ONE

Welding and Welding Processes

Welding is a process of joining two or more pieces of the same or dissimilar materials to achieve complete coalescence. This is the only method of developing monolithic structures and it is often accomplished by the use of heat and or pressure. Although in its present form it has been used since about the beginning of 20th century but it is fast replacing other joining processes like riveting and bolting. At times it may be used as an alternative to casting.

Presently welding is used extensively for fabrication of vastly different components including critical structures like boilers and pressure vessels, ships, off-shore structures, bridges, storage tanks and spheres, pipelines, railway coaches, anchor chains, missile and rocket parts, nuclear reactors, fertiliser and chemical plants, structurals, earth moving equipment, plate and box girders, automobile bodies, press frames and water turbines. Welding is also used in heavy plate fabrication industries, pipe and tube fabrication, jointing drill bits to their shanks, automobile axles to brake drums, lead wire connections to transistors and diodes, sealing of containers of explosives like nitroglycerine, welding of cluster gears, and the like.

1.1. Classification of Welding and Allied Processes

Although almost all materials (metals, plastics, ceramics, and composites) can be welded but not by the same process. To achieve this universality a large number of Welding and Allied Processes have been developed. Most of the industrially important processes amongst them classified depending upon the nature of heat source and its movement resulting in spot, seam or zonal welds; or on the extent of heat generation *viz.*, low heat and high heat, are shown in *Fig. 1.1*. This rather unusual type of process classification has been chosen because often these processes will be referred to accordingly in the remaining text.

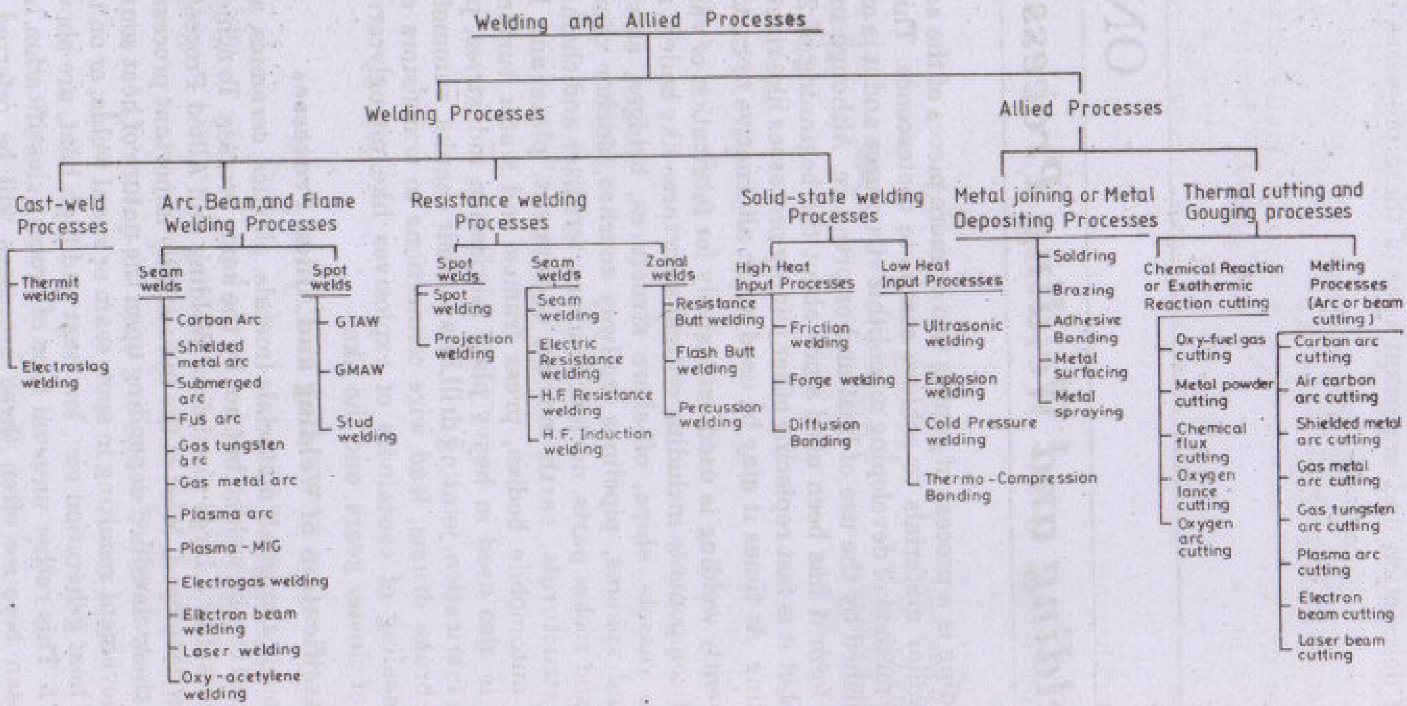


Fig. 1.1. Classification of Welding and Allied Processes.

Brief description and important uses of these processes are given in the following sections.

1.2. Cast-Weld Processes

These processes involve large amount of molten metal resulting in properties close to that of castings. For achieving the desired joint properties such welds are usually given normalisation treatment. Two processes in this class are Thermit Welding and Electroslag Welding.

1.2.1. Thermit Welding

Thermit is a mixture of aluminium powder and metal oxide which when ignited results in a non-explosive exothermic reaction. The heat so generated melts and reduces the metal oxide to metallic form at a high temperature. This molten metal is used for joining metal parts by pouring it between them resulting in what may be termed as a *cast-weld joint*.

One of the most used thermit mixtures is aluminium powder and ferric oxide which on ignition results in the following reaction.

$$8Al + 3Fe_3O_4 \longrightarrow 9Fe + 4Al_2O_3 + 3310 \text{ kJ/mol} \qquad ...(1.1)$$

The molten metal obtained has high temperature of about 2450°C. This metal is poured into the sand mould surrounding the parts to be welded, as shown in Fig. 1.2. The mould is broken soon after the solidification of metal is complete and the excess metal is removed, by chisel and hammer, to give the necessary shape to the weld.

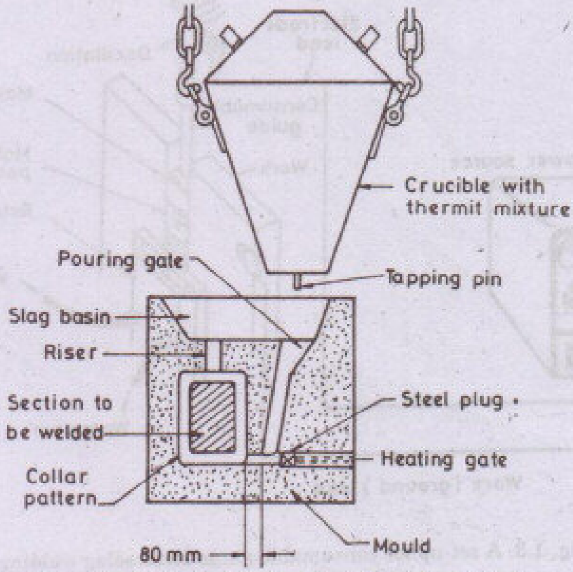


Fig. 1.2. A standard set-up for thermit welding.

Thermit welding is extensively used for joining rails at site, cable conductors, reinforcing bars for R.C.C. structures, and for heavy repairs such as those of broken necks of rollers, and ship sterns.

1.2.2. Electroslag Welding

Electroslag welding (ESW) is a fusion welding process for joining thick workpieces in a single run. This is *not* an arc welding process though most of the set-up is similar to the usual arc welding processes and arcing is required to initiate the process and may also occur subsequently when the process stability is disturbed. Apart from the conventional ESW process in which the usual electrode wire with contact tube is employed there is a popular variant of the process called Consumable Guide ESW Process; Fig. 1.3 shows the process diagram for the latter. An essential feature of the ESW process is that the welding is done with weld joint in vertical position.

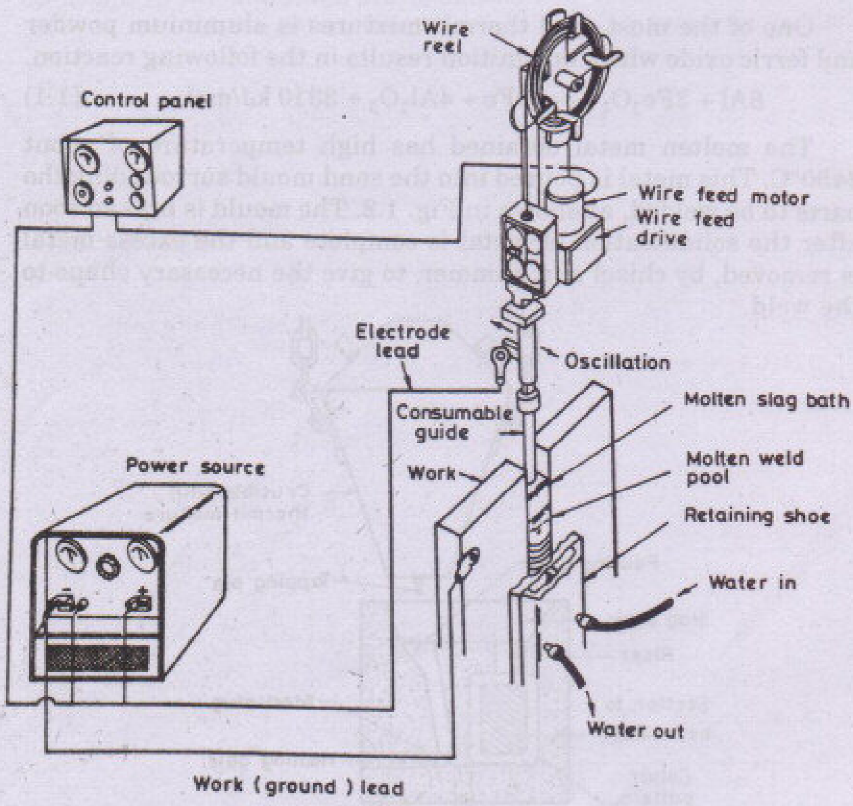


Fig. 1.3. A set-up for consumable-guide electroslag welding.

Due to high heat input the weld pool in ESW is usually quite voluminous resulting in a weld with properties resembling that of a casting which makes post weld heat treatment (PWHT) essential to achieve the desired metallurgical structure to attain the required mechanical strength.

Typically ESW is extensively used in the construction of pressure vessels, press frames, water turbines and heavy plate fabrication industries.

1.3. Arc and Flame Welding Processes

The welding processes included in this class are those which make use of an electric arc or a flame obtained by burning an oxy-fuel gas mixture. The size of the weld pool evolved depends upon the energy input per unit time, and the extent of spread of arc or flame, however the volume of the molten metal in the weld pool, at any given time, is much smaller than that obtained in electroslag welding. These processes are either used to produce welds along seams (*e.g.*, SMAW, GMAW, Oxy-fuel gas welding, etc.) or just at spots (*e.g.*, stud welding, GTAW spot welding, etc.). Brief descriptions of industrially important processes in this class follows.

1.3.1. Seam Welding Processes

These processes are mainly used for welding workpieces along straight or curved seams of desired lengths and include all well known arc and flame welding processes.

1.3.1.1. Carbon Arc Welding

In carbon arc welding heat is produced with an arc between a carbon electrode and the work, and normally no shielding gas is used. The heat from the arc melts the work material and filler wire, if required. *Fig. 1.4* shows the basic circuit for carbon arc welding.

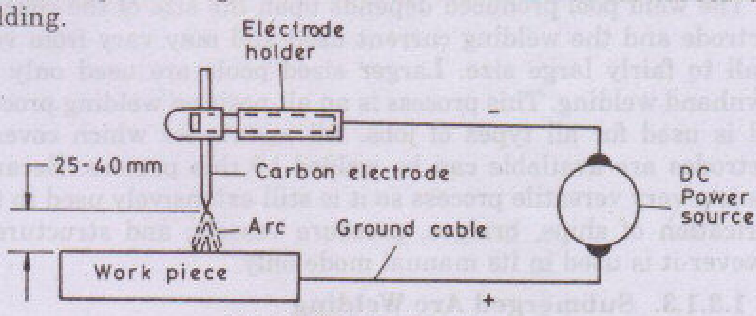


Fig. 1.4. Carbon arc welding.

To avoid excessive heating and consequently accelerated consumption of carbon electrode it is required to use dc (direct current) power source with electrode negative.

The weld pool produced is normally small and therefore in its manual mode carbon arc welding process can be used as an all-position welding process.

Carbon Arc welding can be used for welding copper since it can be used at high current to develop the high heat usually required for the purpose. It can as well be used for welding galvanized steel and repairing of steel castings.

1.3.1.2. Shielded Metal Arc Welding

This process employs coated or covered electrodes for producing an arc to act as a heat source; the covering on burning provides the necessary shield to protect the molten metal from the ill effects of oxygen and nitrogen from the surrounding atmosphere. This process is more popularly known as *Stick electrode welding* or *manual metal arc welding* and is the single most used welding process in the world. Both ac and dc power sources can be used equally effectively. *Fig. 1.5* shows the basic circuit diagram for the process.

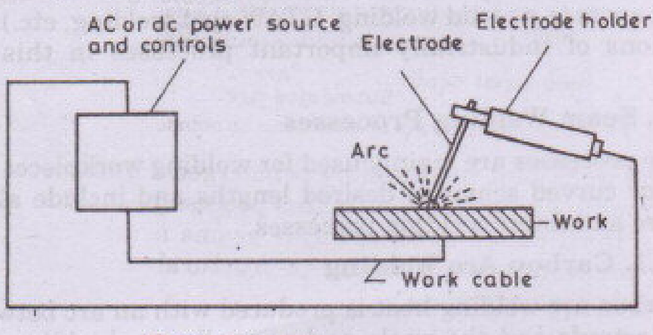


Fig. 1.5. Basic circuit for shielded metal arc welding.

The weld pool produced depends upon the size of the covered electrode and the welding current used and may vary from very small to fairly large size. Larger sized pools are used only for downhand welding. This process is an all-position welding process and is used for all types of jobs. All metals for which covered electrodes are available can be welded by this process. Because this is a very versatile process so it is still extensively used in the fabrication of ships, bridges, pressure vessels, and structurals; however it is used in its manual mode only.

1.3.1.3. Submerged Arc Welding

Submerged arc welding (SAW) is a process in which continuous copper coated spooled wire is used in conjunction with loose granulated flux poured ahead of the arc so as to provide a protective media to ward off the atmospheric gases from reacting with the molten metal pool. The electrode wire diameter may range between 2 and 10 mm. Both *ac* and *dc* power sources are used though *dc* with electrode positive (dcep) is the preferred choice.

SAW is mainly used in the downhand welding position in both automatic and semi-automatic modes. The former is a more popular mode and a set-up for the same is shown in Fig. 1.6.

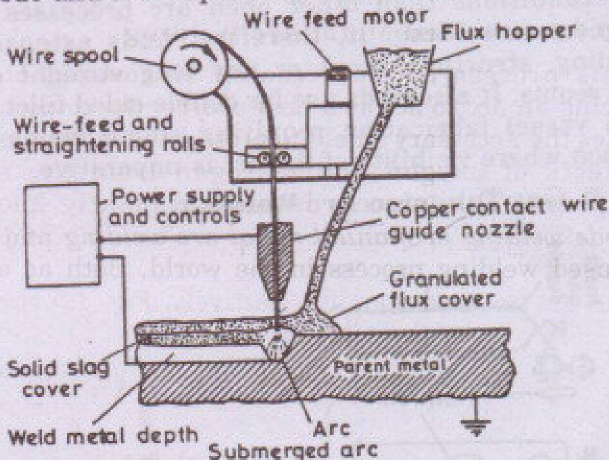


Fig. 1.6. Essential elements of an automatic submerged arc welding unit.

The weld joint produced by submerged arc welding is of very high quality and consequently this process finds extensive use in joining thick plates in long, linear seams as are encountered in ships, pressure vessels, bridges, structural work, welded pipes, and nuclear reactors.

1.3.1.4. Fusarc Welding

This process employs flux coated electrode in which the core wire is helically wrapped with both left and right handed spirals of wire shown in Fig. 1.7; the coating fills the spaces between the spirals. Current to the core wire flows through the contact between the contact tube and the outer wire spiral which is partly bare. Welding current from 200 A to 1000 A can be used depending upon the electrode diameter, however, the upper limit for the current is also set by the ability of the outer spiral to carry it without

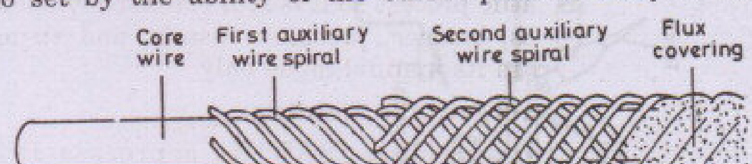


Fig. 1.7. Constructional features of a continuous covered electrode.

overheating and collapse. Long current slide is often used to overcome this difficulty. The set-up for Fusarc welding resembles the set-up used for automatic submerged arc welding excluding the flux supply and recovery system.

Fusarc welding usually employs an additional shield of CO_2 to enhance the protection of weldpool and thereby greatly improves the weld quality.

Fusarc welding is more tolerant of joint fit-up, surface and weather conditions then other open arc processes including submerged arc welding. It, therefore, finds extensive use in shipbuilding, structural work or any long straight or circumferential seams. It also finds use for double-sided fillet welds and pressure vessel fabrication requiring sound welds and good penetration where visibility of the arc is imperative.

1.3.1.5. Gas Tungsten Arc Welding

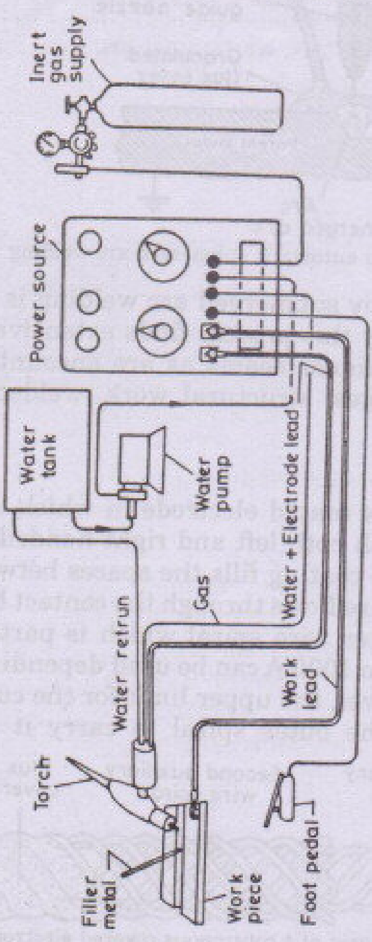


Fig. 1.8. A schematic representation of a GTAW unit.

Gas tungsten arc welding (GTAW) or tungsten inert gas (TIG) welding employs a non-consumable tungsten electrode with an envelope of inert shielding gas (Argon, helium, etc.) to protect both the electrode and the weld pool from the detrimental effects of surrounding atmospheric gases.

Both *ac* and *dc* power sources are used for GTAW. The tungsten electrode employed varies in diameter from 0.5 to 6.5 mm and the current carrying capacity varies accordingly between 5A and 650A. The welding torch used for carrying current higher than 100A is normally water cooled. The process is used mainly in its manual mode. Fig. 1.8 shows a schematic representation of the basic elements of an ac GTAW unit.

GTAW is an all-position welding process and gives the highest quality welds amongst the commonly employed arc welding processes and is, therefore, extensively used for welding most of the industrially useful metals and alloys usually in thin grades. Aircraft industry, rocket and missile fabricators, chemical and nuclear plant fabricators are the typical user industries of this process.

1.3.1.6. Plasma Arc Welding

Plasma is a flow of ionised gas that is obtained by passing a gas through a high temperature arc which results in splitting the gas molecules to atoms and then to ions and electrons.

In plasma arc welding the arc is created between a tungsten electrode and the workpiece, as in gas tungsten arc weiding. However, the plasma arc is constricted by an outer nozzle through which the shielding gas flows.

Power source used for plasma arc welding is invariably of constant current dc type with an open circuit voltage of 70 to 80 volts and a duty cycle of 60%.

There are two variants of the plasma arc welding process called non-transferred type and transferred type. In the *non-transferred type* the tungsten electrode is the cathode and the torch tip the anode. Such a torch is very similar to oxy-acetylene torch as regards its manoeuvrability as workpiece is outside the electrical circuit. However, such a plasma arc is less intense compared with the *transferred arc* wherein the workpiece is the anode. The manoeuvrability of the transferred arc is, however, restricted. But such an arc is very intense and therefore the process results in higher thermal efficiency with consequential higher deposition rates as compared with GTAW, Fig. 1.9. Fig. 1.10 shows the set-ups for two modes of the plasma welding arc.

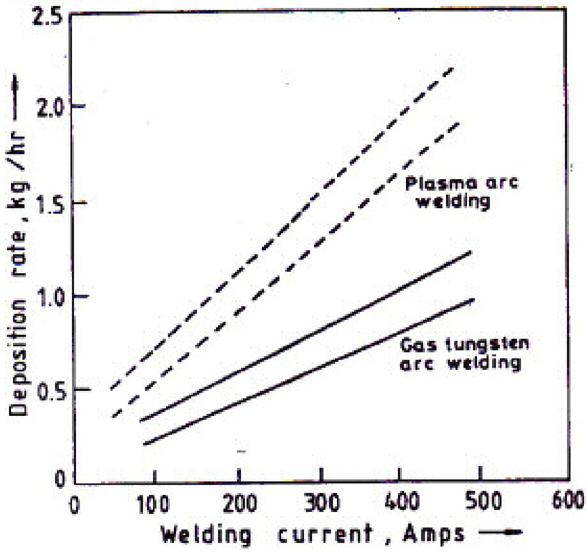


Fig. 1.9. Welding current versus deposition rate for GTAW and plasma arc welding.

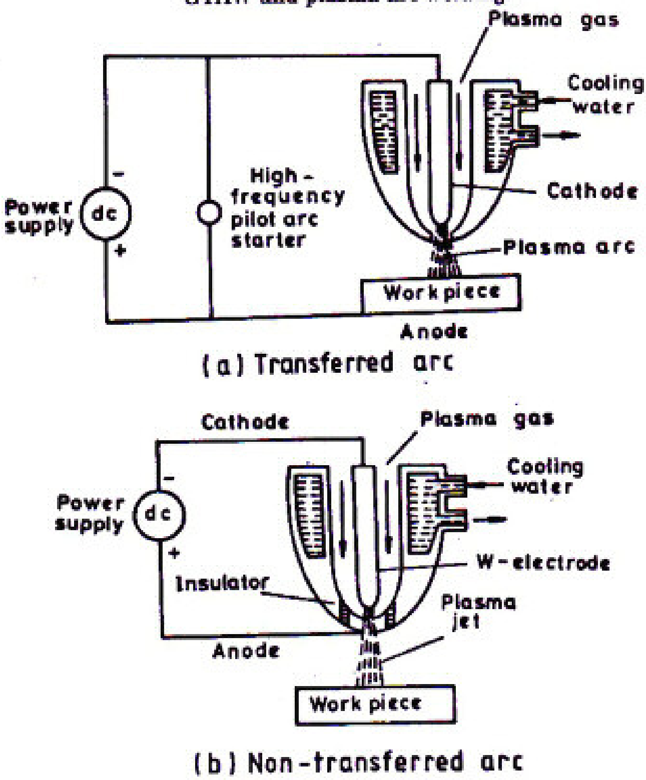


Fig. 1.10. Two modes of plasma arc welding.

Any gas that does not attack the tungsten electrode or the copper nozzle tip can be used for plasma welding. However, argon, and argon-hydrogen mixture are more commonly employed.

A major disadvantage of plasma arc welding process is the noise due to the operation of the plasma source. Because of this, hand-held plasma torches are used to a very limited extent. For most part, remotely operated plasma sources are employed.

Commercially the major users of plasma welding process are the aeronautical industry and jet engine manufacturers. Typically the process is used for making piping and tubing made of stainless steels and titanium.

1.3.1.7. Gas Metal Arc Welding

In gas metal arc welding (GMAW) process a consumable wire, of 0.8 to 2.4 mm diameter and wound in spool form, is fed at a preset speed through a welding torch wherein it is provided the electrical connection and the shielding gas. The arc which is struck by direct contact between the wire electrode and the workpiece, is maintained at a constant length by the interaction of electrical parameters. The power source used is invariably of the rectified dc type. Both, constant voltage and constant current type power sources are in use.

Depending upon the work material, the shielding gas may be argon, helium, nitrogen, carbon dioxide, hydrogen, and their mixtures. When inert shielding gas is used the process is more popularly known as MIG (metal inert gas) welding and when CO_2 is used as the shielding gas it is referred to as CO_2 welding or MAG (metal active gas) welding.

GMAW is an all-position semi-automatic welding process though its automatic versions are also available. A set-up for semi-automatic GMAW process is shown in *Fig. 1.11*.

GMAW is a very versatile process and can be used for welding all metals for which compatible filler wires have been developed. However, its typical applications include medium-gauge fabrication such as structurals, earth moving equipment, plate and box girders, and automobile bodies. This process has great potentials for use with robotic welding systems.

1.3.1.8. Plasma-MIG Welding

This process, as the name implies, has been developed by combining the features of plasma arc welding and MIG welding processes. It has two variants; one with separate non-consumable tungsten electrode and the other uses the torch nozzle as non-

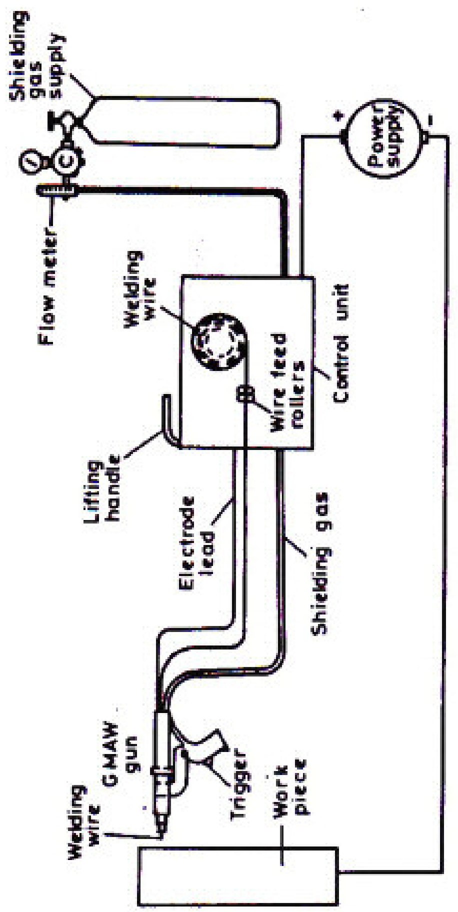


Fig. 1.11. Schematic representation of GMAW process.

consumable electrode. The essential features of torches used for these two types are shown in *Fig. 1.12.*

Essentially plasma–MIG welding process differs from the existing GMAW process in that the electrode wire is enveloped in a plasma sheath which controls heat and droplet transfer in such a way that much higher speeds and deposition rates are attained than possible with GMAW process, as is shown in *Fig. 1.13.*

This process can be used both for welding and surfacing. Most of the materials that can be welded by GMAW can as well be welded by this process and at much faster rates.

1.3.1.9. Electrogas Welding

The equipment used for Electrogas Welding (EGW) is similar in appearance to the one used for electroslag welding. However,

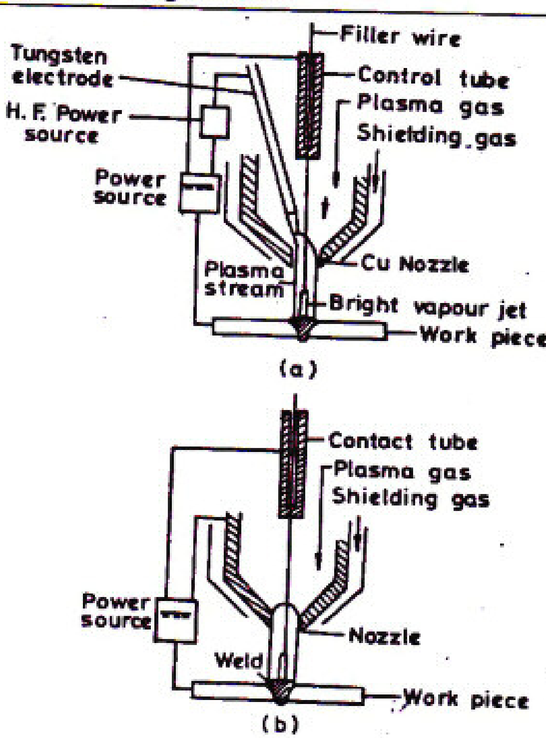


Fig. 1.12. Plasma-MiG welding torches : (*a*) with separate non-consumable electrode : (*b*) with nozzle as non-consumable electrode.

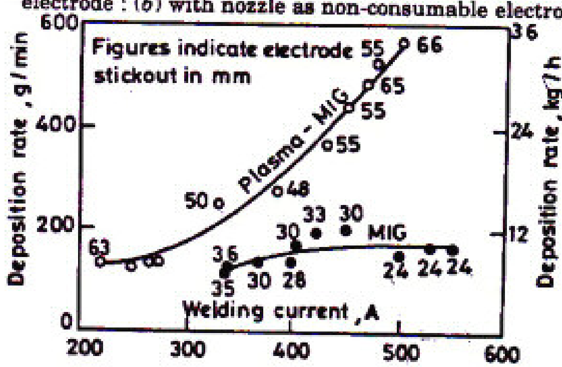
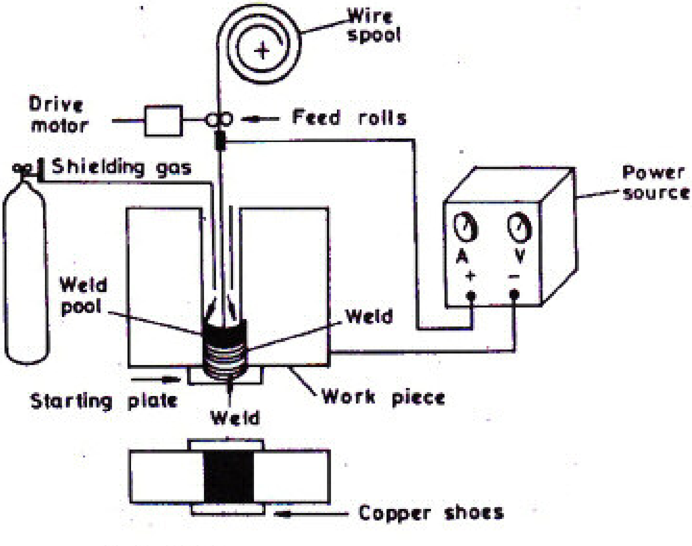


Fig. 1.13. Comparison of deposition rates for MIG and plasma-MIG welding processes.

EGW is an arc welding process and gives welds with properties close to those obtained by submerged arc welding.

Electrogas welding uses the vertical orientation of the weld joint and employs copper shoes for retaining the molten metal in shape at the end of the plate width as in electroslag welding.

However, the wire used in EGW is of the flux-cored type which provides minimal covering to the weld pool. Additional protection is normally provided by the use of CO_2 or argon-rich shielding gas. The rating of the equipment is similar to that of gas metal arc welding equipment. The duty cycle of the power source, however, needs to be 100% as it is a continuous operation. The essential features of a set-up for electrogas welding are shown in *Fig. 1.14.*



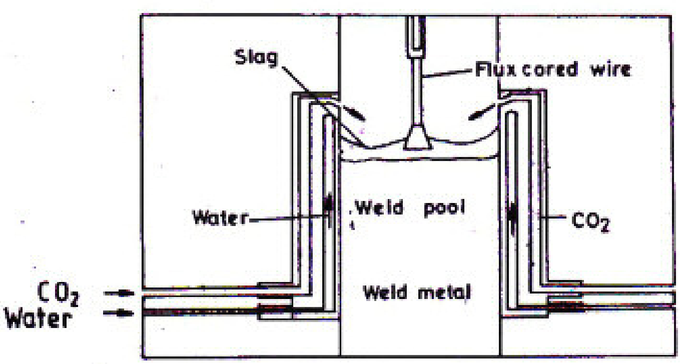


Fig. 1.14. Essential features of a set-up and process details for electrogas welding.

Electrogas welding process is mainly used for joining metals with a thickness of 12 to 75 mm; more on the lower range. Typically EGW is used in shipbuilding, and site fabrication of storage tanks.

1.3.1.10. Electron Beam Welding

In electron beam welding (EBW) a beam of electrons is used to melt the metal for welding. The electron beam, emitted from a heated filament, is focussed on to the desired spot on the workpiece

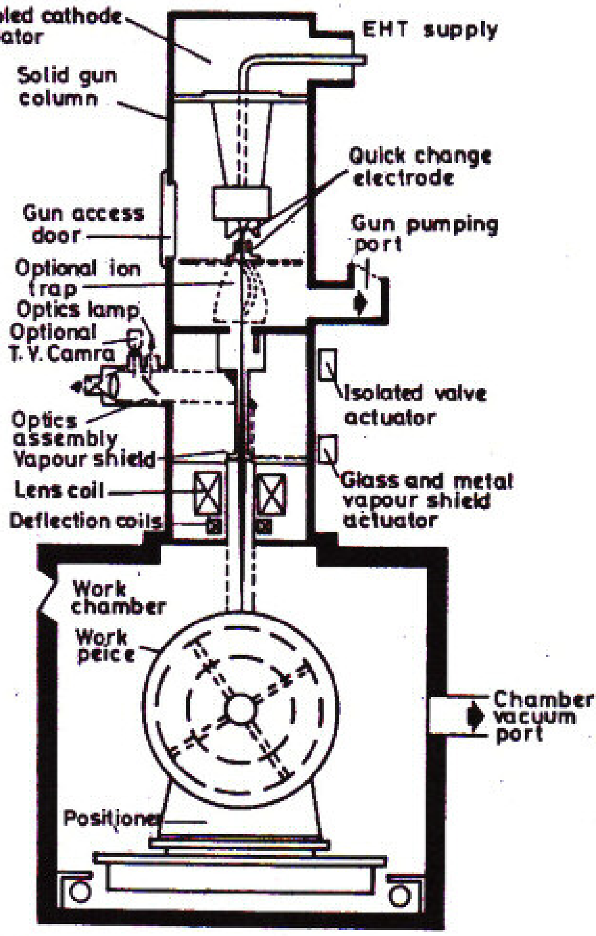


Fig. 1.15. Essential features of an electron beam welding unit.

surface with the help of a focussing coil. The workpiece which is placed in a vacuum chamber can be moved to create the necessary welding speed.

The penetrating power of the electron beam depends upon the speed of the electrons which is controlled by the magnitude of accelerating voltage. Depending upon the accelerating voltage the EBW guns are rated as low voltage and high voltage types with the range of voltages between 15–30 KV and 70–150 KV respectively. *Fig. 1.15* shows a schematic representation of a triode type EBW unit.

The EBW welds are very narrow and can be of the full penetration type with width to penetration ratio of 1 : 20 compared with 5 : 1 of shielded metal arc welding, and 2 : 1 of gas metal arc welding. The energy density of electron beam (EB) being nearly 5×10^8 W/mm^2 it is, therefore, possible to melt and weld any known metal. Due to high energy density of the EB the HAZ is extremely narrow and high welding speeds can be reached.

Electron beam welding is widely used in the electronics, nuclear, missile, and aircraft industries. Typical applications of the process include cluster gears, intricate valve arrangements made of corrosion resistent alloys for automobile industry as well as pressure capsules, and missile hull frames. A portable EBW unit has also been developed for inflight repair welding of satellites.

1.3.1.11. Laser Beam Welding

In laser beam welding a monochromatic (of one wavelength) coherent light beam is used as a heat source. A coherent light is one in which the waves are identical and parallel which can travel a long distance without loss in intensity or deviation. Laser light can be easily focussed without any decrease in intensity to a very small spot giving a very high energy density which may reach 10^9 W/mm^2. Thus, a laser beam like an electron beam, can weld any known material. Due to very high energy density the HAZ is extremely narrow and high welding speeds can be attained.

There are three basic types of lasers *viz.*, the solid-state lasers, semi-conductor lasers, and gas lasers. Although at present the solid-state Nd:YAG (Neodymium doped Yttrium aluminium garnet) lasers are the most used lasers in industry but their heat conversion efficiency is very low usually below 1%. Fig. 1.16 shows the essential features of one such laser unit. The CO_2 lasers with their heat conversion efficiency of 15–25% are now being increasingly installed.

Laser beam welding is more versatile than EBW in that it can weld metals in air, in a gas shield and in vacuum. It can also weld through transparent materials as laser beam can easily pass through such media.

A laser must have a power rating of atleast about 2 KW to be used successfully for welding, however Nd:YAG lasers of 100 W to 1 KW power are used for welding in industry because they can achieve pulses with peak power of the order of 10 KW. Although

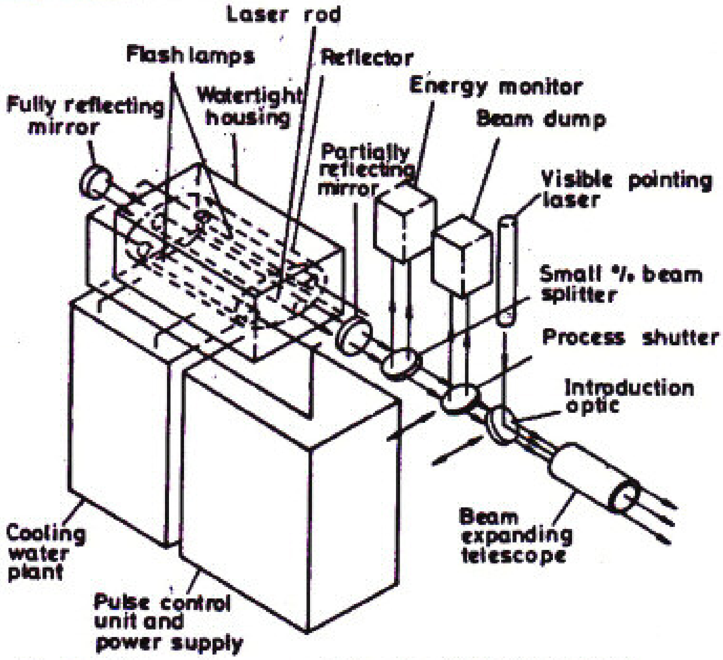


Fig. 1.16. Schematic representation of an Nd:YAG laser unit. (After Dawes)

CO_2 lasers of power rating up to 25 KW have reportedly been installed but presently such a unit is a rare piece of equipment and is extremely expensive.

Commercially laser welding is finding use in radio engineering and electronics where fine wires are often to be connected to films on micro-circuit boards, solid-state circuits, and micromodules. It is also expected to be used in high quality precision work as in aerospace industry and high speed mass production applications as in automobile industry.

1.3.1.12. Oxy-Acetylene Welding

In this process acetylene gas is mixed with oxygen in the gas welding torch and is then burnt at the torch tip to give a flame with a temperature of about 3300°C which can melt most of the ferrous and non-ferrous metals in common use. Fig. 1.17 shows a standard set-up for oxy-acetylene welding.

Three types of flames are used in oxy-acetylene welding. The nature of the flame depends upon the ratio of the two gases. The neutral flame is most often used for the welding of most of the materials like low carbon steels, cast steel, cast iron, etc. The oxidising flame has higher proportion of oxygen than acetylene and is used for welding of Mn-steel, brass, and bronze whereas

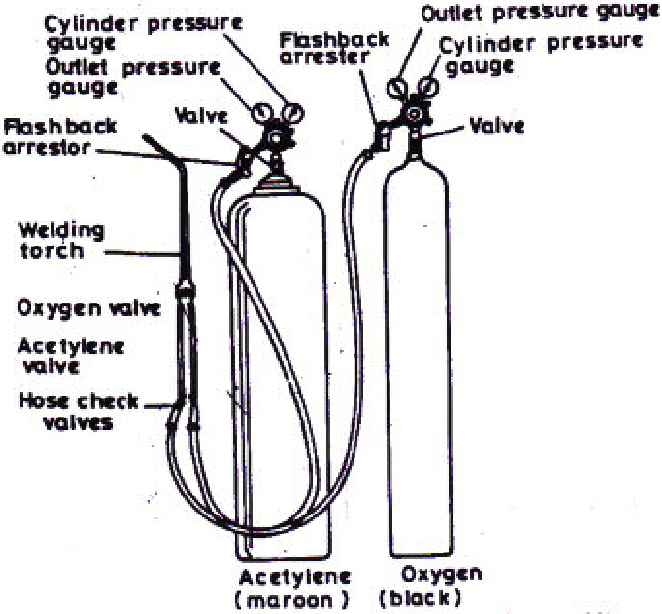


Fig. 1.17. A standard set-up for Oxy-acetylene welding.

the carburising flame has higher proportion of acetylene in it and is used for welding aluminium, nickel, etc.

The heat transfer to the work in this process is very poor (about 30%) and may lead to a wide HAZ around the weld. The welding speed is also accordingly low.

Typical applications of oxy-acetylene welding include welding of root run in pipe and other multi-run welds, light fabrications like ventilation and air-conditioning ducts, and motor vehicle repairs. A large percent of general repair work is also done by this process.

1.3.2. Arc Spot Welding Processes

The processes in this class are used to join workpieces within a narrow zone of desired shape.

1.3.2.1. GTAW Arc Spot Welding

In this process the equipment used is basically the same as for conventional GTAW except that the control system includes timing device and the torch nozzle is modified to develop a spot weld at the intended place. GTAW arc spot welding may be done with ac or dcen (direct current with electrode negative). DCEN is used for all materials except aluminium for which ac with continuous superimposition of high frequency (HF) current is employed. The torch nozzle is made of copper or stainless steel and is often water-cooled as the arc is enclosed completely within

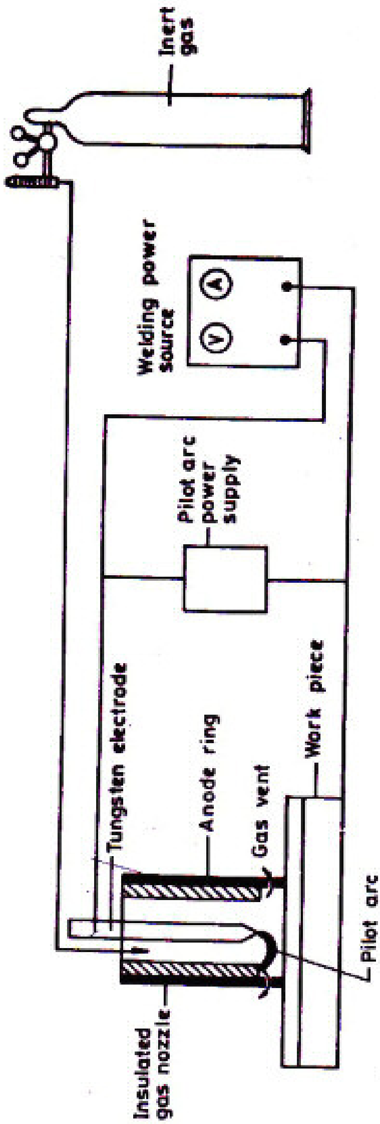


Fig. 1.18. Schematic illustration of a set-up for **GTAW arc spot welding.**

the nozzle. The torch nozzle, usually about 12 mm inside diameter, is provided with venting ports to affect gas flow and escape.

The shielding gas used is either helium or argon with a flow rate of 2.5 to 4.5 lit/min.

To accomplish a spot weld, the arc is initiated by the HF discharge for which the outline circuitry is shown in *Fig. 1.18*. The arc continues for the preset time and the spot weld is achieved.

Normally no filler metal is used but when required it is fed with the help of special wire feeder. Filler wire addition improves nugget configuration and helps in overcoming crater cracking.

This process is mainly used in its semi-automatic mode but it can be mechanised and even controlled by numerically controlled (NC) system to achieve high rate of production.

GTAW arc spot welding is widely used in the manufacture of automatic parts, precision metal parts and parts for electronic components and appliances. It is particularly useful for applications where access to a lap joint can be gained only from one side.

1.3.2.2. GMAW Arc Spot Welding

Normal GMAW equipment can be used for making spot welds between the lapped sheets by providing a special torch with a

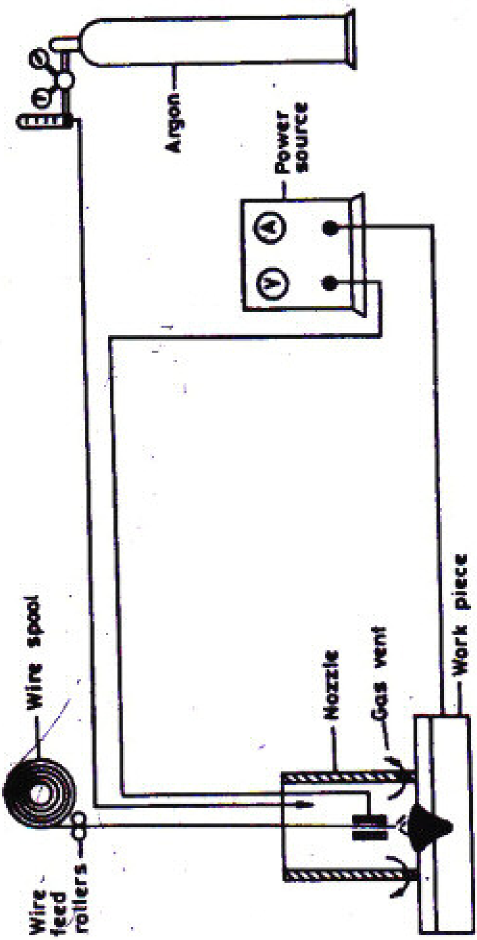


Fig. 1.19. Schematic illustration of a set-up for GMAW spot welding.

nozzle attached to it. A vented metal nozzle of a shape to suit the application is fitted to GMAW gun and is pressed against the workpiece at the desired spot. The operation is carried out for a period of 1 to 5 seconds and a slug is melted between the parts to be joined, as is shown in Fig. 1.19. Timing is usually controlled automatically with the help of a timer.

No joint preparation is required except proper cleaning of the overlapped areas. Argon and CO_2 are the shielding gases commonly used for GMAW arc spot welding.

GMAW arc spot welding process can be used most efficiently for downhand welding position. It can be successfully employed for horizontal position but fails for overhead welding position.

This process does not require a hole to be made in either member, thus it differs from plug welding in that respect. As the upper member is required to be melted through and through its

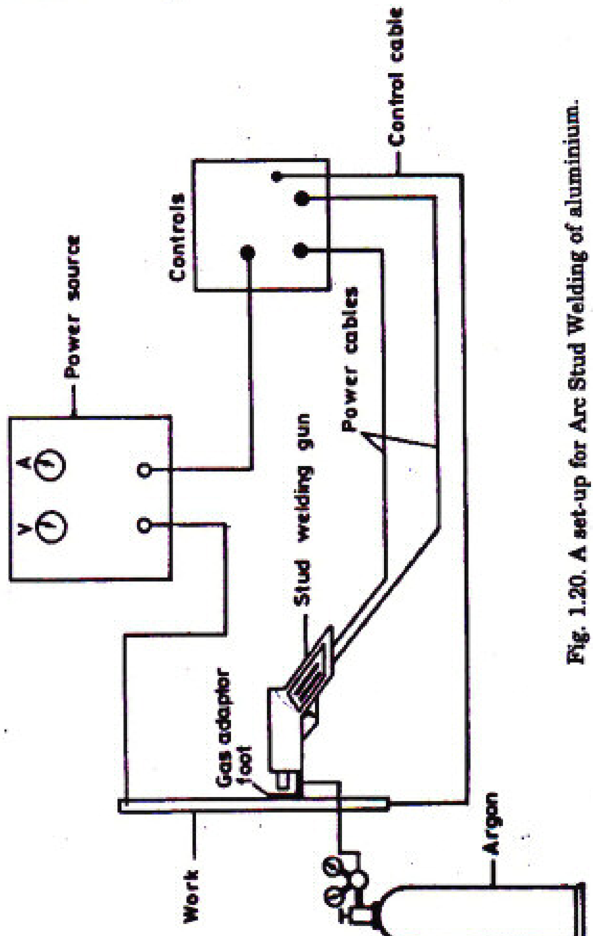


Fig. 1.20. A set-up for Arc Stud Welding of aluminium.

thickness is normally restricted to 3 mm. The thickness of the second member is not important.

GMAW arc spot welding can be used successfully on aluminium, mild-, low alloy-, and stainless steels.

1.3.2.3. Stud Welding

This is a process of welding stud (a headless threaded bolt) or stud-like pieces (*e.g.* bolts, screws, rivets, rods, etc.) to flat pieces like plates.

The main equipment for stud welding consists of a stud welding gun, a time control unit, a dc power source of 300–600 amperes capacity, studs and ceramic protective caps called *ferrules*.

For stud welding the stud is held in the welding gun and a ferrule is slipped on it. The stud is then made to touch the cleaned spot where it is to be welded and the switch, in the form of gun trigger, is pressed and the process is completed in a couple of seconds. Fig. 1.20 shows the basic features of a stud welding unit.

Typical applications of stud welding include steel decks of ships, for attaching brackets, hangers, cover plates, piping, etc. to metal workpieces. The process also finds wide use in automotive rail road machinery manufacturing and construction industries.

1.4. Resistance Welding Processes

In all resistance welding processes the heat is generated at the interface of contacting workpieces due to the resistance offered to the flow of electric current and is expressed by Joule's Law,

$$H = \eta \frac{I^2Rt}{J} \qquad \text{...(1.1)}$$

where,

H = heat generated, calories,

I = welding current, amperes (rms),

R = contact resistance, ohms,

t = time for which the current flows, seconds,

J = the electrical equivalent of heat,

η = thermal efficiency of the process.

The welds produced by resistance welding are normally without the addition of any filler material and are, therefore, sometimes referred to as *autogenous welds*.

Resistance welding processes can be divided into three categories *viz.*, spot, seam, and zonal type welds with some of them falling in more than one category. Brief description of industrially important processes, among them, follows.

1.4.1. Spot Welding Processes

In this class of processes the materials are joined at a spot the size of which depends upon the design specifications and is controlled by the electrode size and the magnitude of the welding current. Two main processes fall in this class *viz.*, resistance spot welding and projection welding.

1.4.1.1. Resistance Spot Welding

In resistance spot welding process overlapping sheets are welded by the flow of current between two cylindrical electrodes. The main equipment for spot welding is the spot welding machine which consists of a step down transformer, a time control unit, and a pair of copper alloy electrodes. As voltage plays no direct role in

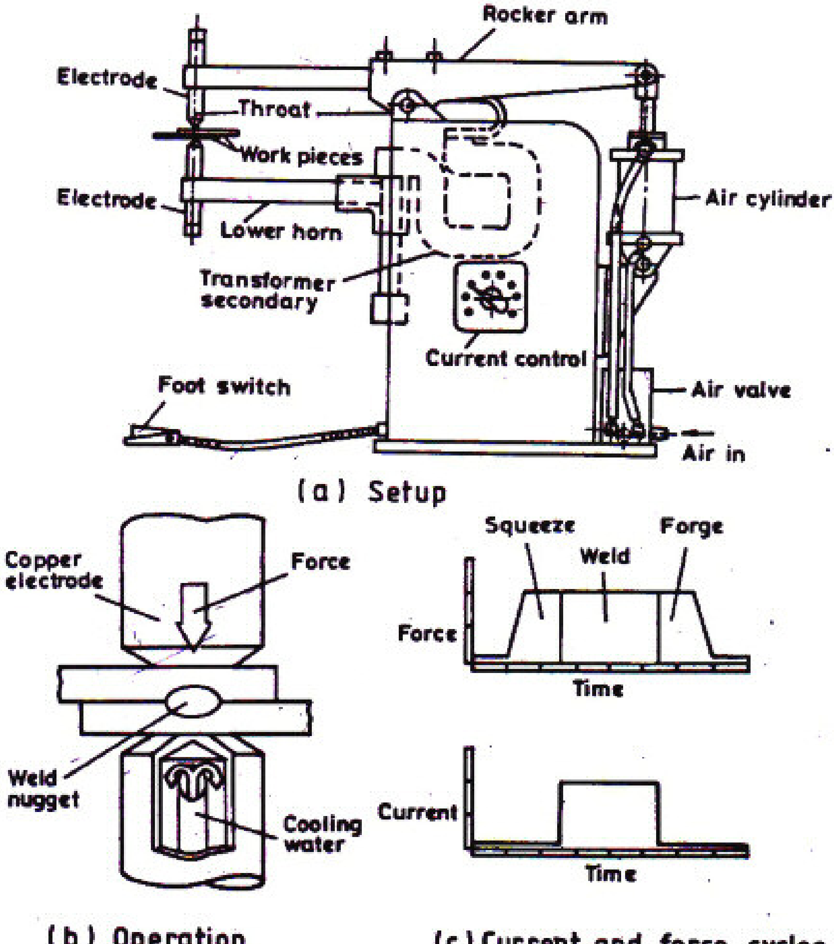


Fig. 1.21. Essential features of a rocker arm type spot welder; operation details with current and force cycles.

resistance welding it is, therefore, kept low between 5 to 25 volts but the current is usually heavy (100–50,000 A); however, it flows only for a short duration of time (0.06 to 3 seconds). Application of pressure to achieve forge between the two sheets is an essential aspect of the process. *Fig. 1.21* shows a general purpose spot welding machine.

Spot welding is mainly used for lap welding of thin sheets particularly in the welding of automobile and refrigerator bodies, and high quality work in aircraft engines.

1.4.1.2. Projection Welding

Projection welding is a process of joining two sheets or a sheet and a thick component, or a small component like nut to a big

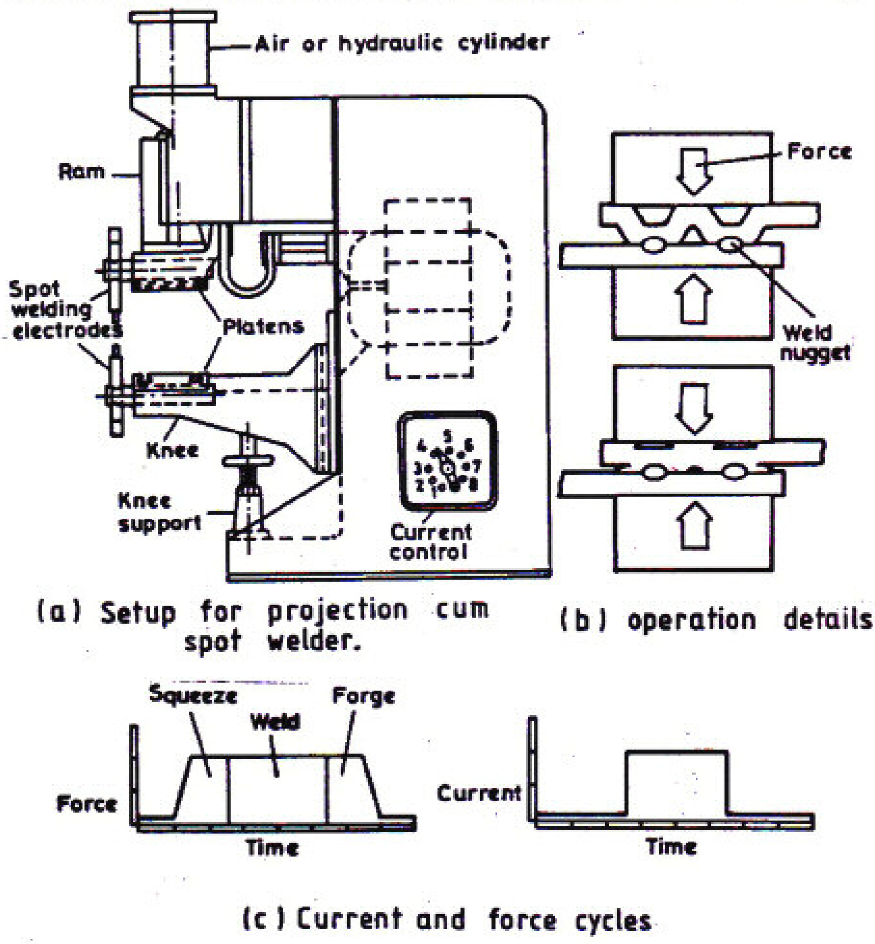


Fig. 1.22. Essential features of a projection welder; operation details with current and force cycle.

body like automobile chasis, by making raised portions or projections on one of the components. The projections are made by embossing or intersection (*e.g.* cross of wires, etc.). There are several types of projections *viz.*, round button or dome type, ring type, elongated projection, shoulder projection, and radius projection. The projections act to localise the heat of welding circuit, because when placed together the sheets touch only at the points of the projections. Projection collapses due to heat and pressure and a fused nugget is formed at the interface.

Equipment used for projection welding is similar to that used for spot welding except that the rod electrodes are replaced by flat copper platens as shown in *Fig. 1.22*; which also shows the force and current cycles for the process.

Typical applications of the process include projection welding of reinforcing rings around holes in sheet metal tanks, welding of threaded studs to backing bar or plate and cross-wire welding. Cross-wire products include such items as refrigerator racks, grills of all kinds, lamp shade frames, wire baskets, fencing, gratings and concrete reinforcing mesh.

1.4.2. Seam Welding Processes

In these processes the weld is established along a seam so as to make a leakproof joint. The seam weld may be produced by making partially overlapping spot welds. Apart from projection welding the main processes in this class include resistance seam welding, electric resistance butt seam welding (ERW), high frequency resistance welding (HFRW), and high frequency induction welding (HFIW).

1.4.2.1. Resistance Seam Welding

In resistance seam welding wheel electrodes are used to produce spot welds overlapping to the extent of 25 to 50%. Due to shunting of current through the already made weld, the current required is higher than in normal spot welding. Pressure is applied to fuse the metal properly into a nugget as in spot welding. *Fig. 1.23* shows the principle of resistance seam welding alongwith force and current cycles employed in the process.

Seam welding is used for producing leak-proof joints in tanks and boxes generally required for the automobile industry. This process is, however, restricted to welding thin materials ranging between 2.5 and 5.0 mm. Also, it is used mainly for welding materials with low hardenability rating, for example, hot-rolled grades of low alloy steels. This process is commonly used for making flange welds for use in water-tight tanks.

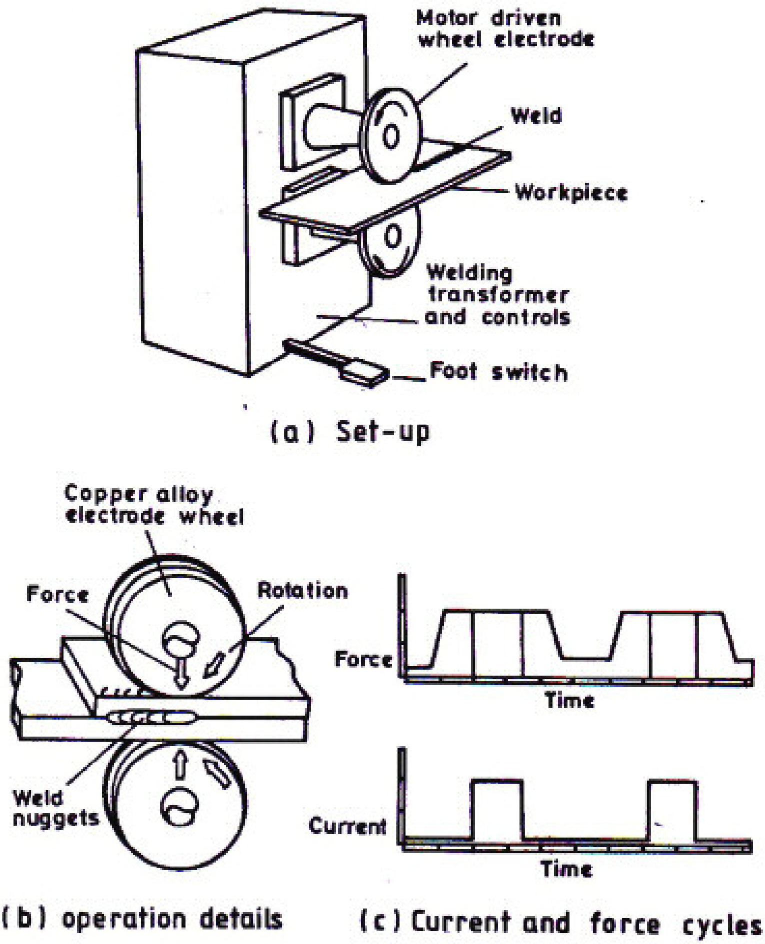


Fig. 1.23. Resistance seam welding.

1.4.2.2. Electric Resistance Butt Seam Welding (ERW Process)

Large quantities of steel tube and pipe are manufactured by resistance butt seam welding from strip which is continuously edge sheared and rolled into tube of desired diameter before welding. Alternating current of up to 4000 A at about 5 volt is introduced across the joint by pressure rolls as shown in *Fig. 1.24*. For introducing heavy current directly to the moving electrodes a rotating transformer with slip rings on the primary side is employed. Unlike the normal resistance seam welding, current and work motion are continuous in this process.

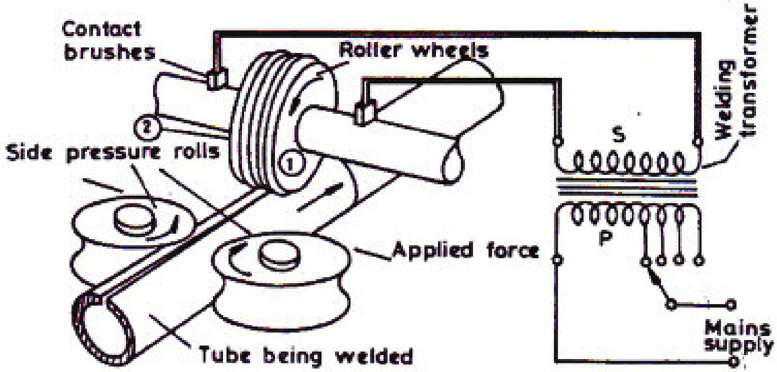


Fig. 1.24. ERW process of tube manufacturing.

The maximum rate of production is limited by the welding current frequency because as the welding speed is increased individual current half-cycles eventually lead to spot welding instead of seam welding. To overcome this difficulty current frequency is usually increased to 350 Hz to achieve welding speed of up to 36 m/min. The tube produced by this process has a fin of upset metal along the weld joint both inside and outside which is usually removed by installing appropriate cutters on the production line. The tube is cut to the desired lengths by employing a cutter which moves along the tube and is synchronised to cut the desired length in the available run in a given cycle.

1.4.2.3. High Frequency Resistance Welding (HFRW Process)

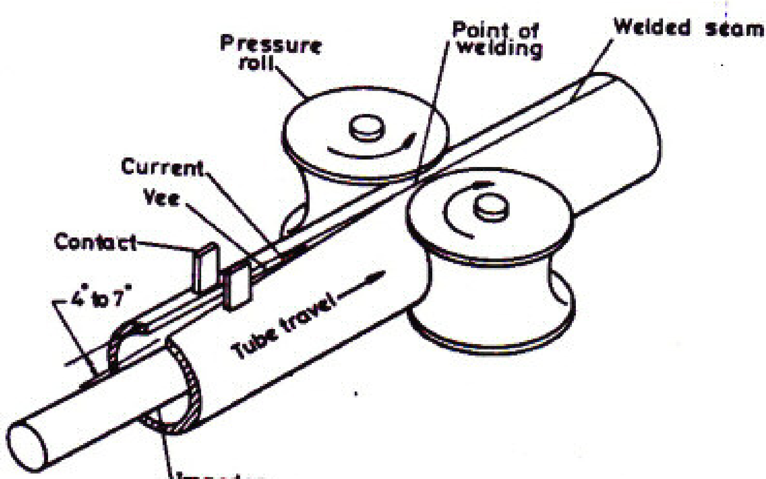


Fig. 1.25. HFRW process of tube manufacturing.

In this process the tube is formed by rollers in the same way as in ERW process but the current in the range of 500 to 5000 A at a frequency (f) of up to 500 KHz and a voltage of about 100 volts is introduced through probes made of copper alloys and silver brazed to heavy water-cooled copper mounts. Contact tip sizes range between 15 and 650 mm^2 depending upon the amperage to be carried. Whereas in ERW process the heat is generated mainly by the interfacial contact resistance in HFRW process it is produced by the *skin effect* due to which the current flows in a shallow depth of the conductor and is proportional to $\sqrt{\frac{1}{f}}$. Pressure rollers, to provide the forging pressure are installed a short distance down the line from the current probes as shown in *Fig. 1.25*. Due to the skin effect the current flow path lies along the strip through the apex of vee formed by the faying surfaces meeting at an angle of 4° – 7° as they close to form the tube. The depth of the heated region is generally less than 0.8 mm and thus affords the optimal condition for weld joint.

HFRW process is used to produce pipe and tubing of diameters ranging between 12 and 1270 mm, and with a wall thickness of 0.25 to 25 mm. Any metal can be welded by this process with a speed range of 5 to 300 m/min depending upon the wall thickness. This process can also be used to manufacture spiral and finned tubes and pipes. Various types of serrated or folded fins can also be welded to tubes.

1.4.2.4. High Frequency Induction Welding (HFIW Process)

High frequency induction welding of tubes is similar to high frequency resistance welding except that the heat generated in the

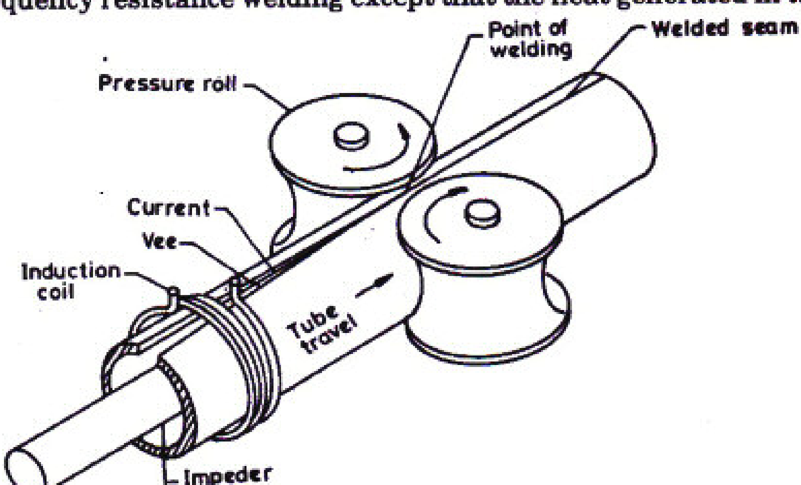


Fig. 1.26. HFIW process of tube manufacturing.

work material is by the current induced into it. Because there is no electrical contact with the work this process can be used only where there is a complete current path or closed loop wholly within the work. The induced current flows not only through the weld area but also through other portions of the work.

Tube edges are brought together in the same manner as in ERW and HFRW processes. A water-cooled induction coil or inductor made of copper encircles the tube at the open end of the vee as shown in *Fig. 1.26*. High frequency current flown through the coil induces a circulating current around the outside surface of the tube and along the edges of the vee, heating them to welding temperature. Pressure is applied to accomplish the weld as in HFRW process.

HFIW process is suitable for tubing made of any metal within a diameter range of 12 to 150 mm with a wall thickness of 0.15 to 10 mm at a welding speed ranging between 5 and 300 m/min.

HFIW process is not limited to tube manufacture but can also be employed to make circumferential welds for welding cap to tube. The process can as well be advantageously used for manufacturing tubing from coated material, small or thin-walled tubing; and it eliminates surface marking by electrical contacts. This process is, however, not suitable for welding high conductivity metals or those which form refractory oxides as there is no effective mechanism for oxide disposal.

1.4.3. Zonal Welding Processes

In these resistance welding processes heat is generated simultaneously over the entire zone which is required to be welded. The processes included in this class are Resistance Butt Welding, Flash Butt Welding, and Percussion Welding.

1.4.3.1. Resistance Butt Welding

In Resistance Butt Welding or Upset Welding the pieces to be welded are held in clamps supported on two platens, one of which is fixed and the other moveable; and form part of the single-turn secondary loop of a heavy duty transformer, as shown in *Fig. 1.27*. The ends to be welded touch each other before the current is switched on. A heavy current is then passed from one workpiece to another and the contacting faces are heated up due to the contact resistance. The two pieces are pressed together firmly after the desired welding temperature of 870 to 925°C, for steels, is reached. The pressing action which results in the increase in lateral dimension of the workpieces is called *upsetting*. Upsetting takes place both during and after the current flow. The upsetting

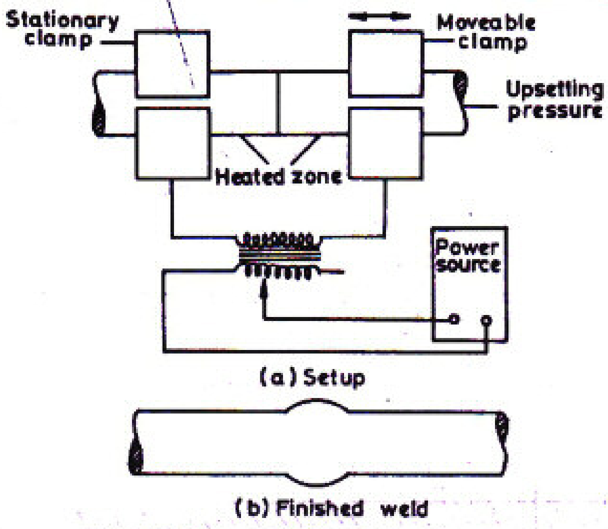


Fig. 1.27. Basic features of upset welding.

action results in welding of end faces with squeezing of a part of the softened metal to form a fin, which can be removed later, if required, by machining.

Resistance butt welding is used for end joining of rods, tubes, bars, and similar other sections for welding a cross-sectional area of up to 150 mm^2. Wire and rod from 1.25 mm to 30 mm diameters can be upset welded. Typical application of resistance butt welding is in wire mills for joining wire coils to each other to facilitate continuous processing.

1.4.3.2. Flash Butt Welding

Flash welding is similar to resistance butt welding except that it is accompanied by arcing and flashing. Flash welding consists of one fixed and one moveable clamp to hold and clamp the workpieces firmly as well as to force them together, a heavy duty single phase transformer with a single turn secondary, alongwith equipment to control welding current, movement of the clamp, force, and time. With a voltage of about 10 volts across the clamps, heavy current flows along the asperities across the contacting faces of workpieces. As the points of contact are melted and the metal is squeezed out in a shower of fine molten droplets, the contact is broken and arcing takes place across the gap. With further movement of the clamp, the process of melting, flashing and arcing repeats itself. Due to flashing contaminants from the contacting faces are removed and the surfaces are heated to a uniform temperature. Finally the movement of the platen (or moveable clamp) is rapidly increased and a high force is applied to achieve a weld with the expelled metal forming a rough fin or flash around the joint. The flash can be removed by subsequent machining. Basic arrangement for flash butt welding process is shown in *Fig. 1.28.*

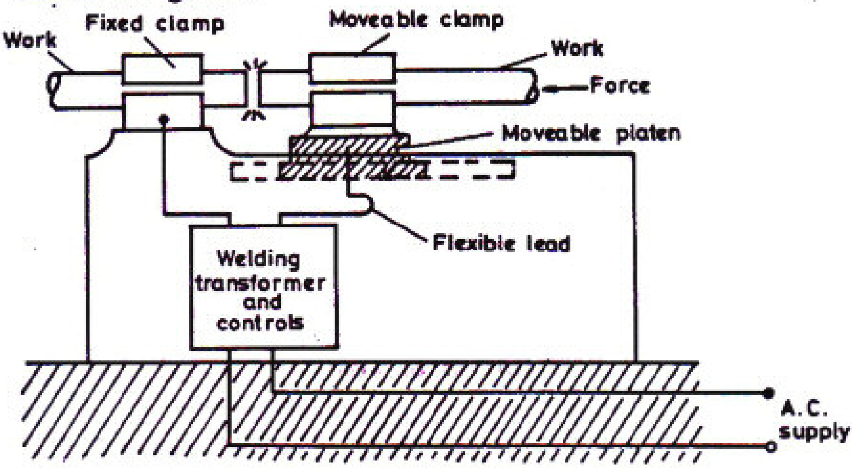


Fig. 1.28. Basic elements of a set-up for flash butt welding.

Flash Butt Welding requires a heavy power supply, for example, currents in excess of 100,000 A can flow across the interface with a power input up to 200 KVA. Transformer used for flash butt welding are single phase which can, thus, place an unbalancing load on normal 3-phase supply from the mains. This necessitates the use of special transformer which can distribute the load uniformly.

In flash butt welding the pieces to be welded must be held with enough force to avoid slipping and that requires a clamping force of up to twice that of the upsetting force. The upset force is around 70 MPa* for mild steel and nearly four times that for high strength materials.

Flash butt welding is extensively used for welding mild steels, medium carbon steels, and alloy steels as well as non-ferrous metals like aluminium alloys, nimonic alloys (80% Ni + 20% Cr) and titanium. Dissimilar metals may be flash welded if their flashing and upsetting characteristics are similar, for example aluminium can be flash butt welded to copper or nickel alloy to steel.

Typical uses of flash butt welding include welding of wheel rims, cylindrical transformer cases, circular flanges, and seals for power transformer cases. The aircraft industry utilises flash butt

* 1MPa = 1 N/mm^2.

welding to manufacture landing gears, control assemblies, and hollow propeller blades while the petroleum industry uses oil drilling with fittings attached by flash welding. Other uses of the process include welding of rails, steel strips, window frames, and heavy duty chain links *e.g.*, anchor chains for ships. To avoid shunting of current the ring-type workpieces are made by welding two halves of each link simultaneously.

1.4.3.3. Percussion Welding

Percussion welding is an arc welding process of joining, end-to-end, two parts of equal cross-section. The arc is produced by a short pulse of electrical energy and pressure is applied in a percussive* manner to produce coalescence simultaneously over the entire abutting surface. In general percussion welding is the term used in the electronics industry for joining wires, contacts, loads, and similar items to a flat surface.

There are two variants of this process *viz.*, magnetic force percussion welding and capacitor discharge percussion welding. Essential steps involved in the process involves, (*i*) establishing an arc between the surfaces, to be joined, with high voltage to ionize the gas between the parts or with high current to melt and vaporise a projection on the part, and (*ii*) move the parts together percussively with an applied force to extinguish the arc to accomplish a weld.

Welding heat is generated by a high current arc between the two parts to be joined. The extremely short duration arc limits melting to a very thin layer on the two surfaces being welded. Consequently, there is very little upset or flash on the periphery of the welded joint. Filler metal is not used nor flux or special atmosphere required.

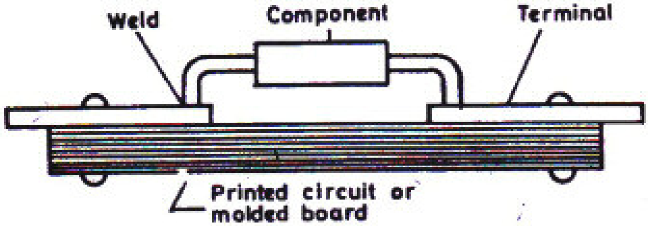


Fig. 1.29. Electronic component welded to terminals by percussion welding.

Percussion welding is usually employed for welding dissimilar metals difficult to weld by other processes and where the avoidance of upset at the joint is imperative.

Percussion welding is particularly good for joining small diameter (0.050–0.400 mm) wires even with widely different

* Forcible striking of one solid body against another.

properties in electronic industry. Large contact assemblies for relays and contactors are often produced by percussion welding. This process is also used to weld electronic components to terminals as shown in Fig. 1.29.

1.5. Solid-State Welding Processes

In solid-state welding processes the material to be welded is heated to a temperature below or just up to the solidus. The coalescence between the parts is achieved under pressure and thus forging or impact action plays an important role in all these processes.

Solid-state welding processes may be divided into two groups *viz.*, high heat input processes and low heat input processes.

1.5.1. High Heat Input Processes

High heat input solid-state welding processes include Forge Welding, Friction Welding and Diffusion Bonding.

1.5.1.1. Forge Welding

Forge welding or *smith welding* is the oldest known welding process and its use has been reported from about 1400 B.C. By this process the pieces to be welded are heated to above 1000°C and then placed together and given impact blows by hammering. In the more recent form of welding of large components the pressure is applied by rolling, drawing and squeezing to achieve the forging action. The oxides are excluded by virtue of design of the workpieces and or by the use of appropriate temperature as well as fluxes. Fluxes commonly used for forge welding low carbon steels are sand, fluorspar, and borax. They help in melting the oxides, if formed.

Proper heating of the workpieces is the major welding variable that controls the joint quality. Insufficient heating may not affect a joint while overheating results in a brittle joint of low strength. Also, the overheated pieces tend to be oxidised which shows itself by spongy appearance. The joints most commonly employed are scarf, cleft and lap types, as shown in *Fig. 1.30.*

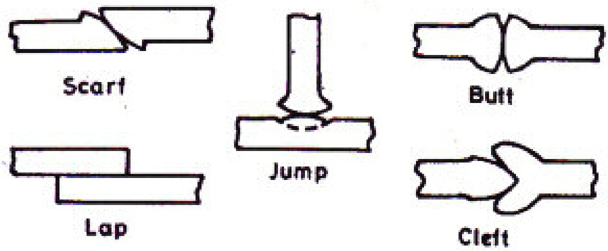


Fig. 1.30. Types of joints used in forge or smith welding.