CHAPTER (2)
FOUNDRY

TOOLS & EQUIPMENTS FOR FOUNDRY

Tools for the molder are made in great variety.

Bellows

This instrument is used by the molder to blow loose sand from the recesses of the mold .A, Fig. 2-1 is a bench type & has no nozzle.

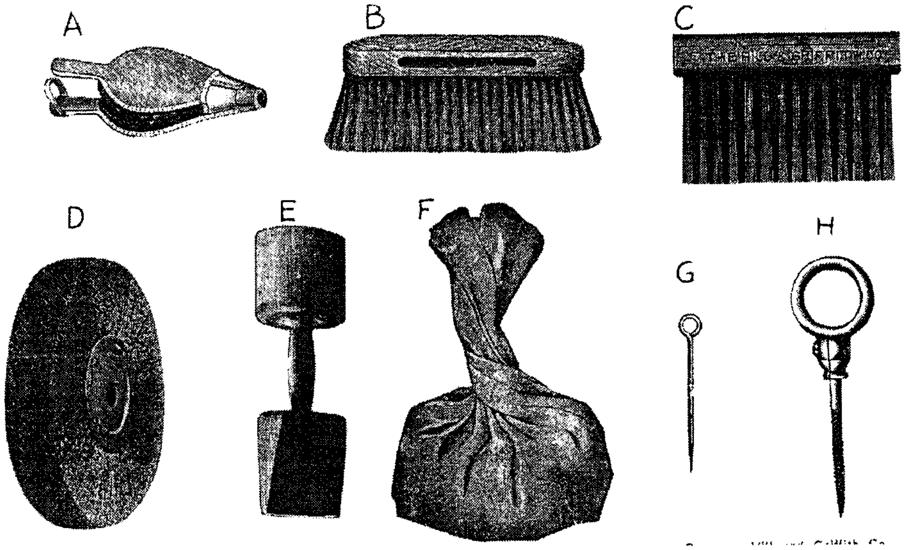


Fig.2-1 Molding Tools

Brushes

The molder uses brushes for cleaning patterns & casting. B, Fig .2-1, is a soft bristle brush & is used for dusting patterns.

Bench Reamer

This is the device the molder uses for packing the sand in the flask. The large round part of E, Fig 2-1, is called the butt, & the wedged-shaped part is the peen.

Dust Bags

The molder to hold the partine or parting compound, which he dusts onto the faces of the mold, uses the dust bag, F, Fig 2-1.

Draw Pin

A draw pin or draw spike is a device used for drawing the pattern from the mold. G Fig 2-1 is a draw pin & H a draw screw.

Chaplets

These are devices for supporting a core or holding it in place while the metal is being poured. Those illustrated in Fig 2-2 are perforated & made of sheet metal with a low melting point which , as it melts , is fused with the metal in the casting. Chaplets of this type can be bent to fit a great variety of situations.

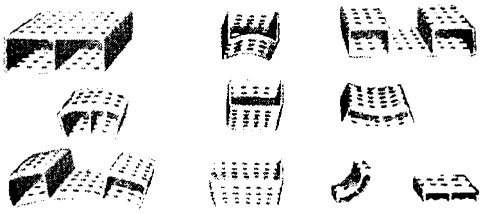


Fig. 2-2 Chaplets

Crucibles

These are devices used for holding metal while it is being reduced to a liquid state. Crucibles usually are made of a combination of graphite and special clay. Small crucibles, Fig 2-3 are made in sizes 0 to 10. A No. 10 crucible will hold approximately 36 pounds of molten brass. Crucible of median capacity range in size from 11 to 20. A No. 20 crucible will hold approximately 74 pounds of brass. Before a new crucible is put into service it should be gradually brought to a temperature of 250°F and held thus for several hours.

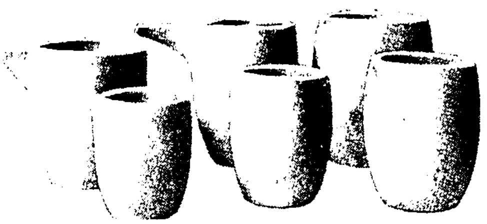


Fig.2-3 Crucibles

Crucible Tongs

Several kinds of tongs and other devices are available for lifting crucibles. A, Fig 2-4 is a type operated by hand, while B is one operated by some form of mechanical lift, C and D respectively are shanks for holding the crucible while pouring the metal. Shanks may be had in sizes to fit all crucibles. E is a pick-up-tongs. It is designed for lifting hot crucibles or metals, but is not intended for lifting hot crucibles.

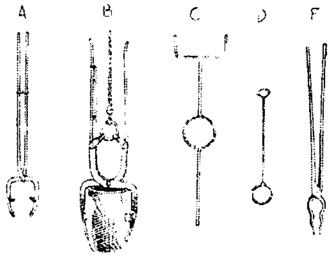
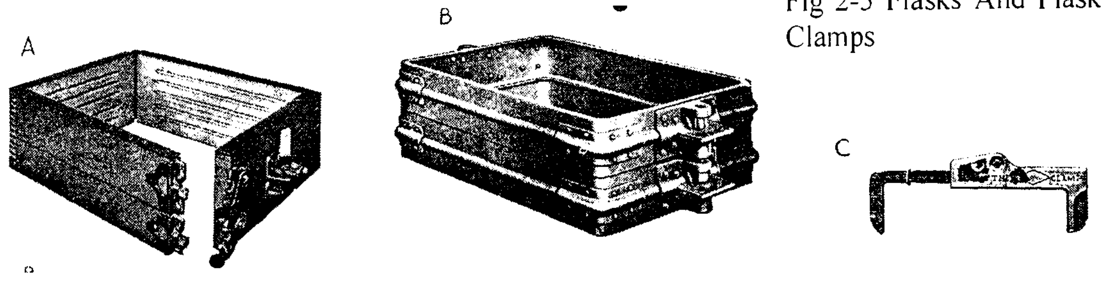


Fig 2-4 Crucible Tongs

Flasks

Flasks are of two kinds, snap and solid, A and B, Fig 77,respectively. Snap flasks are used in production work. After the mold has been rammed and gated it is moved to the poring floor where the flask is opened and removed. A steel jacket is then slipped over the mold. Flasks are made rectangular, trapezoidal or round and in a number of sizes. Commonly used sizes are 12 by 12 inches and 14 by 20 inches. A flask clamp, C, Fig 2-5 is used to hold the cope and drag together when rolling over a heavy mold , also for holding the parts together when pouring.

Fig 2-5 Flasks And Flask Clamps



Riddles

This device, A, Fig 2-6, is used by the molder to removed foreign matter from the sand and to insure the depositing of a coating of fine sand on the surfaces of the pattern. Riddles are made of woven brass or galvanized or steel wire. The size of the riddle is given in inches in diameter and the number of openings per lineal inch. Thus a No. 10 riddle has 10 openings per lineal inch, measured from the center of one wire to the center of the next. For general purposes a 12 or 14 mesh riddle is recommended.

Sponges and Swabs

The bulb sponge, B, Fig. 2-6, and the swab, C, Fig. 2-6, are devices used for moistening the sand at the parting line adjacent to the pattern or elsewhere in the mold as occasion requires.

Sprue Cutters and Gate Cutters

These tools are used for cutting a passageway in the sand along which the metal travels on its way to the cavity in the mold. The tapered sprue cutter, D, Fig. 2-6, is used to make an opening for the metal so that it can pass through the cope part of the mold. The gate cutter, E, Fig. 2-6, is used to cut a passageway through the sand in the drag from the sprue gate to the cavity in the mold.

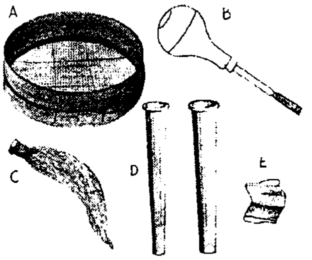


Fig 2-6 Sprue & Gate cutter

Trowels, Slicks, and Lifters

Trowels and slicks are tools used to smooth, patch, and finish molds. A and B, Fig. 2-7 are trowels and are used principally for smoothing and patching large surfaces, while C and D, Fig. 2-7, are slicks and are used to smooth and patch grooves and small breaks. E and F, Fig.2-7, are lifters and are used principally for lifting particles of sand from deep narrow recesses and for making small repairs in close spaces.

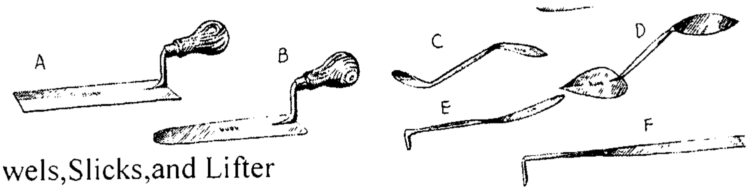


Fig. 2-7 Trowels,Slicks,and Lifter

MOLDING AND CORE MAKING

Molding

The product of the foundry is a casting. The first foundry process involved in the production of a casting. The first foundry process involved in the production of a casting is the construction of a suitable mold. The type of mold is governed by the size and shape of the casting and the kind of metal to be used to make the casting.

Molds are divided into three classes, green sand, dry sand, and loam. The size of the mold further classifies it as a bench mold, light floor mold, crane floor mold, or pit mold.

Green sand molds are made of sand in its green or natural state and may be poured with metal as soon as they are completed. About 85% of all molds made in the foundry are of green sand.

Molding sand must be selected with great care, as much of the success or failure of the casting depends on the sand mold. Molding sand for green sand molding must have the following qualities:

1. Ability of the sand grains to stick together so that the fine detail of the pattern may be transferred to the casting.
2. Ability to permit the air in the mold and the gas and steam created during pouring to escape freely.
3. Ability to resist the burning action and the pressure of the molten metal.

The chemical composition of natural molding sand should be about 80% to 90% silica, 5% to 10% alumina or clay (the bonding agent), and a small percentage of lime, magnesia, and other elements.

Dry sand molds are made of a special mixture of sand rammed in its damp state. When the mold has been completed it is placed in an oven to bake. This process removes all moisture from the mold and leaves the body of the mold firm and dry. Dry sand molds are used extensively in making molds for engine cylinders and cylinder blocks.

Loam molds are used to make large intricate castings. They are constructed around skeletons of patterns and depend upon brickwork for the inner and outer support of the mold. The mold face is composed of a loamy mixture of sand. This type of mold, like the dry sand mold, must be thoroughly dried before metal is poured into it. Loam molding represents the work of a highly skilled craftsman who works with skeletons and sweeps of patterns and a blueprint. The loam mold is more costly than either the green sand or dry sand mold but is of advantage in that expensive and complicated patterns are not required.

Molding Machines

Hand ramming, even when done by the most skillful molder, leaves something to be desired, but it is necessary in many cases and is still widely done. Machine ramming, when it is properly controlled and is applicable, makes more and better molds. Uniform ramming leads to greater dimensional stability in the ultimate castings so that, as a consequence, they can be used to better advantage.

Molding machines jolt, vibrate, squeeze, or hurl the molding sand into the flask and around the pattern. In addition, a well-designed molding machine usually features the ability to perform one or more of the following manipulative operations: rolling over, rocking over, rapping, pattern lifting, flask lifting, and so forth. The cost of any one of these operations is justified only when it gives higher productions rates or saves manpower.

Several types of molding machines are: -

1. The Jolt-Squeeze Molding Machine

2. Jolt-Rollover Pattern-draw Machine
3. Jolt-Rockover Pattern-draw Machine
4. The Rota-Lift Molding Machine
5. Pattern-draw Molding Machines
6. Vibrating-Squeeze Pattern-draw Molding Machines
7. The Sand Slingers

Core-making

Cores are bodies of sand that form an opening or cavity in or through a casting. There are two types of cores, green sand and dry sand. The green sand core is a body of sand projecting into a mold to form a cavity or opening in the casting when the metal is poured. The green sand core is formed by the pattern during the molding process.

A dry sand core is composed of a special mixture of silica sand and a binding material. The core is rammed independently of the mold and baked in an oven to remove all moisture. The baked core is placed in the finished mold before the mold is closed for pouring.

Core-making Machines

Stock cylindrical cores of varying sizes are readily and economically made in the core-making machine illustrated in Figure 2-8 . In general, the machine has an auger that picks up the core material from the hopper and, in meat grinder fashion, forces it under considerable pressure through a suitable die plate. The center vent hole in a core is formed by placing a wire through the center of the auger, allowing the end toward which the core flows to extend slightly beyond the die aperture.

The core-blowing machine (see Figure 2-9) has as its objective the rapid production of high-quality, irregularly shaped cores of small and medium sizes. The core sand mixture is carried by air and deposited with uniform density in a suitably shaped core box. As illustrated in Figure 5-9, compressed air carries the core sand mixtures form the sand reservoir through properly sized and located holes in the blow plate into the core box cavity. Slotted or screened vents permit the free escape of the vehicular air, thus depositing the core sand in the core box cavity. The number of blowing holes should be kept to a minimum, and their locations should be judiciously chosen. Air escape vents should be located with care; since it is by means of these that the sand is deposited uniformly in the core space. Laxity in these design details will invariably lead to cores that have soft spots and low strength. The area of the blowing holes tot the area of the vent holes should be in a ration of about 1 to 5. A core box that is float and open at the top can be fitted directly to the blow plate, whereas an irregularly shaped or booked core box must be provided with blowing

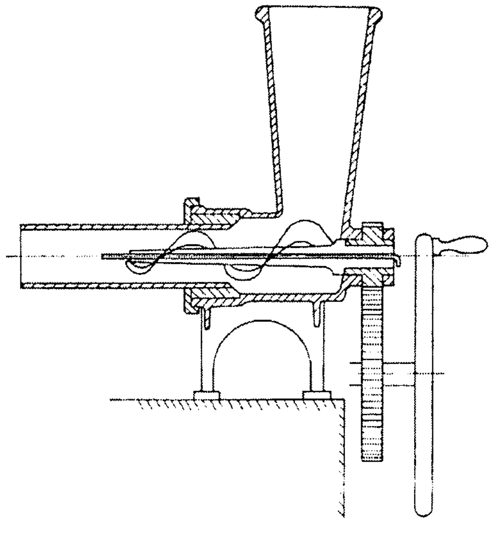


Fig.2-8 Core extrusion machine

holes that correspond to those in the blow plate. Vent wires and reinforcement wires are placed in the core box as shown in Figure 2-10. In the usual operation of the core-blowing machine several duplicate core boxes are on hand to allow the blowing of one core while the one previously blown is being drawn. Core dryers are required for the proper support of irregularly shaped cores.

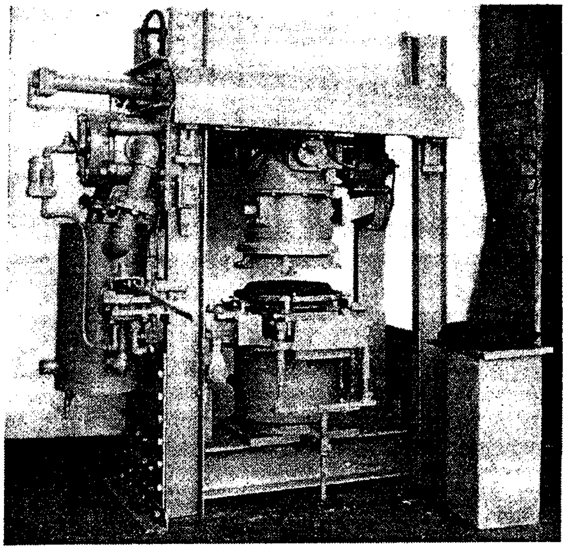


Fig 2-9 The Demmler No.103 stationary
sand machine core blower

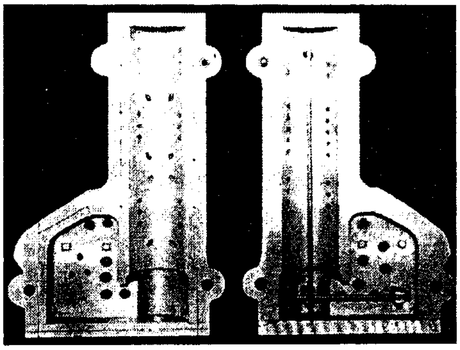


Fig.2-10 Vented core blow box

INTRODUCTION TO PATTEN MAKING

A pattern is a form used to make a cavity in a mold from which a casting is obtained. A pattern may be made of wood, metal, plaster, or any other material that will retain its shape during the molding process.

Patterns are slightly larger than the finished casting because a shrinkage allowance is added to all dimensions by the pattern maker. The shrinkage allowance compensates for the contraction of the metal in cooling and varies with different metals.

The type of casting and the molding procedure in the foundry determine whether the pattern is to be made solid or in two or more parts.

A number of patterns of the same type are mounted on a plate to be molded by machine when quantity production of castings is required.

Some castings have interior cavities that cannot be formed by the pattern during the molding process. A pattern of this type of casting must be fitted with core prints and have a core box to form the dry sand core that will make the interior cavity. Core prints are projections on a pattern that form sockets in the mold to support and locate dry sand cores. Core boxes are forms used independently of the mold to shape dry sand cores. Dry sand cores are composed of a special mixture of sand that is rammed in the core box. The core box is removed and the core baked in an oven until it is firm and dry. The baked core is delivered to the molder, who places it in the mold to form the interior cavity in the casting. A pattern together with all necessary core boxes comprise a pattern unit for making a casting.

Flat-back patterns

Flat-back patterns are those having a large flat surface on the cope side, making it possible to have a straight line parting on the joint between the cope and the drag of the mold.

Patterns with irregular parting

The peculiarities of design of many castings make it is possible to have a flat parting surface. A pattern for this type of casting requires additional time on the part of the molder making the mold. It will be necessary for him to "cut out" or "cope down" the sand on the joint of the mold to make this irregular parting. The extra time necessary to make the mold will add to the cost of production of the castings.

Split patterns

When a number of castings are to be made from a pattern with an irregular parting, it is of advantage to have the pattern made in two parts, split at a flat parting line to facilitate molding. This type of pattern is called a split pattern. The cope and drag portions of the pattern are fitted together accurately with wood or metal pins. A split pattern may take more time to construct that a solid pattern and is therefore more expensive. The extra pattern cost is justified by the amount of time saved in the foundry each time the pattern is used.

Gated patterns

Gated patterns may be made of wood or metal and are used for limited production of small castings. The patterns have a gate pattern attached to them. The time ordinarily spent by the molder in cutting gates and drawing patterns is eliminated by this arrangement. A gated pattern usually requires a hard sand match to form the joint of the mold.

Matchplate patterns

Matchplate patterns are used on molding machines for quantity production of castings.

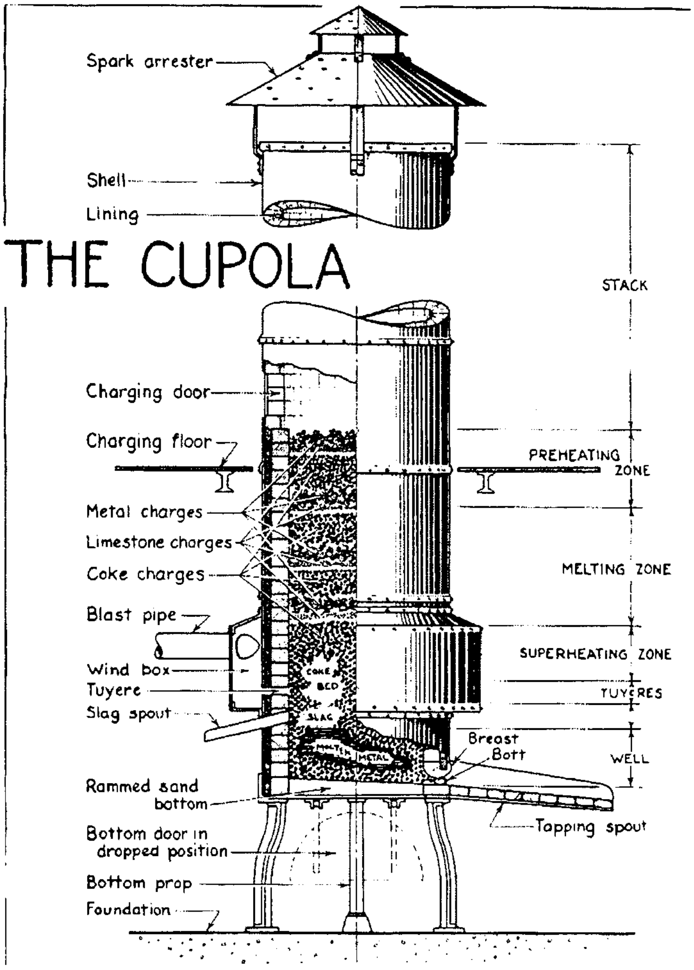
A single pattern or a number of patterns may be mounted on a match plate. Part of the pattern is on the cope side and the remainder on the drag side. Patterns for gates and runners are fastened in place to form the complete matchplate. When the matchplate is lifted off the mold all patterns are drawn, and the gates and runners are completed in the one operation.

Cope and drag patterns are used for production of medium and large-size castings. This type of pattern makes it possible for one molder to produce the drag portion of the mold while another molder produces the cope portion.

The design of the casting may be such that one-half of the patterns can be mounted on one side of the longitudinal centerline of the matchplate and the mating half symmetrically opposite. This method allows both cope and drag molds to be made from the same side of the matchplate.

Matchplate patterns are expensive to construct, but the initial cost is justified when quantity production is desired.

MANUFACTURE OF CAST IRON (CUPOLA)



The cupola furnace is constructed in the form of a hollow vertical cylinder. The outer surface or shell is made of boiler plated riveted at the seams, and is lined with a refractory material to withstand the action of the seams, and is lined with a refractory material to withstand the action of the intense heat. It is supported on four cast iron legs mounted on a concrete base. The bottom of the furnace is closed by one or more cast iron doors hinged to the bed plate of the furnace. These doors are closed and supported by props during the melting operation. The props are removed, and the coke fire, residue metal, and slag are dropped on a sand bed on the floor under the furnace when the melting operation has been completed.

A "wind box" or "wind chamber" encircles the outside of the furnace near the bottom. This chamber is connected to the furnace blower by a pipe known as the blast pipe. Air, which furnishes the source of oxygen required to burn the fuel, is forced through the cupola by a blower. The air enters the cupola through a blast pipe into the wind chamber and thence enters the furnace through a series of openings, called tuyeres, around the circumference of the lining.

Coke, pig iron, scrap metal, and flux are charged into the furnace through an opening above the center of the furnace. This opening, the charging door, is located at a convenient level above the charging platform.

The top of the furnace is shielded by a mesh screen and topped with a cone-shaped spark arrester, which permits the free vent of waste gas and deflects sparks and dust back into the furnace.

An opening in the front of the furnace, on a level with the sand bed, is called the tap hole. The molten metal is drawn from the furnace through this opening and flows down a refractory-lined trough into a receiving ladle.

An opening in the rear of the furnace several inches below the level of the tuyeres is called a slag hole; it is used for drawing off slag from the furnace during the melting process.

Preparation of the Cupola Furnace for Melting

All waste material dumped on the floor under the furnace after the previous heat must be cleared away. The cupola repairman then enters the cooled furnace and chips all projecting pieces of slag from the furnace walls. Burned-out sections of the brick lining are repaired with a refractory material to return the lining to its original shape. A long piece of wood with a true edge is used as a guide in making the lining repair.

When the lining repair is completed, the bottom doors are closed and secured in place by a prop. The iron bottom doors are then covered with a layer of sand. This sand is placed in the furnace through the charging door. The furnace tender enters the furnace through the charging door to ram and shape the sand bottom.

The kindling material, usually soft, dry pieces of wood, is placed on the sand bed, and a charge of coke is put in the furnace. The kindling and bed charge of coke are ignited through the tap-hole opening. The cover plates opposite the tuyeres are opened so that air may enter the furnace to aid combustion. Additional coke is added to the bed charge until it reaches a predetermined level above the tuyeres.

The first charge of metal, pig iron, scrap, and flux, which has been carefully weighed and proportioned, is placed on top of the bed charge of glowing coke. The amount of coke in the charge is calculated to replace the coke that has been burned out of the bed charge during the melting of the first charge of metal. Additional alternating charges of metal, flux, and coke are placed in layers in the furnace through the charging door. When the furnace has been charged to the level of the charging door the cover plates are replaced on the wind chamber, and the air blast is turned on.

The air blast enters the furnace through the tuyeres. The air blast furnishes the oxygen, which unites with the carbon in the coke to form the combustion necessary to create the heat to melt the metal. The amount of air supplied to the furnace is carefully calculated to produce efficient operation. As the charge of metal descends in the furnace it is preheated until it reaches the area where the melting takes place. This area is called the melting zone. The metal melts in small drops, and these drops pass down through the bed charge of coke to the well of the furnace, where they collect to form a bath of liquid metal.

The furnace is tapped by the furnace tender, who uses a sharpened metal tapping bar to remove the clay plug from the tap hole. The metal flows through the tap down the spout into the receiving ladle. When the desired quantity of metal is in the receiving ladle., the furnace tender places a clay plug or bott on the end of a metal bar called a bott stick, and forces it into the tap hole. This stops the flow of metal, retaining it in the furnace well until a sufficient quantity is collected. The tapping process is repeated until all the molten metal has been drawn from the furnace. The air blast is shut off, the tuyeres covers removed, and the prop holding the bottom doors knocked away. The bottom doors swing open, dropping the glowing coke and slag left in the furnace on a bed of sand under the furnace. The dump is wet down with water to quench the fire. When the furnace is cooled it is chipped, and the lining is repaired for the next heat.

The scientific operation of the cupola furnace produces quality and quantity-controlled cast iron for industrial use.

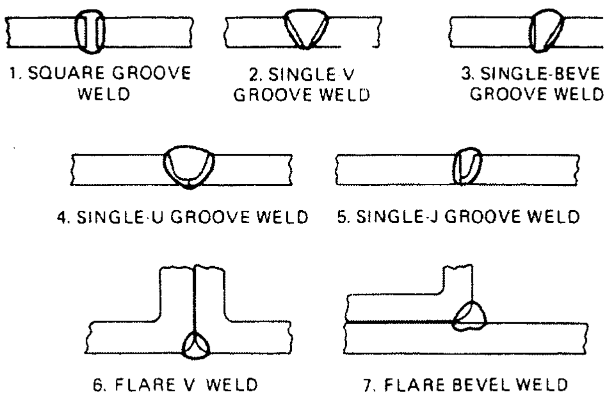


Fig.3-3 The seven basic groove welds

The five basic joints shown by Figure 3-1 are:

B, Butt joint: -- parts in approximately the same place.
C, Corner joint: -- parts at approximately right angles and at the edge of both parts.
E, Edge joint: an edge of two or more parallel parts.
L, Lap joint: between overlapping parts.
T, T joint: parts at approximately right angles, not at the edge of one part.

A weld is a localized coalescence of metal of metal at the junction of metal parts in a specific area. In a weld filler metal may or may not be used and heat with or without pressure is used, but the result is a continuity of solid metal parts.

It is important to distinguish between the joint and the weld—each must be described to completely describe the weld joint. There are many different types of welds and they are best described by their shape when shown in cross section. The most popular weld is the fillet weld named after its cross-sectional shape. Fillet welds are shown by Figure3-2. The second most popular is the groove welds. These are shown by Figure3-3. There are other types of welds: the flange weld, the plug weld, the slot weld, the seam weld, surfacing weld, and the backing weld. Joints are combined with welds to make weld joints. Examples are shown by Figure.3-4.

There are approximately fifty different distinct welding processes. They are subdivided into seven groups.

The arc welding group of processes is the most popular and widely used for metal joining. There are eight distinct arc welding processes and numerous variations. In all of the arc welding processes, the heart of the welding system is the welding power source. This piece of equipment provides the electrical power to sustain the arc so that it can be used for making welds. There are many types, sizes, and variations. Some generate electricity form rotating energy sources, and are called welding generators. Others take the power available from the lines and change it to power suitable for arc welding. These are known as transformers or transformer-rectifier welding machines. Both alternation and direct current can be used for some of the arc welding processes. The welding process will determine the type of power source required.

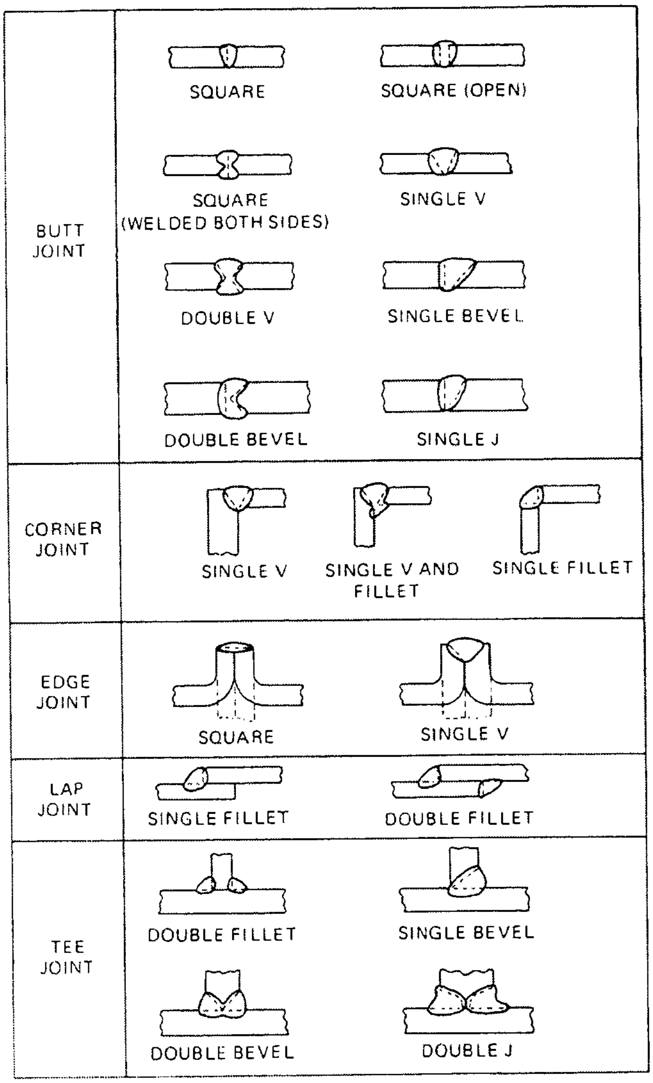


Fig.3-4 Some typical weld joint

The most important part of the welding system is the welder or welding operator, the human element. There is a difference between welders and welding operators and this is primarily a difference of the manipulative skills involved. The welder must exercise skill and ability to manipulate equipment to produce welds. The welding operator may monitor or operate an automatic welding machine.

Another way of dividing or categorizing welding processes relates to whether filler metal is or is not used. Filler metal is "the material to be added in making a welded, brazed, or soldered joint." It becomes the weld fillet or weld metal in a groove weld. In some welding processes, the filler metal is carried across the arc and deposited in the weld. In other filler metal is not carried across the arc but is melted by the heat of the arc and added to the molten puddle. If the weld metal passes through the arc, it is provided by an electrode. If it is melted by the heat of the arc and added to the puddle it is called a welding rod. Welding electrodes and welding rods have special composition requiring detailed specifications to completely describe them. Proper selection of filler metal is important; normally their properties should match the properties of the metal being welded. This metal is called the base metal which is defined as "the material to be welded, soldered, or cut." This is the preferred term. In some countries the word parent metal is used, for thermal spraying the word substrate is used.

The type of base metal often dictates the welding process that can be used. To completely describe the making of weld, it is necessary to specify the welding process to be employed and to indicate the method of applying the process. It is also necessary to describe the welding procedure, which is "the detailed methods and practices including joint design details, materials and method of welding in order to describe how a particular weld or weldment is to be made." It is becoming more and more important to completely described and document the entire welding procedure.

To insure that the welds conform the demanding specifications, specialized inspection techniques are used. These include destructive and nondestructive testing methods. Nondestructive testing includes visual inspection, magnetic particle inspection, radiographic inspection, liquid penetrate inspection, and ultrasonic inspection. Welding quality control is required by most codes and is a necessary requirement for most manufactured products.

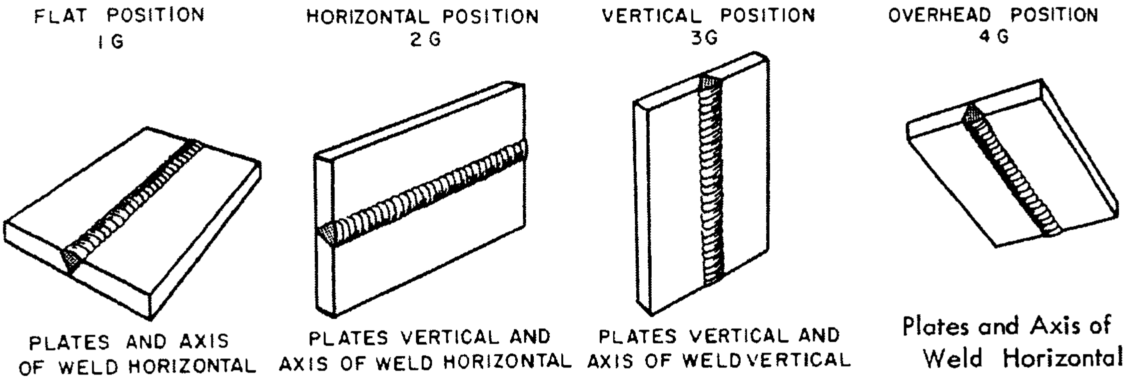


Fig.3-5 Welding position-groove weld-plate

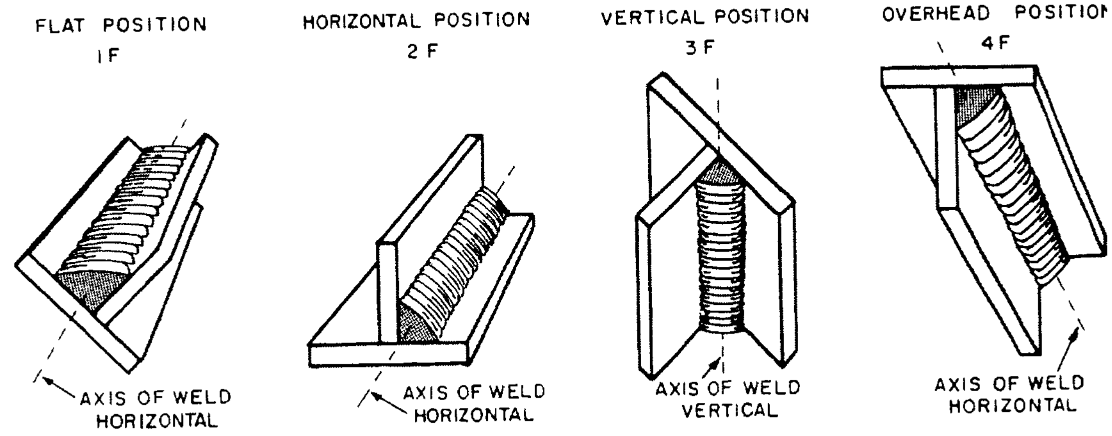


Fig.3-5 Welding position-fillet weld-plate

Welding is often done on structures in the position in which they are found. In view of this, techniques have been developed to allow welding in any position. Certain welding processes have "all-position" capabilities while others may be used in only one or two positions. The welding positions are defined by the American Welding Society. There are four basic welding positions. They are shown by Figures 3-5,3-6,3-7 are described as follows:

Flat: "when welding is performed form the upper side of the joint and the face of the face of the welding is approximately horizontal," Flat welding is the preferred term; however, the same definition is sometimes called downhand.

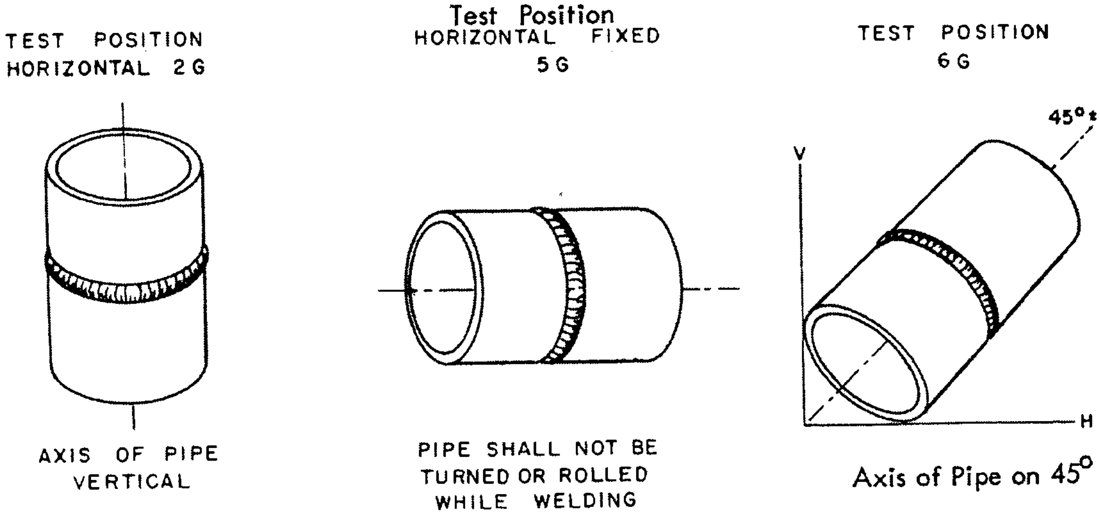


Fig.3-7 Welding position-pipe welds

Horizontal:	"the axis of the weld is approximately horizontal but the definition varies for groove and fillets."
Overhead:	"when welding is performed from the underside of the joint."
Vertical:	"the axis of he weld is approximately vertical."

More terms and definitions will be presented in later chapters. It is important at the beginning of the book to at least briefly define these terms so that you will better understand their meaning as you read further in the book.

The Welding Processes and Grouping

The American Welding Society has made each welding process definition as complete as possible so that is will suffice without reference to another definition. They will suffice without reference to another definition. They define a process as "a distinctive progressive action or series of actions involved in the course of producing a basic type of result." The official listing or processes and their grouping are shown by Figure3-8, the AWS Master Chart of Welding and Allied Processes. The welding society formulated process definitions form the operational instead of the metallurgical point of view. Thus the definitions prescribed the significant element of operation instead of the significant metallurgical characteristics. The AWS definition for a welding process is "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." AWS has grouped the processes together according to the "mode of energy transfer" as the primary consideration. A secondary factor is the "influence of capillary attraction in effecting distribution of filler metal" in the joint. Capillary attraction distinguishes the welding processes grouped under "Brazing" and "Soldering" from "Arc Welding," "Gas Welding," "Resistance Welding," "Solid State Welding," and "Other Processes." The distinguishing feature of eh latter groups of welding processes is the "mode of energy transfer." "Adhesive Bonding" is also included since it is

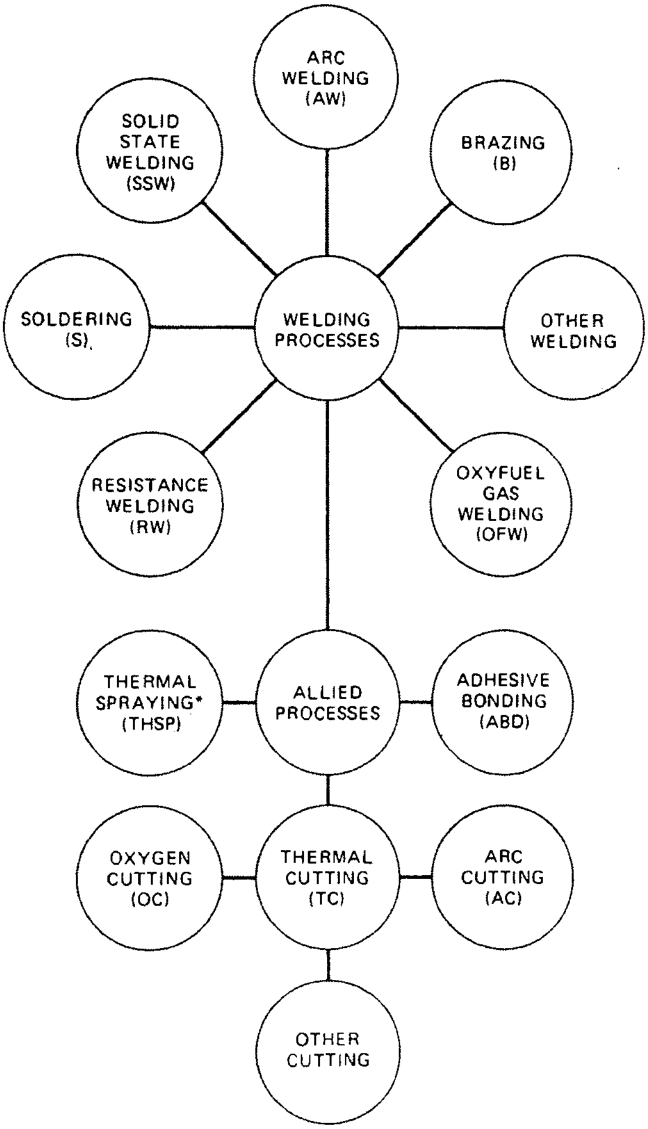


Fig.3-8 AWS master chart of welding and allied processes

being increasingly used to join metals.

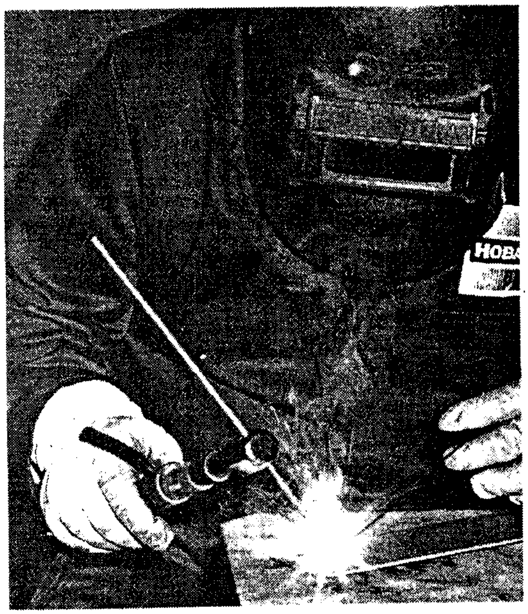
The welding society deliberately omitted the designation of pressure or nonpressure since the factor of pressure is an element of operation of the applicable welding process. The designation "Fusion Welding" is not recognized as a grouping since fusion is involved with many of the processes. Other terms or factors such as the type of current used in arc or resitance welding processes, whether electrodes are consumable or nonconsumbale or continuous or incremental are not shown in process groupings. These and other items characterize the methods by which the processes are performed. In some countries the welding processes are grouped differently; for example, in the United Kingdom Group I is designated for welding processes using heat with pressure and Group II is for welding processes requiring heat alone. In Germany, there is a distinction between pressure welding and fusion welding; the former includes ultrasonic, friction, forge, resistance, stud, and diffusion welding; the latter includes gas welding, electro slag welding, arc welding, plasma welding, electron beam and laser welding. Other countries refer to ht type of energy involved, i.e., thermochemical, electrothermic, mechanical energy, or focalized energy.

Welders sometimes distinguish between welds made with the addition of filler metal and those made by fusing only he joint edges together, and autogenous weld. However, it is best to relate to the welding process. Other ways of classifying are indicating the use of a nonconsumable or continuously fed electrode or the heat source, or by considering an exposed puddle which relates more to the skill of the welder. The AWS designation will be unused throughout the book.

The arc welding processes are defined as "a group of welding processes which produce coalescence of metals by heating them with an arc or arcs with or without the application of pressure and with or without the use of filler metal." Coalescence is defined as a "growing together" or "growth into one body" and is regarded as more applicable to all types of welding than the term consolidation which might imply the use of external force or could mean bolting, riveting, nailing, etc. Coalescence is used in all welding process definitions.

Arc Welding

The arc welding group includes eight specific popular processes, each separate and different form the others but in many respects similar. The arc welding group of processes is defined in the next few pages



.Fig.3-9 Carbon arc welding

Fig.3-10 Shielded metal arc welding

The carbon arc welding (CAW) process is the oldest of all the arc welding processes and is considered to be the beginning of arc welding. The welding society defines carbon arc welding as "an arc welding process which produces coalescence of metals by heating them with an arc between a carbon electrode and the work. No shielding is used. Pressure and filler metal may or may not be used." Figure3-9 shows the single carbon arc process in use. It has limited applications today, but a variation or twin carbon arc welding is more popular. Another variation uses compressed air for cutting and gouging.

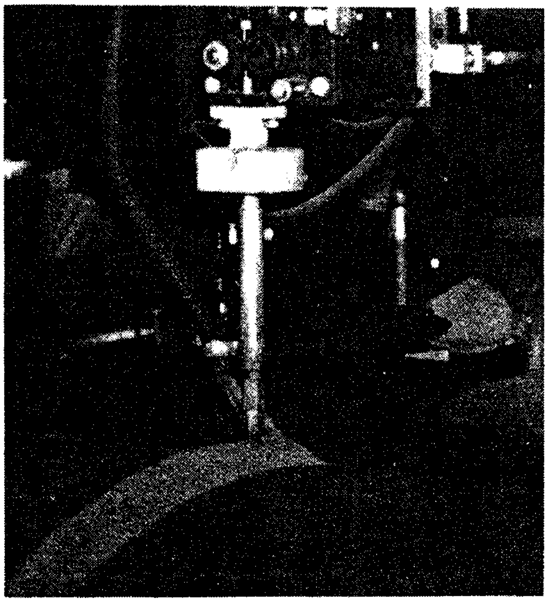


Fig.3-11 Submerged arc welding

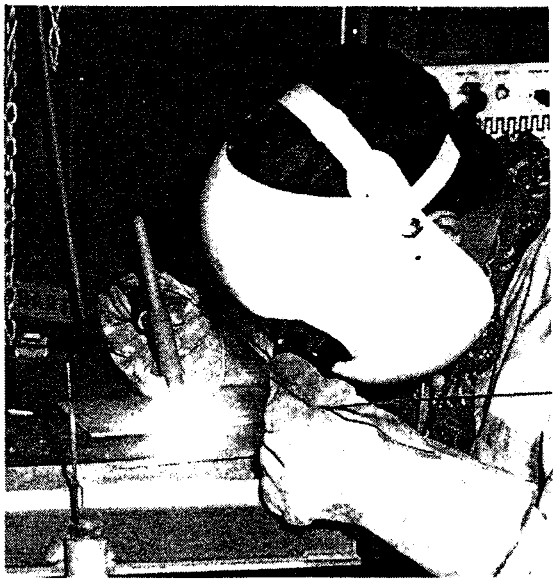


Fig.3-12 Gas tungsten arc welding

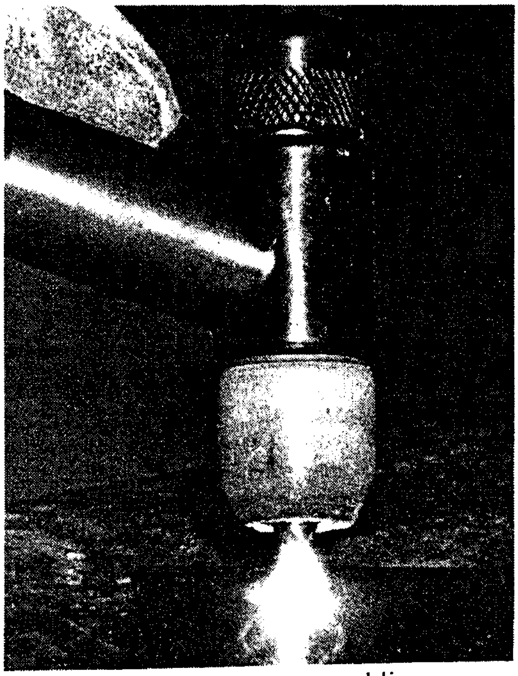


Fig.3-13 Plasma arc welding

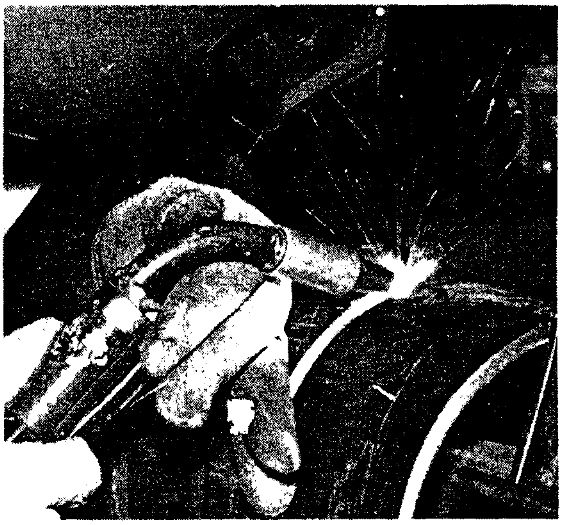


Fig.3-14 Gas metal arc welding

The development of the metal arc welding process soon followed the carbon arc. This developed into the currently popular shielded metal arc welding (SMAW) process defined as "an arc welding process which produces coalescence of metals y heating them with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering Pressure is not used and filler metal is obtained from the electrode." Figure3-10 shows this extremely popular process, which is widely used today to weld steels. It is usually applied manually. It can also be used for metal cutting.

Fig.3-15 Flux-cored arc welding

Fig.3-16 Stud welding

Automatic welding utilizing bare electrode wires was used in the 1920s, but it was the submerged arc welding (SAW) process that made automatic welding popular. Submerged arc welding is defined as "an arc welding process which produces coalescence of metals by heating them with an arc or arcs between a bare metal electrode or electrodes and the work. The arc is shielded by a blanket of granular fusible material on the work. Pressure is no used and filler metal is obtained from the electrode and sometimes from a supplementary welding rod." Submerged arc welding is shown by Figure3-11. It is usually applied by machine or automatic methods; however, it can be applied semi-automatically. It is normally limited to the flat or horizontal position.

The need to weld nonferrous metals particularly magnesium and aluminum challenged the industry. A solution was found called gas tungsten arc welding (GTAW) and was defined as "an arc welding process which produces coalescence of metals by heating them with and arc between a tungsten (nonconsumbale) electrode and the work. Shielding is obtained from a gas or gas mixture. Pressure may or may not use and filler metal may or may not used." The process developed in the late 1930s also became known as Heliarc, or TIG welding and was immediately popular in the air-craft industry where it was used to join "hard to weld" metals. GTAW welding is shown by Figure3-12. Inert gases are used for shielding and it is normally applied manually, although automatic aspplications are becoming more popular. It has limited use for cutting. It has limited use for cutting.

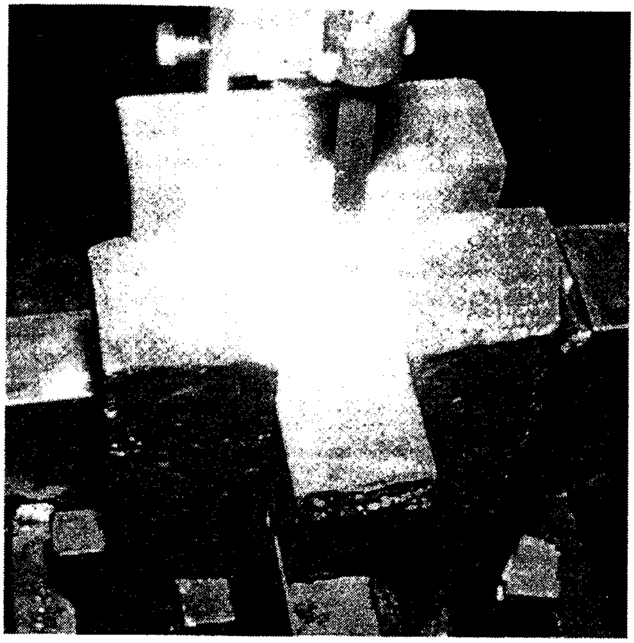


Fig.3-17 Electroslag welding

A very close companion process was developed in the mid-1950s, which is similar to gas tungsten arc except the arc is constricted in such a way to produce plasma. It is called plasma arc welding (PAW) and it's defined as "an arc welding process which produces a coalescence of metals by heating them with a constricted arc between an electrode and the work piece (transferred arc) or the electrode and the constricting nozzle (non-transferred arc). Shielding is obtained from the hot ionized gas issuing from the orifice which may be supplemented by an auxiliary source of shielding gas. Shielding gas may be an inert gas or a mixture of gases. Pressure may or may not be used and filler metal may or may not be supplied." Plasma arc welding is shown by Figure3-13. Filler wire when it is used is normally a "cold" or nonelectrical rod which is added to the molten puddle of the weld by the welder. Plasma welding has been used for joining some of the thinner materials. It is normally manually applied. It is also popular as a cutting process.

Another welding process also related to gas tungsten arc welding is known as gas metal arc welding (GMAW). It was developed in the late 1940s for welding aluminum and has become extremely popular. It is defined as "an arc welding process which produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained entirely form an externally supplied gas or gas mixture." This process sometimes called MIG welding, is shown by Figure3-14.

The electrode wire for GMAW is continuously fed into the arc and deposited as weld metal. This process has many variations depending on the type of shielding gas, the type of metal transfer, and the type of metal welded. It is capable of welding many different metals and is becoming one of the most popular of the arc welding processes. The semiautomatic method of application is the most popular, but the process is also applied automatically.

A variation of gas metal arc welding has become a distinct welding process and is known as flux-cored arc welding (FCAW). It is defined as "an arc welding process which produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is provided by a flux contained within the tubular electrode. Additional shielding may or may not be obtained from an externally supplied gas mixture." This process is shown by Figure3-15. It was developed in the mid-1950s.

The coating material on the outside of a covered electrode with its normal functions are now included in the core or center of the tubular electrode wire. There are two variations; one utilizes external shielding gas and the other does not. Both are used primarily for welding steels and are normally applied by the semiautomatic method of application.

The final process within the arc welding group of processes is known as stud arc welding (SW). This process is defined as "an arc welding process which produces coalescence of metals by heating them with an arc between a metal stud or similar part and the work. When the surfaces to be joined are properly heated they are brought together under pressure. Partial shielding may be obtained by the use of ceramic ferrule surrounding the stud. Shielding gas or flux may or may not be used." This process was developed in the mid1930s. It is shown by Figure. There are several variations of the process and it is normally applied as an automatic method.

Electroslag welding (EW) a nonarc welding process, borrowed from the "other welding processes" group, is included here since it employs equipment used by the gas metal arc, flux-cored arc, and submerged arc welding and is defined as "a welding process producing coalescence of metals with molten slag which melts the filler metal and the surfaces of the work to be welded. The molten weld pool is shielded by this slag which moves along the full cross section of the joint as welding progressed. The process is initiated by an arc which melts the slag. The arc is then extinguished and the conductive slag is maintained in a molten condition by its resistance to electric current passing between the electrode and the work." It is thus not an arc welding process although its initiation starts with an arc. This process was invented in the early 1930s in the U.S.A., but became popular when equipment was designed for its use in Russia in the early 1950s. There are two major variations, the upward-moving system and the consumable-guide system. The consumable-guide variation is shown by Figure3-17. Electroslag welding is used normally to make welds in the vertical position and on steels. It is applied automatically.

Brazing (B)

Brazing is "a group of welding processes which produces coalescence of materials by heating them to a suitable temperature and by using a filler metal, having a liquidus above 450° C (840° F) and below the solidus of the base materials. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction." A braze is a very special form of weld, the base metal is theoretically not melted. There are seven popular different processes within the brazing group. The source of heat differs among the processes. Braze welding relates to welding processes using brass or bronze filler metal, where the filler metal is not distributed by capillary action.

Oxyfuel Gas Welding (OFW)

Oxyfuel gas welding is "a group of welding processes which produces coalescence by heating materials with an oxy fuel gas flame of flames with or without the application of pressure and with or without the use of filler metal." There are four distinct processes within this group and in the case of two of them, oxyacetylene welding and oxyhydrogen welding, the classification is based o the fuel gas used. The heat of ht flame is created by the chemical reaction or the burning of the gases. In the third process, air acetylene welding, air is used instead of oxygen, and I the fourth category, pressure gas welding, pressure is applied in saddition to the heat form the burning of the gases. This welding process normally utilizes acetylene as the fuel gas. The oxygen thermal cutting processes have much in common with the welding processes.

Resistance Welding (RW)

Resistance welding is "a group of welding processes which produces coalescence of metals with the 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." In general, the difference of the resistance welding processes has to do with the design of the weld and the type of machine necessary to produce the weld. In almost all cases the processes are applied automatically since the welding machines incorporate both electrical and mechanical functions.

Other Welding Processes

This group of processes includes those which are not best defined under the other groupings. It consists of the following processes: electron beam welding, laser beam welding, thermit welding, and other miscellaneous welding processes in addition to Electroslag welding which was mentioned previously.

Soldering (S)

Soldering is "a group of joining processes which produces coalescence of materials, by heating them to suitable temperature and by using a filler metal having a liquidus not exceeding 450° C (840° F) and below the solidus of the base materials. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction." There are a number of different soldering processes and methods.

Solid State Welding (SSW)

Solid state welding is "a group of welding processes which produces coalescence at temperatures essentially below the melting point of the base materials being joined without the addition of a brazing filler metal. Pressure may or may not be used." The oldest of all welding processes forge welding belongs to this group. Others include cold welding, diffusion welding, explosion welding, friction welding, hot pressure welding, and ultrasonic welding. These processes are all different and utilize different forms of energy for making welds.

The welding processes, I their official groupings, are shown by Table3-1. This table also shows the letter designation for each process. The letter designation assigned to the process can be used for identification on drawings, tables, etc., and will be used throughout this book. Also shown by Table3-1 is the chapter number in the book for complete information about each specific process

Table 3-1 Welding processes and letter designation

Group	Welding Process	Letter Designation	Chapter
Arc Welding	Carbon Arc	CAW	4-5
	Flux Cored Arc	FCAW	5-4
	Gas Metal Arc	GMAW	5-3
	Gas Tungsten Arc	GTAW	4-3
	Plasma Arc	PAW	4-4
	Shielded Metal Arc	SMAW	4-2
	Stud Arc	SW	4-6
	Submerged Arc	SAW	5-2
Brazing	Diffusion Brazing	DFB	6-1
	Dip Brazing	DB	6-1
	Furnace Brazing	FB	6-1
	Induction Brazing	IB	6-1
	Infrared Brazing	IRB	6-1
	Resistance Brazing	RB	6-1
	Torch Brazing	TB	6-1
Oxyfuel Gas Welding	Oxyacetylene Welding	OAW	6-2
	Oxyhydrogen Welding	OHW	6-2
	Pressure Gas Welding	PGW	6-2
Resistance Welding	Flash Welding	FW	6-3
	High Frequency Resistance	HFRW	6-3
	Percussion Welding	PEW	6-3
	Projection Welding	RPW	6-3
	Resistance-Seam Welding	RSEW	6-3
	Resistance-Spot Welding	RSW	6-3
	Upset Welding	UW	6-3
Solid State Welding	Cold Welding	CW	6-4
	Diffusion Welding	DFW	6-4
	Explosion Welding	EXW	6-4
	Forge Welding	FOW	6-4
	Friction Welding	FRW	6-4
	Hot Pressure Welding	HPW	6-4
	Roll Welding	ROW	6-4
	Ultrasonic Welding	USW	6-4
Soldering	Dip Soldering	DS	6-5
	Furnace Soldering	FS	6-5
	Induction Soldering	IS	6-5
	Infrared Soldering	IRS	6-5
	Iron Soldering	INS	6-5
	Resistance Soldering	RS	6-5
	Torch Soldering	TS	6-5
	Wave Soldering	WS	6-5
Other Welding Processes	Electron Beam	EBW	6-6
	Electroslag	ESW	5-6
	Induction	IW	6-9
	Lasser Beam	LBW	6-7
	Thermit	TW	6-8

Allied and related processes include adhesive bonding, thermal spraying, and thermal cutting.

Welding with Constant Current

The power source is the heart of all of the arc welding processes. There are two basic types expressed by their volt-ampere output characteristics. The conventional machine is known as the "constant current" (CC) machine, also known as the variable voltage types. It has the drooping volt-ampere characteristic curve and has been used for many years for the shielded metal ac welding process.

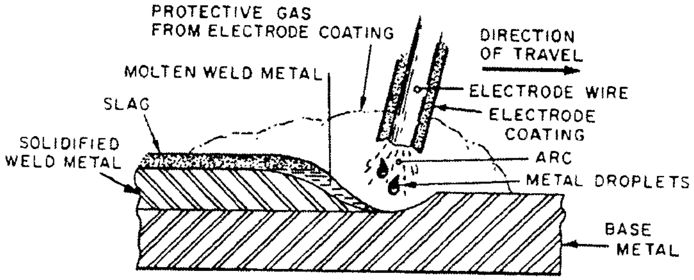
The other type is known as the "Constant Voltage" (CV) machine. It is sometimes called a "Constant Potential" (CP) machine. It has a relatively flat volt-ampere characteristic curve. Both or these terms are slightly misleading since neither machine produces a true constant current or constant voltage output; how-ever, these terms are universally used.

The Shielded Metal Arc Welding Process—SMAW

Shielded metal arc welding is an arc welding process wherein coalescence is produced by heating with an electric arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

Principles of Operation

The shielded metal arc welding process shown by Figure3-18 consists of an arc between a covered electrode and the base metal. The arc is initiated by momentarily touching the electrode to the base metal to form a molten pool at the end of the electrode. The melted electrode metal is transferred across the arc into the molten pool and becomes the deposited weld metal. The deposit is covered by a slag which comes from the electrode coating. The arc and the immediate area are enveloped by an atmosphere of protective gas produced by the disintegration of the electrode coating. Most of the electrode core wire is transferred across the arc; however, small particles escape from the weld area as spatter.



SHIELDED METALARC WELDING

Fig 3-18 Process diagram

The Gas Tungsten Arc Welding Process—GTAW

Gas tungsten arc welding is an arc welding process which produces coalescence of metals by heating them with an ac between a tungsten (no consumable) electrode and the work. Shielding is obtained from a gas or gas mixture. Both pressure and filler metal may or may not be used. This process is sometimes called TIG welding which indicates tungsten inert gas welding. In Europe it is called WIG welding, using Wolframs, the German word for tungsten.

Principles of Operation

The gas tungsten ac welding process shown by Figure3-19 utilizes the heat of an arc between a nonconsumable tungsten electrode and the base metal. The arc is initiated various ways which will be explained later. The arc develops intense heat which melts the surface of the base metal to form a molten pool. Filler metal is not added when thinner materials, edge joints, flange joints, are welded. For all but the thinner materials an externally fed or "cold" filler rod is generally used. The filler metal is not transferred across the arc but melted by it. The arc area is protected from the atmosphere by the inert shielding gas which flows from the nozzle of the torch. The shielding gas displaces the air so that the oxygen and the nitrogen of the air do not come in contact with molten metal of the hot tungsten electrode. As the molten metal cools coalescence occurs and the parts are joined. There is little or no spatter and little or no smoke. The resulting welding is smooth and uniform and requires minimum finishing.

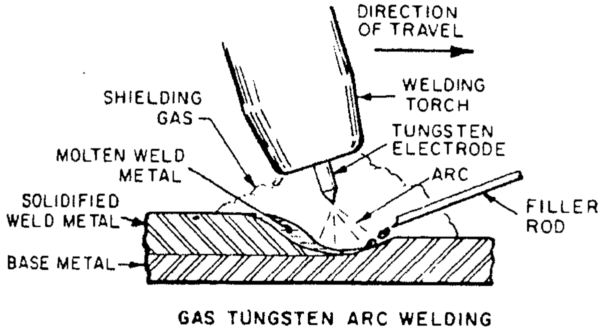


Fig 3-18 Process diagram

The Plasma Arc Welding Process (PAW)

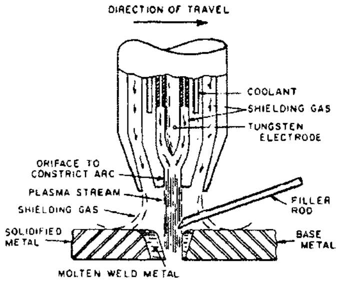


Fig 3-18 Process diagram

Plasma arc welding is a process in which coalescence is produced by heating with a constricted arc between an electrode and the work piece (transfer arc) or the electrode the constricting nozzle (nontransferable arc). Shielding is obtained from the hot ionized gas issuing from the orifice which may be supplemented by an auxiliary source of shielding gas. Shielding gas may be an inert gas or a mixture of gases, pressure may or may not be used, and filler metal may or may not be supplied. It is shown by Figure3-20.

Carbon Arc Welding Process (CAW)

Carbon arc welding is as process in which coalescence is produced by heating with an arc between a carbon electrode and the work, and in which no shielding is used. Both pressure and filler metal may or may not be used.

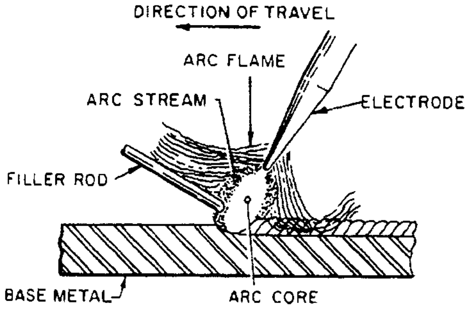


Fig 3-21 Process diagram

Principle of Operation

Carbon arc welding shown by Figure3-21 uses a single electrode with the arc between it and the base metal. It is the oldest arc processes, is included for historical purposes, but is not popular today. There are two variations that are important, however.

In carbon arc welding, the heat of the arc between the carbon electrode and the work melts the base metal and, when required, also melts a filler rod. As the molten metal solidifies a weld is produced. The carbon graphic electrode, considered to be non consumable, erodes away fairly rapidly and in its disintegration produces a shielding atmosphere of carbon monoxide and carbon dioxide gas. These gases partially displace air from the arc atmosphere and prohibit the oxygen and nitrogen from coming in contact with the molten metal. Filler metal when employed is normally the same composition as the base metal. Bronze filler metal can be used for brazing and braze welding.

The Stud Arc Welding Process (SW)

Stud arc welding is a process in which coalescence is produced by heating with an arc drawn between a metal studs or similar part and the other work part until the surfaces to be joined are properly heated when they are brought together under pressure. Partial shielding may be obtained by the use of a ceramic ferrule surrounding the stud. Shielding gas or flux may or may not be used.

Principles of Operation

There are four variations of stud welding. Stud arc welding, also called drawn arc stud welding, is the most popular and will be described in this section; however, the other methods, capacitor discharge stud welding, the drawn arc capacitor discharge stud welding, and the consumable ferrule type stud welding.

It is questionable if stud welding is a true arc welding process. It has a very specialized field of application and is not a metal joining process in the same manner as the other s previously discussed. It end welds prepared studs to the others previously discussed. It end welds prepared studs to the base metal. The process is a combination of arc welding and forges welding. It is based on two steps. First, electrical contact between the stud and the base metal occurs and an arc is established. The heat of the arc melts the surface of the end of the stud and the work surface. As soon as the entire cross section of the stud and an area of equal size on the base metal are melted, the stud is forced against the base metal. The molten end of the stud joins with the molten pool on the work surface and as the metal solidifies the weld is produced. Partial shielding is accomplished by means of a ceramic ferrule that surrounds the arc area and by fixing ingredients sometimes placed o the arcing end of the stud.

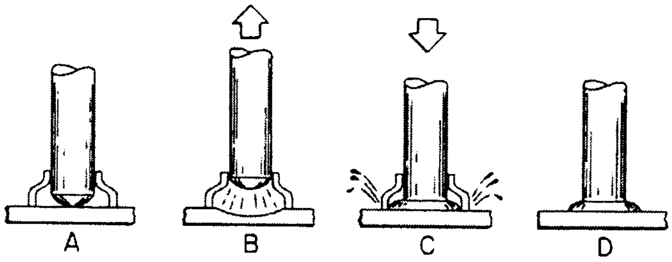


Figure3-22 Stud welding process

The making of a stud weld is shown by Figure3-22 and is explained as follows. The stud gun (step A) holds the stud in contact with the work piece until the welder depresses the gun trigger switch. This causes welding current to flow from the power source through the stud (which acts as an electrode) to the work surface. The welding current flow actuates a solenoid within the stud gun which draws the stud away from the work surface (step B) and establishes the arc. The arc time duration is controlled by a timer in the control unit. At the appropriate time the welding current is shut off and the gun solenoid releases its pull on the stud and the spring loaded action plunges the stud into the molten pool of the work piece (step C). The molten metal solidifies and produces the weld, plus a small reinforcing fillet. After solidification the gun is released from the stud and the ceramic ferrule is broken off revealing the weld (step D).

Other Processes Using Constant Current Power

There are a number of welding processes that utilize the constant current welding power. Some of these are included only from an historical point of view since they are of little industrial significance today. Others are mentioned because they may gain industrial importance. Welding processes are developed and if they full-fill a need they will become widely used in industry. As other processes are developed they may replace earlier ones which will gradually fall into disuse. Some of he following processes never became industrially popular but were stepping stones to some of he modern processes now in use.

The following processes will be briefly described:

Atomic hydrogen welding.

Magnetic rotating arc welding.

Automatic welding using:

Continuous covered wire.

Impregnated tape.

Magnetic flux.

Composite electrode.

Welding with Constant Voltage

The constant voltage (CV) welding machine and the CV system of automatic arc length control is relatively new. The CV principle of operation was introduced at about the same time as gas metal arc welding. It was the combination of theses two inventions that has made gas metal arc welding extremely popular. Prior to the introduction of the constant voltage (CV) welding machine, the drooping characteristic type power source was employed with the voltage-sensing electrode wire feed systems. The reaction time of these systems was not sufficiently fast to avoid burnback and stubbing when using fine wire gas metal arc apparatus. In spite of its widespread use, the CV principle of welding needs a thorough explanation.

The CV electrical system is fairly new to welding but is not new to the electric power industry. It is the basis of operation of the entire commercial electric power system. The electric power delivered to your house and available at every receptacle has a constant voltage. The same voltage is maintained continuously at each outlet whether a small light bulb, with a very low wattage rating, or a heavy-duty electric heater with a high wattage rating is connected. The current that flows through each of these circuits will be different based on the resistance of the particular item or appliance in accordance with Ohm's law. For example, the small light bulb will draw less than 0.01 amperes of current while the electric heater may draw over 10 amperes. The voltage throughout the system remains constant, but current flowing through each appliance depends on its resistance or electrical load. The same principle is utilized by the CV welding system

Submerged Arc Welding (SAW)

Submerged arc welding is a process in which coalescence is produced by heating with an arc or arcs between a bare metal electrode or electrodes and the work. The arc is shielded by a blanket of granular fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplementary welding rod.

Principle of Operation

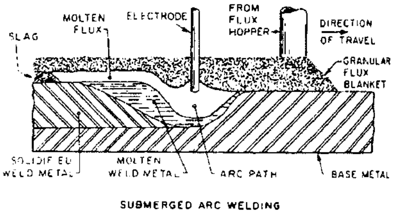


Fig.3-23Process diagram

The submerged arc welding process is shown by Figure3-23. It utilizes the heat of an arc between a continuously fed electrode and the work. The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted off of the electrode is transferred through the arc to the work piece where it becomes the deposited weld metal. Shielding is obtained from a blanket of granular flux, which is laid directly over the weld area. The flux close to the arc melts and intermixes with the molten weld metal and helps purify and fortify it. The flux forms a glasslike slag that is lighter in weight than the deposited weld metal and floats on the surface as protective over. The weld is submerged under this layer of flux and slag and hence the name submerged arc welding. The flux and slag normally cover the arc so that it is not visible. The unmelted portion of the flux can be reused. The electrode is fed into the arc automatically from a coil. The arc is maintained automatically and travel can be manual or by machine. The arcs are initiated by a fuse type start or by a reversing or retrack system.

Gas Metal Arc Welding (GMAW)

Gas metal arc welding is a process in which coalescence is produced by heating with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas or gas mixture.

There are a number of variations of the gas metal arc welding process and the process has been given many different trade names, which tend to create confusion. For example, variations are called MIG welding, CO2 welding, fine wire welding, spray arc welding, pulsed arc welding, electrogas welding, and short-circuit arc welding. These variations and methods are of sufficient importance that each will be more clearly defined and explained later in the chapter.

Principles of Operation

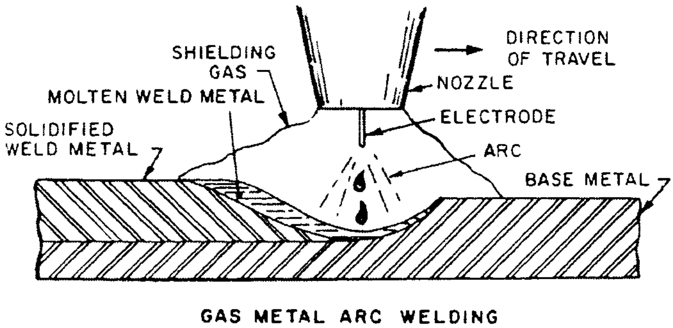


Fig.3-24 Process diagram

The gas metal arc welding process is shown by Figure3-24. The gas metal arc welding process utilizes the heat of an arc between a continuously fed consumable electrode and the work to be welded. The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted off the electrode is transferred through the arc to the work where it becomes the deposited weld metal. Shielding is obtained from an envelope of gas, which may be an inert gas, an active gas, or a mixture. The shielding gas surrounds the arc area to protect it from contamination from the atmosphere. The electrode is fed into the arc automatically, usually from a coil. The arc is maintained automatically and travel can be manually or by machine.

Flux-cored Arc Welding (FCAW)

The flux-cored arc welding process is a process in which coalescence is produced by heating with an arc between a continuous filler metal (consumable) electrode and the work.

Shielding is obtained from a flux contained within the electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture.

There are two variations, one using externally supplied shielding gas and the other which relies entirely upon shielding gas generated form the disintegration of flux within the electrode. There is one major method known as flux-cored arc welding electrogas. This is defined as "a method of flux cored are welding wherein molding shoes confine the molten weld metal for vertical position welding. Additional shielding may or may not be obtained form an externally supplied gas or gas mixture."

Principle of Operation

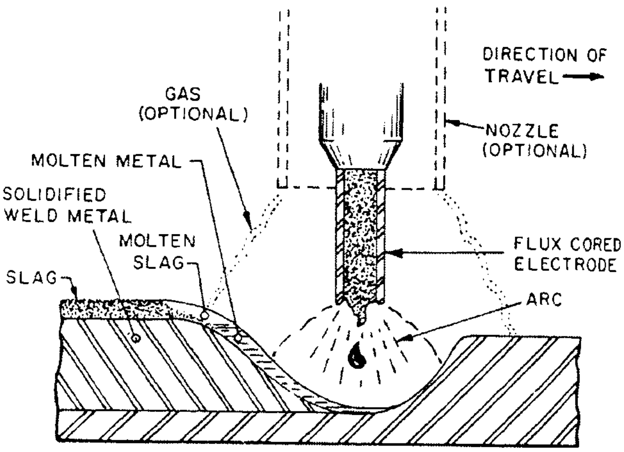


Fig.3-25 Process Diagram

The flux-cored arc welding process is shown by Figure3-25. It utilizes the heat of an arc between a continuously fed consumable flux-cored electrode and the work. The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted off the electrode is transferred through the arc to the work piece where it becomes the deposited weld metal. Shielding is obtained from the disintegration of ingredients contained within the flux-cored electrode. Additional shielding may be obtained from an envelope of gas supplied through a nozzle to the arc area. Ingredients within the electrode produce gas for shielding and also provide deoxidizers. ionizers, purifying agents, and in some cases alloying elements. These ingredients form a glasslike slag, which is lighter in weight than the deposited weld metal, and which floats on the surface of the weld as a protective cover. The electrode is fed into the arc automatically, from a coil. The arc is maintained automatically and travel can be manual or by machine.

Electroslag Welding Process (ESW)

The electroslag welding process is a process in which coalescence is produced by molten slag, which melts the filler metal and the surfaces of the work to be welded. The weld pool is shielded by this slag which moves along the full cross section of the joint as welding pro-gresses. The conductive slag is maintained molten by its resistance to electric current passing between the electrode and the work. Consumable guide electroslag welding variation is a method of electroslag welding in which filler metal is supplied by an electrode and its guiding member.

Principle of Operation

Electroslag welding is not an arc welding process. It is included here since it utilizes the same basic equipment as the other consumable electrode welding processes.

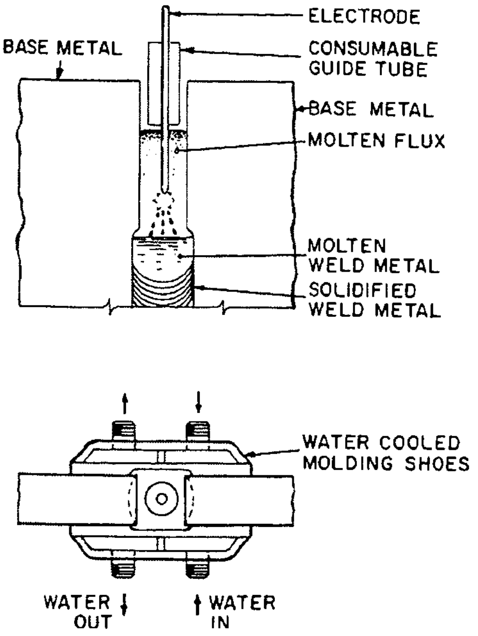


Fig.3-26 Process diagram

The electroslag welding process is shown by Figure3-26. Electroslag welding is done in the vertical position using molding shoes, usually water cooled, in contact with the joint to contain the molten flux and weld metal. The electrode is fed through a guide tube carries the welding current transmits it to the electrode. The guide tube is normally a heavy wall tube. AT the start of the weld, granulated flux is place in the bottom of the cavity. The electrode is fed to the bottom of the joint and for a brief period will create an arc. In a very short time the granulated flux will melt from the heat of the arc and produce a pool of molten flux. The flux is electrically conductive and the welding current will pass from the electrode through the molten flux to the base metal. The passage of current through the conductive flux causes it to become very hot and it reaches a temperature in excess of the melting temperature of the base metal. The high-temperature flux causes melting of the electrode and the end of the guide tube. The melted base metal, electrode, and guide tube are heavier than the flux and collect at the bottom of the cavity to form the molten weld metal. As the molten weld metal slowly solidifies from the bottom it joins the parts to be welded. Shielding of the molten metal from atmospheric contamination is provided by the pool of molten flux. Surface contour of the weld is determined by the contour of the molding or retaining shoes. The consumable guide variation of electroslag welding normally uses fixed of nonsliding molding shoes. The welding head does not move vertically and is normally mounted on tehwork at the top of the weld joint. Multiple electrodes and guides may be employed for welds of larger cross section. It is also possible to oscillate the electrode and guide tube across the width of the joint.

The surface of the solidified weld metal is covered with an easily removed thin layer of slag. The slag loss must be must be compensated for by adding flux during the welding operation. A starting tab is necessary to build up the proper depth of flux so that the molten pool is formed at the bottom of the joint. Runoff tabs arc required at the top of the joint so that the molten flux will rise above the top of the joint. Both starting and runoff tabs are removed from the ends of the joint after the weld is completed.

The normal electro slag welding variation utilizes a welding head which moves up the joint as the weld is made. Retaining shoes usually slide along the joint and rise with the head. Single-or multiple-electrode systems can be employed and they may be oscillated across the width of the joint. All of the other factors involved in operating the process are the same except that the guide tube is not used and therefore the deposit weld metal is supplied entirely by the electrode.

Covered Electrodes

The covered electrode is the most popular type of filler metal used in arc welding. The composition of the covering on the electrode determines the usability of the electrode, the composition of the deposited weld metal, and the specification of the electrode. The composition of coatings on covered arc welding electrodes has been surrounded in mystery and little information has been published. The formulation of electrode coatings is very complex and while it is not an exact science it is based on well-established principles of metallurgy, chemistry, and physics, tempered with experience.

An electrode coating is designed to provide as many as possible of the following desirable characteristics. Some of these characteristics may be incompatible and therefore compromises and balances must be provided and designed into the coating. These desirable characteristics are:

1. Specific composition of the deposited weld metal.
2. Specific mechanical properties of the deposited weld metal.
3. Elimination of weld metal porosity.
4. Elimination of weld metal cracking.
5. Desirable weld deposit contour.
6. Desirable weld metal surface finish, i.e., smooth, with even edges.
7. Elimination of undercut adjacent to the weld.
8. Minimum spatter adjacent to the weld.
9. Ease of manipulation to control slag in all positions.
10. Provide a stable welding arc.
11. Provide penetration control, i.e., deep or shallow.
12. Provide for initial immediate arc striking and restriking capabilities.
13. Provide a high rate of metal deposition.
14. Eliminate noxious odors and fumes.
15. Reduce the tendency of the coating to pick up moisture when in storage.
16. Reduce electrode overheating during use.
17. Provide a strong tough durable coating.
18. Provide for easy slag removal.
19. Provide a coating that will ship well and store indefinitely.

The coatings of electrodes for welding mild and low alloy steels may have from 6 to 12 ingredients such as:

Cellulose: to provide a gaseous shield with a reducing agent. The gas shield surrounding the arc is produced by the disintegration of cellulose.

Metal Carbonates: to adjust the basicity of the slag and to provide a reducing atmosphere.

Titanium Dioxide: to help form a highly fluid but quick-freezing slag. It will also provide ionization for the arc.

Ferromanganese and Ferrosilicon: to help deoxidize the molten weld metal and to supplement the manganese content and silicon content of the deposited weld metal.

Clays and Gums: to provide elasticity for extruding the plastic coating material and to help provide strength to the coating.

Calcium Fluoride: to provide shielding gas to protect the arc, adjust the basicity of the slag, and provide fluidity and solubility of the metal oxides.

Mineral Silicates: to provide slag and give strength to the electrode covering.

Alloying Metals: These include nickel, molybdenum, chromium, etc., to provide alloy content to the deposited weld metal.

Iron or Manganese Oxide: to adjust the fluidity and properties of the slag. In small amounts iron oxide helps stabilize the arc.

Iron Powder: to increase the productivity by providing additional metal to be deposited in the weld.

By using combinations and different amounts of these constituents it is possible to provide an infinite variety of electrode coatings. The binder used for most electrode coatings is sodium silicate, which will chemically combine and harden to provide a tough, strong coating. The design of the coating provides the proper balance to give the electrode specific usability characteristics and to provide specific weld deposit chemistry and properties. In general, the different makes of electrodes that meet a particular classification have somewhat similar compositions.

Cellulose-Sodium (EXXX10): Electrodes of this type have up to 30% cellulosic material in the form of wood flour, or reprocessed paper. The gas shield will contain CO_2 and hydrogen, which are reducing agents. These gases tend to produce a digging arc that produces deep penetration. The weld deposit is somewhat rough and the spatter is at a higher level than other electrodes. It does provide extremely good mechanical properties particularly after aging. This is one of the earliest types of electrodes developed and is widely used for cross country pipe lines using the downhill welding technique. It is normally used with direct with the electrode positive (reverse polarity).

Cellulose-Potassium (EXX11): This electrode is very similar to the cellulose-sodium electrode with the exception that more potassium is used that sodium. This provides ionization of the arc and makes the electrode suitable for welding with alternating current. The arc action, the penetration, and the weld results are very similar.

In both E6011 electrodes, small amounts of iron powder may be added. This will assist in arc stabilization and will also slightly increase the deposition rate.

Rutile-Sodium (EXX12): When the rutile of titanium dioxide content is relatively high with respect to the other constituents, the electrode will be especially appealing to the welder. Electrodes with this coating have a quiet arc, an easily controlled slag, and a low level of spatter. The weld deposit will have a smooth surface and the penetration will be less than with the cellulose electrode. The weld metal properties will be slightly lower than the cellulosic types. This type of electrode provides a fairly high rate of deposition. It has a relatively low arc voltage and can be used on alternating current or on DC with electrode negative (straight polarity).

Rutile-Potassium (EXX13): This electrode coating is very similar to the rutile-sodium type except that potassium is used to provide for arc ionization which makes it more suitable for welding with alternating current. It can also be used with direct current with either polarity. It produces a very quiet smooth running arc.

Rutile-Iron Powder (EXXX4): This coating is very similar to the rutile coatings mentioned above except that iron powder is added. If the addition of iron powder is in the 25-40% category it would result in an EXX14 type electrode. If the iron powder addition is 50% or higher it will result in an EXX24 type electrode. With the smaller amount of iron powder the electrode can be used in all positions, whereas with the high percentage of iron powder it can be used only in the flat position or for making horizontal fillet welds. In both cases the deposition rate is increased based on the amount of iron powder included in the coating.

Low Hydrogen-Sodium (EXX5): Coating that contain a high proportion of calcium carbonate or calcium fluoride are termed low hydrogen and in some cases called lime ferritic or basic type electrodes. In this class of coating cellulose, clays, asbestos, and other minerals that contain combined water are not used. This is to insure the lowest possible hydrogen content in the arc atmosphere. In addition, these electrode coatings are baked at a higher temperature. The low-hydrogen electrode family have superior weld metal properties. They provide the highest ductility of any of the properties. They provide the highest ductility of any of the deposits. These electrodes have a medium arc with medium or moderate penetration. They have a medium speed of deposition but do require special welder technique for best results. Low hydrogen electrodes must be stored under controlled conditions. This type is normally used with direct current with electrode positive (reverse polarity).

Low Hydrogen-Potassium (EXXX6): This type of coating is very similar to the low hydrogen-sodium except for the substitution of potassium for sodium to provide arc ionization. This electrode is used with alternating current and can be used with direct current electrode positive (reverse polarity). It has become considerably more popular than the sodium type. The arc action is smoother but penetration of the two electrodes is very similar.

Low Hydrogen-Iron Powder (EXXX8): The coatings in this class of electrodes are similar to the low-hydrogen type mentioned previously; however, iron powder is added to the electrode and if it is added in the amount of 35-40% the electrode will be classed as an EXX18. This electrode produces excellent weld metal.

Low-Hydrogen Iron Powder (EXX28): Similar to the EXX18 but with 50% or more iron powder added to the coating. This electrode is usable only in the flat position or for making horizontal fillet welds. The deposition rate is higher than the EXX18.

Iron Oxide-Sodium (EXX20): Coatings with high iron oxide content produce a weld deposit with voluminous slag, which is rather difficult to control. This coating type produces high-speed deposition, and a provides medium penetration with a low spatter level. The resulting weld has a very smooth finish. The electrode is restricted to the flat position and for making horizontal fillet welds. The deposit weld metal has good weld metal properties. The electrode can be used with AC or direct current with either polarity. This type of electrode was the original "hot rod" type of electrode. It has become less popular because of the iron powder electrodes.

Iron Oxide-Iron Powder (EXX27): This type of electrode is very similar to the iron oxide-sodium type except that 50% or more iron powder is added to the coating. This greatly increases the deposition rate. This type is quickly supplanting the EXX20 type because although it has similar weld metal deposit characteristics, it is more desirable from the welder's point of view, and it can be used with either alternating or direct current of either polarity.

There are many other types of coatings than those mentioned here, most of which are usually combinations of these types but for special applications such as hard surfacing, cast iron welding, and for non-ferrous metals.

ARC WELDING PROCESS

Introduction

It is a welding process in which to form a molten pool of metal heat is produced by an electric arc, generally without the application of pressure and with or without the application of a filler metal. It uses either AC or DC for striking the arc between the electrode and the workpiece. One terminal is connected to the electrode; the other to the workpiece and circuit is completed through an air gap between the electrode and the workpiece. An air gap is generally 3 to 6 mm. The temperature of the arc varied from 3600°C to 4000°C. The commonly used arc welding processes are:

1. Carbon arc welding.
2. Metal arc welding
3. Inert gas arc welding
4. Submerged arc welding
5. Atomic hydrogen welding
6. Shielded metal arc welding

All the arc welding processes are based on the principle of striking the arc generally between the electrode and the workpiece. The additional metal if required is supplied b the filler rod, Fig shows an electric arc welding circuit. The welding circuit consists of a welding machine, lead cables, electrode holder, electrode and the workpiece itself. Other accessories required are welding helmet, chipping hammer, wire brush and file.

Carbon Arc Welding

It's an arc welding technique using a carbon or graphite electrode as a negative point and the work metal as a positive point. An arc is produced between the electrode and the workpiece which heats the base metal to the melting point. In this process since the polarity is fixed, DC is usually used for welding. The extra metal needed for the weld is added by a filler rod.

Though graphite electrodes are costlier than carbon electrodes they are preferred as they have longer life, more current carrying capacity and lesser electrical resistance.

Metal Arc Welding

In metal arc welding the arc is struck between the work to be welded and the metallic rod that forms the two terminals of the arc. The electrode used may be bare or coated. Coated electrodes are preferred as bare electrodes have a tendency to oxidize. Coated electrodes also form a shielded atmosphere due to production of gas by the decomposition of the electrode coating. Both DC and AC may be used. For current over 750 amperes, AC equipment is preferred as it has high efficiency, negligible loss at peak load and minimum maintenance.

Arc Welding Procedure

An arc welding operation involves the following steps.

1. Thoroughly clean and prepare the edges for proper deposition of the metal.
2. Select the electrode of proper material (having the same composition as base metal) and size according to dimensions of the work piece.
3. Adjust the voltage to proper value.
4. Layout the workpiece and connect with an earth damp.
5. Strike the arc at the correct position.
6. Take a proper run of the welding. If needed take another run of the welding.
7. Clean the weld and chip off the spatter.

Inert Gas Arc Welding

It is a process of welding non-ferrous metals and alloys. Inert gas arc welding processes can be further classified as:

1. Tungsten inert gas arc welding (TIG).
2. Metal inert gas arc welding (MIG).

Tungsten inert gas arc welding (TIG)

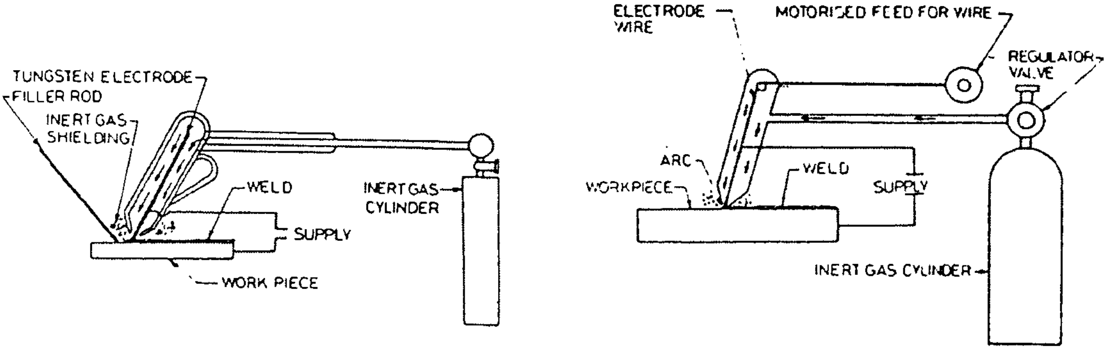


Fig.3-27 TIG and MIG welding

In tungsten inert gas arc welding process the arc is established between the tungsten electrode and the parent metal. The electrode is mounted centrally in a nozzle shaped hood through which an inert gas is passed a shown in Fig.3-27. The inert gases used are helium or argon. Filler metal is required is fed separately. Generally direct current of the order of 500 to 950 amperes is used for most thicknesses. It's a very quick process as it employs a continuous wire filler metal. No electrode coating is required due to shielding by inert gases. This process is specially sued for welding light alloys and non-ferrous materials like aluminium, copper and magnesium. Welds produced by TIG welding are strong, ductile, free from distortion and corrosion resistant.

Metal inert gas welding (MIG)

Is a consumable electrode electric arc inert gas shielded process similar to tungsten inert gas welding. The main difference between TIG and MIG is that in TIG the electrode is made of tungsten whereas in MIG the electrode is made of metal having the same composition as base metal. The metal electrode is fed with a small adjustable speed motor that moves the wire at the small adjustable speed motor that moves the wire at the small adjustable speeds as required for welding. Complete metal inert gas welding equipment consists of source of power supply, MIG gas welding gun, inert gas cylinder, gas regulators, spool for electrode wire, filler metal electrode wire feeding arrangement, apron goggles chipping hammer etc. This process is suitable for welding almost every metal like stainless steel, all types of plain carbon steels, manganese steels, brass copper aluminium magnesium and their alloys. With monitor suitable adjustments of the feeding gun design this equipment can also be used for (a) spray arc welding (b) MIG welding with magnetized flux and (c) MIG welding with flux coated welding wire.

This process is faster, gives deeper penetration with strong and tough joints. The quality of weld produced is high and free from blowholes, porosity and gas contaminants. The cost of the equipment is high and not easily portable, thus unsuitable for outdoor work.

GAS WELDING

Introduction

It is a non-pressure fusion welding process and includes all processes in which gas is used as a source of heat to melt the ends of the pieces to be joined on solidification. A filler metal is needed in welding of sheets above 1.5 mm thickness. A filler metal is added in the form of a filler rod and must be having the same composition as that of the parent metal.

Various gas combinations like oxy-hydrogen; oxy-propane; oxy-acetylene and oxy-coal gas may be used for producing a hot flame for welding of metals. The oxy-acetylene flame is most widely used as it produces very high temperatures (3500°C) and can be used fro welding of a variety of ferrous and non-ferrous materials. It forms an inert gas envelop over the surface and the flame is easily controllable. In addition oxy-acetylene flame can be used for other operations like soldering, brazing and preheating. The main disadvantage of oxy-acetylene flame is that different blow pipes are needed for different operations. Each operation also requires different pressure of gases.

Welding Flames

Combustion of acetylene at the nozzle tip takes place according to the following reaction:

$$2C_2H_2+5O_2 \rightarrow 4CO_2+2H_2O$$

Complete combustion of acetylene requires 2=1/2 parts of oxygen but different processes require different proportions of gases. For normal welding the most suitable mixture is obtained by using equal proportions of oxygen and acetylene as the remaining 1=½ parts required is supplied by the air present in the atmosphere.

Welding flames can be classified broadly into the following three categories.

1. Neutral or balanced flame.
2. Oxidising flame.
3. Carburising or reducing flame.

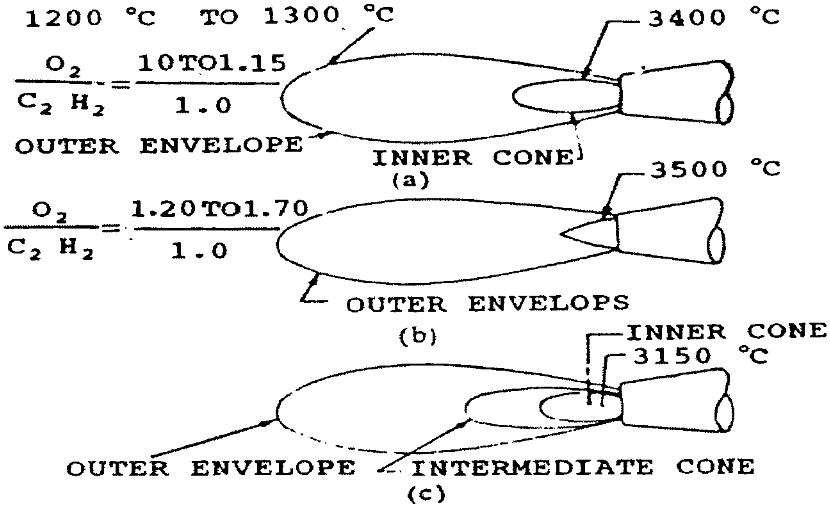


Fig.3-28 Various type of flame
(a)neural(b)oxidizing and (c)reducing

Neutral Flame

A neutral flame is produced when almost equal volumes of oxygen and acetylene drawn from the cylinders burn at the tip of the nozzle. It consists of two clearly visible zones as shown in Fig.3-28(a) It is the most widely used flame and consists of a luminous blue inner zone. This type of flame is used for welding of mild steel, stainless steel, copper, aluminum and their alloys.

Oxidising Flame

When more than one volume of oxygen is mixed with one volume of acetylene an oxidizing flame is produced. This type of flame as shown in Fig3-28(b) used as a cutting flame or preheating flame.

Reducing Flame

A reducing flame is produced by burning of more than one part acetylene with one part of oxygen. As reducing flame consists of excess carbon, its use ensures that steel will absorb carbon. This flame consists of three distinct zones (a) inner cone (b) intermediate cone and (c) outer envelop.

Instruments Used in Oxy-acetylene Welding

A brief description of various instruments used in oxy-acetylene welding is given below.

1. Acetylene cylinders

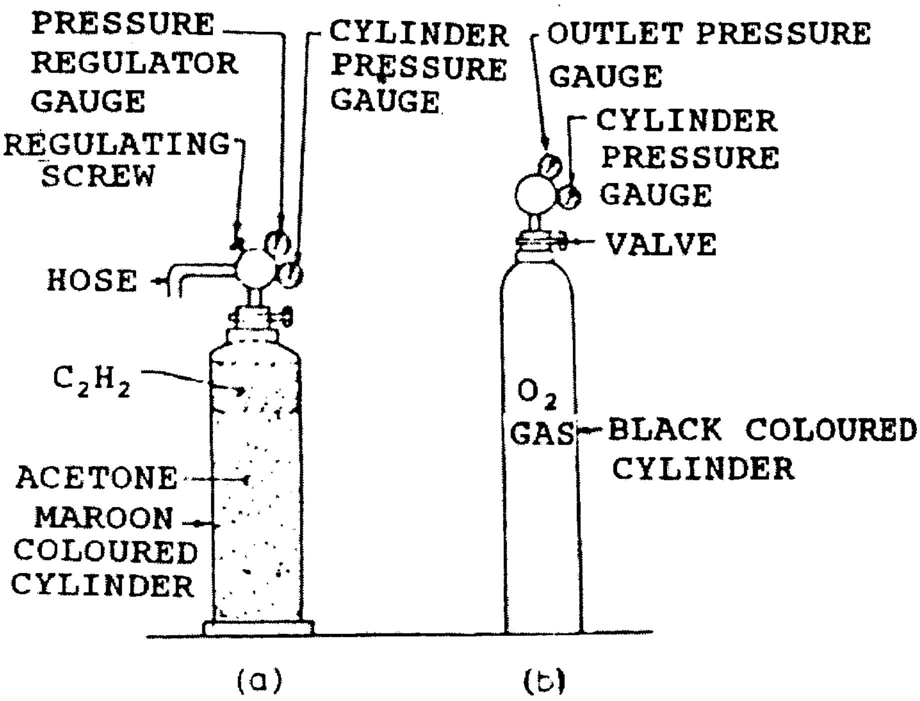


Fig.3-29 (a)acetylene cylinder (b)oxygen cylinder

Fig.3-29(a) Acetylene cylinders are used for storing dissolved acetylene. It is not safe to store acetylene is cylinders above one atmospheric pressure. So acetylene cylinders are filled with acetone. Acetone has the property of absorbing 25 times its own volume of acetylene for each atmospheric pressure applied. An acetone cylinder is partly filled with acetylene. Acetone is stored in these cylinders at a pressure of 16 kgf/cm^2 and capacity of each cylinder is 300 cubic feet. To distinguish from oxygen cylinders, acetylene cylinders are painted maroon. The gas is taken out of the cylinders through a valve provided at the top of the cylinder.

2. Oxygen cylinders

Fig.3-29(b) These are black colored cylinders containing 6.25 cubic metres of oxygen at pressure of 130 to 140 kgf/cm^2. Oxygen cylinders are provided with right handed threaded valves whereas acetylene cylinders are provided with left handed threaded valves. So that the regulator of an oxygen cylinder does not fit on an acetylene cylinder or vice versa. To check against any explosion of accident, oxygen cylinders are also fitted with safety valves.

3. Trolley

It consists a steel structure used for transporting oxygen and acetylene cylinders from one place to another.

4. Hose and hose fitting

These are rubber tubings used for connecting the cylinder regulators to the blowpipe. Houses used are also of red and black colours. A red coloured house is used for acetylene and black coloured hose is used for supply of oxygen.

5. Pressure regulators

Pressure regulators are used for reducing the pressure of the gas being drawn from the cylinders. A red coloured pressure regulator is used for acetylene and a black coloured one is sused for oxygen. Two types of pressure regulators used are (a) single stage regulator and (b) two stage regulator. The two stage regulator is preferred over a single stage regulator as pressure reduction in this regulator is accomplished in two stages.

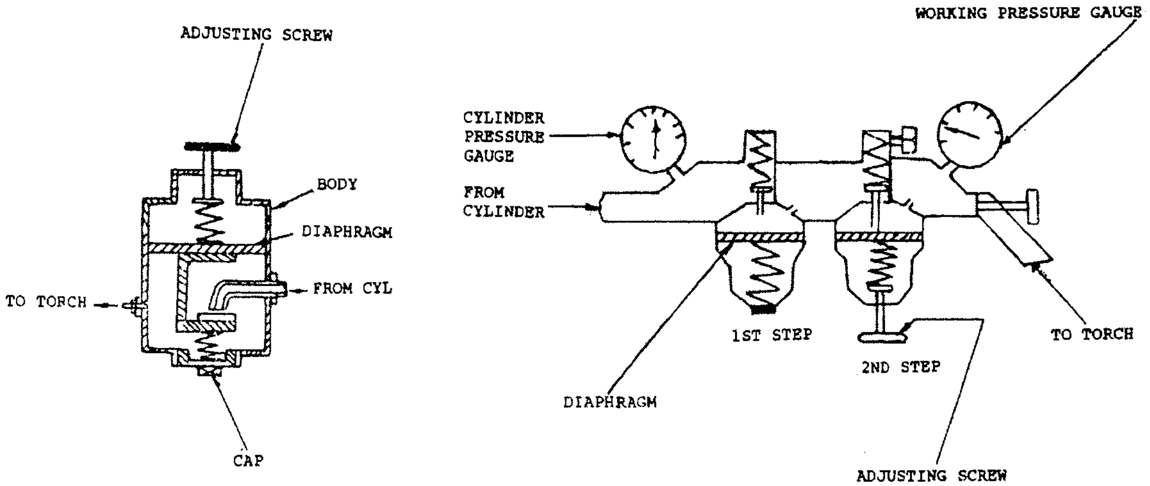


Fig.3-30 (a) single stage regulator and (b) two stage regulator.

6. Welding torch

Fig.3-31 The oxy-acetylene welding torch is the tool in which gases are mixed in the desired volume and burning of the mixture takes place at the end of the tip. It consists of a handle with two inlet valves for oxygen and acetylene gases at one end. Each inlet has a valve to control the volume to the gases passing through. The mixing of gases takes place at the tip of the nozzle. The flame is produced by igniting the mixture with a spark lighter. Two types of commonly used torches are (a) high pressure welding torch and (b) low pressure welding torch. Torches are classified according to acetylene pressure available from

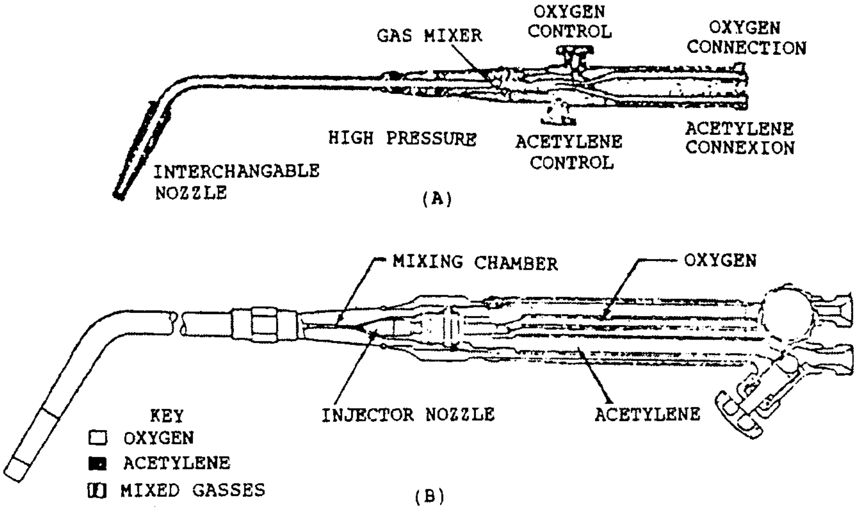


Fig.3-31 (a) high pressure blow pipe
(b) low pressure blow pipe

the source. Acetylene used from cylinders is known as high pressure acetylene while that generated by water and calcium carbide in a drum is known as low pressure acetylene.

7. Goggles

Welding goggles consist of blue coloured glasses and are used for protection of eyes from harmful effects of heat and ultraviolet rays.

8. Spark lighter

It is a tool used for lighting the gasses at the tip of the nozzle.

9. Apron

It is a protective covering made of leather.

10. Gloves

Gloves are used to protect the hands from any accident or mishap. These are generally made of leather, asbestos or canvas.

11. Spindle key

It is an instrument used for opening and closing valves of the gas cylinders.

12. Wire brushes

Wire brushes are used for cleaning a weld prior to welding and removal or rust after welding.

13. Flame and hammer

A file is used for cleaning the surface and a hammer is used for removal of chips.

14. Welding rods and fluxes

Welding rods are used as filler metal and fluxes are used for preventing oxidation.

15. Spanner set

A tool used for opening and loosing the regulators, blowpipes and hose fittings.

Classification of Gas Welding Techniques

Oxy-acetylene welding procedures can be broadly classified as (a) low pressure welding and (b) high pressure welding.

In low pressure welding technique, acetylene is generated in a low pressure acetylene cylinder by the action of calcium carbide on water as shown below, in an equation form.

$$CaC_2 + 2 H_2O = Ca (OH)_2 + C_2H_2$$

Calcium carbide is dropped on water at a controlled rate by a special hopper. The acetylene thus produced is impure and is purified by passing through a purifier. In this system a special injector type blowpipe is used which draws acetylene from the generator by the injector effect of an oxygen jet.

High pressure welding is the most commonly used method of welding. In this system both acetylene and oxygen are used from high pressure cylinders and these cylinders are kept in upright position for easy portability. The essential difference between high pressure and low pressure welding is the pressure of acetylene and design of a welding torch. Low pressure welding process uses low pressure acetylene will specially designed injector blowpipe.

Gas Welding Techniques

The commonly used gas welding techniques are:

1. Leftward or forehand welding.
2. Rightward or backhand welding.
3. Vertical welding.
4. Overhead welding.

1. Leftward welding

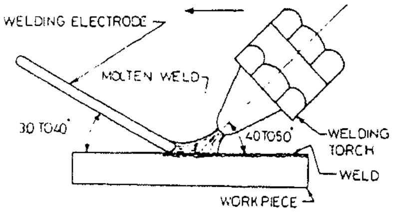


Fig 3-32 Leftward welding

Fig.3-32 It is also known as forehand welding. In this process the torch is held in the right hand at an angle of 40° to 50° and the welding rod in the left hand at an angle of 30° to 40° from the workpiece. The flame is given circular, rotational or side to side motion to obtain uniform fusion throughout. This method is more efficient for welding materials up to 6.00 mm thickness.

2. Rightward welding

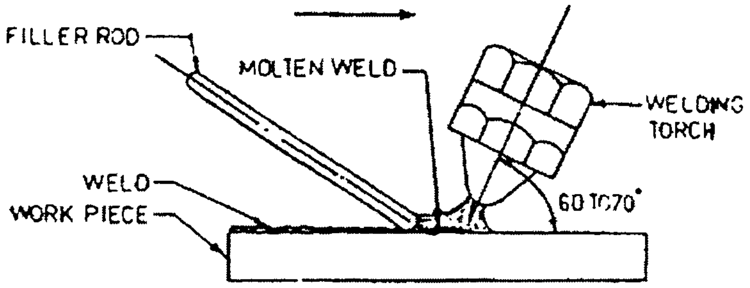


Fig.3-33 rightward welding

It differs from leftward welding in the direction of movement of the torch. In this system the torch moves from left to right. The torch is held in the right hand at an angle of 60 to 70 and the filler rod in the left hand at an angle of 30 to 40 as shown in Fig.3-33 The cone of the flame in rightward welding is deeper than the flame in leftward welding. This process is more suitable for welding plates above 6.0 mm thickness.

Advantages of rightward welding over leftward welding are:

1. The consumption of filler rod and fuel is less.
2. It's a quicker method.
3. The weld thus produced is stronger and tougher.
4. The expansion and contraction of material is lesser.
5. The molten pool is better visible, thus it gives a better control on weld.

3. Vertical welding

This process is used when plates are lying in the vertical position. In this process welding starts at the bottom of the plates and proceeds upwards. The welding torch is held in the right hand and filler rod in the left hand. The filler rod moves ahead of the blowpipe. This process is useful and economical for welding plates up to 6.00 mm thickness specially the tanks, etc., that can't be dismantled easily.

4. Overhead welding

In this process the blowpipe is held almost at right angles to the plates. The molten metal is entirely controlled by the flame. In this process, correct degree of penetration is difficult as the welding operation is performed overhead.

Steps in Gas Welding

The following steps are followed in gas welding operations.

1. Always keep the cylinders upright preferably in a trolley.
2. Blow out the acetylene valves, open acetylene cylinder valve, dislodge any dirt, etc., and close the valve. Repeat the operation with an oxygen cylinder.
3. Thoroughly check the surfaces to be welded, cylinder valves and blowpipe valves.
4. Tighten the regulators on the cylinders.
5. Connect the hosepipes to cylinders and torch.
6. Insert the required size of tip in the blowpipe.
7. Ignite acetylene with a spark lighter.
8. Open the valve of oxygen and adjust the flame.
9. When work is to be stopped, first stop the supply of acetylene and then of oxygen. Close all valves and remove blowpipe, hole and regulators.

Disadvantages of Oxy-acetylene Welding

1. It is a comparatively slower process than arc welding.
2. Oxygen and acetylene gases are expensive.
3. Many safety problems are involved in handling and storing the gases.
4. An oxy-acetylene flame does not provide complete shielding of the weld pool.
5. Harmful thermal effects exist in welded sections.

Safety Precautions In Gas Welding

1. Always keep the cylinders in upright position.
2. Never temper with cylinder valves.
3. Always keep the cylinder key at valve steam.
4. If any leakage is noticed in an acetylene cylinder, remove all materials from its vicinity and let the gas escape into the atmosphere.
5. Always used protective glasses while welding, chipping or grinding.
6. Before starting any welding operation, make sure that connections are gastight.
7. Always used a fraction lighter for lighting torches.
8. Never use oxygen near inflammable materials.
9. Never use acetylene above 1kgf/cm^2 pressure.
10. Don't drop the cylinders.
11. Keep hoses and cylinders away from flying sparks and open flames.

Oxy-acetylene Gas Cutting

This is a very commonly used process for cutting materials. It is based on the principle that oxygen has great affinity for iron and steel at elevated temperatures. When a metallic piece of iron is heated up to 1000°C, it forms iron oxide which has low melting temperature. Thus if the steel is heated to about 1000°C and then a jet of pure oxygen is blown on the surface, the steel is instantaneously burnt to iron oxide to a slag like appearance, which falls down under pressure and steel is cut. The process is very rapid and pieces up to 75 mm thickness can be cut easily.

The operation is carried out with a special torch having several small holes for preheating the steel to red colour. The main central hole in the torch, carries oxygen for cutting action. This process is only suitable for cutting steel and is not suitable for cutting non-ferrous alloys and high manganese steels.