

Welding Processes and Equipment

PART OF THE CWB CERTIFICATE PROGRAMS



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WELDING PROCESSES AND EQUIPMENT

LESSON OBJECTIVES

The objective of this module is to provide a general description of the major welding processes available, with emphasis on the arc welding processes. The intent is to provide the reader with a broad understanding of the principles of operation of the process, general characteristics and equipment used. The following processes will be covered:

- Shielded metal arc welding (SMAW)
- Gas tungsten arc welding (GTAW)
- Gas metal arc welding (GMAW)
- Flux cored arc welding (FCAW)
- Submerged arc welding (SAW)

- Other welding processes including:
 - o Friction welding
 - o Electron beam & laser welding
 - o Resistance welding
 - o Thermit welding
 - o Electroslag & Electrogas welding
 - o Stud welding

Grouping of Welding Processes

There are many ways in which welding processes may be grouped and different countries have adopted various ways to classify them. Welding involves the use of pressure, heat, or both, to produce a joint by the coalescence (i.e. 'growing together') of the material. In some processes *fusion* (melting) of the material occurs which subsequently solidifies to produce the bond. These processes are the most common, and include the major arc welding methods described in this module. Welds made by fusion in which no additional filler metal is added are sometimes called '*autogenous*' welds.

The American Welding Society (AWS) groups welding processes on the basis of the mode of energy transfer and defines a welding process as "*a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone and with or without the use of filler material*". Under the AWS definition, welding processes are therefore divided into the following major categories:

- Arc welding (AW)
- Solid state welding (SSW)
- Resistance welding (RW)
- Oxyfuel gas welding (OFW)
- Soldering (S)
- Brazing (B)
- Other welding
- Allied processes (such as cutting)

Arc Welding

An arc is formed when an electric current is forced to flow across a gap between two electrodes, or an electrode and the work. An electric arc is intensely hot with temperatures exceeding 6,000°F and forms a concentrated heat source suitable for melting most metals rapidly.

The arc may be established between an electrode and the workpiece, or between two electrodes. In the latter case, the arc would be positioned close to the metal being welded, but the electric current would not be passing through it.

In some arc processes the electrode is designed to melt as well as the work piece, (as in ordinary shielded metal arc - 'stick' welding) and these are known as *consumable electrode processes*. Processes such as *gas tungsten arc welding* use electrodes that are designed not to melt and these are called *non-consumable electrode processes*.

The electric current used in a welding arc may be either *direct current* (DC) or *alternating current* (AC). Direct current flows constantly in one direction, but alternating current is continually changing direction.

Arc Shielding

Most metals when melted in air become contaminated with oxides and nitrides through contact with the oxygen and nitrogen in the air. This contamination may result in a poor quality weld so most arc welding processes have some means of shielding the molten metal from the air or some means of removing the harmful effects of the oxygen and nitrogen. The two main methods of arc shielding are:

- *Flux shielding*
- *Gas shielding*

Most of the arc welding processes are distinguished principally by the method of shielding or the way in which it is applied.

Shielded Metal Arc Welding

Shielded metal arc welding (SMAW) or manually operated metal arc welding with stick electrodes is still the most common welding method since it allows freedom of control and design for the least cost of equipment and labour.

The knowledge of joint design, arc action, heat control and metal reaction gained from manual metal arc welding has been of great value in developing all other variations of the arc welding process.

In operation, an arc is struck between the end of the electrode and the metal to be welded, variously called the parent metal, base metal or work piece. The electrode metal progressively melts and is carried across the arc into the weld joint and fuses with the molten base metal.

For many years almost all stick electrode welding has been done with electrodes provided with an extruded flux covering. This flux is melted with the core wire, shielding the arc and the molten metal from the contaminating effects of the oxygen and nitrogen in the air. A further benefit derives from the coating of flux that covers the cooling weld bead and provides further protection and slows cooling.

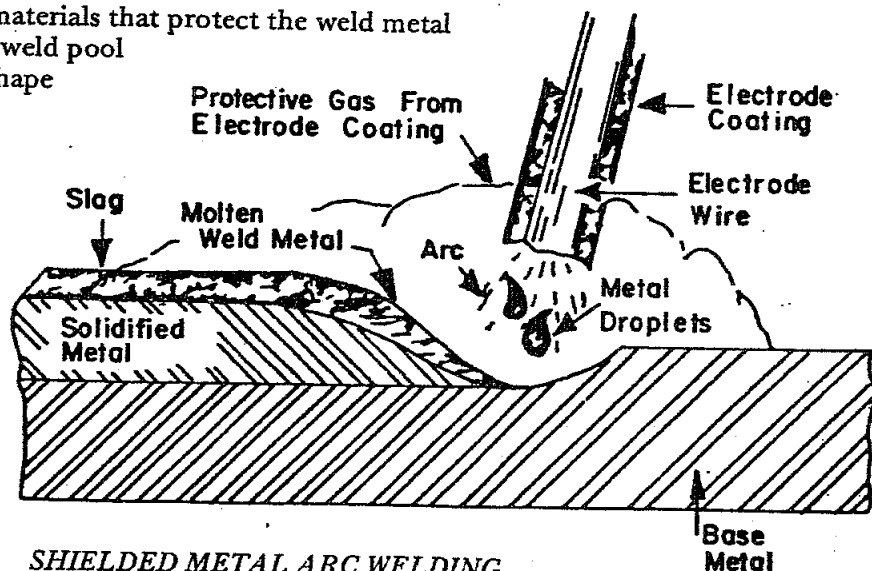
If the operator utilizes a proper technique, the electrode metal can be deposited overhead or vertically almost as easily as in the flat position. This is possible since the force of the arc will propel the molten electrode metal in a spray of globules in any direction required.

Arc welding, like the electric arc furnace, actually produces a very high grade cast deposit often purer in chemical composition than the base metal and in some cases of superior mechanical properties.

Principles of Operation

In the heat of the arc, the electrode and flux covering are melted and perform the following functions:

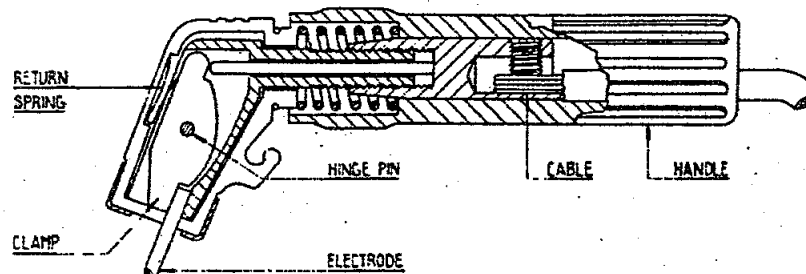
- Produce a gas to shield the molten metal
- Promote electrical conduction across the arc
- Add slag forming materials that protect the weld metal
- Refine the molten weld pool
- Control the bead shape



SHIELDED METAL ARC WELDING

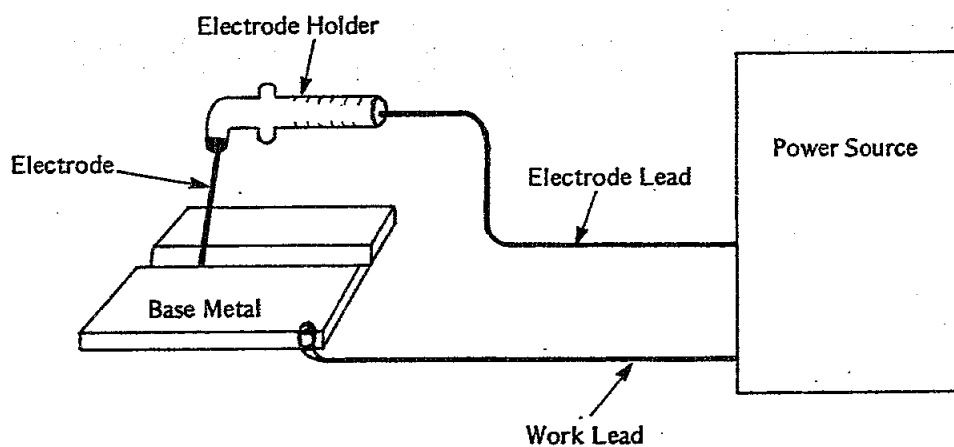
Fig. 1

The equipment used will normally have a drooping volt-ampere curve that promotes the attainment of a constant current. Naturally, adequate size insulated electrode holders must be used together with suitable size cables to prevent excessive power loss. A common type of electrode holder is shown in Fig. 2.



Example of an electrode holder

Fig. 2



Electric circuit for SMAW

Fig. 3

Naturally, in order to complete an electric circuit, it is necessary that a suitable ground or work lead must be connected as shown in Fig. 3.

The range of current which is shown in Table 1 is the total typical range for which the electrode should be satisfactory. However, the total range of current may not be suitable for all situations. When welding on thinner material, the lower end of the range might be applicable. This would also apply when welding in the vertical or overhead positions.

TYPICAL CURRENT RANGES IN AMPERES FOR ELECTRODES

Electrode Diameter Inch mm	EX010 and EX011	EX012	EX013	EX020	EX027	E7014
1/16 1.6		20 40	20 40			
5/64 2.0		25 60	25 60			
3/32 2.4	40 80	35 85	45 90			
1/8 3.2	75 125	80 140	80 130	100 150	125 185	80 125
5/32 4.0	110 170	110 190	105 180	130 190	160 240	110 160
3/16 4.8	140 215	140 240	150 230	175 250	210 300	150 210
7/32 5.6	170 250	200 320	210 300	225 310	250 350	200 275
1/4 6.4	210 320	250 400	250 350	275 375	300 420	260 340
5/16 8.0	275 425	300 500	320 430	340 450	375 475	330 415
						390 500
Electrode Diameter Inch mm	E7015 and E7016	E7018	E7024 and E7028	E7038	E7046	E7048
1/16 1.6						
5/64 2.0						
3/32 2.4	65 110	70 100	100 145*			
1/8 3.2	100 150	115 165	140 190			
5/32 4.0	140 200	150 220	180 250			
3/16 4.8	180 255	200 275	230 305	200 275	135 185	130 165
7/32 5.6	240 320	260 340	275 365	280 400	165 235	150 200
1/4 6.4	300 390	315 400	335 430	380 550	215 300	180 250
5/16 8.0	375 475	375 470	400 525*			

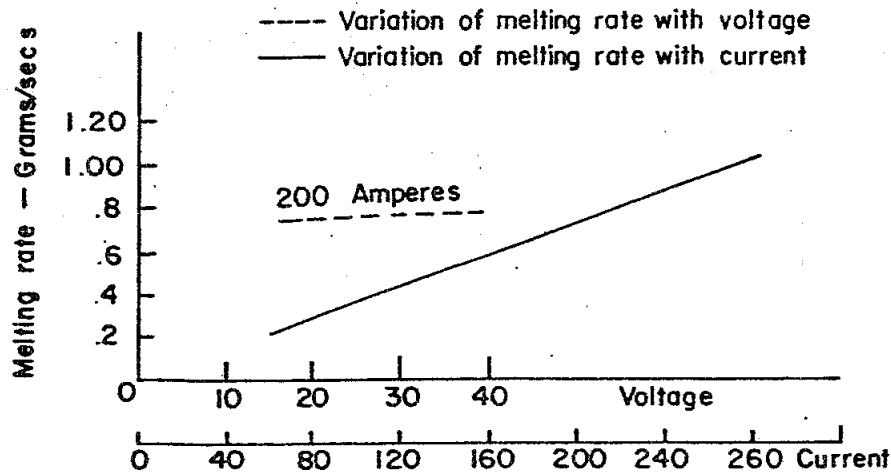
*These values do not apply to the E7028 classification.

Table 1

e.g., 1/8" (3.2 mm) diameter E6010 (E41010) can be used with a typical current range from 75-125 amps as shown in the chart. However, if welding on heavy material in the *flat position*, it would be logical to use the upper part of the range, such as 100-125. If welding in the *vertical up position*, the range might be 90 - 110 since higher currents could necessitate a certain amount of "whipping" in order to control the weld bead.

Melting Rate

The melting rate of electrodes will depend on the current, size of electrode and type of coating. Some electrodes contain iron powder in the flux which increases the deposition rate for a given current. Voltage has little effect on the melting rate as seen in Fig. 4, but the melting rate increases approximately in proportion to the current. A typical melting rate is about 1/2 lb. per min. per 1000 amps which for an electrode operation at 200 amps would be equal to about 6 lbs. per hour.



Effect of current and voltage on electrode melting rate
Fig. 4

Positioning of Work

To increase the rate of welding should be a prime objective. Positioning the work for welding in the flat position, the use of large electrodes and high currents, and taking advantage of the high deposition rate of iron powder electrodes provides the means for doing this.

Special Coated Electrodes and Uses

Manual metal arc welding is extensively used for the manufacture and repair of pressure vessels, pressure and oil line piping, field storage tanks, bridges, buildings, ships, railway cars, trucks and automobiles, all types of machine bases, aircraft parts, nuclear power stations and a great many miscellaneous products.

Special coated electrodes are available for metal arc welding of castings of grey iron, steel, nickel, copper, aluminum and bronze. Other electrodes are available for the welding of rolled sections and plate in low, medium and high carbon steels, low alloy high strength steels, stainless alloys, nickel and copper base alloys, aluminum, magnesium and other non-ferrous alloys.

Metal arc welding is valuable for the hard surfacing of all types of products exposed to combinations of wear, impact, heat and corrosion. A great many single purpose alloy electrodes are designed for such applications.

Some coated arc welding electrodes are designed for use only with direct current. For bare metal electrodes, direct current with straight polarity, (i.e., electrode negative) must be used. Other electrodes are designed specifically for alternating current; on the other hand, these will usually work satisfactorily on DC, but in this case the polarity used should be the one recommended by the electrode manufacturer.

Manual metal arc welding requires experienced welding operators. Simple welding operations may be taught in a few weeks, but an operator capable of making satisfactory welds in all positions, on a variety of metals, is a highly skilled artisan usually of long experience.

Gas Tungsten Arc Welding (GTAW)

Gas tungsten arc welding (also referred to as TIG - tungsten inert gas) is an arc welding process using an inert gas to protect the weld zone from the atmosphere. Heat for welding is provided by an intense electric arc, struck between a non-consumable tungsten electrode and the metal workpiece. Gas tungsten arc welding differs from metal arc welding in that the *electrode is not melted* and used as a filler metal. Where filler metal is required, a welding rod is fed into the weld zone and melted with the base as in oxyacetylene welding.

The molten weld puddle must be protected from the atmosphere during welding or atmospheric oxygen and nitrogen will combine with the molten metal resulting in a weak, porous weld.

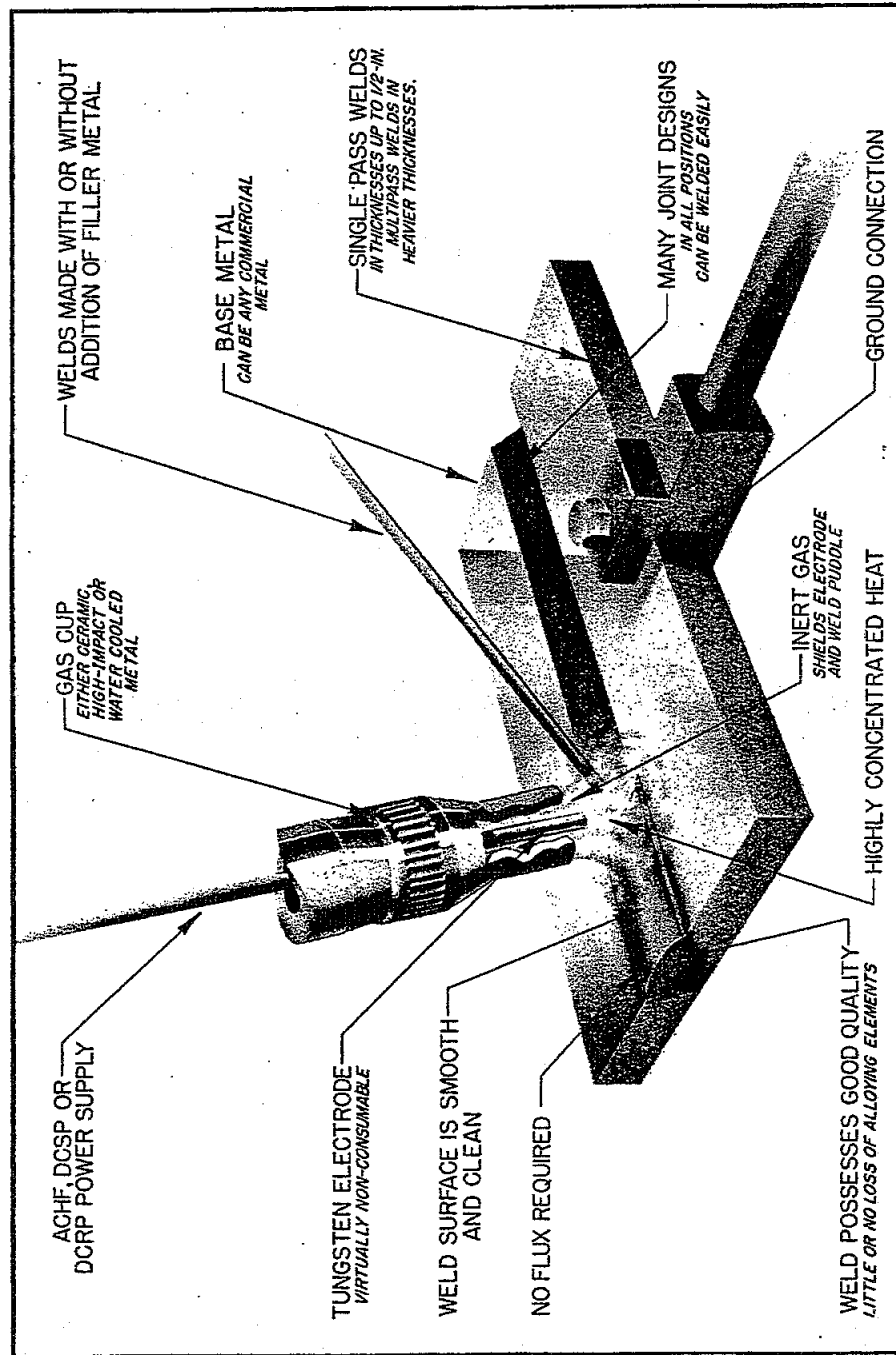
GTAW uses the inert gases, argon or helium. Its first application was in the welding of magnesium and later in welding aluminum, stainless steel, copper, carbon steel and the new space age materials such as titanium and zirconium. The weld may be purely fusion of the base metal, or filler metal can be added. Although originally developed as a manual process it is now regularly used for production welding with automatic travel of the electrode or the work and continuous feed of the filler metal if this is required. Automobile and household appliance parts are some of the applications for automated GTAW and it is widely used for making high quality welds in pipes.

Essentials of the GTAW Process

Figure 5 indicates the essential characteristics of this process and is based on the addition of a filler material because of the geometry of the Vee groove butt joint shown. However, a flange or corner flange joint would be suitable for welding without additional filler metal.

Type of Current and Polarity

This process was first used with direct current electrode positive (*reverse polarity* — dcrp) using low currents and a large diameter tungsten electrode. This method caused heating problems in the electrode and this is one reason that most gas tungsten-arc welding is now done using either direct current electrode negative (*straight polarity* — dcsp) or alternating current with high frequency.



Essentials of the GTAW process
Fig. 5

The sketches shown in Fig. 6 reflect the movement of "Electron Flow" which is contrary to the conventional current flow. The student should note that the gas ions are positive and are attracted to the negative pole. However, the electron flow forms the greatest part of the current flow.

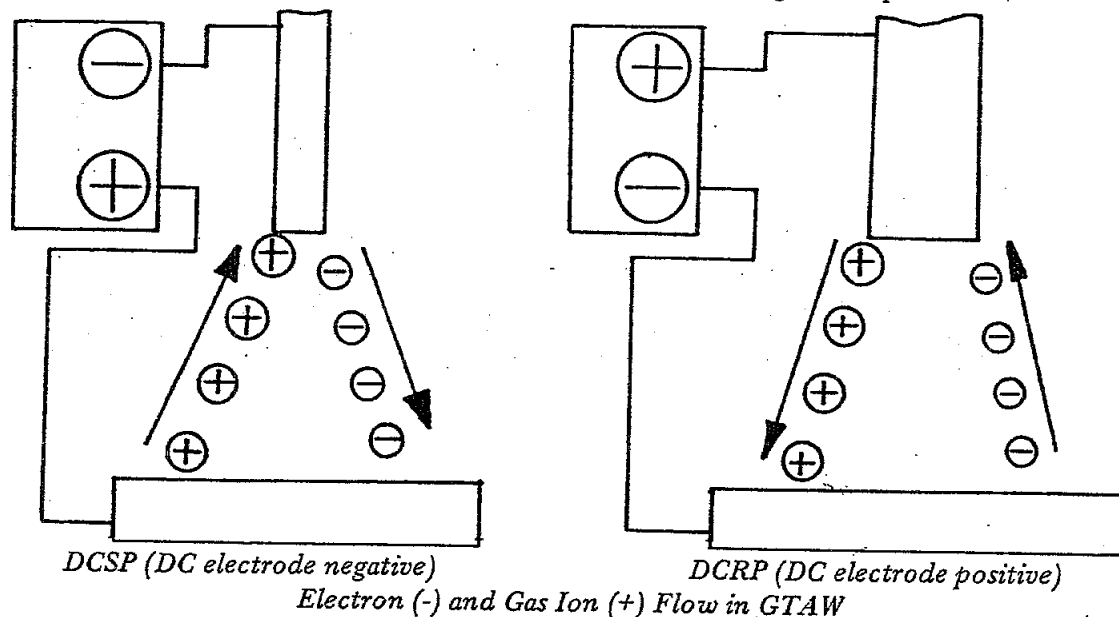


Fig. 6

DCSP (DCEN) shows a heating effect as the electrons stream from the tungsten electrode and hit the plate to be welded. When DCRP (DCEP) is used, the electrons stream from the plate and hit the end of the electrode. This causes the end of the electrode to be heated, and possibly to melt, causing tungsten inclusions in the weld metal.

Therefore, when DCRP is used, a large diameter electrode is required. The permissible current values for direct current (argon gas) are shown in Table 2.

For Tungsten Electrodes (EWP* and EWTh**)			
Electrode Diameter		Direct Current (amps)	
		Electrode Negative	Electrode Positive
1.6	1/16	70-150	10-20
2.4	3/32	150-250	15-30
3.2	1/8	250-400	25-40
4.0	5/32	400-500	40-55
4.8	3/16	500-750	55-80
6.4	1/4	750-1000	80-125

* EWP - Pure Tungsten Electrode

** EWTh - Thoriated Tungsten Electrode

Typical Current Ranges

Table 2

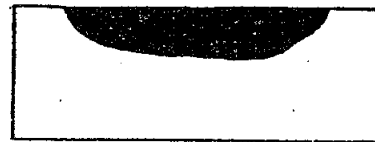
Arc Penetration — GTAW

In *direct current straight polarity* the electrons will stream from the negative electrode towards the positive plate to be welded. This action will greatly increase the temperature in the plate and will result in deep penetration and a narrow weld as shown in Fig. 7.

DCRP or electrode positive, will result in a shallow wide weld. Another point which is of extreme importance in aluminum welding is the surface cleaning action which takes place when electrons leave the work plate to strike the electrode. This action tends to break up surface scale and surface oxides which may be present.



DC Electrode negative — deep penetration narrow weld



DC Electrode positive — shallow wide weld

D-C Electrode Negative. — Deep Penetration
Narrow Weld

D-C Electrode Positive — Shallow Wide Weld

Weld Contours of DCEN (DC Straight Polarity) and DCEP (DC Reverse Polarity).

Fig. 7

Types of Electrodes

The electrodes used in GTAW are referred to as *Non-Consumable Electrodes* although they are consumed very slowly. Therefore additional electrodes must be used when this occurs or when breakage or contamination results from everyday usage.

Electrodes are usually 7 in. in length, and it is possible to obtain various diameters of from 0.02 in. through 1/4 in. The popular sizes are 1/16 in., 3/32 in. and 1/8 in. diameter. Large electrodes have large current-carrying capacity and may be tapered at the arc end to increase the current density and improve arc stability. The common types of electrodes used today for gas tungsten-arc welding are:

- Pure tungsten
- Thoriated tungsten — 1 or 2% thoria
- Tungsten electrodes with a stripe of thoria
- 0.5% zirconia and the balance tungsten

Additions to the tungsten, such as zirconia and thoria improve electron emission and contamination resistance.

When selecting a tungsten electrode, it is important to ensure that the size of the electrode corresponds to the recommended current. Otherwise it is possible to cause overheating of the electrode or for the arc to wander over the blunt end of the electrode.

GTAW Spot Welding

This process can be used for mechanized or manual arc-spot welding. The operation involves making an electric arc in an inert-gas atmosphere between the workpiece and a torch electrode which is usually thoriated tungsten.

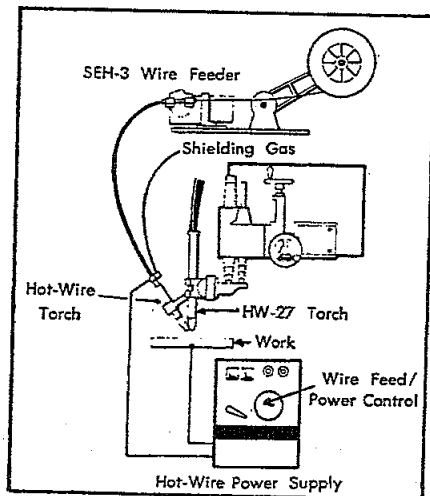
The mechanical method may utilize a high frequency start, a timed interval during which welding occurs, and an automatic shut-off.

The process has several advantages:

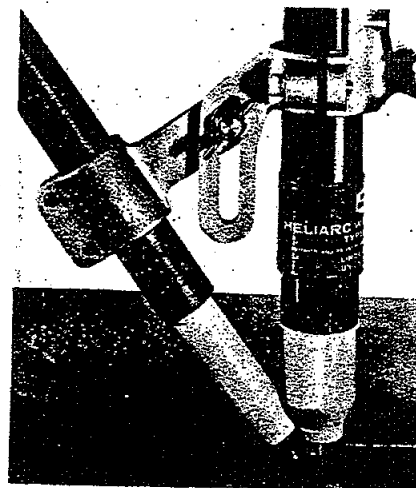
- 1) The completed welds are clean, strong and uniform. Further cleaning is generally not necessary.
- 2) There is no practical restriction on thickness ratio of sheets to be welded except the ability of the process to penetrate into the second sheet.
- 3) Shunting which can be a problem with resistance spot welding is not encountered.
- 4) The surface resistance of the parts is not critical.
- 5) Welds can be made from one side of the work.

Hot Wire Welding

In order to increase the deposition rate of GTAW, the hot wire method provides filler metal pre-heated to a molten state as it is fed into the weld pool behind the arc, thus allowing the heat from the arc to be concentrated on the base material. The wire is continuously fed and heated by AC flowing through it. The wire is fed through a separate torch, with feed and power supply independent of the main GTAW system and adjustable to suit the application. It is claimed that filler metal can be deposited at speeds up to five times that of conventional GTAW. (See Fig. 8 (a) and (b).)



(a)



(b)

Fig. 8 GTAW (TIG) Hot Wire Welding

Gas Metal Arc Welding (GMAW)

Gas shielded arc welding with consumable electrodes has characteristics which are similar to GTAW but, at the same time, it extends the use of the gas shielded process to the welding of heavier thicknesses and thereby greatly broadens its possible range of usefulness. It has had the greatest growth of all processes, in recent years, having replaced the stick electrode in many applications and its percentage of the electrode market is still increasing. It should be mentioned that both the tungsten and consumable electrode processes were originally used only with inert gases, and hence became known as TIG (Tungsten Inert Gas) and MIG (Metal Inert Gas). Further developments resulted in gases other than inert being used and caused the present official designations to come into being.

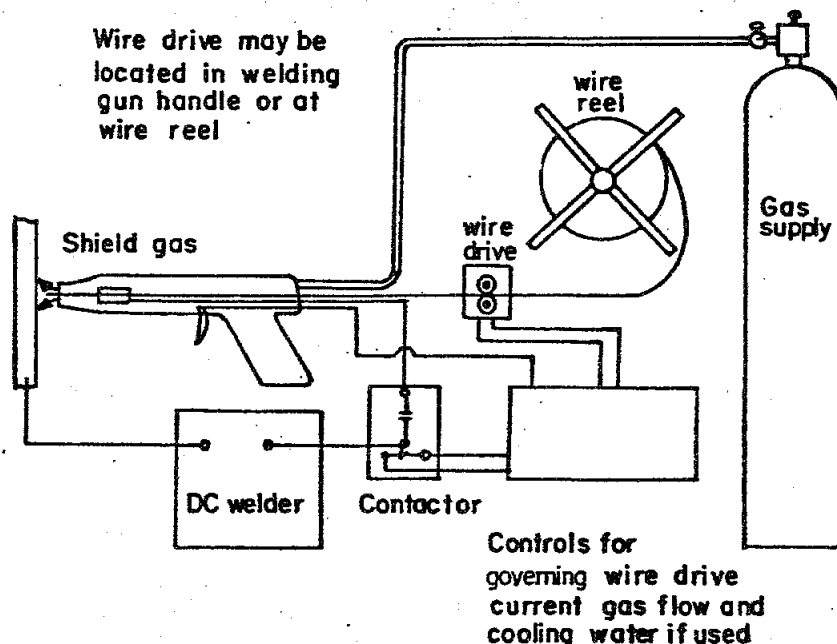
This process was first applied to the welding of aluminum and it became a popular substitute for GTAW because production was about four times faster.

Basic Principle of GMAW

The basic principle of GMAW is the use of a continuously fed electrode so controlled that it automatically maintains the correct arc length and burn-off rate, with shielding furnished by gas introduced through the torch or gun.

The power source normally used is DC with the electrode positive although some electrodes are used with straight polarity.

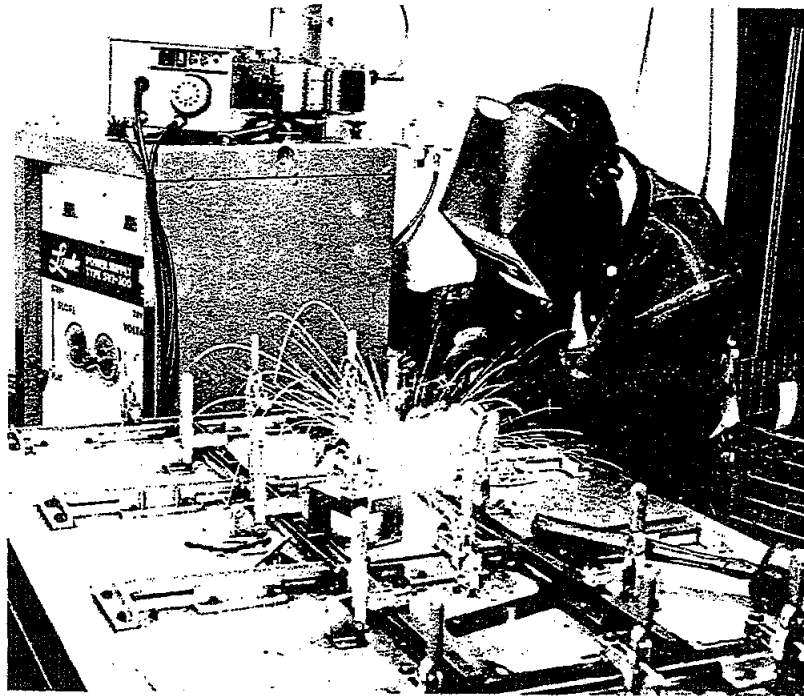
This arrangement is schematically shown in Fig. 9 and a typical application using jigs for holding the parts is shown in Fig. 10.



Schematic diagram of gas metal arc welding process

Fig. 9

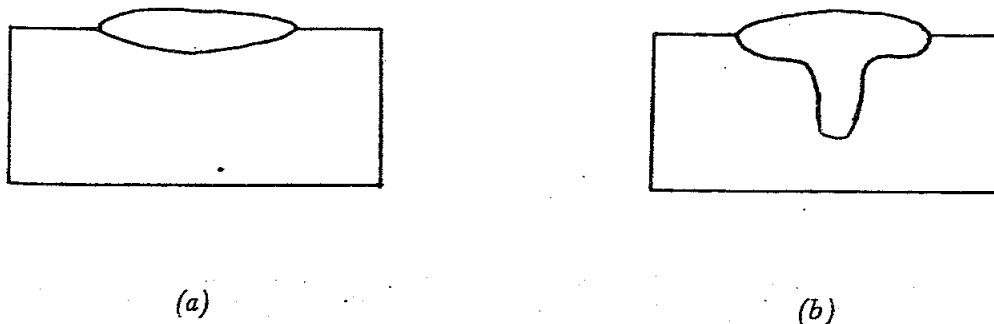
TEST QUESTION.



GMAW Process in use on well jigged application
Fig. 10

Type of Current and Polarity

The effect of polarity on penetration in GMAW is the opposite to that observed in GTAW. In the latter case it was shown that the electrode negative gave deep penetration, since electrons are emitted from the tungsten and strike the work piece. In the GMAW process the positive ions play a larger role in the heating process, and maximum heating of the workpiece occurs when ions travel from the electrode to the work piece, i.e., electrode positive. This is illustrated in Fig. 11. In most cases GMAW is carried out with the electrode positive, and most electrodes listed in CSA W48.4 or AWS A5.18 are for electrode positive use.



GMAW (a) with electrode negative (b) electrode positive
Fig. 11

Modes of Metal Transfer

TEST QUESTION

- Axial Spray Transfer - FINE MIST
- Globular Transfer - GLOBULE BIGGER THAN WIRE SIZE
- Short Circuiting Transfer - GLOBULE SMALLER THAN WIRE SIZE

There are three general modes of transfer of metal from electrode to the work although one may merge with another. In spray transfer, as illustrated in Fig. 12, the metal crosses the arc in a spray of fine droplets. In its preferred form, axial spray, the metal is transferred in line with respect to the work. This arc stiffness is highly advantageous since the drops can be easily directed without affecting arc behaviour. In globular transfer, as seen in Fig. 13, relatively large globular drops fall at random from the end of the wire and the arc becomes erratic. Such a transfer mode is avoided in practice. Table 3 shows the range of conditions over which various transfer modes are obtained.

Spray Transfer

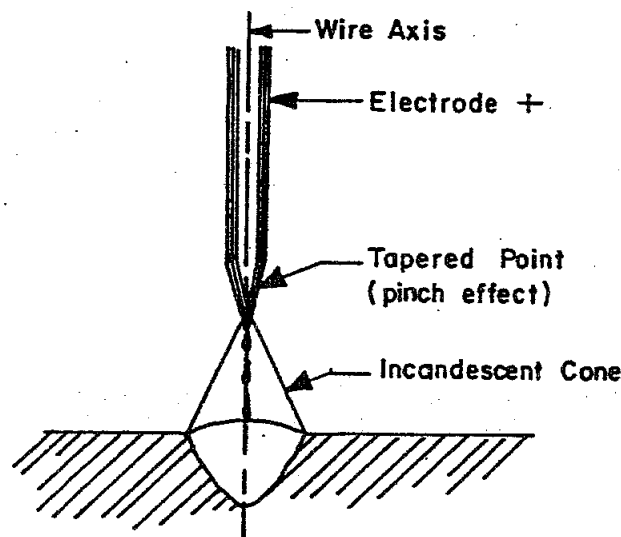


Fig. 12 Controlled axial spray transfer

Globular Transfer
Reverse Polarity

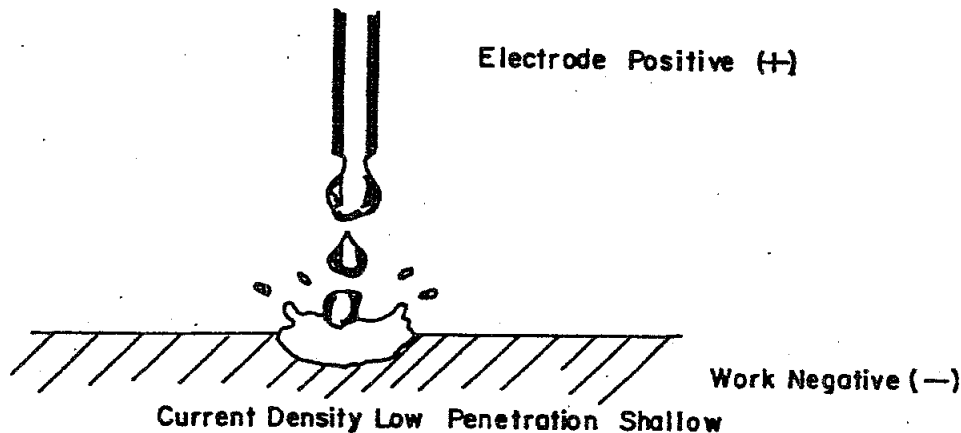


Fig. 13 - Random erratic globular transfer

Effect of Current Density

Fig. 14 shows the effect of current density on the mode of transfer. For a given wire size, current density increases with the current and in the case illustrated, the so-called transition point between globular and spray occurs at a current of 220 amperes.

Metal Transfer Types in Mild Steel — GMAW Using CO ₂ Shielding Gas			
Transfer Mode	Operating Range		Type of Applications
	Arc Volts V	Current A	
Short circuit transfer or dip transfer.	16 - 22	40 - 190	Sheet in all positions. Plate in vertical and overhead positions.
Semi-short circuiting arc	24 - 28	200 - 300	Medium gauges in the downhand position.
Free flight or spray transfer.	28 - 40	200 - 500	Plate thicknesses in the downhand position.

Table 3

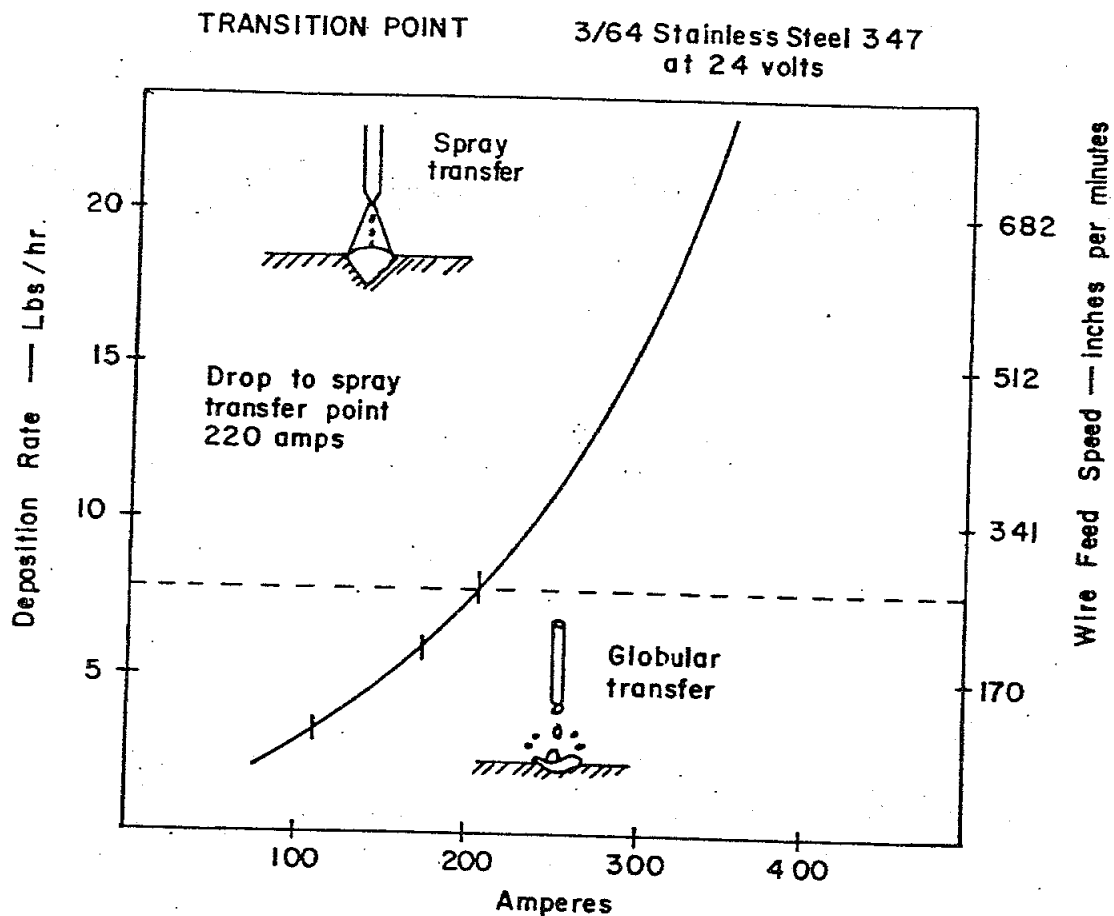


Fig. 14 Effect of current density on mode of metal transfer
Note: Transition Point C from globular to spray type.

Short Circuiting Transfer

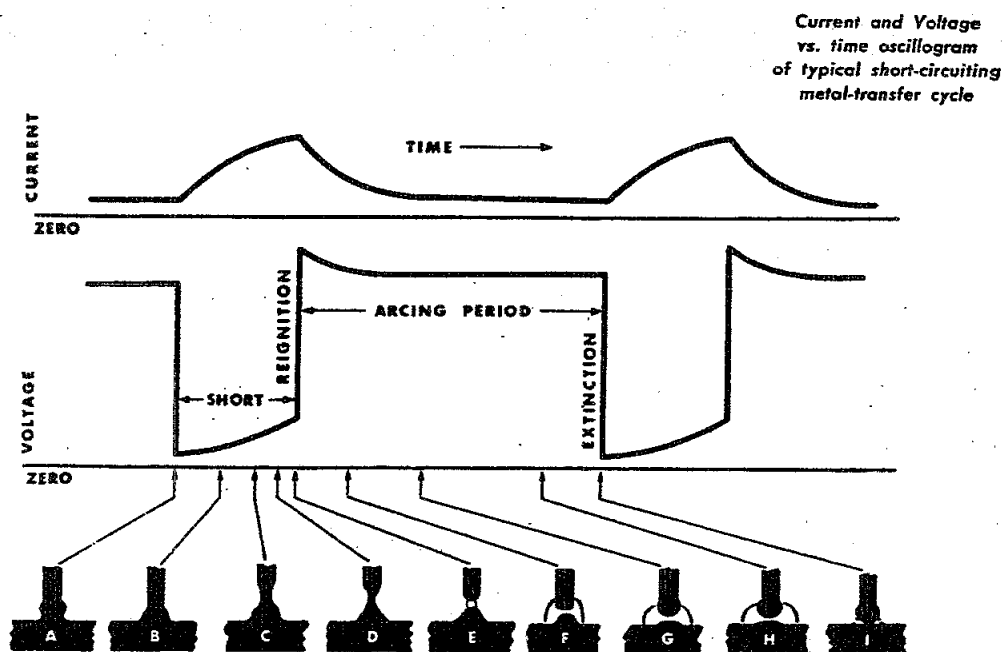
The third mode, called short-circuiting or dip transfer can, with a proper power source, give excellent results with low currents, thus rendering it particularly useful for light gauge material. Also, the relatively high viscosity of the molten weld metal makes it suitable for out-of-position welding.

Table 4 indicates the deposition rates when using GMAW at the maximum current for short circuiting metal transfer to occur. Above this current the mode of transfer will start to change.

Wire Diameter in. mm	Maximum Wire Feed Rate in/min	Current A	Arc Voltage V	Deposition Rate	
				lb/hr	lb/hr.A
1/32 0.8	300	130	18	7.5	0.058
3/64 1.2	160	175	19	9.5	0.055
1/16 1.6	80	175	20	9.0	0.050
3/32 2.4	40	175	21	8.5	0.047

Deposition rates of mild steel electrodes (CO₂ coverage) at maximum short circuiting conditions
Table 4

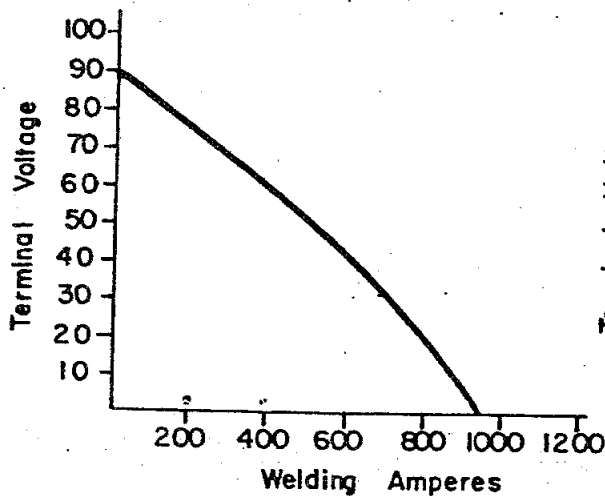
The sequence illustrated in Fig. 15 demonstrates the short circuiting transfer. It will be seen that transfer takes place during repetitive short-circuits through contact of the molten electrode with the weld puddle. These short circuits may occur well over a hundred times per second.



Sequence in short circuit on dip transfer of globule
Fig. 15

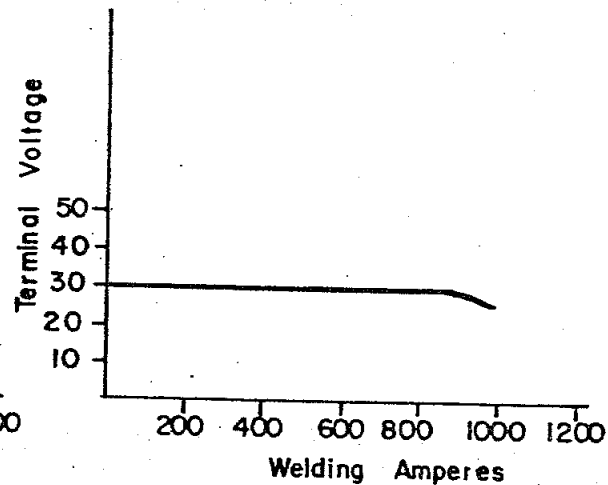
Power Sources for GMAW

Although several types of power sources have been used in the past for GMAW, the type most widely used now is the *constant potential* (i.e., constant voltage) type. Constant potential refers to the shape of the volt-ampere characteristic curve and is a plot of the voltage recorded across the arc when a given current is drawn from the power source. Two types of characteristic curves are shown in Figs. 16 and 17. The one on the left being a constant current and the one on the right a constant potential. The use of a constant potential power source in GMAW provides a degree of automatic arc length adjustment.



WELDING AMPERES
Fig. 16

Characteristic volt ampere curve of a constant current conventional welder for single operator; normally used for stick electrodes.



WELDING AMPERES
Fig. 17

Characteristic volt ampere curve of constant voltage machine for GMAW.

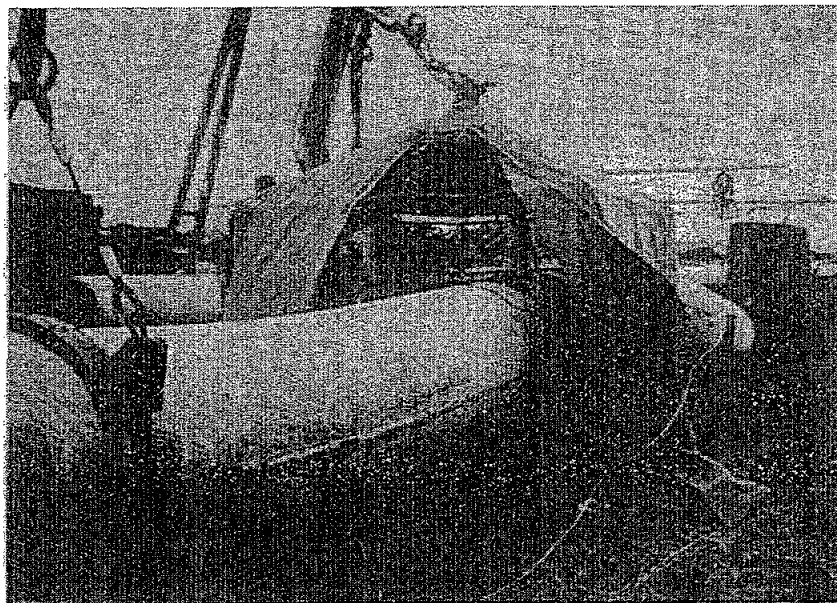
Gases

Initially, the inert gases, argon and helium, were used with the gas shielded processes. Further investigation revealed that small additions of oxygen or other reactive gases gave improved results in some applications and the use of 1 to 5 per cent oxygen with argon is now quite general. At an early stage, attempts were made to substitute a cheaper gas than argon or helium and much research was centred on the use of carbon dioxide (CO_2). At first, this process was characterized by excessive spatter and porosity but the problems were gradually solved and CO_2 is now widely used as a shielding gas for mild steel welding, either alone or with argon and oxygen. It is used with the solid wires, with either spray or dip transfer, and with the composite wires and spray transfer technique.

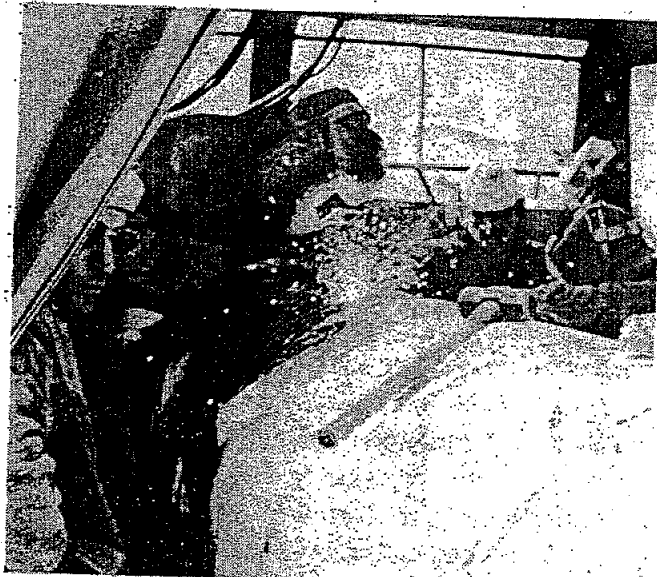
Use of GMAW

The use of GMAW has increased greatly in recent years and has replaced SMAW in many applications. In the welding of aluminum, it is the dominant process, with a limited usage of GTAW where there is difficulty in using GMAW. It is used to a great extent in the welding of stainless steel and almost exclusively in the welding of many other metals. With the development of satisfactory CO_2 processes its application in carbon and low alloy steel welding has been widespread. The high current densities and correspondingly high deposition rates, together with the increase in operating factors, give it substantial economic advantages, in many applications, over stick electrodes. The prospective user should, however, be aware of certain factors inherent in the process, which may limit the speeds and savings actually obtained. The welding operator needs to be trained to manipulate the torch properly. Poor manipulation, particularly with solid wire, can result in fusion defects that are not readily observable. The high travel speeds require greater care and quicker reactions than are necessary with stick electrodes. Lack of skill or care can cause loss of productive time owing to such mishaps as the electrode freezing to the work or burning back inside the holder. Properly maintained equipment, sound training and conscientious supervision will result in the advantages of the process being fully realized.

The process also can be readily converted to automatic operation by suitable fixturing and head or work travel mechanisms. When used in the normal semi-automatic (i.e., semi-mechanised, but hand held) manner it can be the most economical method for much work in both shop and field, even when fairly short runs are involved. Typical examples of the use of GMAW are shown in Figs. 18, 19 and 20.



GMAW dip transfer in use on 36" diameter pipe in England for North Sea Gas Line
Fig. 18



GMAW dip transfer under rain and wind proof tent on North Sea Gas Line project
Fig. 19



Welding of circumferential seams of storage tank using two GMAW units with CO₂ shielding gas and flux cored wire. Joint is welded from both sides at the same time with canvas protection from wind.

Fig. 20

Advantages of GMAW

A summary of its advantages includes:

- a) High deposition rate;
- b) Greater percentage of arc time since electrode changing is infrequent;
- c) A more economical use of filler metal since there is virtually no stub loss;
- d) Deeper penetration, which allows smaller groove angles and, hence, less weld metal;
- e) A potential for high quality weld metal with low hydrogen.

Flux Cored Arc Welding (FCAW)

This process is very similar to the gas metal arc process previously described, but, rather than using a solid wire, a hollow wire containing various fluxing or alloying ingredients is used. It is a consumable electrode process in that an arc is struck between the electrode and the workpiece causing the electrode (and flux ingredients) to melt. The electrode wire is continuously fed into the arc from a coil.

There are two main variations of the process, one using an external shielding gas and the other self-shielding. In the latter, gases are generated from the flux and special ingredients are included to reduce contamination of the weld metal by oxygen and nitrogen. The principal of operation of the two versions are shown in Figs. 21 and 22.

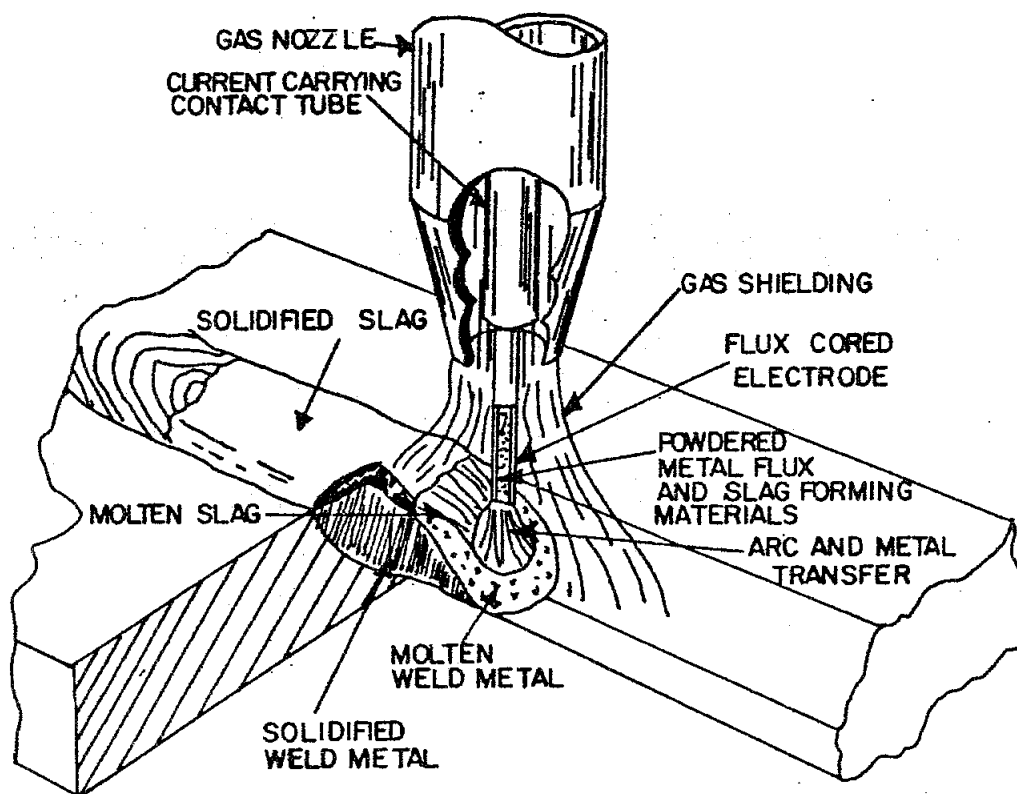


Fig. 21 — Gas shielded flux cored arc welding

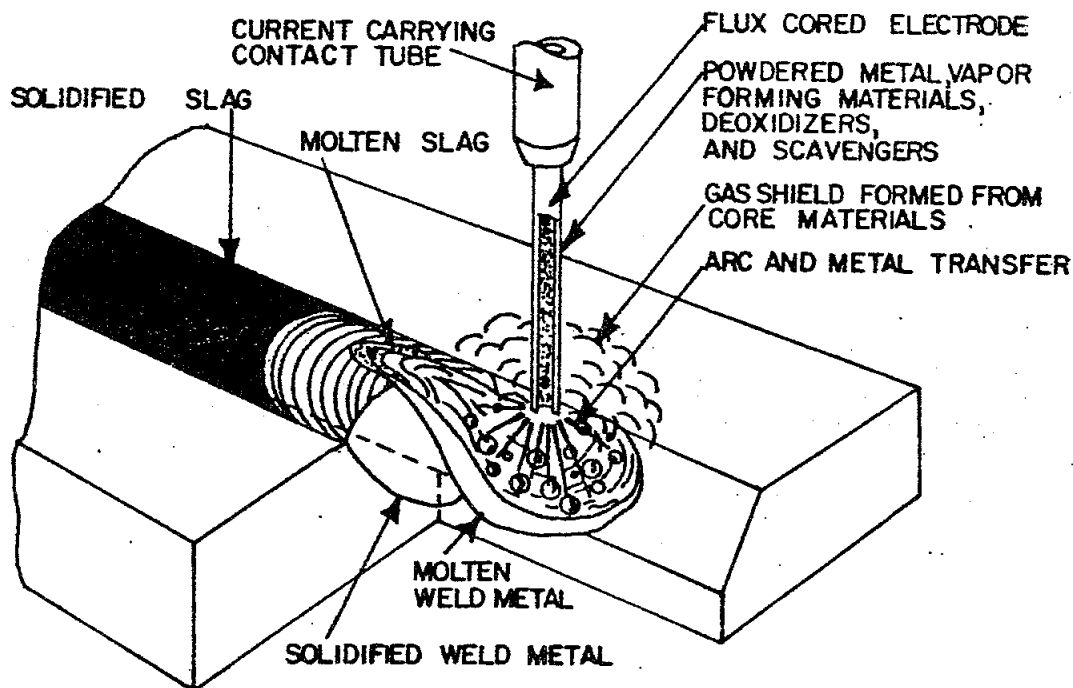


Fig. 22 — Self-shielded flux cored arc welding

Although the gun can be mounted on a carriage as a fully mechanized process, it is most widely used in the semi-automatic (i.e. semi-mechanized) mode in which the gun is hand held and manipulated by the welder. In this way the process retains the flexibility of shielded metal arc welding, but has the advantage of a high duty cycle and high deposition rate. The flux cored process can produce high quality welds and is being used increasingly on steel fabrication in the medium thickness range.

Types of Wire Construction

A wide range of tubular flux cored wires are available and several types of wire construction have been used. Some examples are shown in Fig. 23. The majority of flux cored wires are not copper coated, but seamless type wires, which can be copper coated, have been developed.

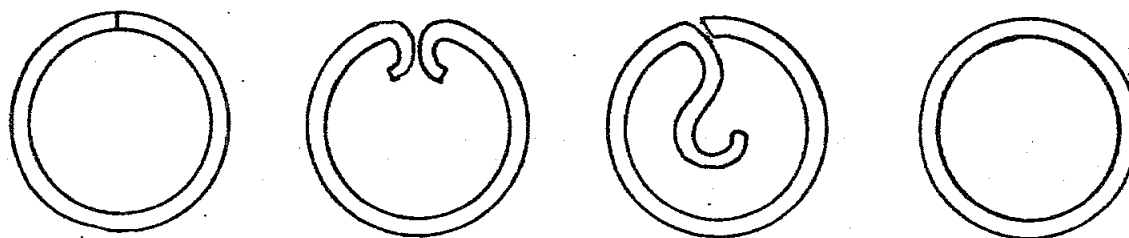


Fig. 23 — Cross sections of various types of cored wires.

Gases

The most common gas used with flux cored welding is *carbon dioxide* CO_2 at a typical rate of 35 cu.ft/hr (16.5 L/M). High penetration is achieved with this gas, and steel up to 1/2 in. (13 mm) thick may be welded without an edge preparation. With CO_2 , the transfer of metal is usually globular.

Because of the oxidizing nature of a CO_2 gas shield, the wire contains various deoxidizing elements (usually silicon and manganese), which react with the oxygen in the weld metal and prevent porosity. As with solid wire CO_2 shielded GMAW carbon also reacts with the gas and weld metals tend to remelt in about 0.1% carbon regardless of the original carbon in the wire on plate. Gas mixtures may be used, and a 75% argon, 25% CO_2 mixture is popular and often preferred for welding out of position.

With the self shielding system, no external gases are required and all of the necessary shielding, deoxidation and denitrifying comes from ingredients in the core of the wire. This makes the equipment simpler and also makes the process more tolerant to wind which could disturb an external gas shield in an outdoor application.

Materials

The flux cored process is used primarily for welding steels including structural grades, pressure vessel grades, alloy steels and some stainless steels. It is also used on cast iron and can be used for hard surfacing, overlaying and repair build-up.

Electrodes

Specifications for flux cored tubular wires are covered in AWS 5.20 and CSA W48.5. There are differences between the American and Canadian Specifications which should be noted.

Flux cored wires have the designation 'T', meaning *tubular* and several types are specified covering both gas shielded and self-shielded types. Most gas shielded wires are operated electrode positive, but some (including some self-shielded wires) are operated electrode negative.

Welding Parameters

The relation between the electrode feed rate (in/min) and the current for various wire sizes is shown in Fig. 24 for an E70T-1 type wire (CO_2 shielded). To maintain a controlled arc length, a constant potential power source is used, as with the GMAW process previously described.

Voltage can have an important effect on the bead shape. A high voltage leads to a wide bead and may give excessive spatter, while too low a voltage will reduce penetration and give a convex bead. In the self shielding system incorrect voltage may also lead to increased pick up of nitrogen from the air.

Typical Welding Conditions

Typical current ranges used with FCAW are shown in Table 5. Some examples of typical procedures and joint preparations used are also given in Table 6.

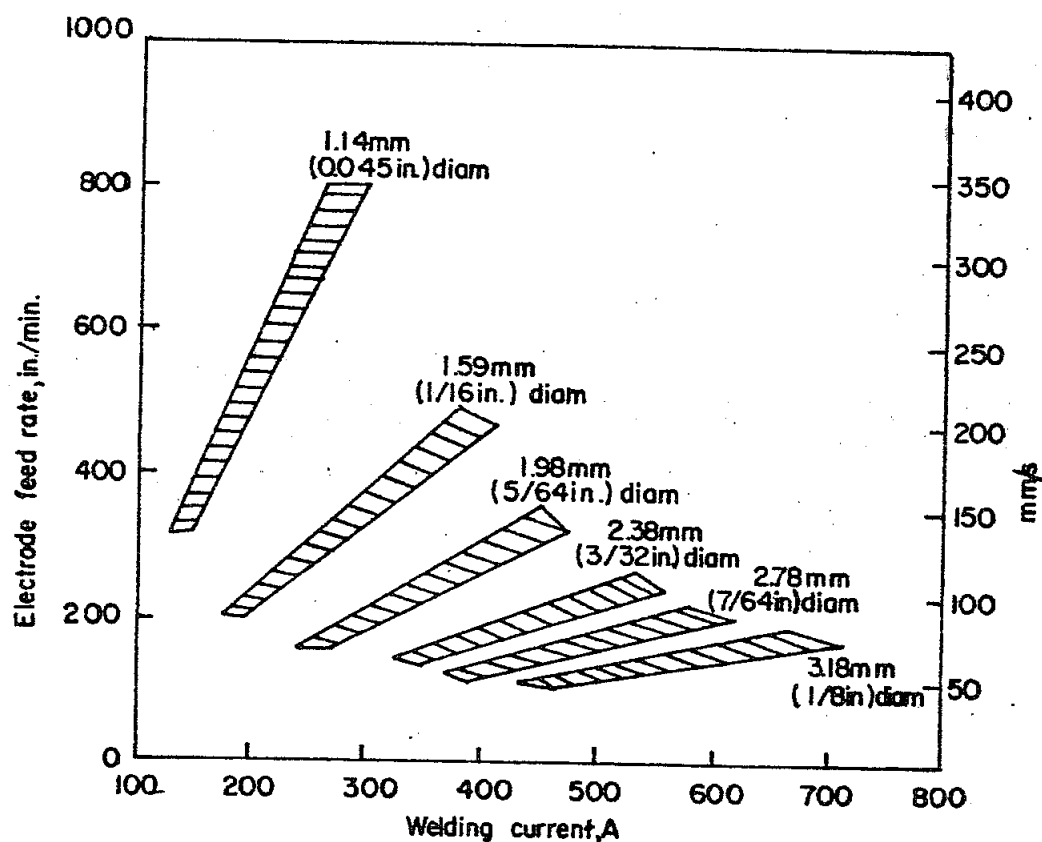


Fig. 24 — Electrode feed rate vs welding current range for E70T-1 steel electrodes with CO₂ shielding

ELECTRODE SIZE		FLAT POSITION		HORIZONTAL POSITION		VERTICAL POSITION	
in.	mm	Ampere	Voltage	Ampere	Voltage	Ampere	Voltage
0.045	1.2	150-225	22-27	150-225	22-26	125-200	22-25
1/16	1.6	175-300	24-29	175-275	25-28	150-200	24-27
5/64	2.0	200-400	25-30	200-375	26-30	175-225	25-29
3/32	2.4	300-500	25-32	300-450	25-30	—	—
7/64	2.8	400-525	26-33	—	—	—	—
1/8	3.2	450-650	28-34	—	—	—	—

Table 5 — Typical Current Ranges for FCAW (direct current electrode positive)

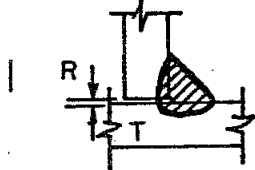
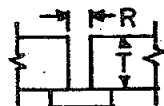
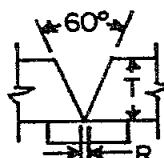
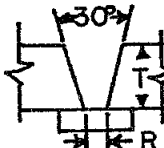
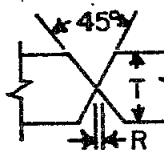
Typical Gas Shielded Flux Cored Arc Welding Procedures for Carbon Steel (E70T-1 electrodes)										
Joint design	Thickness T		Root Opening R		Total passes	Electrode Diameter		Welding Power dcrp. (ep)		
	mm	in.	mm	in.		mm	in.	V	A	
	Horizontal position fillet weld (semi-automatic)									
	5	3/16	0	0	1	1.98	5/64	28	350	
	13	1/2	0	0	3	2.78	7/64	30	450	
	Flat position groove welds (semi-automatic)									
	3	1/8	1.6	1/16	1	1.98	5/64	28	325	
	13	1/2	6	1/4	2	2.38	3/32	32	450	
	13	1/2	0	0	2	2.38	3/32	30	480	
	25	1	0	0	6	2.78	7/64	32	525	
	16	5/8	5	3/16	3	2.78	7/64	32	525	
	25	1	5	3/16	6	2.78	7/64	32	525	
	25	1	0	0	6	2.78	7/64	32	525	
	51	2	0	0	20	2.78	7/64	32	525	

Table 6

Gas, Wire and Water Supply

For GTAW and GMAW welding, with whatever source, provision must be made for the supply of shielding gas to the arc. This is usually carried through a control box which incorporates electrical devices to start and stop the gas flow, as required. The gas flow is normally continued for a set period after the arc is broken, so as to give protection to the cooling weld metal and, in the case of GTAW, to protect the tip of the tungsten electrode until it cools. In some applications a purging flow of gas is provided before the arc is struck. The shielding gas is led through a hose to the torch or gun and leaves it through an annular space around the electrode, thus providing a full shroud for the arc. With GMAW there is the further requirement of feeding continuous electrode into the arc. In the "push" type of equipment, the wire is supplied from a reel mounted on the machine and propelled by the motor driven wire feed rolls through a conduit to the gun. For fine or soft wire where difficulty is often encountered in securing even feed of the wire through the conduit, the "pull" type is often used, in which motor driven rolls mounted on the gun pull the wire through the conduit. Combinations of these systems are also used. Some units have a small spool of wire mounted on the gun and feed from there. Another arrangement is to have a portable reel and feeder which can be carried close to the job site. These various types are illustrated in Figs. 25, 26, 27 and 28.

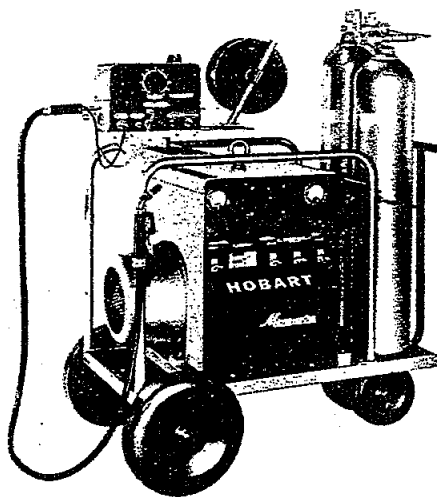


Fig. 25 – GMAW Unit with MG Set, Wire Feeder and Gas Cylinder

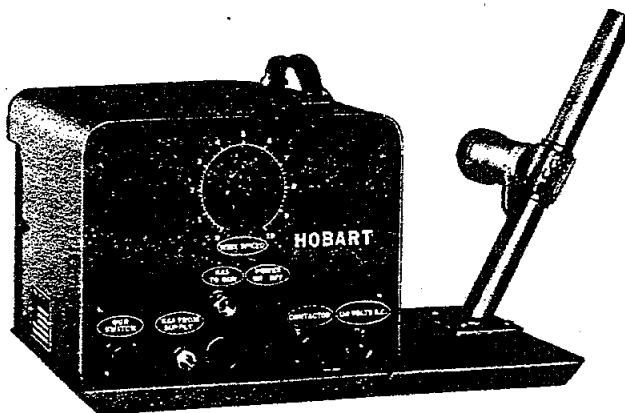
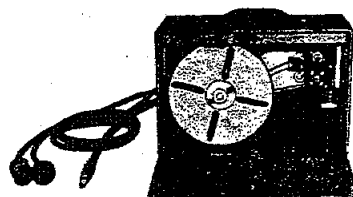


Fig. 26 (a)– Control Box with Wire Reel Holder, arranged for operation remote from power source

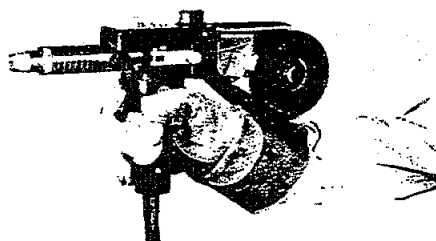


(b)

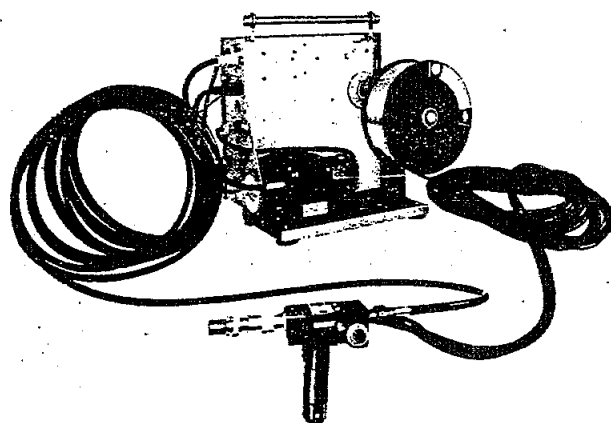


(c)

Fig. 26 (b) and (c) — Wire Feeder with 8 lb spool for remote operation



*Fig. 27 — Wire Feeder and Spool
Integral with Gun*



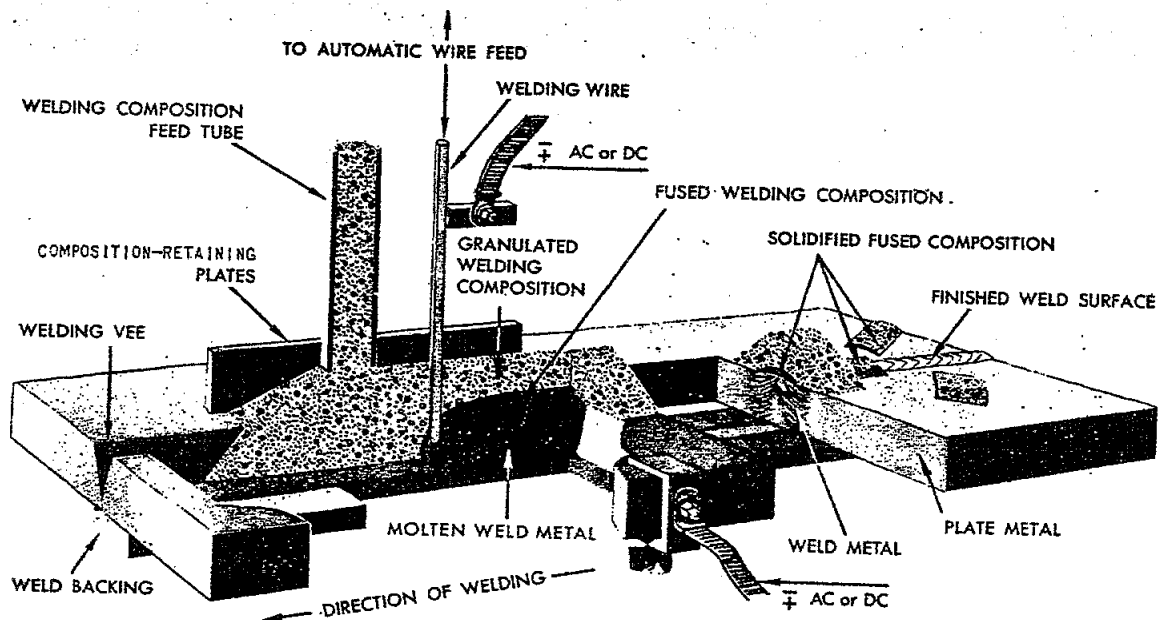
*Fig. 28 — Combination Push-Pull Wire
Feed and Gun*

A further complication in design arises with both GTAW and GMAW when high currents are used, necessitating some form of artificial cooling for the gun. This is provided by circulating water through the gun from a normal water supply for a circulating system carried with the machine. Inlet and outlet water connections are usually carried through the control or wire feeder box. Pressing the trigger of the gun, closes the electrical circuit, at the same time starting the wire feed and the gas and cooling water supply. Cooling water is generally carried in a hose, surrounding the welding cable so as to assist in cooling it. The various services are frequently enclosed in a composite cable. Those concerned with the use of water cooled guns should be aware of the danger of leaks. A leak in the gun, which may be small enough to go unnoticed in normal operation, may result in hydrogen entering the weld deposit with consequent porosity and cracking tendency. The gun should be carefully examined from time to time to ensure that no leaking is taking place.

Submerged Arc Welding (SAW)

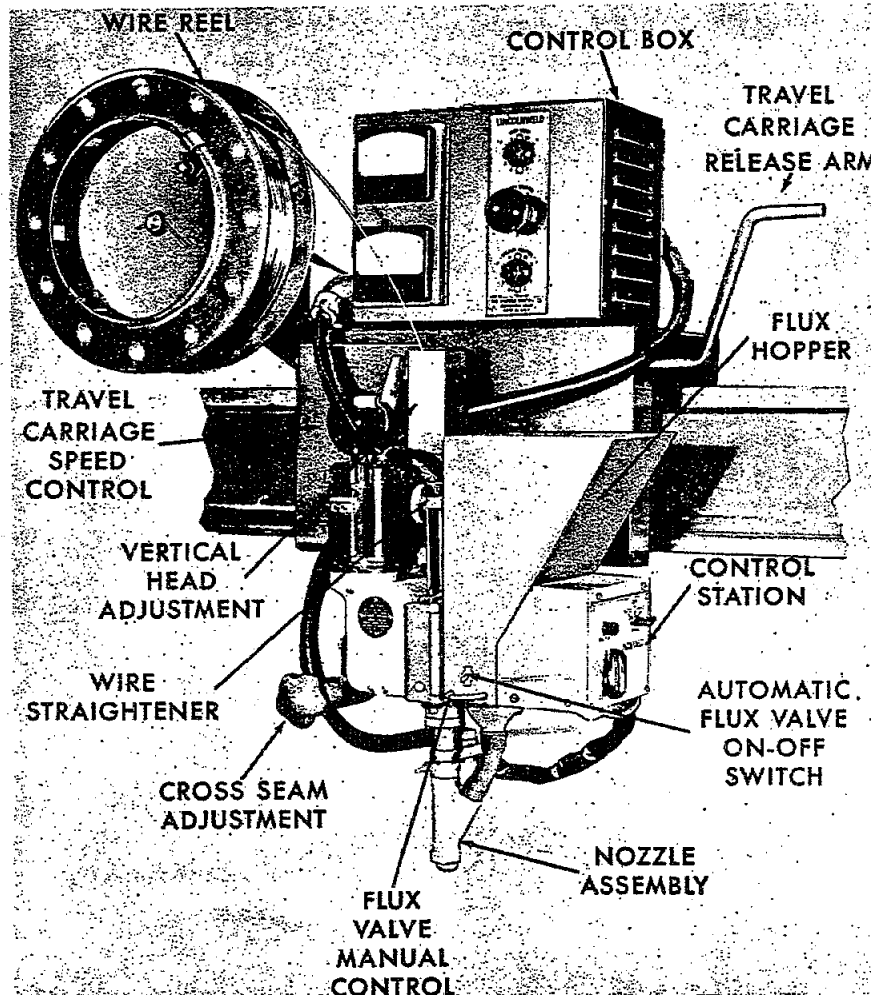
This process was in general use before the gas shielded process had any wide acceptance. It is shown schematically in Fig. 29, and Fig. 30 shows a typical carriage mounted head.

As will be seen in the sketch, granular flux is deposited on the unwelded seam ahead of the consumable solid electrode. The arc is struck underneath the flux which, although a non-conductor when cold, becomes highly conductive when molten, which occurs at about $2,370^{\circ}\text{F}$. This forms a path for the current and the generated heat keeps the flux molten. The welding operation takes place beneath the flux without sparks, spatter, smoke or flash, thus protective shields or helmets are not needed. The molten flux, which is lighter than the weld metal, rises to the surface of the weld and solidifies as a glass-like covering for the weld bead, protecting it from oxidation, slowing its rate of cooling and producing a smooth well shaped bead. The cold flux is readily removable, sometimes popping off the bead spontaneously. Excess, unmelted flux can be salvaged and re-used after proper processing. Both DC and AC are used and the machines may be of either the conventional drooping voltage characteristics or constant potential type. There are advantages in the use of each of these types of current supply, dependent upon the application. With constant potential, the arc length is self-adjusting, similar to the action of this supply in GMAW. In a machine with drooping characteristics, a voltage sensitive relay adjusts the wire feed to maintain the desired arc voltage. Two electrodes may be used in series or parallel and two or more heads with separate power supplies for each. Currents as high as 4,000 amperes may be used although normally they will not exceed 2,000 amperes.



Submerged arc welding process (Granular flux shielding)

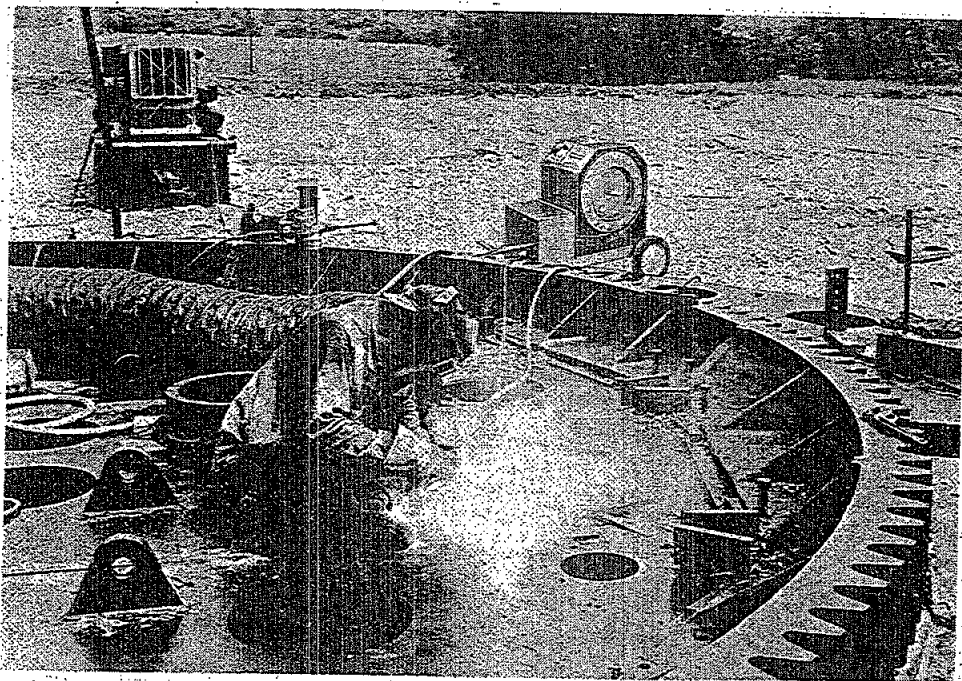
Fig. 29



Carriage mounted head for automatic submerged arc welding

Fig. 30

Originally developed for fully automatic operation, a semi-automatic version is also available with automatic control of the flux feed, arc conditions and sometimes travel; but a welding operator must provide guidance. This gives much higher rates of welding than stick electrode while at the same time preserving some of the flexibility in use of the latter. Figure 31 shows a semi-automatic submerged arc unit in operation.



*Semi-automatic submerged arc unit in operation
under guidance of operator. Flux is automatically fed*

Fig. 31

High currents and deposition rates are inherent in submerged arc welding, and for long runs of repetitive or similar work the process offers the maximum in economy together with first class weld quality. Very deep penetration is attainable leading to substantial savings in edge preparation.

By the use of alloyed wires to provide the weld metal with suitable alloying elements, a wide range of low alloy steels can be welded and various stainless, nickel steels and other metals can be used as electrodes when the application warrants.

High standards of fit-up and preparation, where the latter is required, must be maintained and full advantage taken of the use of positioners and manipulators.

Recommended Currents

Table 7 indicates typical current ranges for each particular electrode size.

Wire Diameter (in.)	Current (amp)
5/64	200 — 650
3/32	230 — 650
1/8	300 — 900
5/32	420 — 1000
3/16	480 — 1100
7/32	600 — 1200
1/4	700 — 1600
5/16	1000 — 2500
3/8	1500 — 4000

Table 7 — Typical Current Ranges for Submerged Arc Wires

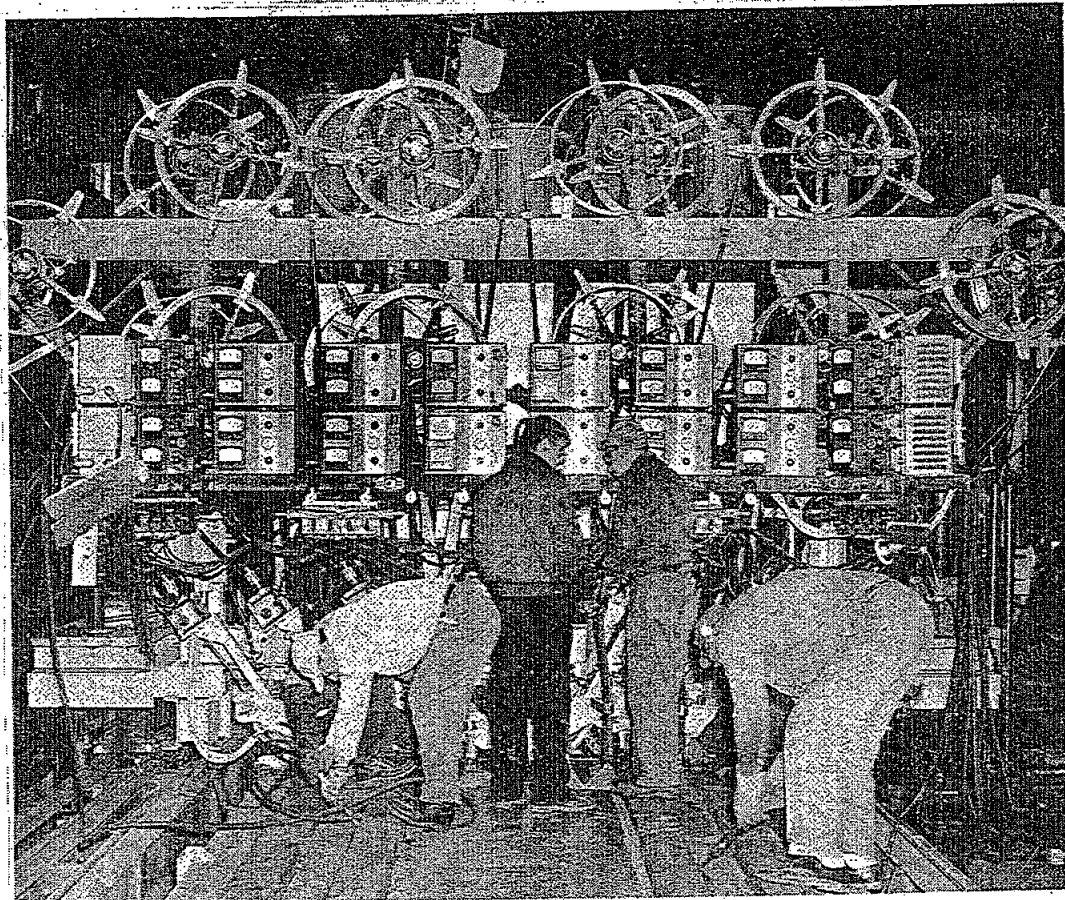
DCRP (DCEP) is the recommended type of current and polarity when deep penetration is important and high speeds and small welds are involved. Welds made using DCRP will exhibit better resistance to porosity.

DCSP (DCEN) will give a greater deposition rate than reverse polarity. This might be considered as approximately one-third greater than would be obtained using the same current.

From a practical point of view a change from DCRP to DCSP may necessitate an increase in voltage (about 3-4 volts) if a similar bead shape is required.

Multiple Heads with SAW

Of recent years, the constant search for still more efficient means for welding has led to the use of multiple heads for submerged arc, sometimes combined with automatic GMAW. In one application, involving the welding of 8 inch thick plates to 2,300 lbs. per foot H sections, three heads were used. The leading GMAW head put in the root pass and provided preheat and the two following SAW heads deposited 48 lbs. of weld metal per arc hour. The use of ten pairs of tandem mounted submerged arc heads giving ten welds in one pass is illustrated in Fig. 32.

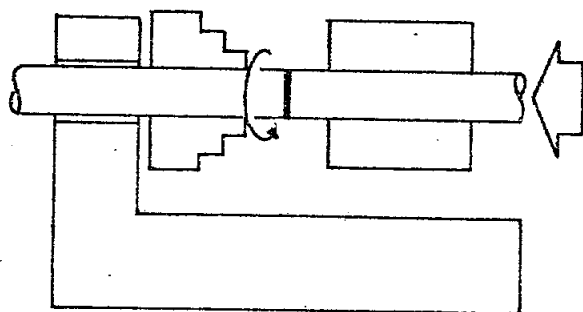


Multiple head production machine making ten welds in one pass

Fig. 32

Friction Welding

In the friction welding process, heat is generated by the friction between a rotating and stationary part when brought together under load. When the joint area is sufficiently plastic the rotation is stopped and the forging load increased to produce the weld. The general principles are illustrated in Fig. 33. The heat generation is proportional to the square root of the applied pressure and power dissipation is independent of speed. High speeds give more rapid welding and narrower heated zones. In mild steel, a surface speed of 1.3 - 3.0 m/sec is used. Higher pressures are required for metals with higher melting temperatures and higher hot strengths.



General principles of friction welding

Fig. 33

Materials having a relatively low high temperature strength and a thin oxide film may be readily welded with welding conditions not being critical. Material with good high temperature strength (including the high nickel alloys) require a forging cycle and longer welding times. The high conductivity metals, such as copper, can be welded, and this is facilitated by high rotational speeds and short welding times to increase the energy input rates. Austenitic stainless steel and titanium can be friction welded without difficulty. Friction welding can be particularly useful in joining dissimilar metals which are hard to weld by other means.

Friction welding, in which heat generated by the friction of a rotating component against a fixed component, results in a weld *without a weld metal region with characteristic solidification structure*. The process therefore avoids many of the problems that can arise from the weld metal structure such as hot cracking.

The two chief variations of the process are the conventional friction welding method and the inertia method. In the latter, the energy is stored in a fly-wheel system which is then brought to rest during welding thus consuming all the stored energy. This method has the advantage of shorter welding times. Some representative conditions for the friction and inertia welding of various metals are given in Tables 8 and 9.

Material	Diameter ins	Relative Rotational Speed rpm	Contact Pressure		Total Time sec
			Heating Phase psi	Forging Phase psi	
Stainless Steel	1.0	3,000	12,000	16,000	7
	5.5 OD	800	20,000	20,000	35
	4.5 ID				
Copper	1.0	6,000	5,000	10,000	18
Aluminum	0.75	3,800	4,000	6,500	6

Table 8 — Representative Friction Welding Parameters

Material	Weld Parameters			Resultant Weld Conditions		
	Speed rpm	Thrust lbs	Inertial Mass lb-ft ²	Energy ft-lbs	Upset ins	Weld Time secs
Superalloys	1500	50,000	130	50,000	0.15	3.0
Stainless Steel	3500	18,000	14	30,000	0.10	2.5
Copper	8000	5,000	1.0	10,000	0.15	0.5
Titanium	6000	8,000	1.7	16,000	0.10	2.0

Table 9 — Representative Conditions for Inertia Welding (One Inch Bars)

Friction welding requires a large piece of equipment usually custom built for specific applications. The largest machines built to-date have a forging force of 250 tons and can join up to 19,350 mm² of medium carbon steel in less than 60 seconds.

The friction welding operation is completely automatic and can give welds of high reliability. A flash or metal upset is produced which can be removed by shearing on the same machine.

The friction and inertia welding variations of the process are very reproducible and this, combined with the short weld times, makes them appealing for mass production. Quality control depends essentially on ensuring that the primary variables (speed, force etc.) are within prescribed limits although most materials are quite tolerant to variations. The most common control is to measure the upset (axial displacement) which in practice can be maintained within 5%.

Electron Beam Welding

This process uses a concentrated stream of electrons which are accelerated under high-voltage potential (15-200 kV) and focused on the workpiece (See Fig. 34). The electron beam transfers the energy very efficiently, which results in narrow, deep-penetrating welds and heat-affected zones. Welding is usually done in a vacuum chamber to avoid electron scattering, but non-vacuum and partial vacuum systems have been developed more recently.

Original EB units used hard vacuums of better than 10^{-3} torr but, since 1966, medium vacuum systems have been widely used. In the latter, a high vacuum is maintained in the gun itself, but the workpiece has a vacuum of 10^{-2} to 10^{-1} torr. This can be reached with mechanical pumps without the need for diffusion pumps and greatly reduces the pumpdown time. Another advantage is in designing seals for local vacuum welding where 10^{-2} torr is reached readily with simple sealing methods.

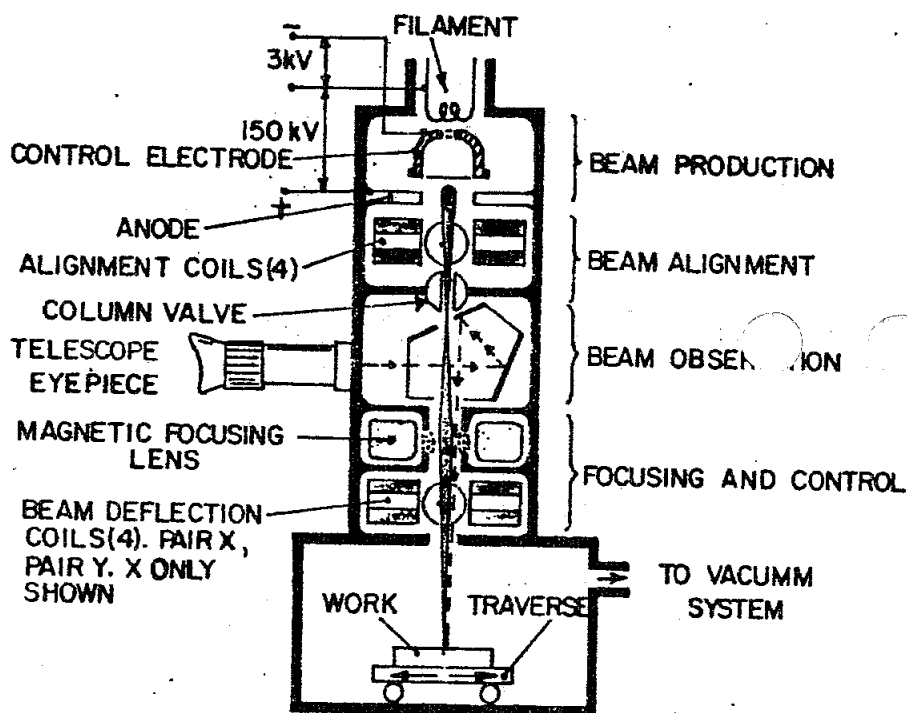
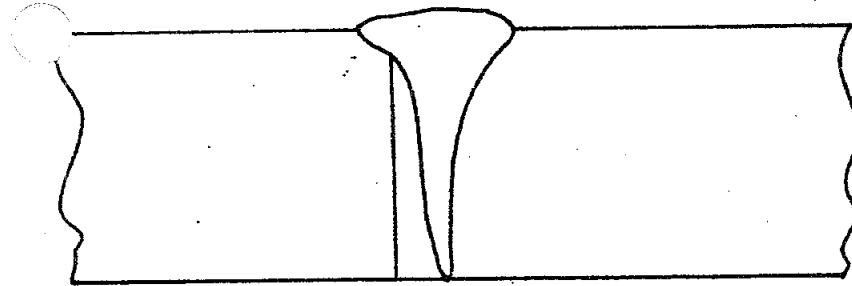


Fig. 34 : Arrangement of high voltage electron beam welder

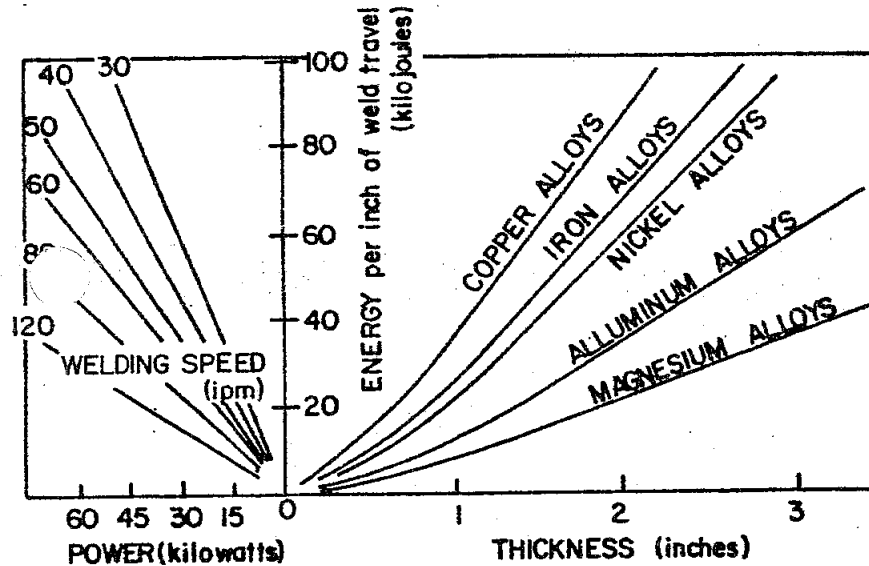
Since the width of the electron beam weld is very narrow, accurate assembly of pieces and accurate tracking is necessary to ensure that the joint is not missed. Due to the characteristic nail head shape of the weld it is possible that a missed joint is not visible on the surface (Fig. 35). A variety of methods are available for tracking since electronic methods have become popular and electronic viewing of the work piece is also feasible. The use of beam deflection to maintain joint alignment and beam rotation, to take account of fit-up errors and minimize porosity problems is widely employed.



Missed joint not detectable from surface

Fig. 35

The typical power requirements for various metals in a hard vacuum system are shown in Fig. 36. The penetration depends upon both the thermal conductivity and the melting point of the materials being welded for a given heat input.



Hard vacuum electron beam welding energy requirements for full penetration welding in several materials as a function of the joint thickness

Fig. 36

The advantages of the process include low distortion, a narrow weld and heat-affected-zone, and mechanical properties of EB welds which usually exceed those of the parent material.

EB welds can suffer from defects, many of which are similar to those that occur in arc welds. Defects include porosity, spatter, shrinkage cavities, cracking, undercutting, cold shuts and missed joints. The possibility of these defects occurring is higher in thicker material, thus requiring that reliable methods of inspection must be available.

In many cases defective EB welds are repaired by simply rewelding after the cause of the problem has been corrected. It is unlikely that additional welding methods would be necessary for the types of defects encountered in EB welding.

Laser Welding

In a laser, (*light amplification by stimulated emission of radiation*), a beam of coherent light is generated which can be focused to create a small spot of intense heat. This high power density makes the laser suitable for the fusion welding of metals. A schematic of a laser set-up for welding is illustrated in Fig. 37. It comprises essentially the laser tube itself in which the light reflected between the end mirrors is amplified, the output window through which energy is extracted, and a system for focusing and directing the light energy to the workpiece. There has been rapid development of high power lasers in the last few years and continuous lasers of kW capability are now in existence.

Three types of continuous wave, carbon dioxide (CO_2) lasers which radiate in the far infrared at a wavelength of $10.6 \mu\text{m}$ are available.

1. *Discharge-tube types* (Fig. 38 a) with output power in the range 0.05 kW per metre length of lasing cavity. Many of this type, with total output power up to about 0.5 kW, are in existence and being applied to micromachining, welding and cutting of thin sheet.
2. *Axial flow types* (Fig. 38 b) are limited to about 0.7 kW per metre. The limitation of power comes from the limited cooling capacity and CO_2 lasers cannot operate efficiently over about 200°C . Applications in welding are limited to thin sheet.

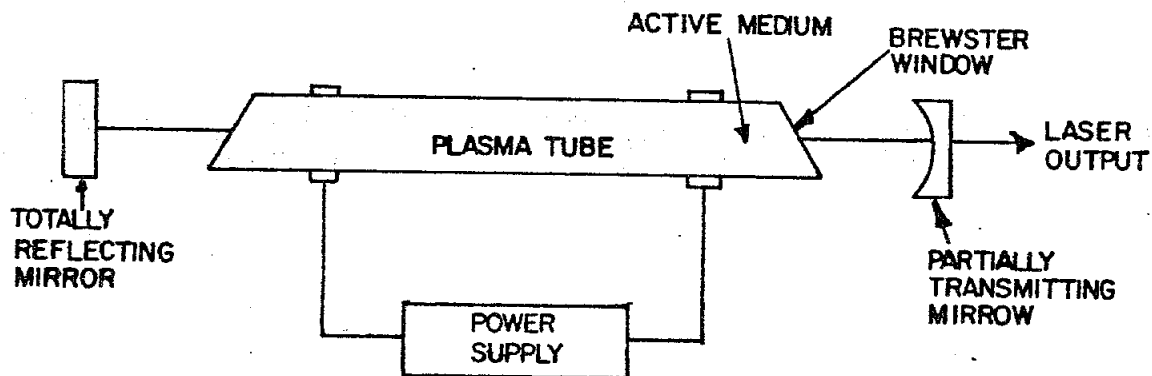
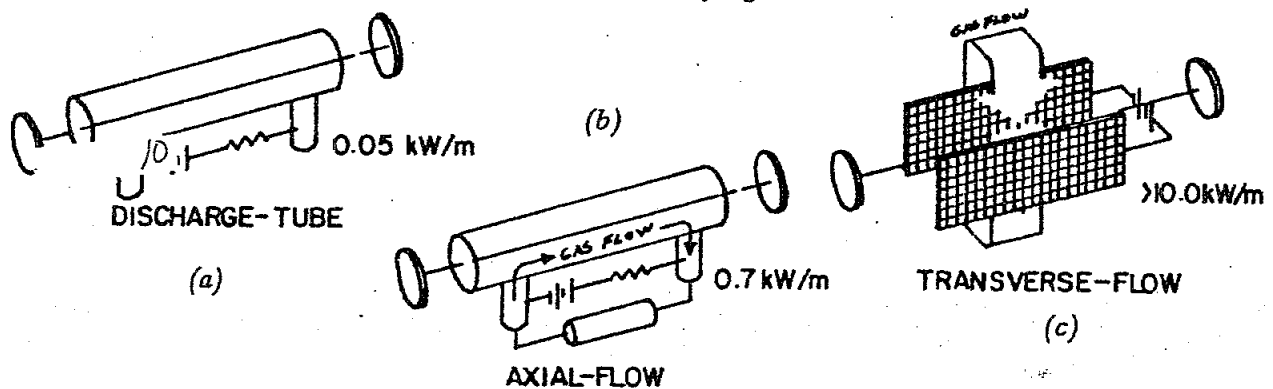


Fig. 37: Schematic of a gas laser



Three basic types of gas lasers showing practical limits of laser output power per metre length of lasing cavity

Fig. 38

3. *Transverse-flow types* (Fig. 38c) solve many of the problems inherent in the discharge tube and axial flow type and allow high power levels exceeding 10 kW per metre. High power lasers with power exceeding 15 kW are available.

Potential Advantages of Laser Welding

Laser welding has many potential advantages, many of which are not shared by other welding processes, and a few of the more significant ones are listed below.

- (a) Welding could be made in areas impossible to reach by conventional processes.
- (b) Because of the energy density, metallurgical changes can be minimized.
- (c) Welds can be made in a magnetic field.
- (d) Welds can be precisely located and several possibilities for monitoring exist.
- (e) No physical contact with the workpiece is necessary, and it could be separated from the source by transparent media.
- (f) All metals can be fused.
- (g) Welds can be made in air, vacuum or inert gas atmosphere.
- (h) Distortion is small.
- (i) Laser welding lends itself to remote television viewing which can also form the basis of an adaptive control tracking system.
- (j) Since it is a fusion system, it can be used for repairing defects by rewelding over the defective area.
- (k) The majority of defects that could occur with laser welds could be repaired with the same system and thus obviate the need for other welding equipment.

The characteristics of laser welds are similar to electron beam welds having a narrow and deep weld shape. The high energy density leads to a narrow heat-affected-zone. The mechanical properties would be expected to be as good as EB or GTAW welds.

The chief disadvantages of the process are the high capital cost and the difficulty of making deep penetration welds in thick material. It is presently limited to about 20 mm thickness.

Diffusion Welding

In this process heat and pressure are used to obtain coalescence of the contacting surfaces. Two stages are involved: first, mechanical contact, and second, metallic bonding. Initial contact area is limited by the surface condition, stress, and yield strength of the material. As temperature increases and yield strength drops, this contact area increases until oxide films disrupt and metallic bonding occurs. In metals such as titanium the removal of the oxide film is facilitated by the solubility of oxygen in the metal. Where solubility is low, as in aluminum, agglomeration of the oxides takes place leaving inclusions. Fig. 39 shows the type of bond formed at constant temperature for different pressures.

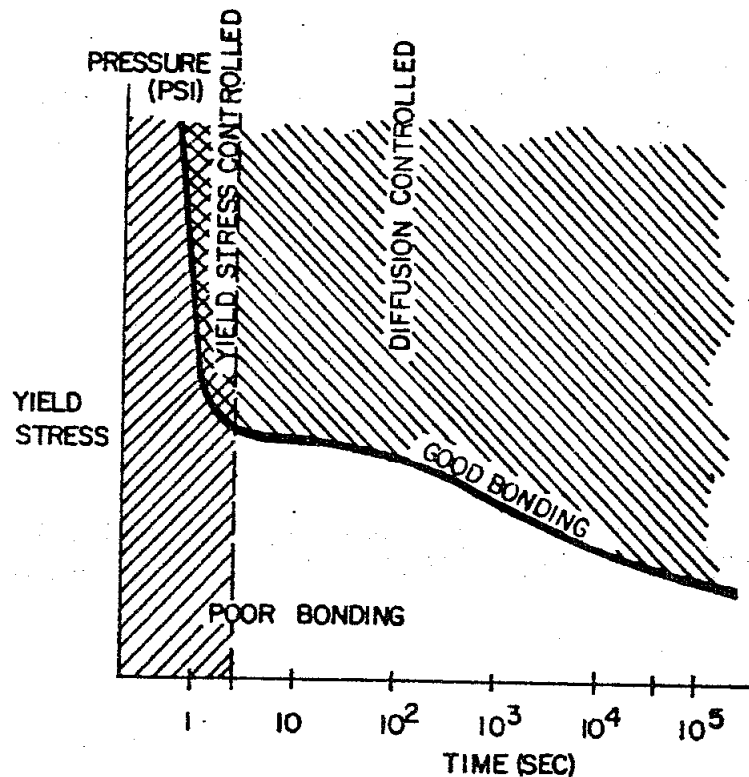
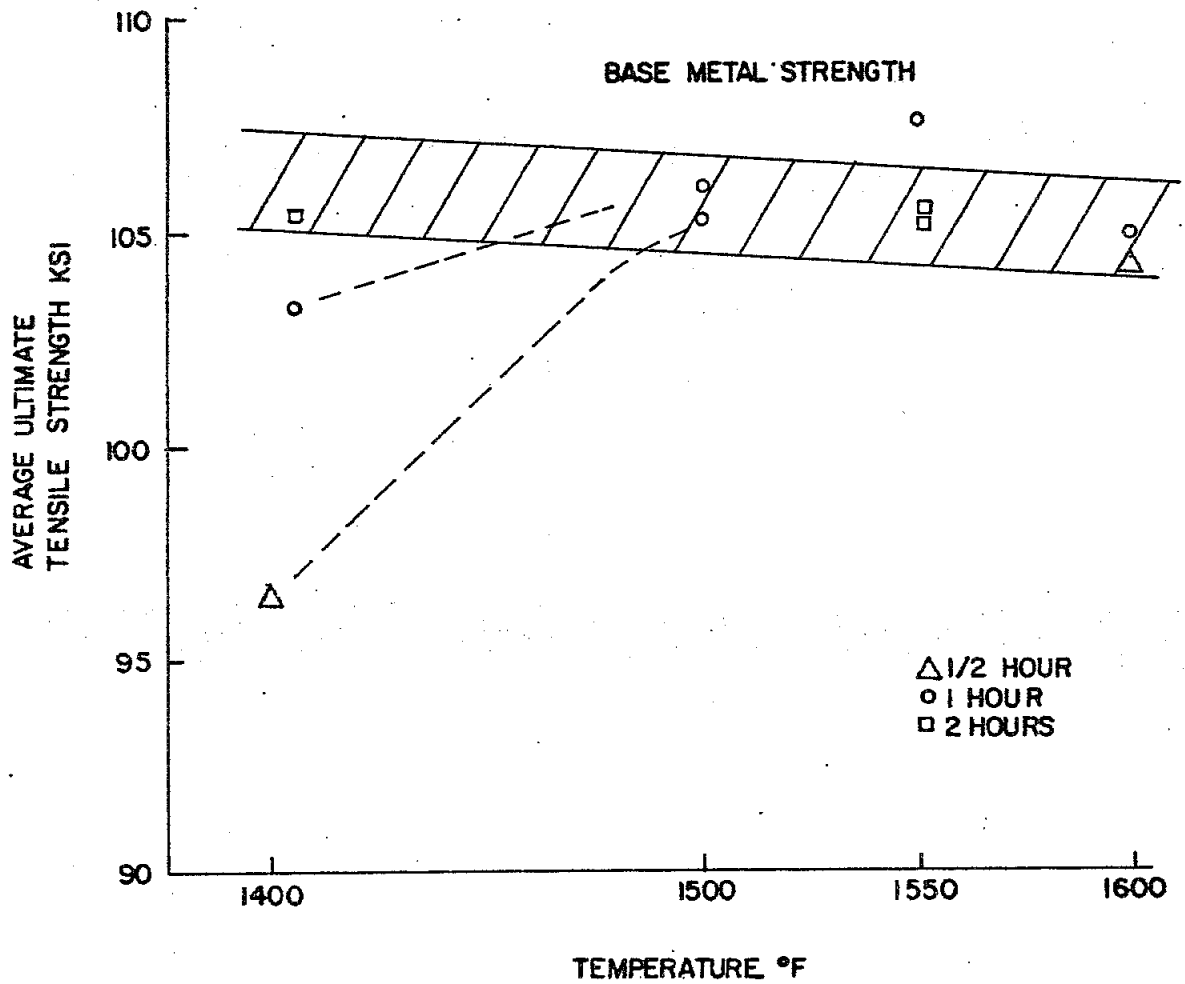


Fig. 39 – Types of diffusion bond process at constant temperature

Surface preparation is of vital importance for correct bonding. Initial finish is produced by machining which is followed by fine grinding or lapping to give the necessary finish and flatness. This can be followed by chemical etching or pickling to remove oxide films and the worked surface-layer. Degreasing, using conventional solvents, is universally used. After preparation the surface must be protected from re-oxidation and components are usually stored in a vacuum or with a gaseous cover. Inert gases can be used, but must be very pure. Hydrogen has the advantage of reducing oxides, but is detrimental to certain metals such as titanium.

The temperature, time and pressure required are specific to the metal used and the joint strength required. Of growing interest is the use of thin interlayers of another metal. These have several advantages such as promoting more rapid diffusion, minimizing distortion and allowing dissimilar metals to be joined.



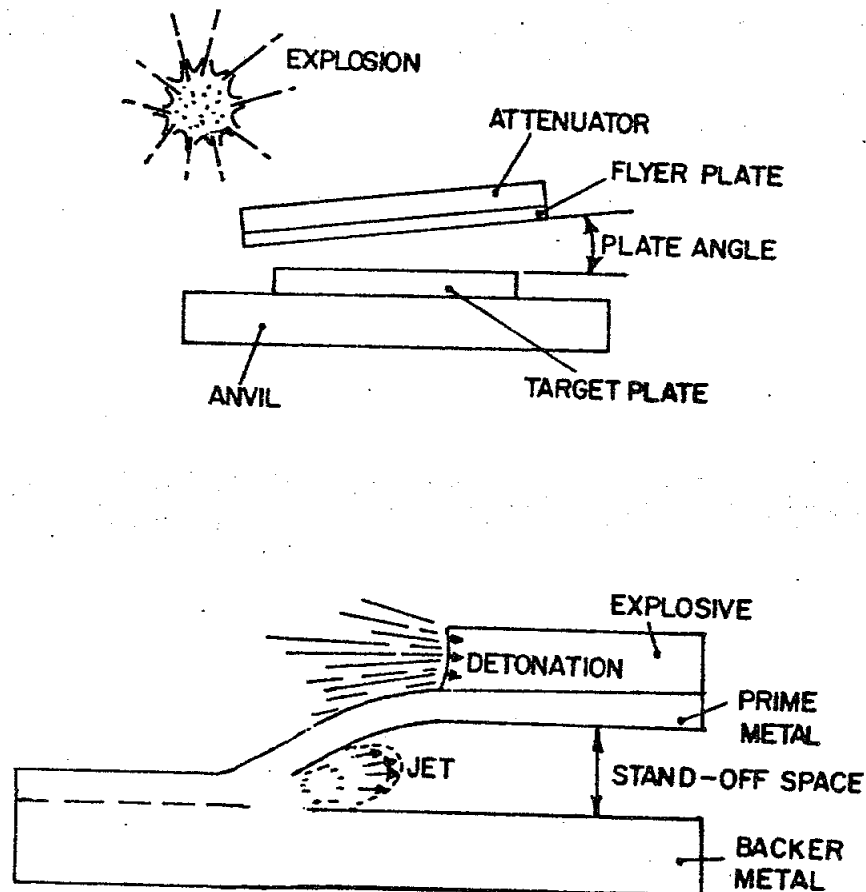
Average strength of diffusion bond in commercially pure titanium as a function of temperature for three periods of time

Fig. 40

Fig. 40 shows that an optimum combination of time and temperature is required to provide a bond with strength comparable to the base material.

Explosive Welding

In this process two plates are impacted together by an explosive charge and under appropriate conditions the two surfaces will weld together. The angle between the plates is quite critical (usually less than 5°) and the two plates may be initially separated by a small distance (Fig. 41). Surface preparation is not critical. The bond usually has a wavy appearance and the bond region can have a hardness considerably higher than the parent material.



General principles and collision geometry in explosion welding
Fig. 41

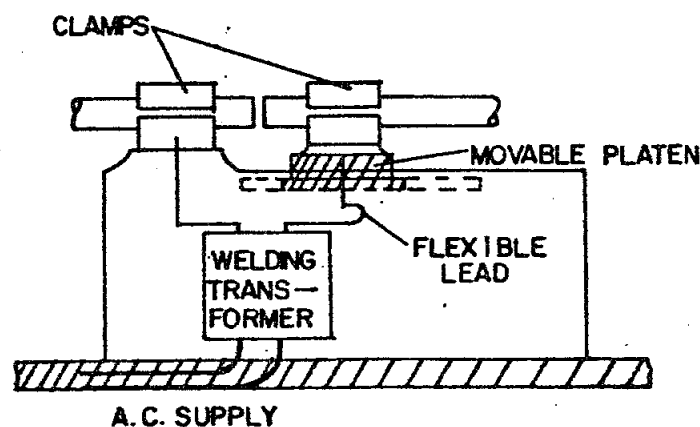
The strength of joints in several materials are shown in Table 10 and indicate that, in theory, effective welding could be obtained in a wide range of materials. The main application of the process has been in joining dissimilar materials, as with making clad material where a large bonded area is required.

Cladding Metal on Carbon Steel Backing	Typical Shear Strength psi
Stainless steels	66,700
Nickel and nickel alloys	60,500
Titanium (stress relief annealed)	39,500
Copper	22,000

Table 10 — Typical Shear Strengths for Commercial Available Explosion Welded Plates

Flash Welding

The flash welding process has many applications such as joining bars, rails and pipes. The essential principles of the process are shown in Fig. 42. When the parts to be joined are brought into contact and a voltage applied, the initial points of contact melt and form arcs. As the parts are moved together, molten metal is expelled carrying oxides with it. Initiation of the arcing process requires relatively poor contact between the parts and a good fit can lead to difficulties in starting. Control of the current and pressure cycle is critical to achieving a good weld.



Basic arrangement for flash welding

Fig. 42

For large areas to be joined, very high currents and consequently a large generator or transformer is required. A major disadvantage of the process, when it is run from the mains supply, is the surge of power required. Upset forces of 10 to 40 ksi are required, the force depending on the material.

If defects occur in the welds (such as unwelded sections) repair would have to be made by conventional means unless the entire weld was removed and rewelded. As with other solid state "one shot" processes, careful control of parameters is required.

Resistance Welding

This consists of a group of welding processes which produce coalescence of metals with heat obtained from resistance of the work to electric current in a circuit of which the work is a part, and by the application of pressure.

There are several variations of this process, the main ones being:

- o Resistance Spot Welding (RSW)
- o Resistance Seam Welding (RSEW)
- o Projection Welding (RPW)

Resistance Spot Welding

In this process, sheets to be spot welded are held between two copper alloy electrodes which have a very low resistance to current. Current passes from one electrode into the work sheet, through the first sheet, then via the interface between the sheets, then through the second sheet, finally back into the other electrode. Heat is generated by the resistance at the interface.

A typical spot welder for light, medium and heavy-duty applications is shown in Fig. 43.

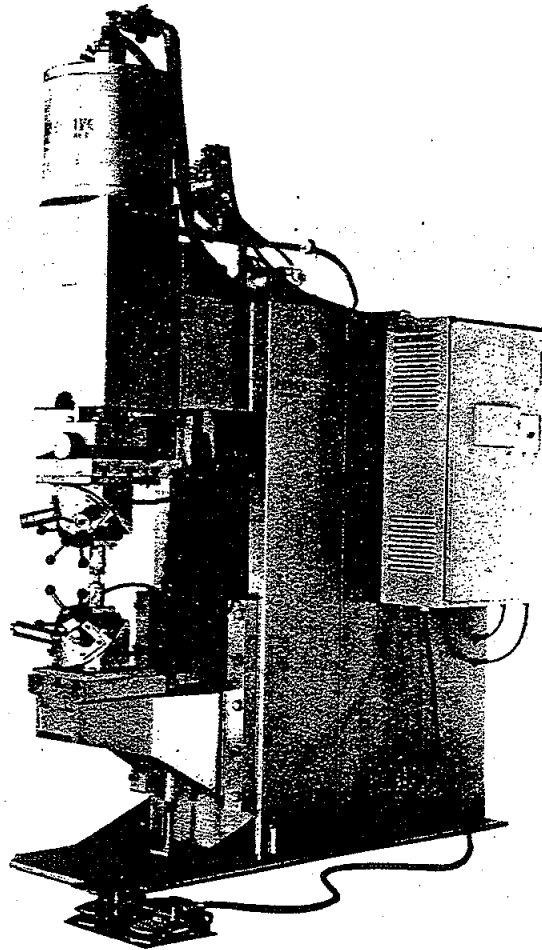
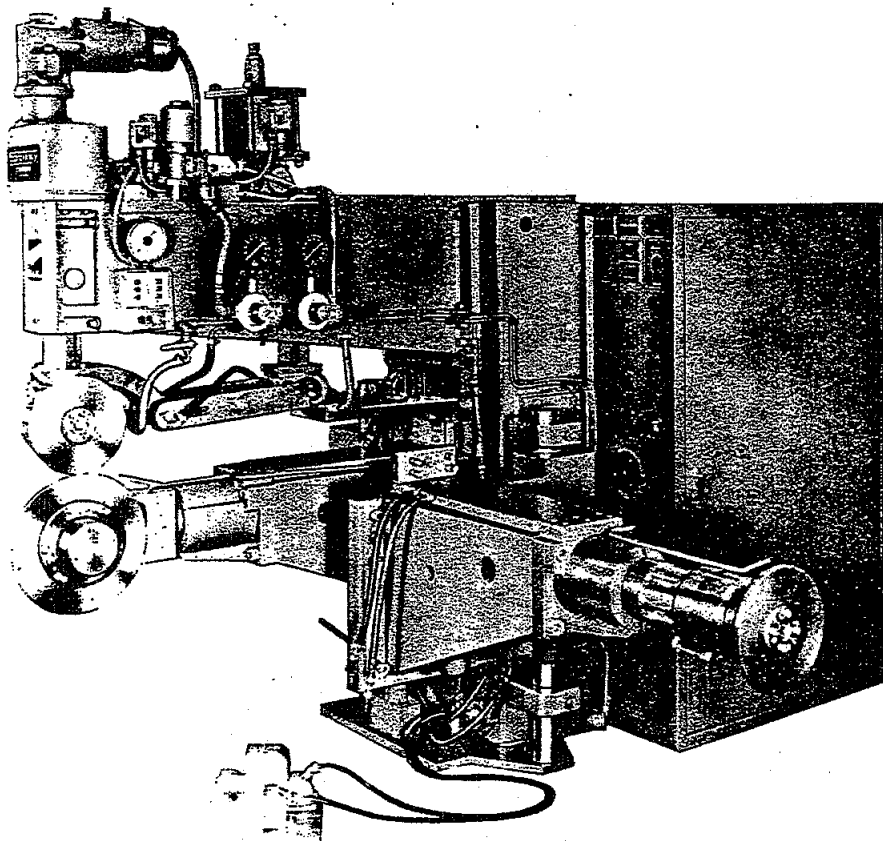


Fig. 43 A Typical Spot Welder

Resistance Seam Welding

This is similar to the resistance spot welding process except the electrode is in the form of a wheel. It is used when continuous overlapping spots are required or to form a pressure tight seam.

A typical Seam Welder is shown in Fig. 44. The machine illustrated has a quick change mechanism for replacing electrode welding wheels.



Typical Seam Welder with roller-head construction

Fig. 44

Projection Welding

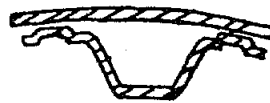
This is a similar process to resistance spot welding but, in order to localize the current, a projection or an embossment is used at predetermined points.

There are three main advantages to this process:

- Larger electrode life is obtained by the use of electrodes with large contacting surfaces.
- Increased output since a number of welds can be made simultaneously.
- Irregular shaped parts can be projection welded which would be impossible by spot welding.



12 to 13 ga.



12 to 5 ga.



Examples of Projection Welding

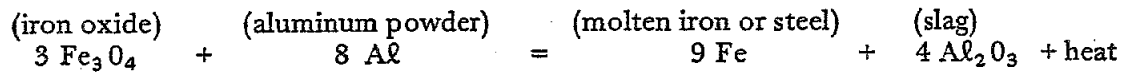
Fig. 45

The size and shape of the projections have been determined by practice over a period of time. Experience has indicated that projections of the form shown in Fig. 45 are satisfactory for most work in irregular stampings. Projections that are round, oblong, square, oval, or in fact any shape, may be made conveniently. However, the weld grows from the centre outwards to obtain a uniform growth, the round projection is theoretically desirable.

Projection welding is a firmly established process widely used in joining light gauge parts in the automotive, aircraft and appliance industries.

Thermit Welding

This is based on a principle which has been known for a hundred years. The required heat and molten metal is obtained from an exothermic reaction involving aluminum powder and various metal oxides. In the case of steel this produces molten steel, slag and a large amount of heat. The basic chemical equation is as follows:



It should be noted that the chemical reaction is very fast and usually only takes around one minute after the reaction has started. Carbonaceous material can be added to the mix in order to obtain the required percentage of carbon in the molten metal. The equipment that is used to make a thermit weld is shown in Fig. 46.

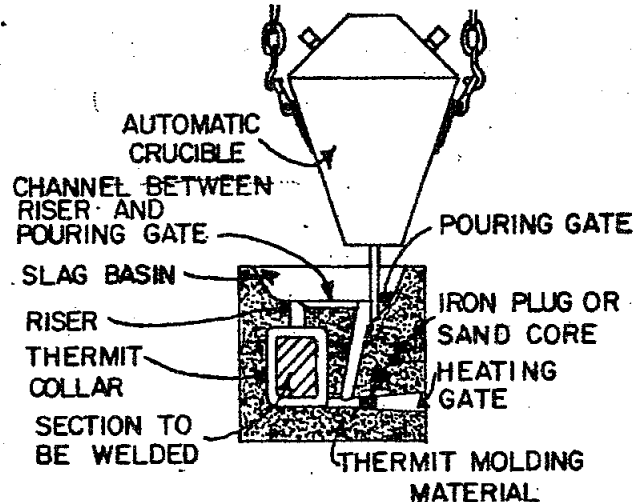


Fig. 46: General principle of thermit welding

The thermit process shown in Fig. 47 is being used to join a rail under track conditions. This process can be used by relatively untrained personnel with respect to their knowledge of welding. It should be noted that a number of joints can be made simultaneously.

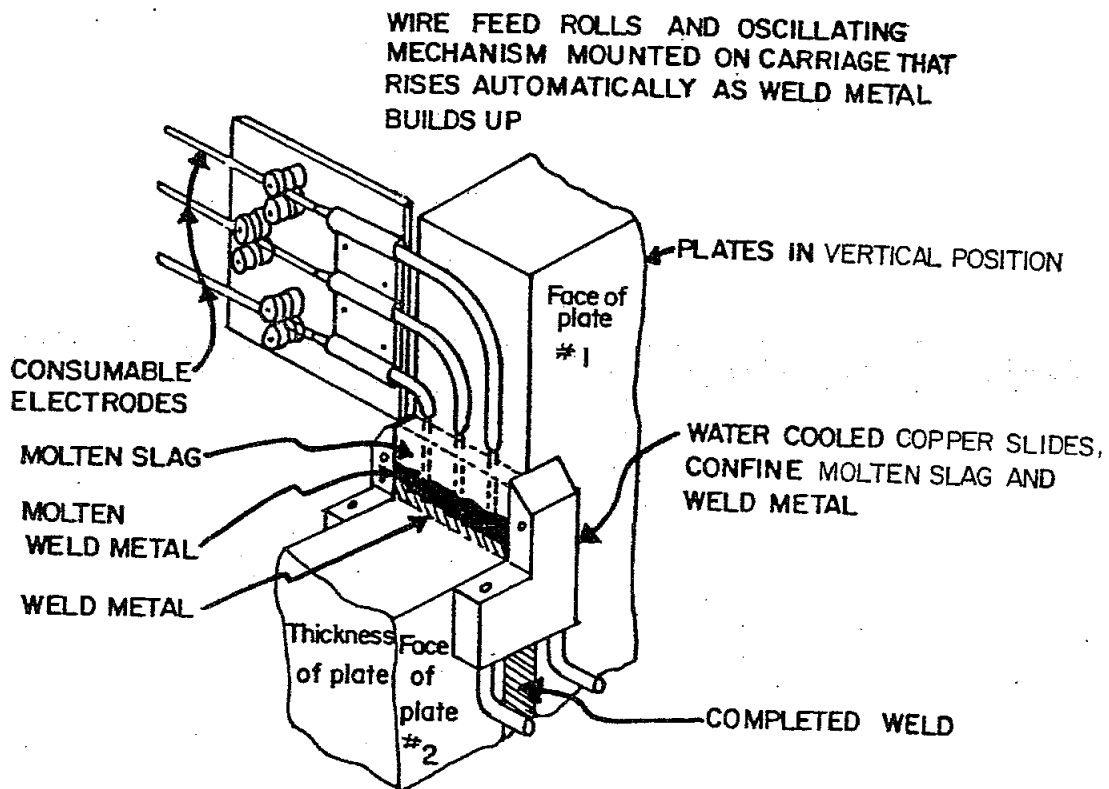


Fig. 47: Thermit welding of rails

Electroslag and Electrogas Welding

The *Electroslag* process was developed during the 1950's and is now widely used on certain applications. A similar process is the *Electrogas* process. These are particularly suited to the welding of thick sections (2 inches to 30 inches and more) in short or moderate lengths. For such applications, the high currents that may be used, the complete shielding that is provided and the absence of the necessity for preparation result in the lowest cost of any process for such applications. The quality of the weld metal is, in general, excellent although impact properties may be lower than with processes of lower heat input.

The Electroslag process is schematically illustrated in Fig. 48. Three electrodes are shown in the sketch but one, two or more may be used depending upon the thickness of the joint.

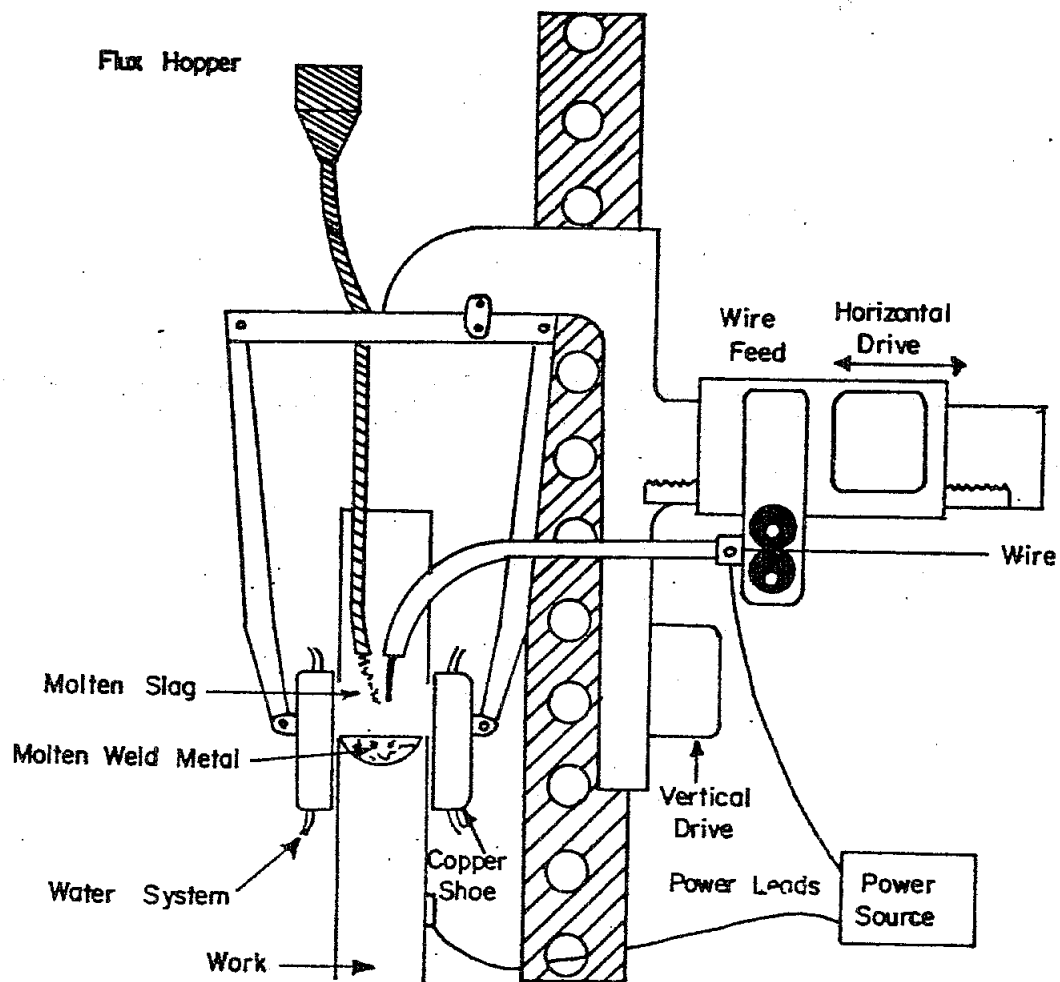


A three wire electroslag welding operation shown diagrammatically. The molten slag floats above the weld metal and helps prevent oxidation.

Fig. 48

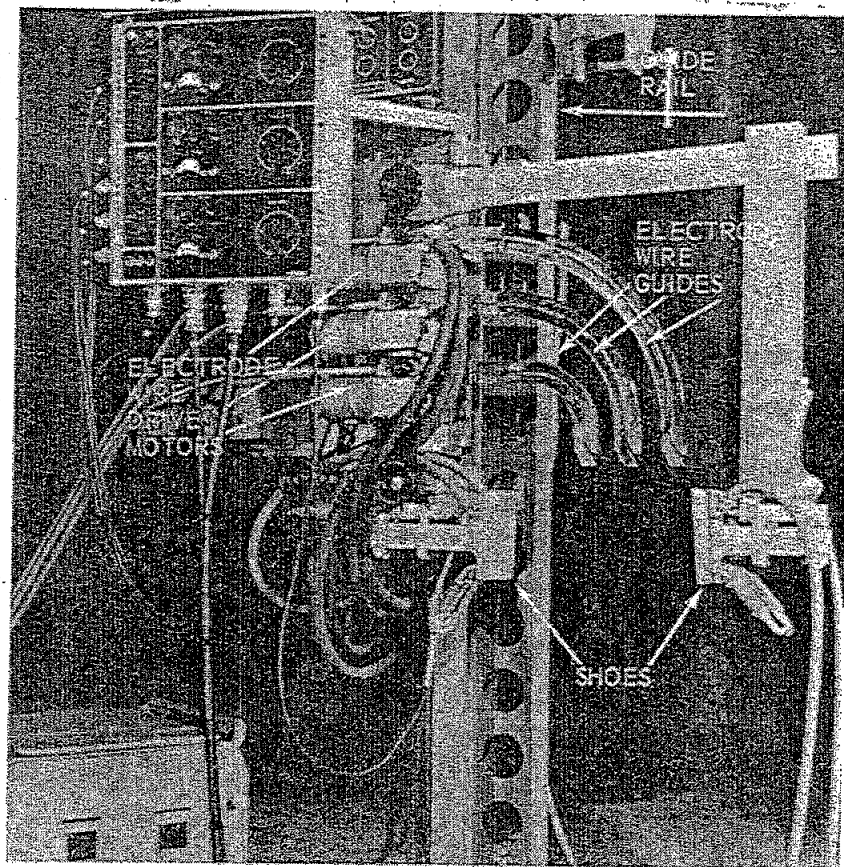
The members to be joined are placed so that welding proceeds vertically. No preparation is required and the gap between members normally varies from 1 inch to 1 3/4 inch. Copper shoes (usually water-cooled) are placed on each side of the weld and either run the full length or move up as welding proceeds. A mold is thus formed for the molten weld metal. Initially an arc is struck between the electrode wire or wires and the bottom of the mold underneath a deposit of flux.

This arc serves to melt the flux and raise its temperature to such an extent that, as the electrode is fed into the molten flux, the wire melts and an arc is no longer formed, nor is it necessary. As welding proceeds the electrode continues to be fed and more flux added. This continues until the gap between the members is filled and a suitable run-out added. Figs. 49 and 50 illustrate the equipment used. In some versions of the process, the electrode is fed through a non-consumable nozzle, but in others a consumable nozzle is used and provides additional weld metal. (See Fig. 51.)



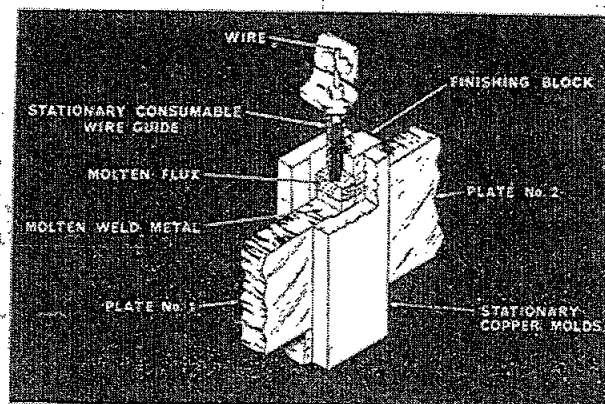
Electroslag welding operation showing the flux hopper, electrode wire feed, shoes, and the rail on which this equipment moves up as welding proceeds.

Fig. 49



The electroslag welding station for three electrode feed. Notice the water cooled shoes and the fact that each of the wire feed mechanisms has its own drive motor.

Fig. 50



Electroslag welding with consumable nozzle. Wire feeds through consumable nozzle and both wire and nozzle melt

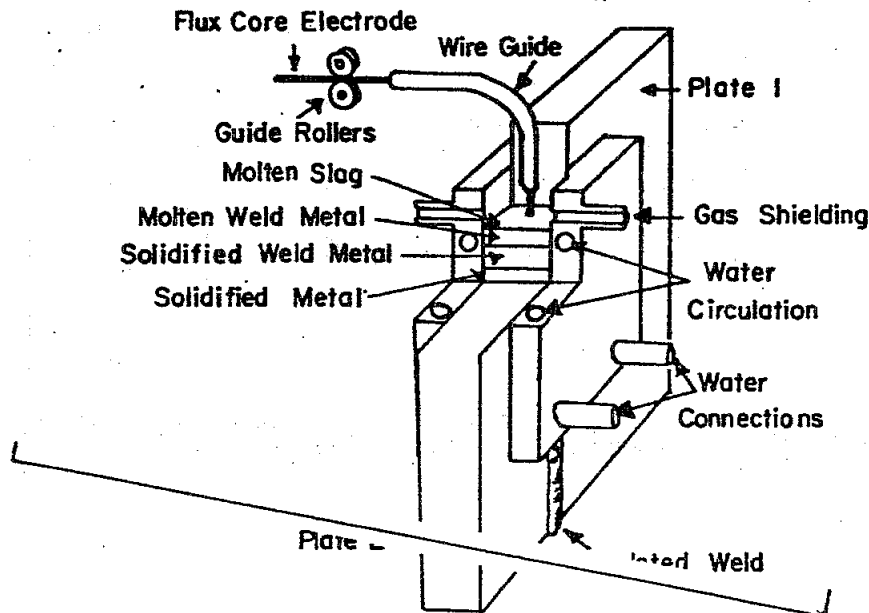
Fig. 51

This consumable nozzle may be fabricated from metal strip, sheet or tube in which a channel is provided for passage of the electrode wire and it may or may not be flux covered. In the non-consumable nozzle process, for joint thicknesses greater than about 1 1/2 inches, it is usual to impart an oscillating motion to the wire guides in the direction of the long axis and sometimes a transverse motion also. With consumable nozzles of suitable size and shape this motion is not needed and the process is, thus, considerably simplified.

The electroslag process can also be used for circumferential joints by placing the parts on powered turning rolls and maintaining the turning speed at a level to match the weld progression.

Electrogas Welding

Electrogas welding is a later development, providing shielding of the molten metal by gas rather than by flux. In this process, melting is performed by the arc which is continuously maintained. A variation of this process using flux-cored wire and CO₂ gas is illustrated schematically in Fig. 41.



Schematic drawing of an electrogas weld in progress. The shoes are water-cooled and are moved up as the weld proceeds. A shielding gas protects the molten weld metal from oxidation
Fig. 52

Arc Spot Welding

Arc spot welding provides a means of spot welding two sheets together, using an arc welding process, with access from only one side. It also has the advantages of portability and the fact that standard GTAW or GMAW equipment may be used with the addition of a timing device and suitable gun. The sequence of the operation with GMAW is shown in Fig. 53.

Arc Stud Welding

*COULD BE TEST QUESTION ALSO IN
CODE SECTIONS.*

Electric arc stud welding and Capacitor-discharge stud welding have become widely used processes for attaching fasteners of various types to metal surfaces. The earlier process, electric-arc, is suitable for a wide range of thicknesses of fasteners from 1/8 inch to 1 1/4 inches diameter (or equivalent cross-section). The capacitor discharge process is limited to studs of 1/8 inch to 1/4 inch or 5/6 inch diameter but has the advantage of a shorter cycle, resulting in little or no marking on the reverse side of thin gauge plates together with a reduction in distortion. Capacitor-discharge has many applications in the automotive and appliance industries as well as others where the smaller range of studs is used. There is no upper limit to the thickness of base material with either process.

The torch is placed over the joint. In this particular case, the upper plate has been drilled for a plug weld. The wire electrode is stationary. Water coolant and argon shielding gas are turned off.

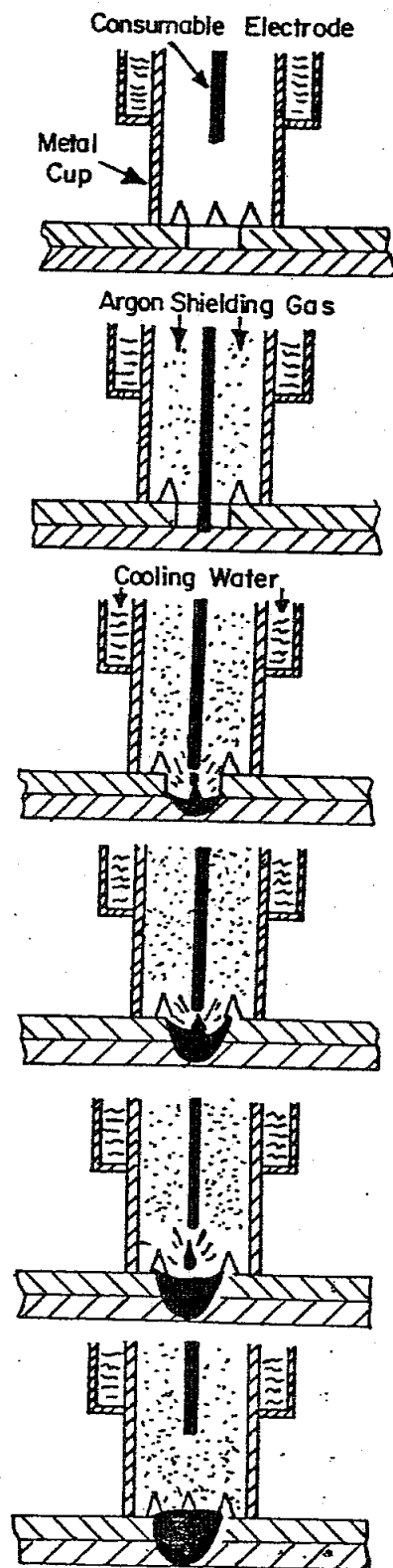
When the operator presses the torch trigger, argon and water start to flow, and welding power is applied. Wire feed begins and the electrode touches the work.

A current surge instantly burns back the wire to establish an arc. The force of the arc causes the weld to penetrate the bottom plate.

Wire continues feeding at a uniform rate to maintain a constant arc length. Welding current adjusts automatically. Arc voltage is always that of the constant potential power supply.

Molten filler wire and base metal fuse together to make a strong weld. At the proper time, wire feed stops and welding current remains on for the split second required to burn back the wire enough to prevent electrode sticking.

After welding action stops, water and inert gas continue flowing for a pre-selected length of time to furnish the post-weld shielding that ends the cycle. Pressing torch trigger will not start a new weld cycle until the preceding cycle is complete.



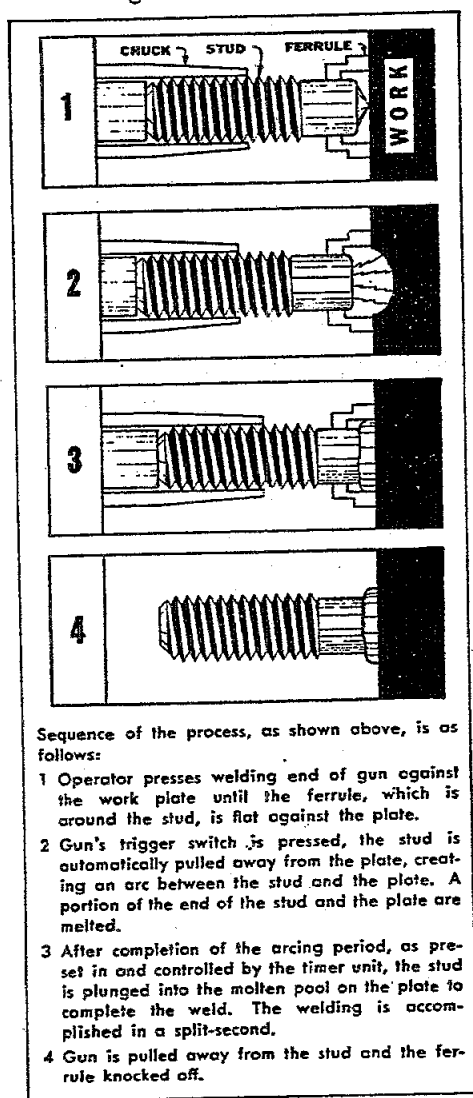
The sequence of operation in making arc spot welds

Fig. 53

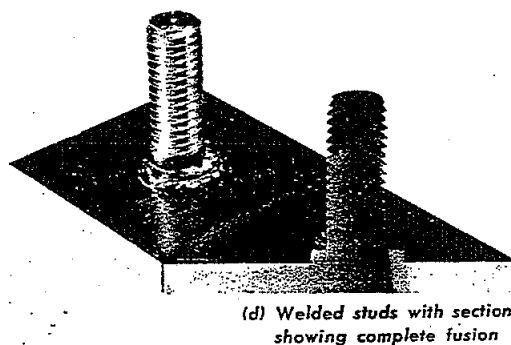
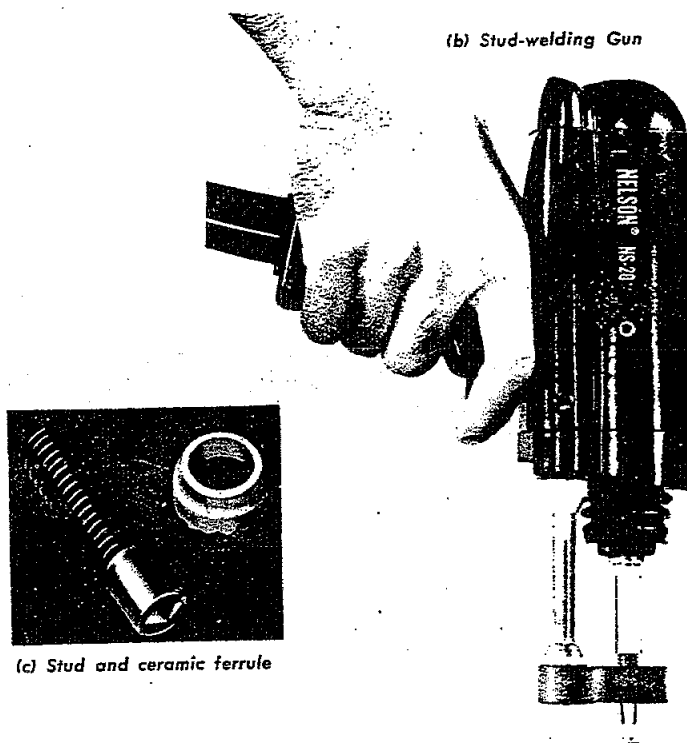
The electric-arc system with its larger capacity is widely used in fastening shear connectors to bridges and buildings, to provide an anchor for concrete, and in many other applications in ships, pressure vessels, railway equipment and machinery.

Figs. 54 (a), (b), (c), (d) and Fig. 55 illustrate typical stud welding equipment and the sequence of operation. Power is supplied by conventional welding machines of suitable capacity or by sources designed especially for the high currents and low duty cycles encountered.

Fig. 56 shows the sequence of operation of one type of capacitor-discharge welding. Power is furnished by capacitors which are connected to a standard AC supply, storing energy between cycles and discharging it at high current values at the moment of welding. The weld cycle takes place in approximately 6/1,000th of a second. This type uses a stud with a small projection on the end. The projection is brought in contact with the base material and pressure applied. When the contactor of the controller is closed, the stored energy is discharged through the projection. This presents a high resistance and the projection rapidly disintegrates, causing an arc to be formed and



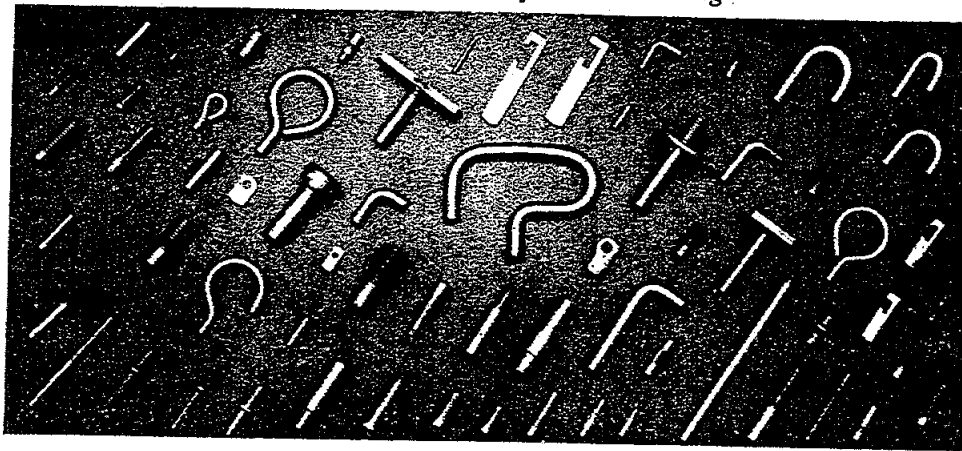
(a) Stud-welding Process



Stud Welding Process and Equipment

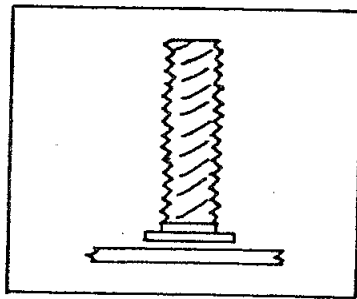
Fig. 54

Typical attachments for stud welding

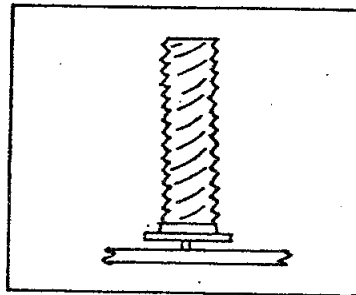


Arc Stud Welding
Fig. 55

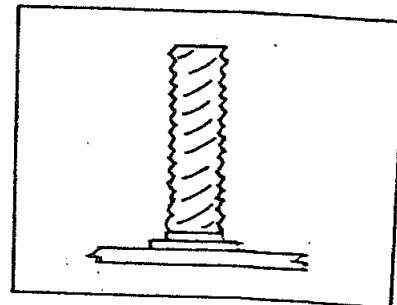
thus melting the surfaces to be joined. During the arcing period the two surfaces are being brought together by spring action or air pressure. When they are pressed together, fusion takes place and a weld is made. No flux is used and, as mentioned earlier, the welding cycle is so brief that a layer of only a few thousandths of an inch on each part is melted. Another method, called Drawn-arc Capacitor discharge, uses studs with no projection, which are brought into full contact with the work and then withdrawn a set distance, causing an arc. The stud is then plunged into the molten pool on the base material. The welding cycle is somewhat longer than the method using a projection on the stud but does not require as clean a surface as the latter. Figs. 57 and 58 show equipment for capacitor discharge stud welding. The equipment in Fig. 57 is for use either with the system requiring studs with projections or the drawn arc method. The equipment in Fig. 58 is designed for the drawn-arc system.



The trigger is pulled, releasing the electrical energy stored in the capacitors. The current produced disintegrates the projection on the end of the stud and creates an arc between the stud and the work resulting in a molten state on the surface of the plate and the stud.



The stud is located on the spot to which it is to be welded and the stud welder footpiece is seated on the plate.



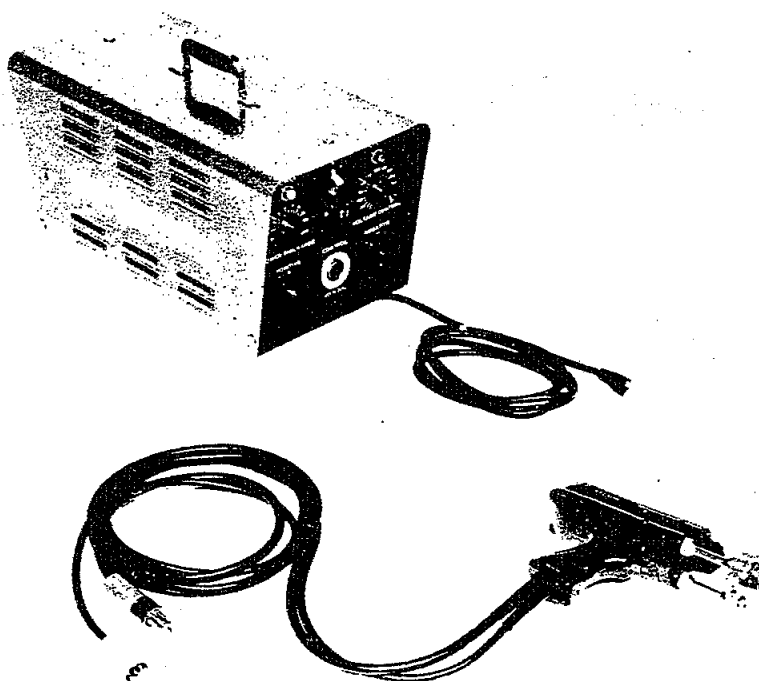
At the instant the tip is completely melted, spring pressure forces the stud into the molten pool, completing the weld. The entire weld cycle takes place in approximately 6 milliseconds. The completed fastening develops the full strength of the stud and plate material and will not break in the weld area.

Fig. 56

Studs for electric-arc welding usually include an insert or covering of flux on the end. This, together with the surrounding ceramic ferrule, which is always used in this process, provides shielding from the atmosphere. The flux also helps to initiate the arc and to stabilize it. The ferrule, which is broken off and discarded after the weld is made produces an even fillet as will be seen in Fig. 54 (d).



*Capacitor Discharge gun and control panel for either projection or drawn arc method
Fig. 57*



*Capacitor Discharge unit gun and controls for drawn arc system
Fig. 58*

Stud Welding Equipment

In the early stages of electric-arc stud welding, standard welding power sources were used. Demands for higher capacity and a more economical design for this specific application, however, resulted in the development of special units for stud welding. The process calls for high currents for relatively short periods. For example, in welding 7/16 inch base diameter studs, a 400 ampere DC welding unit could be used, giving double its rated output for perhaps one or two seconds. For welding a 1 inch diameter stud, 3,000 or 4,000 amperes would be momentarily required and it is usual to parallel two or more machines for such heavy demands. These special units are rated at 20 percent duty cycle or less.

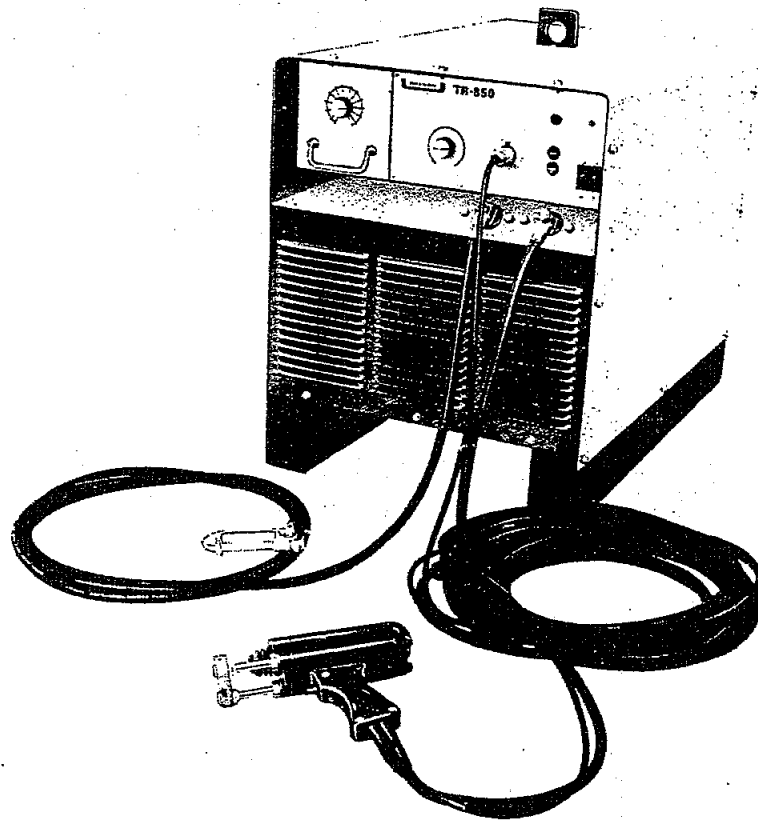
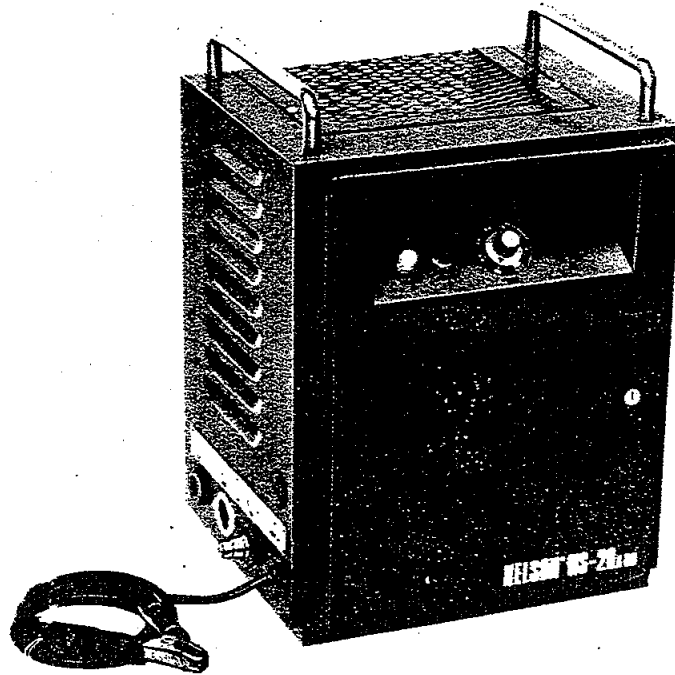


Fig. 59 Solid State Welding Source for Stud Welding

Fig. 59 illustrates a complete unit which consists of a power control unit and welding gun. It has a steel stud capacity from 12 gauge to 1 1/4" weld base diameter.

Other units such as shown in Fig. 60 need to operate with a separate DC power source. This has an output stud range from 5/8" to 1 1/4". The maximum weld stud rate that would be permitted with this type of equipment will depend on the stud size and the current required to make the stud. The recommended maximum for 3/4" stud, would be approximately 10 to 12 studs per minute.



Heavy Duty Stud Welding System

Fig. 60

Automated Stud Feed Systems

Dramatic cost cutting can be effected by replacing manually fed studs with an automatic stud feeding mechanism. Fig. 61 indicates the various components that form part of the automatic feed mechanism. Some fabricators have estimated that both time and labour can be cut in half by using this automated system.

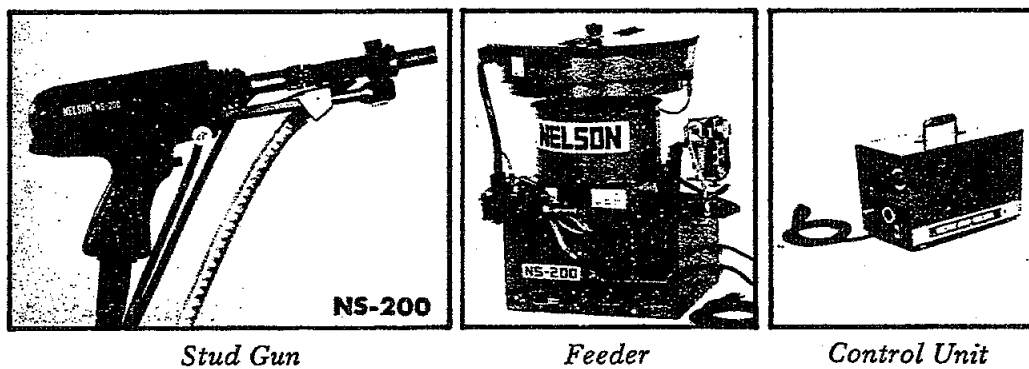


Fig. 61

The unit comprises the portable stud welding gun which is fitted with the appropriate feed tube, a vibratory bowl feeding system plus the regular control unit which operates on DC power from a welding power source. This type of equipment can reduce assembly steps such as punching, drilling, sticking, gas welding, grinding and polishing.

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For a general treatment of the major welding processes, the following books are recommended:

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2. *Modern Welding Technology*, by Howard Cary, published by Prentice Hall.
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GUIDES AND EXERCISES

MODULE 4

WELDING PROCESSES

AND

EQUIPMENT

WELDING PROCESSES AND EQUIPMENT

MODULE 4

Guides & Exercises

To obtain maximum benefit from this module we suggest that you follow this guide and complete the exercises as indicated. It is important that you work through the text methodically, studying each section thoroughly before moving on. The exercises are designed to give you an indication of whether you have learned the material and can move on or whether you need to go back and study the section again.

Do the exercises honestly. They will not help you unless you take them seriously. If you get a question wrong go back through the text until you understand where you have gone wrong and know the correct answer.

The length of time required to complete the module will vary from student to student. Find your own pace. Do not rush. Remember you are trying to teach yourself something, not win a race.

Some people like to underline sections when they read a text. We suggest that you use caution if you do this. What you think is important first time you read it may be different after reading it three times. We suggest you read a section three times thoroughly before highlighting anything.

The last exercise is designed to give you an indication of whether you are ready to take the WIC closed-book exams. The exercise questions are of a similar standard to the official exams. Do not take the exam until you feel you are ready and you may wish to study several Modules before taking the exams on each. The details of the examination procedures are on a separate sheet.

If you have any difficulties with this Module do not hesitate to ask for help. You may find you learn more by attending some of the seminars and you should also contact your local WIC Chapter to see if they can be of assistance. Remember, if you fail the examination you can always try again later.

MODULE 4

Guide 1

Carefully read pages 2 to 10 and answer the following questions:

1. In arc welding the electric arc is intensely hot with temperatures exceeding:
 - (a) 8,000°F
 - (b) 6,000°F
 - (c) 7,000°F
 - (d) 9,000°F
 - (e) 7,900°F
2. Name the two main methods of arc shielding.
3. What is the full description of S.M.A.W.?
4. What is the GTAW method also referred to as?
5. In the GTAW process what type of penetration and weld width can be expected when using D.C. electrode positive?

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 4

Guide 2

Carefully read pages 11 - 20 and answer the following questions:

1. Complete the following sentence:

When using the GTAW hot wire method, the rate at which filler metal can be deposited is up to times that of conventional GTAW.

2. The illustration shows welds made with the GMAW process.

Complete the illustration by assigning the type of polarity to each picture (a) and (b).



(a)



(b)

3. Name three advantages of the GMAW process as listed in the module.

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

Carefully read pages 21 to 31 and answer the following questions:

1. The most common gas used with gas shielded flux cored welding is:

- a) Argon
- b) Helium
- c) Hydrogen/Argon
- d) Carbon Dioxide

2. True or False?

In the submerged arc welding process, granular flux is deposited on the unwelded seam behind the consumable electrode.

3. In the friction welding process which of the following statements applies?

- a) Heat is generated by the friction between a rotating and stationary part when brought together under load.
- b) Heat generation is proportional to the square root of the applied pressure.
- c) In mild steel a surface temperature of 13.0 - 30.0 m/sec is used.
- d) Lower pressures are required for metals with higher melting temperatures and higher hot strengths.

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 4

Guide 4

Carefully read pages 32 to 42 and answer the following questions:

1. The electron beam welding process results in:
 - a) Wide, deep penetrating welds and heat affected zones
 - b) Narrow, deep penetrating welds and heat affected zones
 - c) Narrow, shallow penetrating welds and heat affected zones
 - d) Wide, shallow penetrating welds and heat affected zones
2. How many types of continuous wave, carbon dioxide (CO₂) lasers which radiate in the far infrared at a wave length of 10.6 m are available?
3. Complete the following sentence:

In the explosive welding process the bond region can have a hardness which is than the parent material.

 - a) Lower
 - b) The same as
 - c) Harder

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

Guide 5

Carefully read pages 43 to 54 and answer the following questions:

1. In thermit welding what is the name of the reaction from which the required heat and molten metal is obtained?
 - a) Exothermic
 - b) Duo Thermic
 - c) Interthermic
 - d) Thermic

2. In the electroslog and electrogas welding processes what is the usual cooling medium used on the copper shoes?
 - a) Dry ice
 - b) Air
 - c) Oil
 - d) Water

3. In the arc stud welding process the studs usually include an insert or covering of flux on the end. This, together with another item which is always used in this process provides shielding from the atmosphere.

What is the other item?

Check your answers for accuracy. If any of your answers are wrong re-study the guide subject matter until you understand it.

MODULE 4

ANSWERS

Guide 1

1. (b)
2. Flux shielding and Gas Shielding
3. Shielded Metal arc Welding
4. T.I.G. (Tungsten Inert Gas)
5. Shallow penetration - Wide weld

Guide 2

1. Five
2. (a) Negative (b) Positive
3. a) High deposition rate
b) Greater percentage of arc time since electrode changing is infrequent
c) A more economical use of filler metal since there is virtually no stub loss
d) Deeper penetration, which allows smaller groove angles and, hence, less weld metal
e) A potential for high quality weld metal with low hydrogen

Guide 3

1. (d)
2. False
3. (a) and (b)

Guide 4

1. (b)
2. Three
3. (c)

Guide 5

1. (a)
2. (d)
3. Ceramic Ferrule

MODULE 4

TEST

This test is designed to determine whether you are ready to attempt the formal examination.

Complete the ANSWER SHEET and compare the results with the TEST KEY. If you have a pass mark less than 70% you are advised to re-study the material.

1. With a tungsten arc most of the current across the arc is carried by:
 - (a) electrons
 - (b) ions
 - (c) molecules of CO_2
 - (d) nuclei
 - (e) there is no current

2. The chief feature of an electron beam weld is:
 - (a) a smooth fillet weld
 - (b) high shrinkage
 - (c) very shallow penetration
 - (d) a very narrow weld and heat affected zone
 - (e) a high deposition rate

3. Which gases are used with the GMAW process?
 - (a) no gases are used
 - (b) any gas including CO_2 , hydrogen, fluorine, etc.
 - (c) only carbon dioxide (CO_2), hydrogen, fluorine, etc.
 - (d) many gases including argon, CO_2 and various mixtures
 - (e) only helium

MODULE 4

TEST continued

4. Which of the following processes is a non-consumable electrode process?
- (a) SMAW
 - (b) SAW
 - (c) GMAW
 - (d) GTAW
 - (e) FCAW
5. Projection welding is a resistance spot welding process in which:
- (a) the parts are projected towards each other under high pressure
 - (b) the current is localized by using a projection or embossment on the part to be joined
 - (c) the weld is made in a projection of the piece which is removed after
 - (d) the current is localized by using a high magnetic field
 - (e) extra long electrodes are used
6. Which of the following processes is not used in the overhead position:
- (a) SAW
 - (b) GMAW
 - (c) SMAW
 - (d) FCAW
 - (e) GTAW
7. An advantage of the stud welding process is:
- (a) no melting of the base plate actually occurs
 - (b) a continuous electrode is used
 - (c) it is only used with hollow studs
 - (d) very deep penetration is obtained
 - (e) it is rapid and reproducible

MODULE 4

TEST continued

8. The deposition rate of some shielded metal arc electrodes is increased by including which of the following in the flux coating:
- (a) basic fluxes
 - (b) aluminum
 - (c) deoxidants
 - (d) iron powder
 - (e) fluorides
9. The electrode in flux cored arc welding is:
- (a) a tubular wire containing gases
 - (b) a solid wire with flux coating
 - (c) a hand held rod with flux in the core
 - (d) a flux cored tungsten electrode
 - (e) a tubular wire containing flux or other ingredients
10. What would be a typical current range for a 5/32 in. (4 mm) E7018 (E48018):
- (a) 25 - 70 amps
 - (b) 150 - 220 amps
 - (c) 2.5 - 7 amps
 - (d) 15 - 22 amps
 - (e) 650 - 875 amps

G12

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Answer Sheet - Module 4

Complete the "Answer Sheet" and compare the results with the "Test Key". If you have a pass mark less than 70%, you are advised to re-study the material.

Please circle only ONE letter corresponding to the answer you think is most correct.

QUESTION	ANSWERS				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

The answer key below is provided for your use in the event that you wish to retest yourself.

QUESTION	ANSWERS				
1	a	b	c	d	e
2	a	b	c	d	e
3	a	b	c	d	e
4	a	b	c	d	e
5	a	b	c	d	e
6	a	b	c	d	e
7	a	b	c	d	e
8	a	b	c	d	e
9	a	b	c	d	e
10	a	b	c	d	e

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Test Key - Module 4

Compare your answer sheet to this key.

QUESTION	ANSWERS				
1	☒ a	b	c	d	e
2	a	b	c	☒ d	e
3	a	b	c	☒ d	e
4	a	b	c	☒ d	e
5	a	☒ b	c	d	e
6	☒ a	b	c	d	e
7	a	b	c	d	☒ e
8	a	b	c	☒ d	e
9	a	b	c	d	☒ e
10	a	☒ b	c	d	e