

AWS D19.0-72

Welding
Zinc-Coated
Steel



American Welding Society

AWS D19.0-72

Welding Zinc-Coated Steel

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Published by **AMERICAN WELDING SOCIETY, Inc.**
550 N.W. LeJeune Rd., Miami, FL 33126

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First Edition – 1972

Reprint No. 1, August 1983
Library of Congress No. 72-91061
ISBN No. 0-87171-102-8

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

The excellent long-term protection of steel by galvanizing or metallizing, together with the attendant low maintenance cost, have led to the widespread application of zinc coatings to large structures such as highway bridges, power and television transmission towers, etc.

The use of zinc-rich paints in the form of welding primers for the temporary protection of shotblasted steel during fabrication and prior to the application of the final paint coating is also increasing each year, typical applications being ship hulls and plating and all forms of structural steelwork.

To exploit the exceptional advantages of zinc coatings, both for permanent and temporary protection, it is essential to be able to weld zinc-coated steel and to produce joints having qualities equal to those of joints in uncoated steel.

With this objective in mind, the International Lead Zinc Research Organization, Inc. (ILZRO) sponsored a four-year program of work on the arc and gas welding of zinc-coated steels at The Welding Institute, Cambridge, England. The work identified the problems that can occur when welding zinc-coated steel; solutions to these problems have been found. The manual is based on the results of this work and also includes data from other published work.

The American Welding Society is grateful to ILZRO for providing most of the material used in this manual. The original report has been edited to reflect U.S. terminology in accordance with AWS standards. Some additional text material has been added in several sections for more complete coverage of the subject.

It should be noted that this manual deals primarily with gas and arc welding processes used commercially for joining zinc-coated steels. Reference should be made to AWS C1.3-70, Recommended Practices for Resistance Welding Coated Low Carbon Steels, for information on resistance — spot, resistance — seam and projection welding of zinc-coated (galvanized only) steels.

ACKNOWLEDGMENTS

The basic report made to ILZRO by the Welding Institute, Abington Hall, Cambridge, England, was prepared by E. N. Gregory. The report also acknowledged the financial support of ILZRO on the project, as well as advice, assistance and cooperation from the following firms and organizations:

Canada

Steel Company of Canada

England

B. O. C. — Murex, Ltd.

Crittall-Hope, Ltd.

Imperial Smelting Corp.

I. C. I. Paints, Ltd.

Metallisation, Ltd.

Research Association of British Paint,

Colour & Varnish Manufacturers

B. & E. Wedge, Ltd.

British Steel Corporation

Holland

Philips Bedryfsappatur, Nederland, N.V.

United States

Hobart Bros., Inc.

United States Steel Corporation

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Section 1 — Zinc Coatings

Methods of Application to Steel

There are five methods of applying a coating of zinc to steel to increase its corrosion resistance: 1) hot-dip galvanizing, 2) metallizing, 3) painting with zinc-rich paints, 4) zinc plating (electrogalvanizing) and 5) sherardizing. The first three methods, which may be applied to steel that is to be subsequently fabricated by fusion welding, are described more fully below.

Hot-dip Galvanizing

Steel in the form of strip, plate, girders, beams, piping or fabricated articles is cleaned by means of an acid pickle or by shotblasting and then dipped in molten zinc. A reaction takes place between the zinc and steel surface to produce a chemically bonded (alloyed) coating. Steel strip up to 1/8 in. (3.2 mm) thick can be continuously galvanized by running large coils through a zinc bath, which produces coating thicknesses of approximately 10-50 microns (coating weights 0.5-2.5 oz/ft² or 153-763 g/m² including both sides). Individually dipped articles have coatings of 85-200 microns thick (coating weights 2.5 oz/ft² or 610-1246 g/m² each side). Galvanizing is used to impart a corrosion-resistant coating to steel for a very wide range of products including building frames, girders and beams used in road and railway bridges, electricity pylons, television transmitting towers, automobile and truck chassis, railway rolling stock, piers, deck equipment of ships, street lighting poles, etc.

The size of a component that can be galvanized is limited by the capacity of the galvanizing bath; for example, steel beams up to 80 ft (25 m) long could be hot-dip galvanized by dipping one end at a time in a 45 ft (17 m) bath.

Metallizing

Zinc in the form of powder or wire is fed into the flame of a metallizing gun where the zinc is atomized and the finely divided droplets of molten zinc are projected towards the shotblasted workpiece by means of a jet of compressed air. A recently developed electric arc metallizing process uses two coils of wire which are consumed by an electric arc maintained between the ends of the wires. Again, the molten zinc is directed onto the workpiece by means of compressed air.

The zinc coating thickness is generally at least 0.004 in. (0.1 mm or 100 microns). Metallizing is used to protect a large variety of components and can be applied in situ to protect structures such as bridges without any limitation on size.

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Painting with Zinc-rich Paints

Zinc-rich or zinc-dust paints have been developed which have similar properties to a zinc coating applied by galvanizing or metallizing in that the underlying steel is to a certain extent protected sacrificially, provided that sufficient zinc is present in the paint film.

Zinc-rich paints are widely used in the form of zinc primers or welding primers for the temporary protection (up to 12 months) of shotblasted steel during the period of fabrication by welding, before the final paint coating system is applied. For welding primers, 92-95 weight percent of zinc is used in a variety of binding agents such as sodium silicate, sodium ethyl silicate, epoxy resin or chlorinated rubber. Film thicknesses vary from 0.0005-0.003 in. (12-75 microns) depending on the type of paint and method of application. The most widespread use is for ship hulls and plating, and for all forms of structural steel work. Most shipyards have for some time incorporated an automatic shotblasting and painting plant, and a more recent trend is for steelmakers to supply primed plate direct from the steel works.

Section 2 — Gas Welding

Gas welding uses the heat of combustion of a fuel gas with oxygen, the most commonly used fuel gas being acetylene which gives a flame temperature above 5030 F (3000 C). The oxyacetylene flame may be used for fusion welding (oxyacetylene welding) (OW) of steel in which the edges of the joints are melted and a steel filler rod is melted into the joint, or it may be used for braze welding in which the melting point of the filler rod is below that of the base metal but above 800 F (427 C) and in which the edges of the joint are not intentionally melted.

Fusion Welding

Galvanized steel may be oxyacetylene fusion welded with copper-coated mild steel filler rod (e.g., AWS specification A5.2-69; RG45, RG60, RG65; B.S. Specification 1453:1972; A1, A2). Preparation for welding is similar to that for welding uncoated steel, i.e., the use of jigs and clamps to prevent distortion caused by heat buildup, and removal of any grease or dirt from the weld area. A neutral flame should be used with no excess of either oxygen or acetylene and the size of the nozzle should be the same as that used for welding uncoated steel of similar thickness.

Because of the low travel speed of oxyacetylene welding, necessary to bring the joint edges to the fusion temperature, the zinc coating is volatilized and completely removed for at least $\frac{1}{4}$ in. on each side of the weld. For a further $\frac{1}{4}$ in. or so on each side, partial volatilization occurs resulting in a reduction in corrosion resistance; beyond this region, for up to $\frac{3}{4}$ in., a change in the appearance of the zinc coating due to heat effects has been reported^{1*} but without any deterioration in corrosion resistance. In order to minimize the area over which the galvanizing is removed and to reduce the amount of repair required after welding, the torch should not be moved from side to side. The leftward or forehand method of welding, Fig. 2.1, should be used in which the torch flame points in the direction of welding and the welding rod precedes the torch flame. Compared with the rightward or backhand method, in which the torch flame points back at the completed weld with the welding rod interposed between the flame and the completed weld, more zinc will be burnt off in front of the weld pool and will cause less interference with welding. Welds should not be remelted by the flame in order to improve their appearance because this practice, sometimes used when welding uncoated steel, will result in additional loss of galvanizing.

Repair procedures are described in Section 11.

* See references at end of manual.

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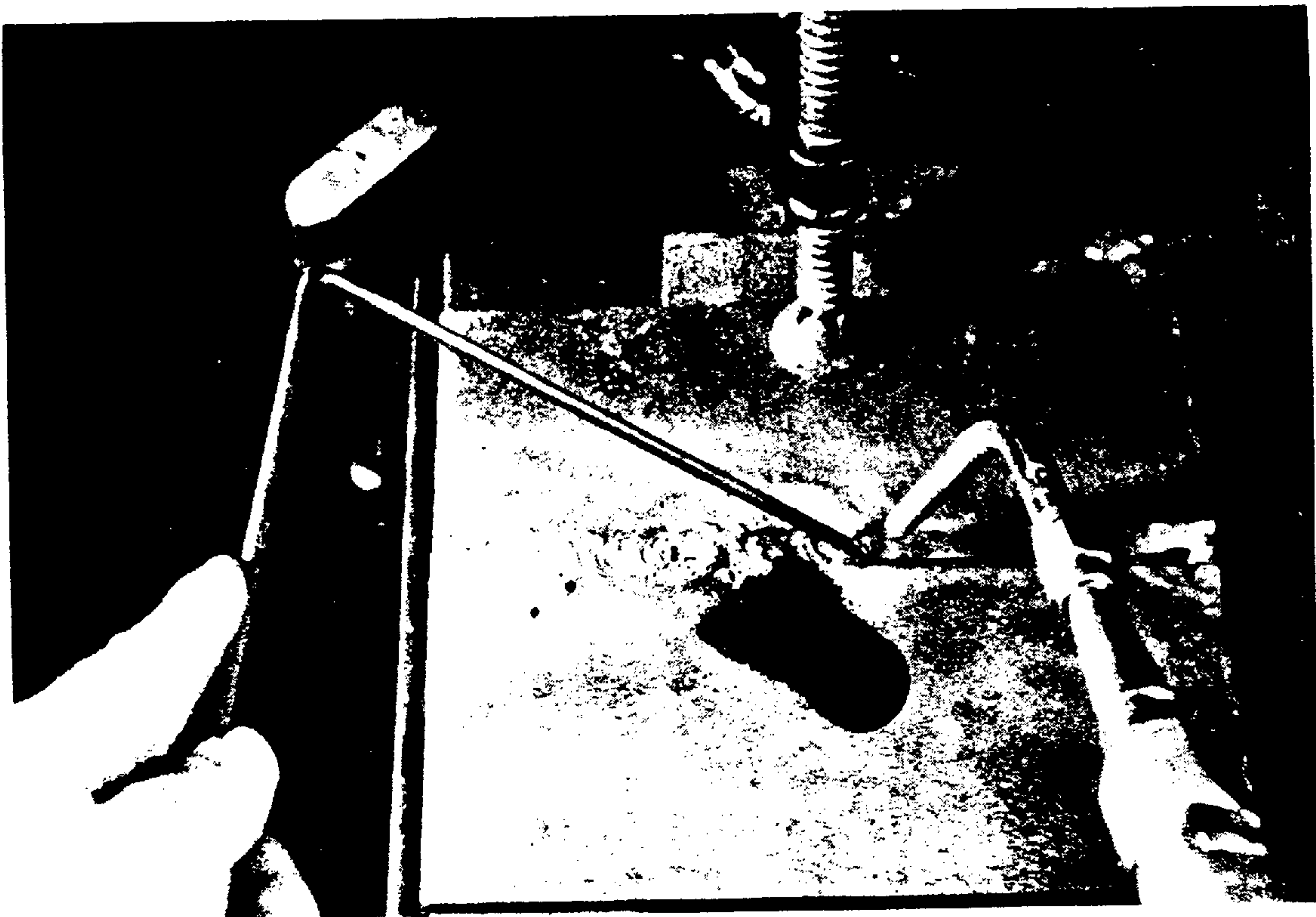


Fig. 2.1 – Leftward or forehand welding.

Braze Welding

Braze welding is accompanied by a lower heat input than fusion welding and the base metal is not melted so that there is negligible loss of the zinc coating from the steel. A 60% copper-40% zinc filler rod is generally used which melts between 1650 and 1700 F (900 and 930 C) and which flows over the edges of the joint and alloys with or tins the steel to provide a strong corrosion-resistant joint. A typical welding technique for braze welding is as follows:

1. Remove grease or dirt from the regions of the joint by means of degreasing agents, wire brushing or steelwool.
2. Prepare sheet edges for butt joints as shown in Table 2.1. Lap or tee joints can also be used (Table 2.2).
3. Use jigs or clamps to hold the work and prevent distortion during welding. Parts that are shown by experience not to suffer from distortion can be held together by tack welding before the joint is welded.
4. Mix braze-welding flux to a stiff paste with water and apply generously to upper and reverse sides of the seam and also to the filler rod.
5. Use torch nozzle size two times smaller than for fusion welding sheet of the same thickness.

6. Use 60 Cu-40 Zn alloy filler rod, e.g., AWS Specification A5.7-69, RB CuZn-A*, or B.S. Specification 1453:1957:C2.[†] The diameter of the filler rod should be 1 ½ times the sheet thickness for material up to 3/16 in. (4.8 mm). For material over 3/16 in. thick, use a ¼ in. (6.4 mm) diam rod.
7. Adjust the flame to a slightly oxidizing condition – more so than for welding uncoated steel.
8. When the joint area reaches a dull red heat, deposit the filler metal; direct the flame more on to the rod than the workpiece.
9. Use leftwards or forehand technique and avoid any lateral or weaving motion of the torch so as to reduce the buildup of heat.

* Composition: Cu 57-61%; Sn 0.25-1.00%; Al 0.01% max; Pb 0.05% max; total other elements 0.50% max; Zn remainder.

† Composition: Cu 57-63%; Si 0.2-0.5%; Sn 0.5% max; Al 0.03% max; Zn remainder.

TABLE 2.1 – Edge preparation for braze welding butt joints in galvanized sheet.

Joint Design	Sheet thickness (t)		Edge preparation	Root opening	Root face
	(in.)	(mm)			
	1/8 max	3.2 max	Square	$\frac{t}{2}$	-
	Over 1/8 and up to 1/4	Over 3.2 and up to 6.4	70-90° groove angle	$\frac{t}{4}$	(a)

Note (a) Root face is not generally specified but sharp corners should be rounded off which will result in a root face of 1/16 in. (1.6 mm).

TABLE 2.2 – Examples of lap and tee joints for braze welding galvanized steel. (a)

Joint Design	Type of joint	Type of weld
	Lap	Single fillet
	Lap	Double fillet
	Tee	Single fillet
	Tee	Double fillet

Note (a) There is no thickness limit and dissimilar thicknesses can be joined.

Section 3 — Gas Tungsten-Arc Welding

Fusion Welding

In the gas tungsten-arc welding (GTAW)* process, an arc is maintained between a tungsten electrode and the workpiece, and the arc zone is shielded from the atmosphere generally by means of argon or helium or mixtures of these two gases. Argon generally produces an arc which operates more smoothly and quietly and is less penetrating than helium. The lower arc voltage characteristic of argon facilitates the welding of thin materials because the risk of burn-thru is lessened, and when welding galvanized steel, the low penetration obtained with argon reduces the amount of zinc volatilized. When GTA welding is applied to galvanized steel, the end of the electrode may rapidly become contaminated by zinc and lose its point, resulting in erratic arc action. Blocking of the torch nozzle by particles of spatter can adversely affect the flow of shielding gas.

Electrode contamination can be minimized by holding the torch at an angle of 70 deg to the plate surface instead of the conventional 80 deg and increasing the gas flow rate from the conventional 15 cfh (7 l/min) to 25 cfh (12 l/min). This has the effect of flushing the zinc vapor from the arc area. Minimum currents just sufficient to obtain penetration restrict the amount of volatilized zinc and can give neat butt welds. Corner welds in which the sheet edges are sheared and therefore free from zinc should be relatively easy to make, but tee joints would be more likely to give trouble because of the zinc at the faying surface. Suitable conditions for making butt joints in 1/16 in. (1.6 mm) sheet are given in Table 3.1.

If the base metal is rimming-quality steel, the same precautions must be taken as with uncoated rimming steel, i.e., a deoxidized filler wire must be used to prevent the formation of porosity. The following technique factors may be considered:

1. Use lowest current consistent with adequate penetration.
2. Increase gas flow.
3. Decrease torch angle to 70 deg.
4. Use long arc, 3/16 in. (4.8 mm).
5. Use deoxidized filler on rimming steel.
6. Use uncoated, i.e., sheared edges.
7. Use sheet with low zinc coating weight.

* GTAW is also called TIG welding.

TABLE 3.1 — Conditions for GTAW butt joints in 1/16 in. continuously-galvanized sheet.(a)

Edge preparation	Condition of edges	Root opening		Current (A)	Torch angle (deg)	Argon flow rate	
		(in.)	(mm)			(cfh)	(l/min)
Square	Uncoated (sheared)	1/32	1	60	70	25	12

Note (a) Zinc coating weight 1 1/4 oz/ft² (381 g/m²) including both sides. 1/8 in. (3.2 mm) thoriated tungsten electrode; direct current straight polarity. 3/64 in. (1.2 mm) diam Si-Mn deoxidized filler rod. Copper backing bar, 3/16 x 0.025 in. (4.8 x 0.64 mm) groove.

Braze Welding

The GTAW process can be used to produce braze-welded joints in which the amount of base metal melted is minimized by either pushing a filler rod into the joint or laying the wire flat in the joint and maintaining the arc between the tungsten electrode and the filler rod. GTA braze welds can be carried out with either alternating current (ac) or direct current-straight polarity (dcsp) and suitable filler rods, e.g., silicon bronze (AWS A5.7-69, RCuSi-A).

Suitable conditions for braze welding butt and lap joints in 3/64 in. (1.2 mm) galvanized sheet with silicon-bronze or tin-bronze filler rod are given in Tables 3.2 and 3.3.²

TABLE 3.2 — GTA braze welding conditions for 3/64 in. galvanized sheet. (a)

Type of joint	Type of current	Diameter of tungsten electrode		Diameter of filler rod		Argon flow rate		Current (A)
		(in.)	(mm)	(in.)	(mm)	(cfh)	(l/min)	
Butt	ac	5/64	2	1/16	1.6	17	8	45
1/32 in. (1 mm) root opening	dc	1/16	1.6	1/16	1.6	17	8	35
Lap	ac	5/64	2	1/16	1.6	17	8	45
	dc	1/16	1.6	1/16	1.6	17	8	35

Note (a) Filler rod: Copper, 2.5 % tin.

8 | *Welding Zinc-Coated Steel***TABLE 3.3 – GTA braze welding conditions for 3/64 in. galvanized sheet. (a)**

Type of joint	Type of current	Diameter of tungsten electrode		Diameter of filler rod		Argon flow rate		Current (A)
		(in.)	(mm)	(in.)	(mm)	(cfh)	(l/min)	
Butt	ac	5/64	2	3/32	2.5	17	8	48
1/32 in. (1 mm) root opening	dc	5/64	2	3/32	2.5	17	8	33
Lap	ac	5/64	2	3/32	2.5	17	8	45
	dc	5/64	2	3/32	2.5	17	8	45

Note (a) Filler rod: Copper, 2.5 % tin

Section 4 — Carbon-Arc Welding

Carbon-arc welding (CAW) utilizes the heat from an arc between a carbon electrode and the workpiece or from an arc maintained between two carbon electrodes. This process is largely obsolete, having been superseded by more modern welding methods. A few small workshops still carry out carbon-arc welding and carbon-arc torches are available on the market, so that it is worth noting that galvanized sheet can be joined by means of this process.

A braze welding technique should be used with the filler rod held in contact with the joint, either at an angle of 10 deg to the horizontal or placed flat in the joint. As with GTA braze welding, the arc should be directed and maintained on the filler rod and not in contact with the galvanized sheet. Low currents should be used, approximately 25% greater than for the same gauge in uncoated steel, and weaving should be avoided to restrict the volatilization of zinc. A nonferrous filler rod of silicon-bronze, phosphor-bronze, aluminum-bronze or copper-silicon-manganese alloys should be used, and the filler rod and joint faces should be coated with flux similar to that used for oxyacetylene braze welding.

Carbon-arc braze welds are porous and the joint strength varies between 50 and 90% of that of the steel base metal.

Section 5 — Gas Metal-Arc Welding

General

Gas metal-arc welding (GMAW)* is a well-established semiautomatic process (Fig. 5.1) in which a consumable wire electrode is fed from a reel to a welding gun. Fairly small diameter electrodes are used (0.020-0.062 in.; 0.5-1.6 mm diam) with currents generally between 80 and 350 amperes (A). The high current density on the small diameter wire gives a high degree of self-adjustment to the arc so that the arc length remains approximately constant even when the welder increases or decreases the distance between the welding gun and the workpiece. The power source is designed to supply additional welding current when the arc length is shortened so that the electrode melts off at a higher rate and the original arc length is rapidly re-established. Conversely, when the arc is lengthened, less current is supplied and the electrode is consumed at a lower rate. A shielding gas, such as argon (Ar), helium (He), carbon dioxide (CO₂) or mixtures of these, flows through the nozzle of the welding gun and protects the molten weld metal from the air and thus prevents the formation of brittle nitrides and oxides or porosity.

Two different types of metal transfer are used in GMAW: spray transfer and short-circuiting arc transfer. Spray transfer, in which droplets of metal are detached from the electrode and cross the arc in "free flight", is the high current-high voltage form of the process which is used in the flat position on plate thick enough to prevent burn-thru. Spray transfer can also be accomplished using pulsed current GMAW, wherein a high current pulse is superimposed on a lower background current; a droplet is transferred with

* GMAW is also called MIG welding.

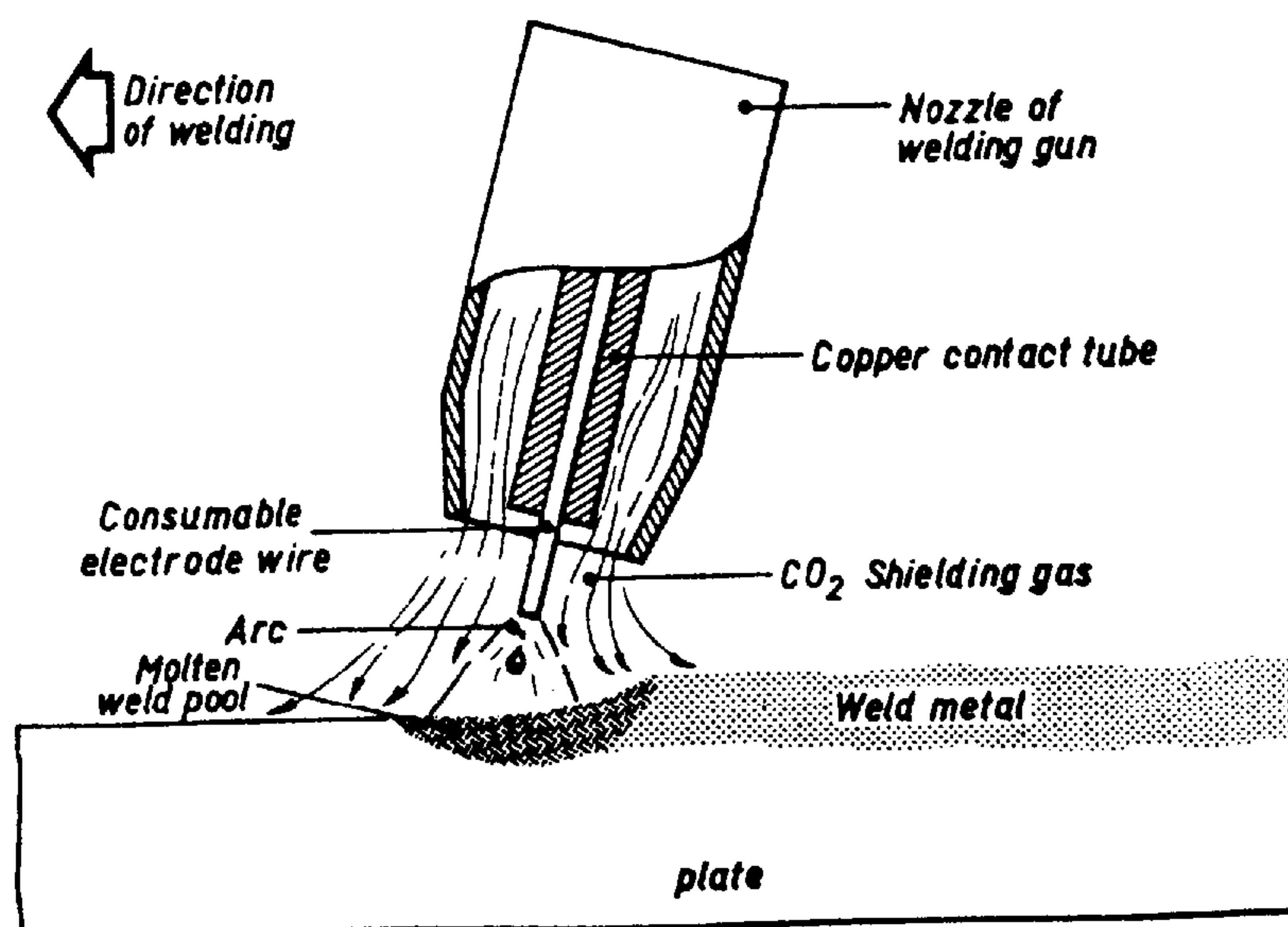


Fig. 5.1 — Diagrammatic illustration of CO₂ welding.

each current pulse. Pulse frequencies range from 60 to 120 Hz, and the process permits all-position welding of all thicknesses.

In short-circuiting arc transfer, lower currents and voltages are used and the end of the electrode dips into the molten weld pool while a globule of metal is being transferred. Short-circuiting occurs about 100 times per second and the process is used for welding thin sheet and for positional welding of all thicknesses.

Galvanized Steel

Welding Conditions for Galvanized Sheet up to 1/8 in. Thick

The least expensive and most common shielding gas for welding steel is carbon dioxide, and suitable conditions for CO₂ welding galvanized steel with a short-circuiting arc are given in Tables 5.1 to 5.6, inclusive. A diagram of the different types of joints and welding positions is shown in Fig. 5.2.

For welding uncoated mild steel, there are certain advantages in a shielding gas consisting of 80% Ar-20% CO₂, with respect to superior appearance, weld bead shape and reduced spatter compared with welding in a CO₂ gas shield. These advantages do not appear to apply to galvanized steel, but a welding shop which normally uses the Ar-CO₂ gas mixture can also use it for zinc-coated steels; suitable welding conditions are given in Tables 5.7 and 5.8.

Welding Techniques

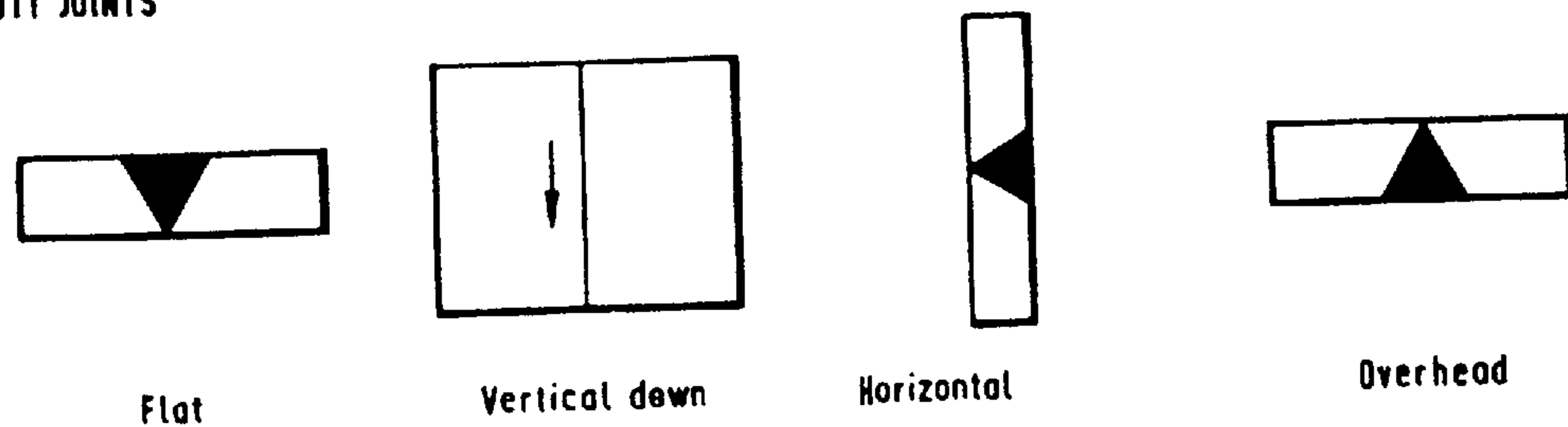
When welding galvanized sheet steel, the manipulation of the welding gun in most cases is similar to that used when welding uncoated steel. Penetration is reduced slightly when welding galvanized steel compared with that obtained on uncoated steel. This means that wider gaps are required in square edge butt welds in sheet up to 1/8 in. (3.2 mm) thick. In the case of flat butt welds in 1/8 in. galvanized sheet, the slightly wider gap makes the control of penetration difficult and it is necessary to move the welding gun with a slight side-to-side weaving motion to prevent burn-thru or excessive penetration. Table 5.1 shows that butt welds in 1/16 in. (1.6 mm) galvanized steel with either 1 ¼ or 2 ½ oz coatings can generally be made with the same welding conditions. An exception to this is overhead butt welds on sheet with a 2 ½ oz coating where it is generally necessary to increase the current by 10 A and the voltage by 1 V to achieve complete penetration.

In the case of fillet welds, sheet having the thicker coating may be welded more readily if the current is increased by 10 A because the increased heat input helps to burn away the extra zinc at the front of the weld pool.

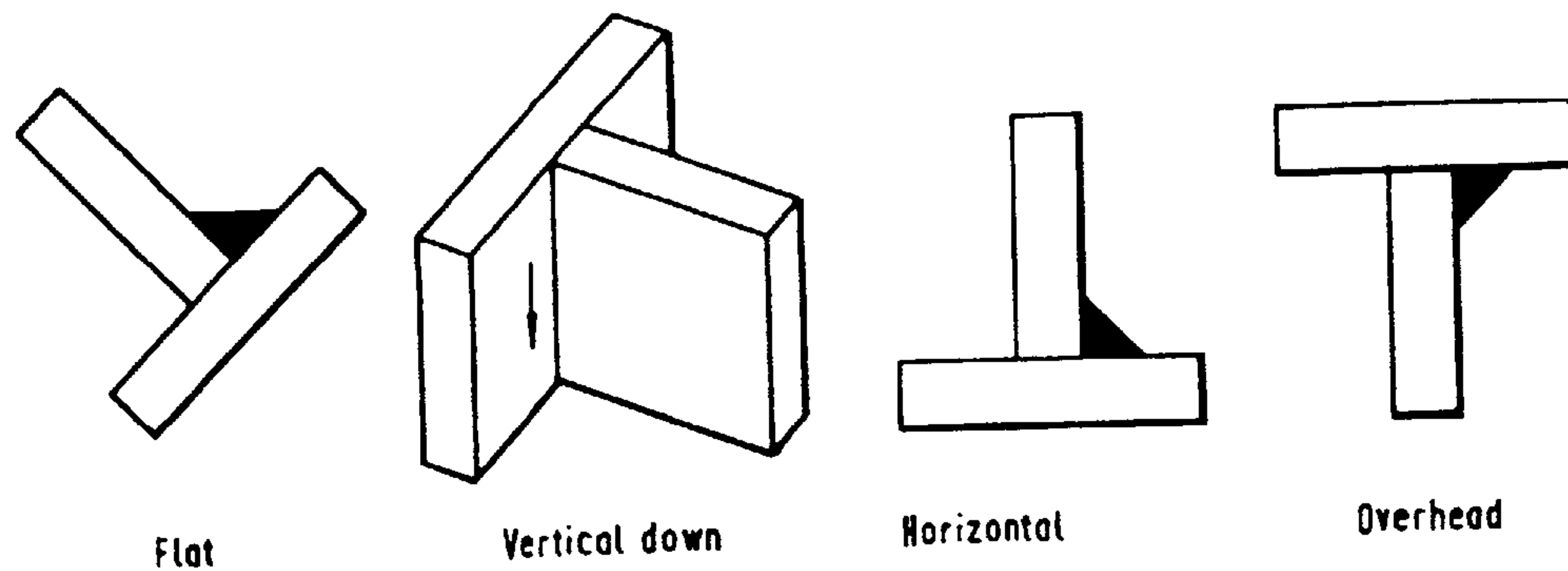
When welding galvanized steel sheet, lower welding speeds are necessary to allow the zinc to burn off at the front of the weld pool, and the reduction in welding speed appears to be related to the thickness of the zinc coating, the

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BUTT JOINTS



T JOINTS



LAP JOINTS

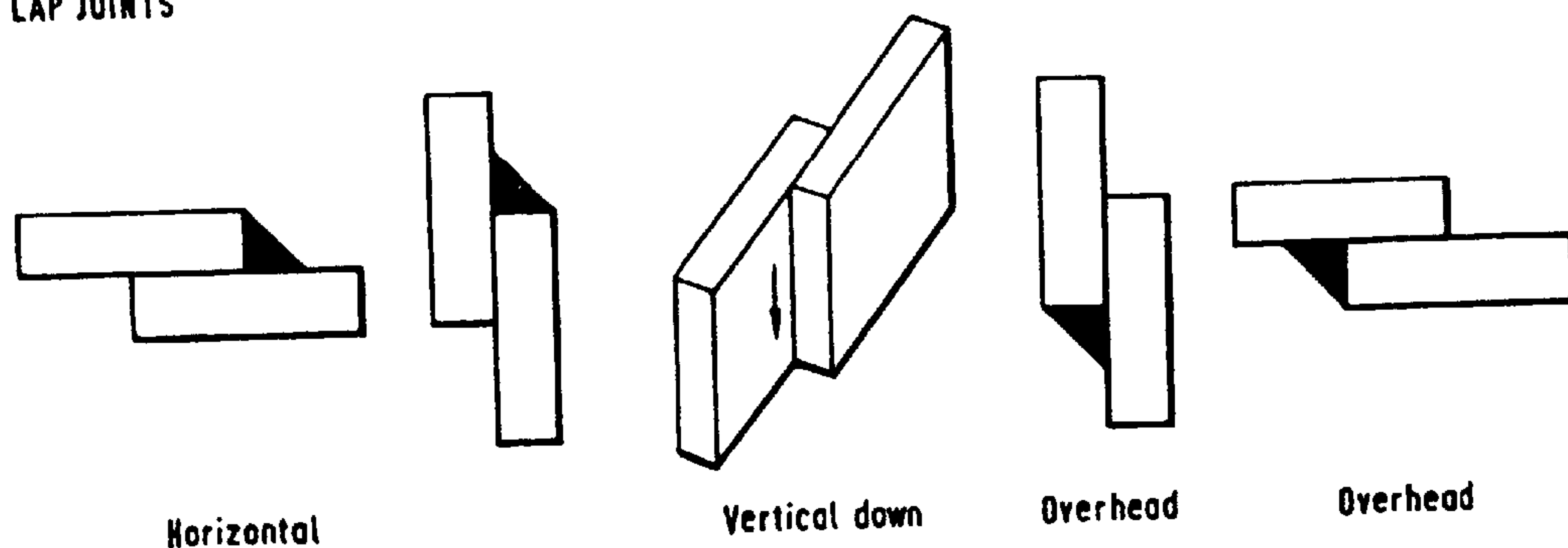


Fig. 5.2 – Chart showing joint types and welding positions.

joint type and the welding position. For example, welding speeds are lower on batch-galvanized than on continuously-coated sheet and lower on tee joints than butt joints. Tee joints have extra zinc at the faying surface, and a lower travel speed is required to allow at least some of the extra zinc to burn away. Welds made vertically downwards require 25-50% reduction in speed depending on the coating thickness and joint type. This reduction in speed is necessary because zinc vapors tend to rise into the arc zone and interfere with arc stability.

Butt welds made in the overhead and horizontal positions suffer very little reduction in speed because zinc vapors tend to rise away from the arc zone. With both horizontal and flat fillet welds, welding is easier if a 1/16 in. (1.6 mm) gap is maintained between the sheets. If a weld is subsequently deposited

TABLE 5.1 — Typical conditions for CO₂ welding butt and tee joints in 1/16 in. continuously-galvanized sheet. (a)

Zinc coating weight (oz/ft ²)	Type of joint	Welding position	Welding conditions			Travel speed				
			Current (A)	Voltage (V)	Wire feed speed (in./min)(cm/min)	Travel speed (in./min)(cm/min)	on uncoated steel (in./min)(cm/min)			
1½ or 2½	Butt, unbacked	Flat	70 90	20 17	140 192	356 488	12 17	30.5 43.2	- 19	- 48.3
1½ or 2½	Butt, copper backing bar	Flat	85 95	20 21	170 200	432 508	12 14	30.5 35.6	- -	- -
1½ or 2½	Butt, unbacked	Vertical down	90	17	194	493	14	35.6	19	48.3
1½ or 2½	Butt, unbacked	Flat	80	18	90	229	-	-	-	-
1½ or 2½	Butt, unbacked	Vertical down	100	18	117	297	-	-	-	-
1½ or 2½	Butt, unbacked	Horizontal	100	18	117	297	20	50.8	19	48.3
1½ 2½	Butt, unbacked	Overhead	100 110	18 19	117 132	297 335	- -	- -	- -	- -
1½ 2½	Tee, fillet welds	Flat	100 110	18 18	117 132	297 335	- -	- -	- -	- -
1½ 2½	Tee, fillet welds	Vertical down	110 120	19 19	132 156	335 396	- -	- -	- -	- -
1½ 2½	Tee, fillet welds	Overhead	110 110	19 20	132 132	335 335	14 -	35.6 -	16 -	40.6 -
1½ 2½	Tee, fillet welds	Horizontal	100 110	18 20	117 132	297 335	- -	- -	- -	- -
2½	Tee, fillet welds	Horizontal	120	20	140	356	12	30.5	17	43.2

Note (a) Zinc coating weight (including both sides) 1 1/4 or 2 1/2 oz/ft² (381 or 762 g/m²). Electrode stickout 1/4-3/8 in. (6.4-9.5 mm). Si-Mn deoxidized wire 0.035 in. (1 mm) diam. Gas flow rate 40 cfh (19 l/min). Root opening nil.

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TABLE 5.2 — Typical conditions for CO₂ welding lap joints in 1/16 in. continuously-galvanized sheet. (a)

Zinc coating weight (oz/ft ²) — (g/m ²)	Welding position	Welding conditions				Travel speed	
		Current (A)	Voltage (V)	Wire feed speed (in./min)(cm/min)	Travel speed (in./min)(cm/min)	on uncoated steel	(in./min)(cm/min)
1½ or 2½ 381 or 762	Horizontal (plates horizontal)	100	18	117	297	16	41 18 46
1½ or 2½ 381 or 762	Horizontal (plates vertical)	100	18	117	297	12	30 19 48
1½ 381	Vertical down	100	18	117	297	16	41 22 56
2½ 762	Vertical down	100	18	117	297	13	33 22 56
1½ 381	Overhead (plates vertical)	100	18	117	297	12	30 15 38
2½ 762	Overhead (plates vertical)	100	18	117	297	10	26 15 38
1½ or 2½ 381 or 762	Overhead (plates horizontal)	100	18	117	297	10	26 15 38

Note (a) Electrode stickout 1/4 - 3/8 in. (6.4 - 9.5 mm). Si-Mn deoxidized wire 0.045 in. (1 mm) diam.
Gas flow rate 40 cfh (19 l/min).

TABLE 5.3 — Typical conditions for CO₂ welding 1/8 in. continuously-galvanized sheet. (a)

Type of joint	Root opening (in.) (mm)	Welding position	Wire diam (in.) (mm)	Welding conditions				Travel speed on uncoated steel (in./min)(cm/min)			
				Current (A)	Voltage (V)	Wire feed speed (in./min)(cm/min)	Travel speed (in./min)(cm/min)				
Butt, unbacked	1/16 1.6	Flat	0.045 1.2	130	20	130	330	12	30	15	38
Butt, copper backing bar (b)	1/16 1.6	Flat	0.045 1.2	130	20	130	330	12	30	15	38
Butt, unbacked	1/16 1.6	Vertical down	0.045 1.2	130	20	130	330	14	36	18	46
Butt, unbacked	1/32-1/16 0.8-1.6	Flat	0.035 1	135	20	168	427	13	33	18	46
Butt, unbacked	1/32-3/32 0.8-2.5	Vertical down	0.035 1	135	20	168	427	18	46	20	51
Butt, unbacked	1/32-1/16 0.8-1.6	Horizontal	0.035 1	135	20	168	427	16	41	16	41
Butt, unbacked	1/32 0.8	Overhead	0.035 1	135	20	168	427	13	33	15	38
Tee, fillet welds	- -	Flat	0.035 1	135	20	168	427	11	28	12	30
Tee, fillet welds	- -	Horizontal	0.035 1	135	20	168	427	12	30	14	36
Tee, fillet welds	- -	Overhead	0.035 1	135	20	168	427	10	25	12	30
Tee, fillet welds	- -	Vertical down	0.035 1	135	20	168	427	14	36	14	36

Note (a) Zinc coating weight (including both sides) 1 1/4 oz/ft² (381 g/m²) Electrode stickout 1/4 - 3/8 in. (6.4 - 9.5 mm). Si-Mn deoxidized wire. Gas flow rate 40 cfh (19 l/min).

(b) 3/16 in. x 0.050 in. (4.8 mm x 1.3 mm) groove in backing bar.

TABLE 5.4 — Typical conditions for CO₂ welding lap joints in 1/8 in. continuously-galvanized sheet. (a)

Welding position	Welding conditions				Travel speed on uncoated steel (in./min)(cm/min)
	Current (A)	Voltage (V)	Wire feed speed (in./min)(cm/min)	Travel speed (in./min)(cm/min)	
Horizontal (plates horizontal)	130	19	160 406	10 26	14 36
Horizontal (plates vertical)	130	19	160 406	9 23	15 38
Vertical down	130	19	160 406	12 30	15 38
Overhead (plates vertical)	120	19	140 356	9 23	14 36
Overhead (plates horizontal)	120	19	140 356	8 20	14 36

Note (a) Zinc coating weight (including both sides) 1 1/4 oz/ft² (381 g/m²). Electrode stickout 1/4-3/8 in. (6.1 - 9.5 mm). Si-Mn deoxidized wire 0.035 in. (1 mm) diam. Gas flow rate 40 cfh (19 l/min).

TABLE 5.5 — Conditions for CO₂ welding of 1/8 in. batch-galvanized sheet. (a)

Type of joint	Root opening (in.)	Root opening (mm)	Welding position	Wire diam (in.)	Wire diam (mm)	Welding conditions					Travel speed on uncoated steel (in./min)(cm/min)		
						Current (A)	Voltage (V)	Wire feed speed (in./min)(cm/min)	Travel speed (in./min)(cm/min)				
Butt, unbacked	1/16-3/32	1.6-2.5	Flat	0.035	1	120	17	140	356	12	30	15	38
Butt, copper backing bar	1/16	1.6	Flat	0.035	1	120	17	140	356	12	30	15	38
Butt, unbacked	1/16-3/32	1.6-2.5	Vertical down	0.035	1	140	20	180	457	15	38	18	46
Butt, unbacked	5/64	2.0	Horizontal	0.035	1	110	20	130	297	8	20	11(c)	30
Butt, unbacked	1/16	1.6	Overhead	0.035	1	110	20	130	297	7	17	12(c)	30
Tee, fillet welds	0-1/16(b)	0-1.6	Horizontal	0.035	1	140	20	180	457	8	20	13	33
Tee, fillet welds	0-1/16(b)	0-1.6	Horizontal	0.030	0.8	100	19½	198	503	7	17	8	20
Tee, fillet welds	1/16	1.6	Flat	0.030	0.8	100	19½	198	503	7	17	8	20
Tee, fillet welds	0-1/16(b)	0-1.6	Vertical down	0.035	1	135	19	168	427	7	18	15	38
Tee, fillet welds	-	-	Overhead	0.030	0.8	100	19½	198	503	7	19	8	20

Note (a) Zinc coating weight (each side) 2 oz/ft² (610 g/m²). Electrode stickout 1/4-3/8 in. (6.4-9.5 mm).
Si-Mn deoxidized wire. Gas flow rate 40 cfh (19 l/min).

(b) Easier to weld with root opening.

(c) 3/64 in. (1.2 mm) root opening.

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TABLE 5.6 — Typical conditions for CO₂ welding lap joints in 1/8 in. batch-galvanized sheet. (a)

Welding position	Wire diam (in.)(mm)	Welding conditions				Travel speed on uncoated steel (in./min)(cm/min)
		Current (A)	Voltage (V)	Wire feed speed (in./min)(cm/min)	Travel speed (in./min)(cm/min)	
Horizontal (plates horizontal)	0.030 0.8	120	19	249 632	9 23	14 36
Horizontal (plates vertical)	0.030 0.8	120	19	249 632	9 23	14 36
Vertical down	0.030 0.8	120	19	249 632	10 26	15 38
Vertical down	0.035 1.0	120	19	140 356	10 26	15 38
Overhead (plates vertical)	0.030 0.8	120	19	249 632	8 20	14 36
Overhead (plates horizontal)	0.030 0.8	120	19	249 632	8 20	14 36

Note (a) Zinc coating weight (each side) 2 oz/ft² (610 g/m²). Electrode stickout 1/4-3/8 in. (6.4-9.5 mm) Si-Mn deoxidized wire. Gas flow rate 40 cfh (19 l/min).

TABLE 5.7 — Welding conditions for joints made with 80% Ar-20% CO₂ shielding gas. (a)

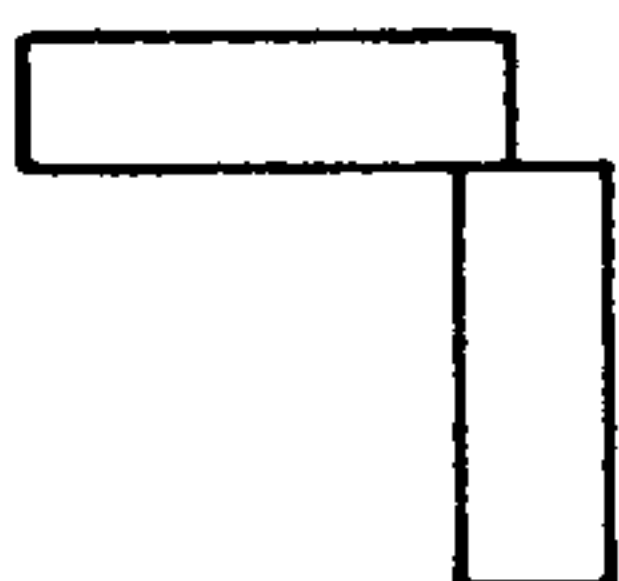
Sheet thickness (in.) (mm)	Joint type	Welding position	Wire diam (in.) (mm)	Wire feed speed (in./min) (cm/min)	Current (A)	Voltage (V)	Travel speed (in./min) (cm/min)
1/16 1.6	Butt. Gap:nil Cu backing bar (b)	Flat	1/32 1	220 560	120	18	18 46
1/16 1.6	Butt. Gap:nil unbacked	Flat	1/32 1	220 560	120	18	15 38
1/8 3.2	Butt. Gap:1/16 in. Cu backing bar (b)	Flat	1/32 1	290 737	130	20	12 31
1/8 3.2	Butt. Gap:1/16 in. unbacked	Flat	1/32 1	290 737	130	20	12 31
1/16 1.6	Butt. Gap:1/32 in. unbacked	Vertical down	1/32 1	175 445	90	18.5	18 46
1/8 3.2	Butt. Gap:1/8 in. unbacked	Vertical down	3/64 1.2	100 254	140	19.5	16 41
1/16 1.6	Fillet	Horizontal	1/32 1	280 711	120	19	14 36
1/8 3.2	Fillet	Horizontal	3/64 1.2	180 458	150	20	12 31
1/16 1.6	Fillet	Horizontal	1/32 1	180 458	100	18	16 41
1/8 3.2	Fillet	Horizontal	3/64 1.2	125 318	135	18.5	14 36
1/16 1.6	Double lap	Horizontal	1/32 1	220 560	120	19	11 28
1/8 3.2	Double lap	Horizontal	3/64 1.2	185 470	155	19.5	13 33

Note (a) Electrode stickout 1/4-3/8 in. (6.4-9.5 mm). Si-Mn deoxidized steel filler wire. Gas flow rate 40 cfh (19 l/min).

... in ... in (1.2 mm x 1.2 mm) groove in backing bar.

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TABLE 5.8 – Typical conditions for GMA short-circuiting arc welding galvanized sheet using 80% Ar-20% CO₂ shielding gas. (a)

Sheet thickness		Joint type	Electrode diameter		Current (A)	Voltage (V)
(in.)	(mm)		(in.)	(mm)		
0.03	0.7		0.023	0.6	45	16
0.04	1.0		0.023	0.6	60	16
0.05	1.3	Square edge butt joint welded from one side	0.031	0.8	80	18
0.07	1.7		0.031	0.8	100	20
0.10	2.5		0.039	1.0	140	22
0.05	1.3		0.031	0.8	80	18
0.07	1.7	Square edge butt welded from both sides	0.031	0.8	100	20
0.10	2.5		0.039	1.0	140	22
0.03	0.7		0.023	0.6	45	16
0.04	1.0		0.023	0.6	60	16
0.05	1.3	Raised edge butt joint	0.031	0.8	80	18
0.03	0.7		0.023	0.6	45	16
0.04	1.0		0.023	0.6	60	16
0.05	1.3		0.031	0.8	80	18
0.07	1.7		0.031	0.8	100	20
0.10	2.5	Corner joint	0.039	1.0	140	22
0.05	1.3		0.031	0.8	80	20
0.07	1.7		0.031	0.8	110	22
0.10	2.5	Tee joint	0.039	1.0	140	24

Note (a) Silicon-manganese deoxidized steel filler wire.

on the second side of a tee joint, this weld may be difficult to make because any zinc vapor formed has to escape via the side being welded, because the first weld effectively blocks any avenue of escape on the other side of the joint. The weld on the second side, however, has a satisfactory appearance.

Fillet welds are difficult to make in the flat position unless a gap is left between the sheets to encourage the escape of zinc vapor. Without a gap, increased spatter is formed and the particles of spatter fall down to the corner of the joint. The accumulation of spatter in the corner makes welding difficult because of the instability of the welding arc.

The possible combinations of welding situations for fillet welds are summarized in Table 5.9.

Welding Conditions for $\frac{1}{4}$ in. and $\frac{1}{2}$ in. Galvanized Plate

Suitable conditions for CO_2 welding butt joints in $\frac{1}{4}$ in. (6.4 mm) galvanized plate and for welding tee joints in $\frac{1}{2}$ in. (12.7 mm) plate are given in Tables 5.10 and 5.11 respectively. The purpose of the $\frac{1}{16}$ in. (1.6 mm) gap between the $\frac{1}{2}$ in. plates in the tee joints is to reduce intergranular cracking which can occur in fillet welds made by CO_2 welding on galvanized plate $\frac{1}{4}$ in. and thicker, as described in more detail in Section 10. There appears to be some evidence that intergranular cracking caused by zinc penetration could be prevented even if there were no gap between the plates, provided that a low-silicon filler wire complying with AWS A5.18-69, E70S-2 was used.

Spatter Formation

With the CO_2 process, each short circuit causes a momentary rapid rise in current which fuses the molten metal contact and re-establishes the arc. Re-ignition is accompanied by the ejection of small particles of molten metal in the form of spatter. In the case of both CO_2 and 80% Ar-20% CO_2 shielding gas, spatter is increased when welding galvanized steel compared with uncoated steel.

When welding uncoated steel, the rate of rise of short-circuit current and the amount of spatter formed can be reduced by increasing the inductance of the circuit. This is done by changing the setting of an adjustable choke which is normally built into the power source. When welding galvanized steel, considerable spatter is still evolved when the variable inductance is at its optimum setting.

If it is found that spatter particles adhere to the workpiece and cause an unsightly appearance, the problem can be simply overcome by the application of a silicone-, petroleum- or graphite-based spatter release compound, from an aerosol spray, to the workpiece, before welding. Adhering spatter particles can then be easily brushed off. Trouble may also be experienced due to the buildup of spatter in the nozzle of the welding gun which can interrupt the flow of shielding gas and, in extreme cases, can cause erratic wire feed. Again, the application of antispatter compound reduces the adherence of spatter particles so that they can be periodically removed after each few feet of welding by tapping the nozzle of the welding gun lightly against the bench or the workpiece.

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TABLE 5.9 — Effect of root opening and welding position on CO₂ welding of tee joints in 1/8 in. batch-galvanized steel.

Welding position		Ease of welding	
First side	Second side	First side	Second side
Sketch designation (a)	Sketch designation (a)	Root opening (in.) (mm)	Root opening (in.) (mm)
Horizontal	Horizontal	Nil	Nil
Horizontal	Horizontal	1/16	1.6
Flat	Flat	Nil	Nil
Flat	Flat	1/16	1.6
Flat	Horizontal	1/16	1.6

Note (a) Sketches correspond to letter designations as shown below:

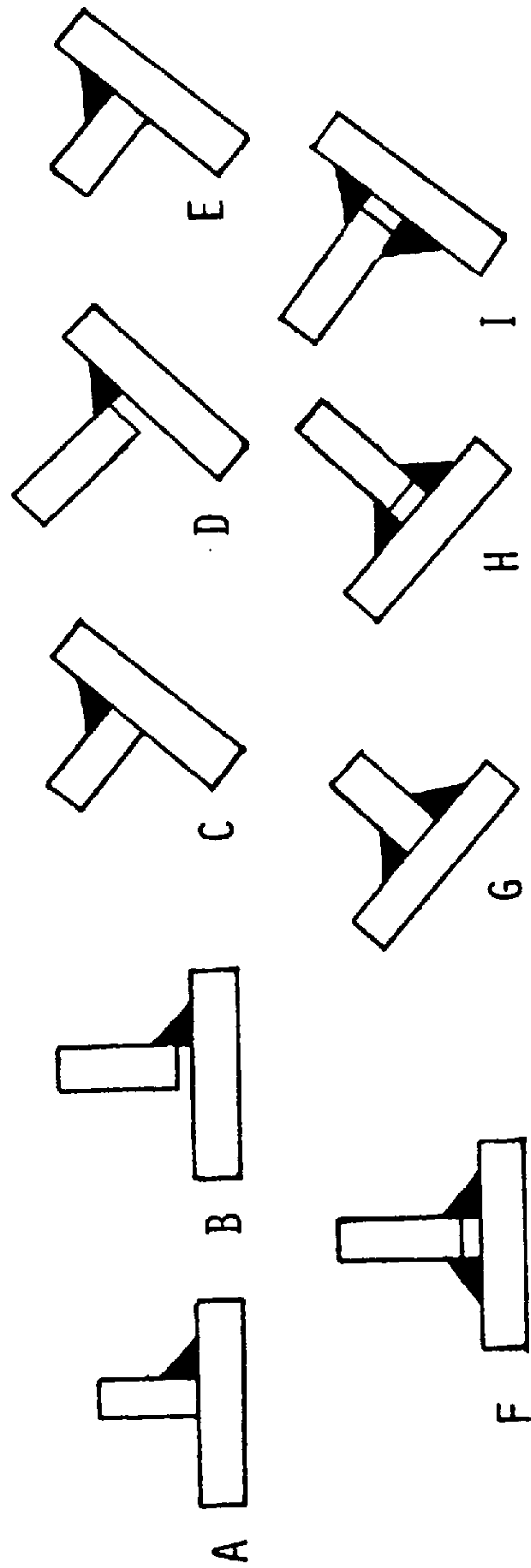


TABLE 5.10 — Typical conditions for CO₂ welding butt joints in 1/4 in. galvanized or metallized steel. (a)

Welding position	Number of passes	Pass no.	Welding conditions				Travel speed on uncoated steel (in./min)(cm/min)
			Current (A)	Voltage (V)	Wire feed speed (in./min)(cm/min)	Travel speed (in./min)(cm/min)	
Flat	2	1	135	19 1/2	145	368	7 10 25.4
		2	165	21	210	534	8 11 27.9
Overhead	2	1	115	18	135	336	6 15.2 15.2
		2	115	18	135	336	5 7 17.8
Vertical up	1	1	135	19 1/2	145	368	3 4 1 1/2 11.4
Horizontal	3	1	135	19 1/2	145	368	5 9 22.9
		2	135	19 1/2	145	368	17 43.2 43.2
		3	135	19 1/2	145	368	10 25.4 40.6

Note (a) Electrode stickout 1/4-3/8 in. (6.4-9.5 mm). 0.035 (1 mm) diam Si-Mn deoxidized wire. Gas flow rate 30 cfh (14 l/min). Edge preparation 60 deg Vee 1/16 in. (1.6 mm) root face, 1/16 in. (1.6 mm) root opening .

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When welding galvanized steel with both CO_2 and 80% Ar-20% CO_2 shielding gases, it is possible to make welds at least 10 ft long before welding is interrupted to clean the nozzle, which is a simple matter when an antispatter compound is used.

Spatter formation increases with the thickness of the zinc coating and is therefore greater on batch-galvanized steel than on continuously-coated sheet. As noted previously, when tee joints in batch-galvanized steel are welded in the flat position, spatter particles tend to roll into the corner of the joint causing difficulty in welding. Spatter formation is also troublesome when welding in the overhead position as it is inclined to fall into the nozzle of the welding gun. Spatter formation is reduced when 0.030 in. (0.8 mm) diam electrode is used — probably because of its higher electrical resistance compared with that of 0.045 in. (1.2 mm) wire. Higher resistance limits current rise at short circuit and produces less force at arc re-ignition resulting in less spatter. The use of a thinner 0.020 in. (0.6 mm) diam filler wire does not produce any further improvement.

Radiographic Appearance

Up to 1/8 in. (3.2 mm) thick butt welds made by the GMAW process on galvanized sheet should be free from defects and give clear radiographs. Fillet-welded tee joints may contain variable amounts of porosity restricted to the root of the weld and not visible at the weld surface. This internal porosity is generally more extensive in the second weld deposited in a double-fillet weld, probably because the first weld cuts off one avenue of escape for volatilized zinc. In the case of continuously-coated sheet, an increase in zinc coating thickness — for example, from 1 1/4 oz/ft² (381 g/m²) to 2 1/2 oz/ft² (762 g/m²) — may give rise to increased porosity in both the first and the second welds made.

The extent of porosity will depend upon heat input, welding speed and solidification rate of the weld metal as well as upon the thickness of zinc coating. In the case of batch-galvanized steel, the coating thickness on the edges may well be variable. As explained in Section 12 on Mechanical Properties, the porosity that can occur when welding galvanized steel has no apparent effect on the mechanical properties of a joint.

Butt welds in galvanized plate 1/4 in. (6.4 mm) and thicker should be free from porosity. Fillet welds made by the CO_2 process are also generally sound although occasional pores may be present if the plate edges have excessively thick coatings of zinc.

Metallized Steel

Suitable conditions for CO_2 welding of tee joints and butt joints in 1/2 in. zinc-metallized steel are given in Tables 5.11 and 5.12 respectively. The gap of

1/16 in. (1.6 mm) between the plates in a tee joint prevented the occurrence of intergranular zinc penetration. Alternatively, the use of a low-silicon filler wire without the provision of a gap would also prevent this defect. The amount of spatter formed when CO₂ welding metallized steel is equal to that formed on galvanized steel, and the use of a spatter-release agent is essential both on the workpiece and the nozzle of the welding gun which should be cleaned out frequently to remove the spatter.

Radiographic Appearance

Vee-groove butt welds in metallized steel can be free from porosity even when the plate edges are metallized after beveling. Fillet welds may contain extensive porosity at the root which can be reduced by the use of a 1/16 in. (1.6 mm) gap between the plates or, alternatively, by removing the zinc coating from the edge of the standing plate which would be free from zinc if the plates were cut after metallizing.

Work has shown that a zinc-metallized coating gives more extensive porosity than any other form of zinc coating.

Zinc-rich Painted Steel

Butt joints and tee joints in 1/2 in. plate coated by normal film thicknesses of zinc-rich primers can be CO₂ welded in all positions with the welding conditions used for uncoated steels without any reduction in travel speed. Coatings of zinc-rich primers produce less spatter than galvanized or metallized steel but more than uncoated steel. The use of spatter-release agents on the workpiece is not necessary because the spatter particles do not adhere to the primed surface and can be easily brushed off. The inside of the gun nozzle, however, should be sprayed with a spatter-release agent to facilitate periodic removal of accumulated spatter.

Radiographic Appearance

Variable amounts of porosity occur in welds on zinc-primed plate in all welding positions, the extent depending on the coating thickness and, to a certain extent, the welding conditions. The conditions given in Tables 5.11 and 5.12 for metallized steel can be used for welding zinc-rich painted steel but the welds will contain porosity. In the case of welds made in the flat or horizontal positions, porosity can be minimized by increasing the heat input. Welding conditions of 170 A-22 V produce double-fillet welds in which the first weld deposited is usually free from porosity, the second side welded containing a few pores per foot of weld. In the vertical and overhead positions, porosity may be slightly more extensive but can usually be eliminated from double-fillet welds by the use of a 1/16 in. (1.6 mm) gap between the plates.

TABLE 5.11 — Typical conditions for CO₂ welding butt joints in 1/2 in. galvanized or metallized steel. (a)

Welding position	Welding conditions				Travel speed on uncoated steel (in./min)(cm/min)
	Current (A)	Voltage (V)	Wire feed speed (in./min)(cm/min)	Travel speed (in./min)(cm/min)	
Horizontal	135	20	145	5	8 12.7
Vertical down	135	20	145	10	10 25.4
Vertical up	135	20	145	5	5 12.7
Overhead	135	20	145	5 1/2	8 20.3

Note (a) Electrode stickout 1/4-3/8 in. (6.4-9.5 mm). 0.035 in. (1 mm) diam Si-Mn deoxidized wire.
Gas flow rate 30 cfh (14 l/min). 1/16 in. (1.6 mm) root opening.

TABLE 5.12 — Typical conditions for CO₂ welding butt joints in 1/2 in. metallized plate. (a)

Welding position	No. of passes	Current (A)	Voltage (V)	Decrease in speed compared with welding uncoated steel. (%)
Flat	6 plus sealing pass	160	21	10
Vertical up	3	115	19	0
Overhead	3	115	19	13
Horizontal	9	115	19	15

Note (a) 0.035 in. (1 mm) diam Si-Mn deoxidized wire; CO₂ flow rate 30 cfh (14 l/min). Electrode stickout 1/4-3/8 in. (6.4-9.5 mm). Edge preparation: Root face 1/16 in. (1.6 mm); Root opening 3/32 in. (2.4 mm).

GMA Braze Welding of Galvanized Sheet

If a silicon-bronze or aluminum-bronze electrode is used instead of the conventional steel filler metal, the joining process becomes a braze-welding operation in which little or no melting of the base metal occurs. The short-circuiting process is used with argon shielding gas and the weld metal has excellent corrosion resistance.

Silicon-Bronze Electrode

Typical GMA braze welding conditions are given in Table 5.13.³ The currents are fairly critical because high currents cause too much dilution of the weld metal by the ferrous base metal, which can lead to transverse cracks in the weld; on the other hand, if currents are too low, poor wetting of the base metal occurs with a rough deposit. Because of the low heat input, gaps are required when making butt welds to obtain full penetration, and a grooved copper backing bar is advisable to control the penetration. The high travel speeds in Table 5.13 which are used to decrease heat input and prevent cracking are too high for semiautomatic welding except possibly for short welds. Therefore, conditions given should only be used for fully automatic welding. Suitable conditions for semiautomatic welding are given below for aluminum-bronze electrodes.

Aluminum-Bronze Electrode

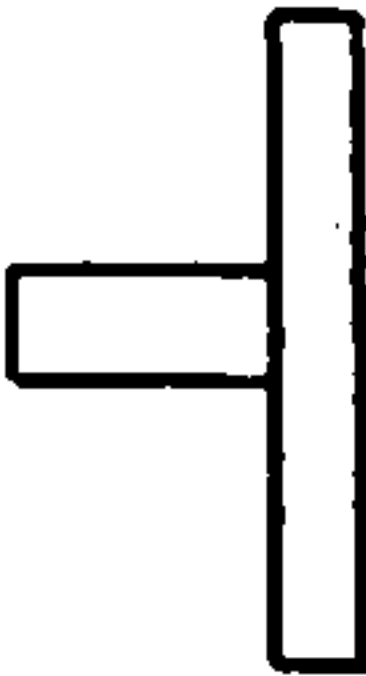
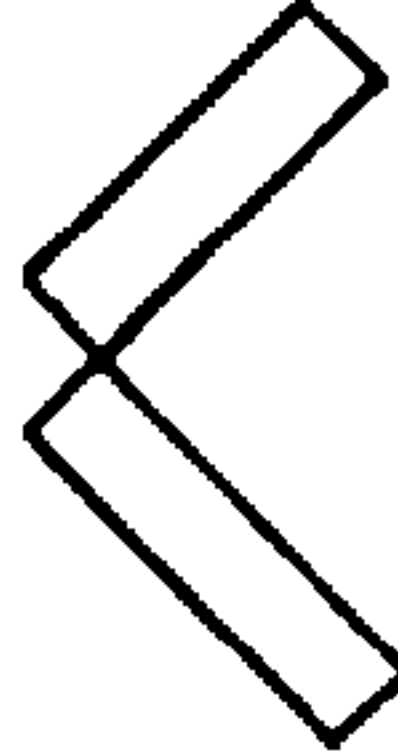
Typical GMA braze welding conditions are given in Table 5.14 and are suitable for semiautomatic or automatic welding.

TABLE 5.13 — GMA braze welding conditions for butt and lap joints in galvanized steel. (a)

Sheet thickness (in.) (mm)	Joint type	Root opening (in.) (mm)	Welding position	Electrode angle (deg)	Travel speed		Current		Voltage		Wire feed speed	
					(in./min)	(cm/min)	(A)	(V)	(in./min)	(cm/min)	(in./min)	(cm/min)
0.048 1.2	Lap	0	Horizontal	60	40	102	135	14 1/2	400	1016		
0.048 1.2	Butt	0.031 0.8	Flat	90	35	89	110	14	370	940		
0.058 1.5	Lap	0	Horizontal	60	25	64	110	14	300	762		
0.058 1.5	Butt	0.031 0.8	Flat	90	25	64	110	13 1/2	340	864		
0.075 1.9	Lap	0	Horizontal	60	25	64	130	15	370	940		
0.075 1.9	Butt	0.035 0.8	Flat	90	25	64	110	14	315	800		
0.108 2.7	Lap	0	Horizontal	60	25	64	140	15	400	1016		

Note (a) Argon shielding gas. Gas flow rate 30 cfh (14 l/min). Electrode composition: Si 2.8-4.0%, Cu balance; 0.035 in. (1 mm) diam. Copper backing bar grooved for butt joints, 1/8 in. x 0.010 in. (3.2 mm x 0.03 mm) groove.

TABLE 5.14 — Typical conditions for GMA braze welding galvanized sheet. (a)

Joint type	Sheet thickness (in.) (mm)	Filler wire diameter (in.) (mm)	Wire feed speed (in./min) (cm/min)	Welding current (b) (A)	Arc Volts (V)	Travel speed (in./min) (cm/min)
	0.062 1.6	0.031 0.8	256 650	100	18	18 45
	0.062 1.6 0.080 2.0	0.031 0.8 0.047 1.2	280 710 162 410	130 150	19 16	18 16 45
	0.062 1.6 0.080 2.0	0.031 0.8 0.047 1.2	256 650 152 380	100 140	18 16	14 18 35 45
	0.062 1.6	0.031 0.8	260 660	110	18	18 45

Note (a) Aluminum bronze (Cu-90 %; Al 10 %) filler wire. Argon shielding gas. Gas flow rate 40 cfh (19 l/min).

(b) Direct current, reverse polarity.

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This process is used to make discrete connections in sheet metal and is a rapid semiautomatic method which can be used when access to the sheets to be joined is available on one side only. CO₂ welding equipment is modified for spot welding by the incorporation of a timer in the circuit. This timer, which is actuated by the gun trigger, switches off the welding current after a pre-set time has elapsed. Often the circuitry also incorporates a burn-back device which allows the arc to be maintained for a short period after the wire feed is stopped. This is designed to prevent the electrode wire from remaining in the molten weld pool when it freezes.

A spacer nozzle is usually attached to the welding gun which is pressed against the workpiece and presets the gun nozzle-to-work distance. CO₂ spot welding can be carried out on galvanized sheet provided that the zinc coating weight is low in relation to the sheet thickness. Sound CO₂ spot welds can be made in 1/8 in. (3.2 mm) sheet, with a zinc coating weight of 1 1/4 oz/ft² (381 g/m²) (Figs. 5.3 and 5.4). While spot welds in 1/16 in. (1.6 mm) galvanized sheet with a coating weight of 1 1/4 oz/ft² (381 g/m²) give adequate strength,



Fig. 5.3 – CO₂ spot welds in 1/8 in. continuously-coated galvanized (left) and uncoated steel (right). Zinc coating weight 1 1/4 oz/ft². Welding conditions: 3/64 in. diam wire, 280 A, 34 V, 3 s.

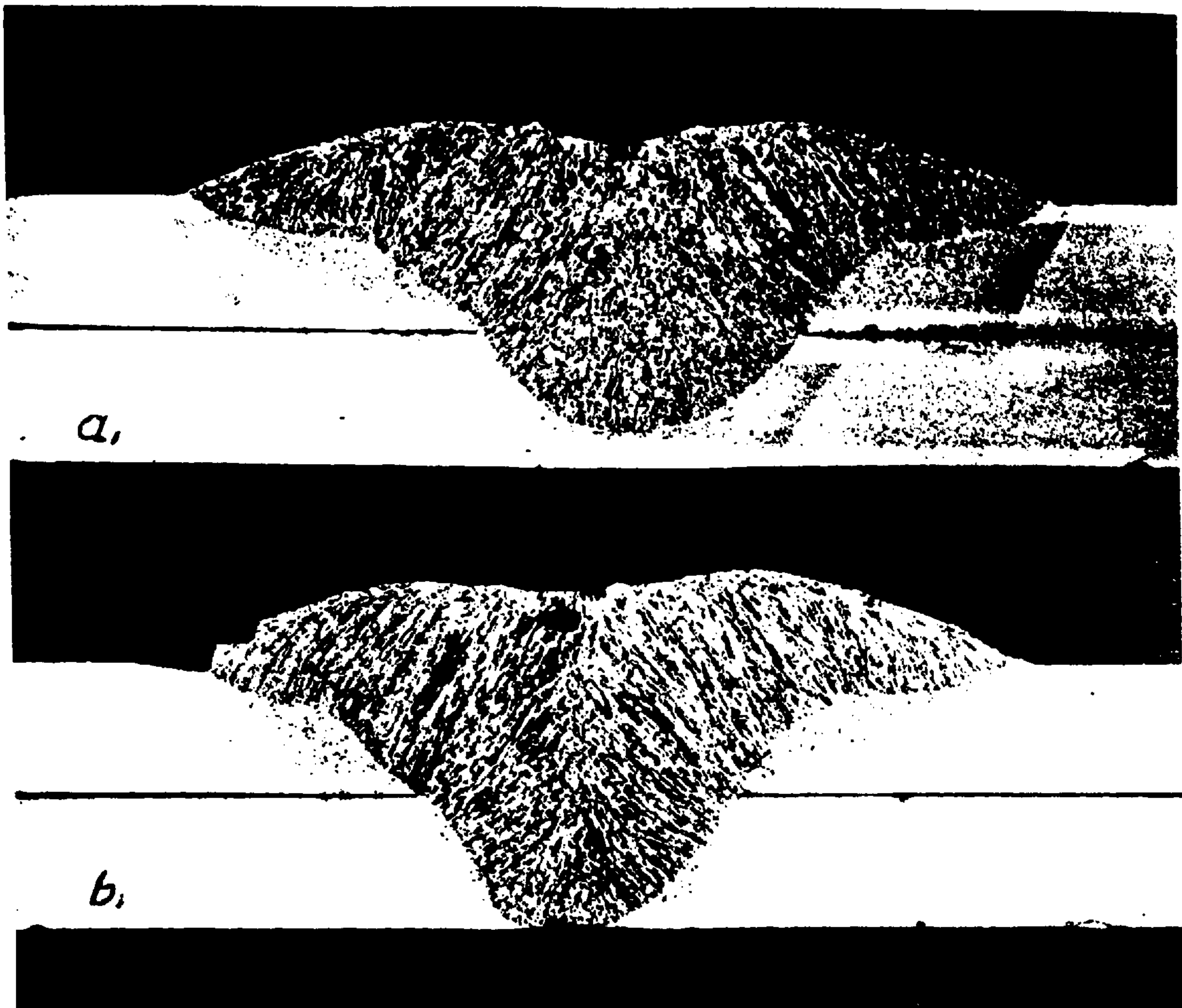


Fig. 5.4 – Macrosections of CO₂ spot welds shown in Fig. 5.3. a) Uncoated steel.
b) Galvanized steel. (x 4)

the welds contain porosity and would be generally unacceptable for high quality work. If the ratio of zinc coating weight to sheet thickness is reduced to that of 1/8 in. (3.2 mm) continuously-coated sheet, acceptable welds should be obtained. In the case of 1/16 in. sheet, this would represent a coating weight of 5/8 oz/ft² (191 g/m²) but it is possible that this might be

TABLE 5.15 – Conditions for CO₂ spot welding continuously-galvanized sheet (Lap joints). (a)

Sheet Thickness (in.) (mm)		Maximum recommended zinc coating weight (including both sides) (oz/ft ²) (g/m ²)		Current (A)	Voltage (V)	Time (s)
1/16	1.6	3/4	229	180	28	1
1/8	3.2	1 1/4	381	280	34	3

Note (a) 3/64 in. (1.2 mm) diam Si-Mn deoxidized filler wire.

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increased to, for instance, $3/4$ oz/ft² (229 g/m²) without adversely affecting the arc-spot welding characteristics.

The arc-spot welding of batch-galvanized steel gives poor results because the volatilization of the zinc at the interface of the sheets disrupt the weld pool and causes excessive porosity visible at the weld surface. Typical conditions for CO₂ spot welding lap joints are given in Table 5.15.

Increased spatter is formed when CO₂ spot welding galvanized steel compared with uncoated sheet, but the use of a spatter-release compound facilitates spatter removal.

Section 6 — Shielded Metal-Arc Welding

General

Shielded metal-arc welding (SMAW)* is a manual welding process in which flux covered electrodes of 10 to 18 in. (250 to 457 mm) in length and 1/16 to 1/2 in. (1.6 to 12.7 mm) diam (Fig. 6.1) are used. This process accounts for about 85% of all arc-welding work carried out at the present time and can be used with either alternating or direct currents of between 50-400 A depending on the size of electrode. The composition of the flux covering, which consists of a mixture of minerals, such as rutile, calcium carbonate and cellulose, generally falls within a certain type depending on the purpose for which the electrode is to be used, e.g., pipe welding, general mild steel construction, welding of alloy steels. Electrode coverings are described and classified in AWS A5.1-69, Specification for Mild Steel Covered Arc-Welding Electrodes, and in B.S. 1719 Classification and Coding of Covered Electrodes for Metal Arc Welding.

The main purpose of the electrode covering can be briefly summarized as follows:

1. To stabilize the arc.

* This is the terminology used in the United States. In Great Britain it is known as manual metal-arc welding. SMAW is also called stick electrode welding.

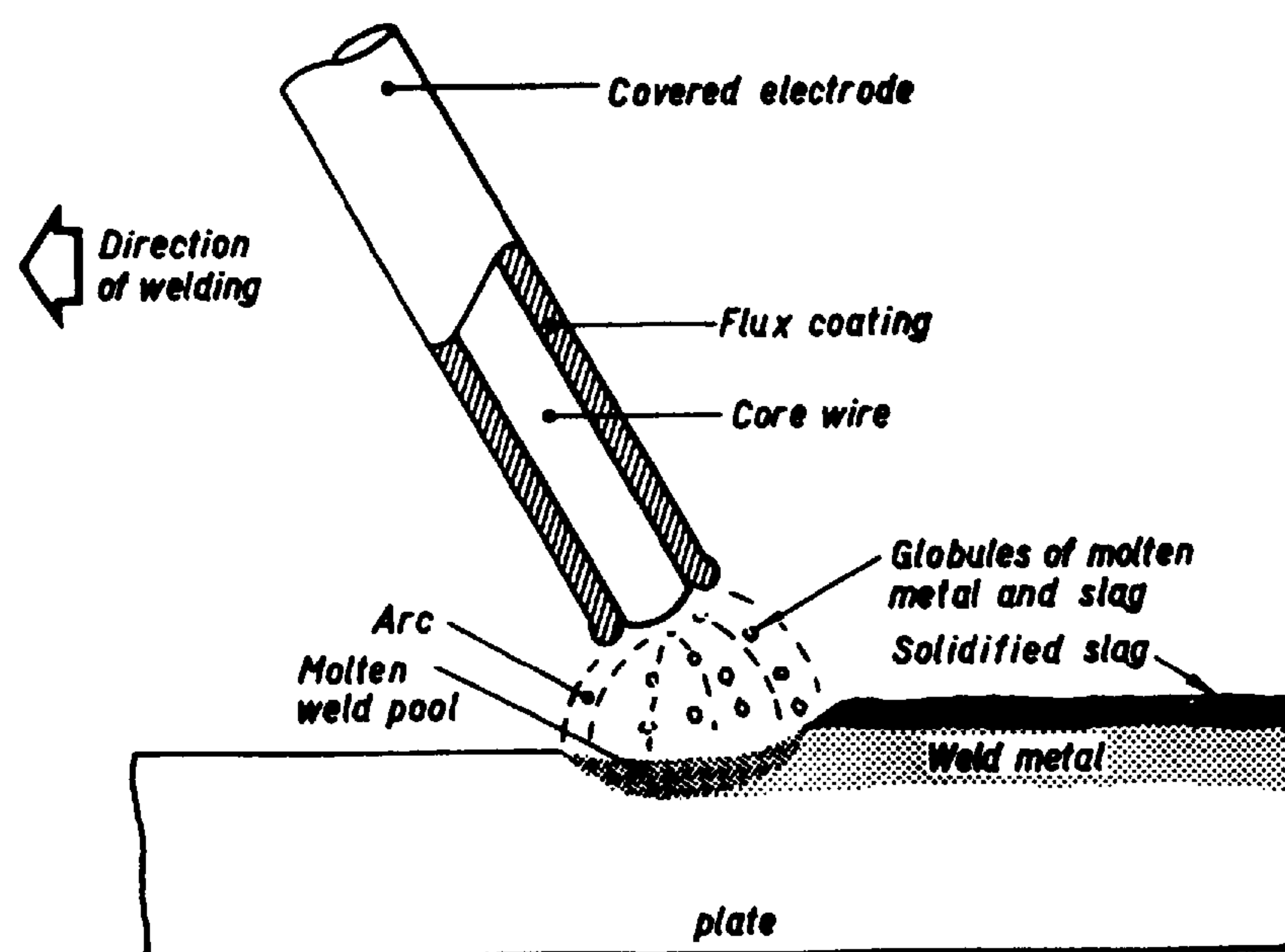


Fig. 6.1 — Diagrammatic illustration of shielded metal-arc welding.