,5,6	6	15	
	5,6 Lap		110-130	100-120 Up	100-120	1/16	10	Everdur	1/16	4,5,6	4,5,6	6	15	
	7 Corner		100-130	90-110 Up	90-110	1/16	12	Everdur	1/16	4,5,6	4,5,6	6	15	
	8,9 Fillet		110-130	100-120 Up	100-120	1/16	10	Everdur	1/16	4,5,6	4,5,6	6	15	
1/8	1,2 Butt		130-150	120-140 Up	120-140	1/16	12	Everdur	3/32	6,7,8	6,7,8	6,8	15	
	5,6 Lap		140-160	130-150 Up	130-150	1/16 ,3/32	10	Everdur	3/32	6,7,8	6,7,8	6,8	15	
	7 Corner		130-150	120-140 Up	120-140	1/16	12	Everdur	3/32	6,7,8	6,7,8	6,8	15	
	8,9 Fillet		140-160	130-150 Up	130-150	1/16 ,3/32	10	Everdur	3/32	6,7,8	6,7,8	6,8	15	
3/16	1,2 Butt		150-200	—	—	3/32	—	Everdur	1/8	6,7,8	6,7,8	6,8	20	
	5,6 Lap		175-225	—	—	3/32	—	Everdur	1/8	6,7,8	6,7,8	6,8	20	
	7 Corner		150-200	—	—	3/32	—	Everdur	1/8	6,7,8	6,7,8	6,8	20	
	8,9 Fillet		175-225	—	—	3/32	—	Everdur	1/8	6,7,8	6,7,8	6,8	20	
1/4	1,2 Butt		150-200	—	—	3/32	—	Everdur	1/8 or 3/16	7,8,10	7,8,10	6,8	20	Three Passes
	3 Butt		250-300	—	—	1/8	—	Everdur	1/8 or 3/16	7,8,10	7,8,10	6,8	20	One Pass — Square Butt
	6 Lap		175-225	—	—	3/32	—	Everdur	1/8 or 3/16	7,8,10	7,8,10	6,8	20	Three Passes
	8,10 Fillet		175-225	—	—	3/32	—	Everdur	1/8 or 3/16	7,8,10	7,8,10	6,8	20	Three Passes
3/8	3 Butt		230-280	—	—	1/8	—	Everdur	1/8 ,3/16		8,10,12	8	20	Three or Four Passes
	6 Lap		250-300	—	—	1/8	—	Everdur	1/8 ,3/16		8,10,12	8	20	Three Passes
	8,10 Fillet		230-280	—	—	1/8	—	Everdur	1/8 ,3/16		8,10,12	8	20	Three Passes
1/2	3 Butt		250-300	—	—	1/8	—	Everdur	1/8 ,3/16		8,10,12	8	20	Four or Five Passes
	6 Lap		275-325	—	—	1/8	—	Everdur	1/8 ,3/16		8,10,12	8	20	Six Passes
	8,10 Fillet		275-325	—	—	1/8	—	Everdur	1/8 ,3/16		8,10,12	8	20	Seven Passes
3/4	3,4 Butt		300-350	—	—	1/8	—	Everdur	3/16			8	20	Nine or Ten Passes
	6 Lap		300-350	—	—	1/8	—	Everdur	3/16			8	20	Twelve Passes
	8,11 Fillet		300-350	—	—	1/8	—	Everdur	3/16			8	20	Fourteen Passes
1	3,4 Butt		300-350	—	—	1/8	—	Everdur	3/16 ,1/4			8	20	Thirteen Passes
	6 Lap		325-350	—	—	1/8	—	Everdur	3/16 ,1/4			8	20	Sixteen Passes
	8,11 Fillet		325-350	—	—	1/8	—	Everdur	3/16 ,1/4			8	20	Twenty Passes

⊕OXWELD No. 26 Welding Rod for "Everdur" alloy.
**For welding in flat position.*

5. ALUMINUM BRONZE

(a) General: No flux is required; ACHF will produce the best weld results; a forehand welding technique, with an aluminum bronze rod should be used. Aluminum bronze rod also provides good wear-resistance surfaces when deposited on steel, cast iron, copper, and other metals.

(b) Welding Conditions

Plate Thick in.	Edge Prep.	Welding Current Amperes ACHF	Argon Flow at recommended 20 psi cfh	Electrode Diameter in.	Number of Passes
1/4	90° V, sharp nose	200	15-20	1/8	2
3/8	60° V, sharp nose	250	15-20	5/32	3
1/2	60° V, sharp nose	260	15-20	5/32	4

6. OTHER COPPER ALLOYS

The table below gives basic recommendations for some of the less commonly welded copper alloys. Welding conditions not specified below will in general approximate those given for deoxidized copper. Specific conditions for particular applications may be obtained from Linde Company on request.

	Type of Welding Current	Flux	Welding Technique	Rod
Red Brass Zinc Bronze Low Zinc Brass Common Brass Muntz Metal	DCSP on thicknesses greater than 0.050-in. ACHF on thinner material.	BRAZO	Forehand	OXWELD 26
Phosphor Bronze	DCSP	None	Forehand	OXWELD 26
Leaded Bronzes	DCSP	None	Forehand	OXWELD 26
Beryllium-Copper	ACHF	None	Forehand	Be-Cu

E. Plain Carbon and Low Alloy Steels

1. WELDABLE MATERIALS

Two general types of plain carbon or low alloy steels are "killed" steel and "rimmed" steel. The former is deoxidized during the refining process; little difficulty is experienced in welding this type. In the making of rimmed steel, however, deoxidation is incomplete. When this type of steel is subsequently melted in the welding operation, gases are given off and can be a major cause of porosity if proper care is not exercised. Proper care can be taken by using OXWELD 65 triple deoxidized wire; or where simple fusion is desired without the addition of wire, LINDE's Deoxidizing Powder, Part No. 379268, should be used.

2. WELDING RODS

For welding all low carbon steel, OXWELD 65 rod is used. For low-alloy steels, use a rod with composition as similar as possible to the base metal. Alloy losses during welding will be negligible.

3. WELDING CONDITIONS

Thickness (in.)	Amperes DCSP	Suggested Rod Size (in.)	Average Welding Speed (in.)	Argon Flow C.F.H.
0.035	100	1/16	12-15	8-10
0.049	100-125	1/16	12-18	8-10
0.060	100-140	1/16	12-18	8-10
0.089	140-170	3/32	12-18	8-10
0.125	150-200	1/8	10-12	8-10

F. TIG Welding of Pipe

The chief advantage of HELIARC welding for the fabrication of piping systems, is that the welds are smooth, fully penetrated, and free from obstructions or crevices on the inside. Also, HELIARC welds are stronger and more resistant to corrosion than welds made by any other process.

The brief instructions contained here are written for the standard vee joint with bevel of 37 degrees on each side, a nose of 1/16 in., and a spacing of 1/16 in. to 3/32 inch. The operator should practice welding in the flat position, or on a rolled joint until the technique has been acquired.

1. ROOT PASS WELDING

After the joint has been properly packed and put in position, the arc is struck on the side and carried down to the bottom of the joint. Rod is then added until the puddle bridges over the joint. Control of penetration is the most important factor in successful pipe welding. Such control can be obtained only by repeated practice. After the puddle bridges the joint, the arc is held on the puddle for a moment. Then the puddle flattens out and becomes wedge shaped, straight across the front, and with rounded corners at the rear. When this takes place, the puddle has fully penetrated the joint.

In general, the same technique is used for welding in the horizontal-fixed position. However, the puddle must be controlled more closely to prevent sag when welding in the overhead position. In the vertical-fixed position, the puddle is formed on the upper side and kept above the center line of the joint. This will prevent under-cutting of the top side of the bead and avoid the tendency for the puddle to sag due to gravity.

2. FILLER PASS WELDING

Weave beads, produced by weaving the torch across the joint, can be used on carbon and low-alloy steel in the rolled or horizontal-fixed position. Stringer beads, laid parallel to the joint, are used for welding stainless steel pipe since there is less tendency toward carbide precipitation. Stringer beads are recommended for welding all carbon and low alloy pipe in the vertical-fixed position. The advantage of using weave beads, in the rolled or horizontal-fixed position, is that it requires less time to complete the welds.

3. FINISH PASS WELDING

Finished welds should be 1/8 in. wider than the joint and evenly spaced on either side. Reinforcement should be about 1/16 in. above the surface of the pipe. The weld edges should be straight, without any undercutting. Weave beads can be used to make the finish pass on carbon or low-alloy steel pipe in the rolled or horizontal-fixed position. Stringer beads are required for stainless steel pipe in all positions, and also for carbon and low-alloy pipes in the vertical-fixed position as well.

For more detailed information on the welding of pipe, see F-1216, "HOW TO DO 'HELIARC' WELDING OF PIPE".

G. Nickel, Monel and Inconel

WELDING CONDITIONS

Metal	Joint Type	Thickness Inches	Argon Flow CFH	Welding Current DCSP	Welding Rod
Nickel	Butt	1/8	25	200	Inco 61
"Monel"	Butt	1/8	25	200	Inco 60
"Inconel"	Butt	1/8	25	200	Inco 62

H. Welding Dissimilar Metals

Materials to be Joined	Type of Current	Rod Type	Remarks
Stainless Steel to Cast Iron	DCSP	OXWELD 26	Direct welding arc on the rod - not on cast iron.
	DCSP	Nickel and Stainless Steel	Step (1) Deposit nickel bead on edge of cast iron. Step (2) Weld nickel bead to stainless steel w/rod.
Stainless to Carbon or Low Alloy Steel		310 Stainless	
Copper to Stainless Steel	DCSP	None Required	
Copper to "Everdur"		OXWELD 26	
Cupro-Nickel to "Everdur"		OXWELD 26	
Nickel to Steel	DCSP	Nickel	
HASTELLOY Alloy C to Steel	DCSP	HASTELLOY W; "Inconel"; Nickel; or 310 Stainless	
Aluminum to Steel	ACHF	No. 25M Bronze Rod; B.T. Silver Brazing Alloy; OXWELD 14 Al. Rod	Step (1) Tin edge of steel w/bronze rod using oxy-acetylene process (2) HELIARC weld silver strip (1/8-in. thick x 1/2-in. wide) to tinned edge w/B.T. alloy (3) HELIARC weld Al. sheet to silver strip w/No. 14 rod.
Stainless Steel to "Inconel"	DCSP	310 Stainless	
Tungsten to Molybdenum		Platinum	
Copper and "Everdur" to Steel	DCSP	Copper or 26 "Everdur"	

I. Hard-Facing and Surfacing

Base Metal	Surfacing Material	CURRENT Type	CURRENT Amps.	ROD Type	Welding Technique	Argon Flow CFH	DEPOSIT Rc Hardness	REMARKS
Mild & Stainless Steels	HAYNES STELLITE Alloys	ACHF*		STELLITE #1	Backhand	25	54	
		ACHF*		STELLITE #6	Backhand	25	39	
		ACHF*		STELLITE #12	Backhand	25	47	
		ACHF*		STELLITE #93	Backhand	25	62	
		ACHF*		HASCROME	Backhand	25	23-43	Extruded rod has better weld characteristics than rolled rod.
Copper	STELLITE #6 Alloy	DCSP	180-230 for 3/16-in. material	STELLITE #6	Forehand	15	42	Arc directed mainly at welding rod.
Steel, Copper & Silicon Bronze	Aluminum Bronze	DCSP		Aluminum-Bronze Rods	Forehand	10	150-300	
Mild Steel & Cast Iron	Bronze & Copper	ACHF or DCSP	150 for 1/2-in. material	Al-Bronze & Copper Rods	Forehand	10		
Stainless Steel	Silver	ACHF	160 for 1/2-in. material		Either	10		Plates pickled prior to surfacing.
Mild Steel	Stainless Steel	ACHF or DCSP			Forehand	10		
Mild Steel	Lead	DCSP	75		Forehand	10		Steel ground or pickled then coated with liquid soldering flux prior to surfacing.
Carbon & Alloy Tool Steels	Tungsten Carbide	DCSP	300-375	Tube of 8/15 mesh Tungsten Particles		30		

*ACHF *develops maximum hardness values; DCSP will permit higher welding speeds.*

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LINDE DIVISION

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