Types of Welding Processes

- Some 50 different types of welding operations have been cataloged by the American Welding Society (AWS).
- They use various types or combinations of energy to provide the required power.
- We can divide the welding processes into two major groups: **(A) Fusion Welding (B) Solid-State Welding**

- For the **fusion welding,** in which coalescence is accomplished by melting the two parts to be joined, in some cases adding filler metal to the joint.
- For the **solid-state welding,** in which heat and/or pressure are used to achieve coalescence, but no melting of the base metals occurs and no filler metal is added.
- **Fusion welding** is by far the more important category. It includes **(1) arc welding, (2) resistance welding, (3) oxyfuel gas welding, and (4) other fusion welding processes (electron beam welding and laser beam welding).**

(A) Fusion Welding

(1) Arc Welding

- Arc welding (AW) is a fusion-welding process in which coalescence of the metals is achieved by the heat of an electric arc between an electrode and w.p.
- A generic AW process is shown in Figure (5-8).
- An electric arc is a discharge of electric current across a gap in a circuit. It is sustained by the presence of a thermally ionized column of gas (called a plasma) through which current flows.
- To initiate the arc in an AW process, the electrode is brought into contact with w.p. and then quickly separated from it by a short distance.
- The electric arc produces temperatures of 5500°C (10,000°F) or higher.
- A pool of molten metal, consisting of base metal(s) and filler metal (if one is used) is formed near the tip of the electrode.
- In most arc welding processes, filler metal is added to increase the volume and strength of the weld joint.
- As the electrode is moved along the joint, the molten weld pool solidifies in its wake.

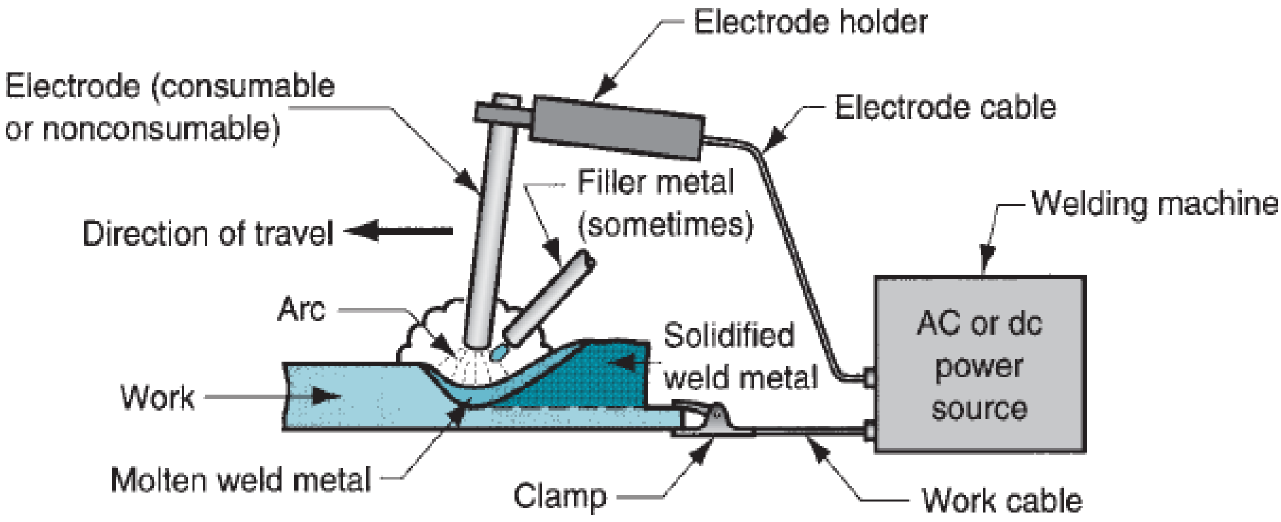

Figure (5-8) The basic configuration and electrical circuit of an arc-welding process.

- Movement of the electrode relative to w.p. is accomplished by either a human welder (manual welding) or by mechanical means (i.e., machine welding, automatic welding, or robotic welding).

General Technology of Arc Welding:

- ***Electrodes:*** used in AW processes are classified as consumable or nonconsumable.
  Consumable electrodes provide the source of the filler metal in arc welding.
- These electrodes are available in two principal forms: rods (sticks) and wire.
- Welding rods are typically 225 to 450 mm (9 –18 in) long and 9.5 mm (3/8 in) or less in diameter.
- The problem with consumable welding rods, is that they must be changed periodically, reducing arc time of the welder.
- Welding productivity is measured as *Arc Time*:

Arc Time= (time arc is on / hours worked)

- Consumable weld wire it can be continuously fed into the weld pool from spools containing long lengths of wire, thus avoiding the frequent interruptions that occur when using welding sticks (rods).
  Nonconsumable Electrodes are made of tungsten (or carbon, rarely), which resists melting by the arc.

- Despite its name, a nonconsumable electrode is gradually depleted during the welding process (vaporization is the principal mechanism), wearing of a cutting tool in a machining.
- For AW processes that utilize nonconsumable electrodes, any filler metal used in the operation must be supplied by means of a separate wire that is fed into the weld pool.

Arc Shielding At the high temperatures in arc welding, the metals being joined are chemically reactive to oxygen, nitrogen, and hydrogen in the air.

- The mechanical properties of the weld joint can be seriously degraded by these reactions.
- Arc shielding is accomplished by covering the electrode tip, arc, and molten weld pool with a blanket of gas or flux, or both, which inhibit exposure of the weld metal to air.
- Common shielding gases include argon and helium, both of which are inert. In the welding of ferrous metals with certain AW processes, oxygen and carbon dioxide are used, usually in combination with Ar and/or He, to produce an oxidizing atmosphere or to control weld shape.
- A flux is a substance used to prevent the formation of oxides and other unwanted contaminants, or to dissolve them and facilitate removal.
- During welding, the flux melts and becomes a liquid slag, covering the operation and protecting the molten weld metal.
- The slag hardens upon cooling and must be removed later by chipping or brushing.
- Flux is usually formulated to serve several additional functions: (1) provide a protective atmosphere for welding, (2) stabilize the arc, and (3) reduce spattering.

Power Source in Arc Welding Both direct current (DC) and alternating current (AC) are used in arc welding.

- AC machines are less expensive to purchase and operate, but are generally restricted to welding of ferrous metals.
- DC equipment can be used on all metals with good results and is generally noted for better arc control.
- In all arc-welding processes,

$$P = I\,E$$

P: power to drive the operation
I: current passing through the arc
E: voltage across it

- This power is converted into heat, but not all of the heat is transferred to the surface of w.p.
- The effect of the losses (Convection, conduction, radiation, and spatter) is expressed by the heat transfer factor f_1.
- Heat transfer factors are greater for AW processes that use consumable electrodes because most of the heat consumed in melting the electrode is subsequently transferred to w.p. as molten metal.
- The process with the lowest f_1 value is gas tungsten arc welding, which uses a non-consumable electrode.
- Melting factor f_2 further reduces the available heat for welding.

- The resulting power balance (rate of heat generation) in arc welding is defined by:

$$R_{Hw} = f_1 f_2 IE = U_m A_w v$$

E: voltage (V),
I: current (A)
R_{Hw}: watts = J/sec. (1 Btu = 1055J and 1 Btu/sec = 1055 watts)

Example (7):
A gas tungsten arc-welding operation is performed at a current of 300A and voltage of 20V. The melting factor f_2=0.5, and the unit melting energy for the metal Um = 10 J/mm^3. Determine (a) power in the operation, (b) rate of heat generation at the weld, and (c) volume rate of metal welded. Take the heat transfer factor f_1=0.7.
Solution:
(a) Power in arc-welding process:
P = (I E) = 300(20) = 6000 W **Answer**
(b) Rate of heat generation:
$R_{Hw} = f_1 f_2 IE = 0.7(0.5)(6000) = 2100\, W$ **Answer**
(c) volume rate of metal welded:
$R_{Hw} = U_m R_{WV} \;\rightarrow\; R_{WV} = \frac{R_{Hw}}{U_m} = \frac{2100}{10} = 210\, mm^3/s$ **Answer**

AW PROCESSES — CONSUMABLE ELECTRODES

(a) Shielded Metal Arc Welding (SMAW):

- Shielded metal arc welding (SMAW) is an AW process that uses a consumable electrode consisting of a filler metal rod coated with chemicals that provide flux and shielding. The process is illustrated in Figure (5-9).
- The welding stick (SMAW is sometimes called stick welding) is typically 225 to 450mm (9–18 in) long and 2.5 to 9.5mm (3/32–3/8 in) in diameter.
- The filler metal used in the rod must be compatible with the metal to be welded, the composition usually being very close to that of the base metal.
- The coating consists of powdered cellulose (i.e., cotton and wood powders) mixed with oxides, carbonates, and other ingredients, held together by a silicate binder.
- Metal powders are also sometimes included in the coating to increase the amount of filler metal and to add alloying elements.
- The heat of the welding process melts the coating to provide a protective atmosphere and slag for the welding operation. It also helps to stabilize the arc and regulate the rate at which the electrode melts.
- During operation the bare metal end of the welding stick (opposite the welding tip) is clamped in an electrode holder that is connected to the power source.
- The holder has an insulated handle so that it can be held and manipulated by a human welder.
- Currents typically used in SMAW range between 30 and 300 A at voltages from 15 to 45 V.
- Selection of the proper power parameters depends on the metals being welded, electrode type and length, and depth of weld penetration required.

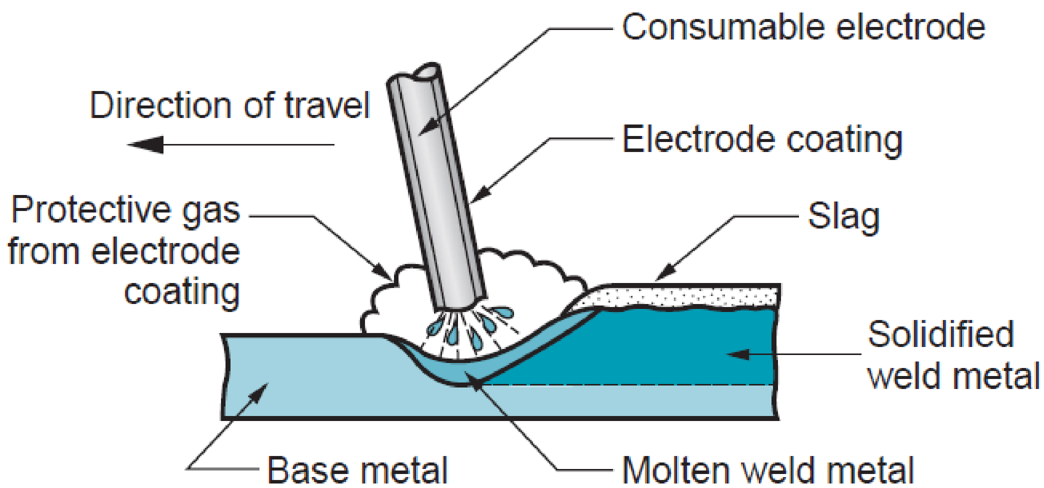

Figure (5-9) Shielded metal arc welding (SMAW).

- SMAW is usually performed manually.
- Common applications include construction, pipelines, machinery structures, shipbuilding, job shop fabrication, and repair work.
- It is preferred over oxyfuel welding for thicker sections [above 5 mm (3/16 in)] because of its higher power density.
- Base metals include steels, stainless steels, cast irons, and certain nonferrous alloys.
- It is not used or seldom used for aluminum and its alloys, copper alloys, and titanium.
- **SMAW Disadvantages:**

1- Use of the consumable electrode stick.
2- As the sticks periodically be changed, this reduces the arc time.
3- Because the electrode length varies during the operation and this length affects the resistance heating of the electrode, current levels must be maintained within a safe range or the coating will overheat and melt prematurely when starting a new welding stick.

(b) Gas Metal Arc Welding (GMAW):

- Gas metal arc welding (GMAW) is an AW process in which the electrode is a consumable bare metal wire, and shielding is accomplished by flooding the arc with a gas.
- The bare wire is fed continuously and automatically from a spool through the welding gun, the process is illustrated in Figure (5-10).

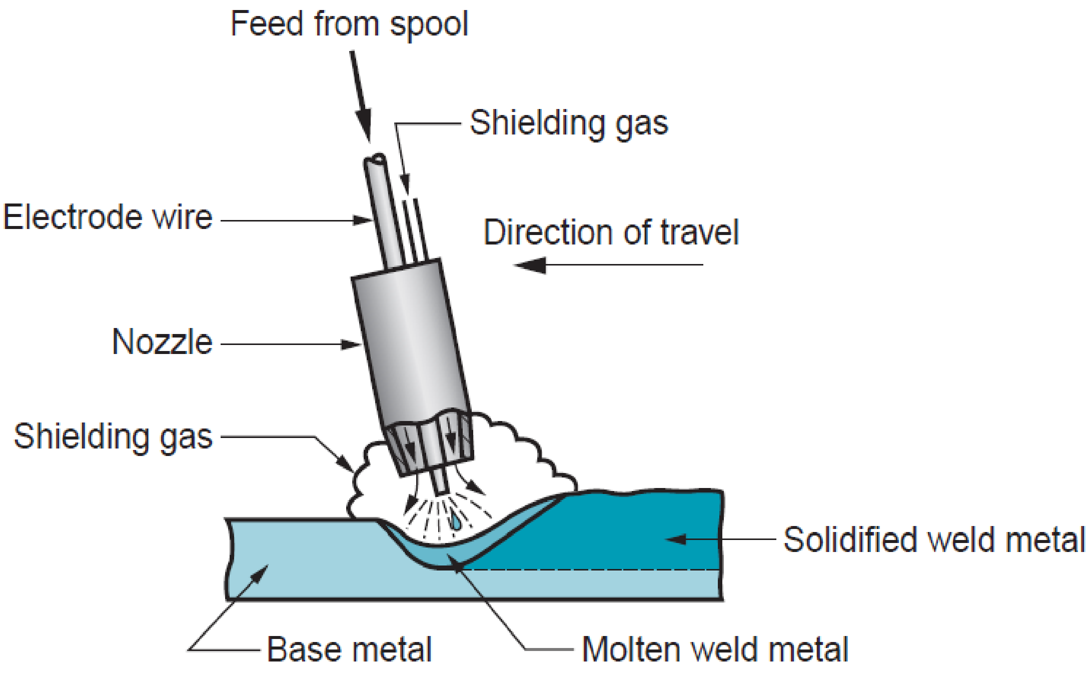

Figure (5-10) Gas metal arc welding (GMAW).

A welding gun is shown in Figure (5-11).

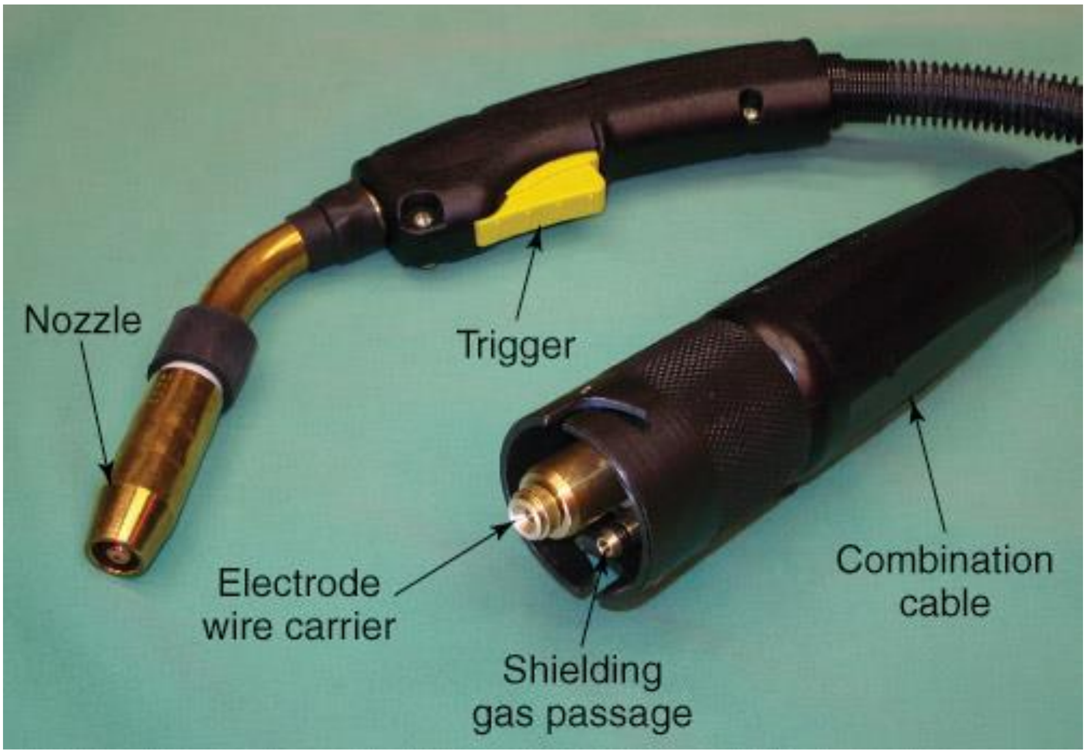

Figure (5-11) Welding gun for gas metal arc welding (GMAW).

- Wire diameters ranging from 0.8 to 6.5mm (1/32–1/4 in) are used in GMAW.
- The size depending on the thickness of the parts being joined and the desired deposition rate.
- Gases used for shielding include inert gases such as argon and helium, and active gases such as carbon dioxide.
- Selection of gases (and mixtures of gases) depends on the metal being welded.
- Inert gases are used for welding aluminum alloys and stainless steels, while CO_2 is commonly used for welding low and medium carbon steels.
- The bare electrode wire and shielding gases eliminates the slag covering on the weld bead and thus precludes the need for manual grinding and slag cleaning.
- The GMAW process is therefore ideal for making multiple welding passes on the same joint.
- **Variety of names for GMAW was used:**
  (a) Welding of aluminum, using Argon (arc shielding): MIG welding (Metal Inert Gas).
  (b) Welding of steel, using CO_2 (arc shielding): CO_2 welding.
  (c) Refinements in GMAW for steel welding, use of gas mixtures (CO_2 + argon, and (O_2 and argon.

- **<u>GMAW Advantages:</u>**

1- GMAW is widely used in fabrication operations in factories for welding a variety of ferrous and nonferrous metals.
2- GMAW have over SMAW in terms of arc time when performed manually.
3- For the same reason, it also lends itself to automation of arc welding.
4- The electrode stubs remaining after stick welding in (SMAW) also wastes filler metal, so the utilization of electrode material is higher with GMAW.
5- Elimination of slag removal (since no flux is used), higher deposition rates than SMAW, and good versatility.

(d)<u>Flux-Cored Arc Welding (FCAW)</u>:

- It is an adaptation of SMAW to overcome the limitations imposed by the use of stick electrodes.
- FCAW is an arc-welding process in which the electrode is a continuous consumable tubing that contains flux and other ingredients in its core.
- Other ingredients may include deoxidizers and alloying elements.
- The tubular flux cored ‘‘wire’’ is flexible and can therefore be supplied in the form of coils to be continuously fed through the arc-welding gun.
- There are two versions of FCAW: **(1) self-shielded and (2) gas shielded.**
- In **self-shielded FCAW** to be developed, arc shielding was provided by a flux core, thus leading to the name self-shielded flux-cored arc welding. The core in this form of FCAW includes not only fluxes but also ingredients that generate shielding gases for protecting the arc.
- In **gas shielded FCAW**, developed primarily for welding steels, obtains arc shielding from externally supplied gases, similar to **GMAW**. This version is called gas-shielded flux-cored arc welding.
- Shielding gases typically employed are carbon dioxide for mild steels or mixtures of argon and carbon dioxide for stainless steels.
- Figure (5-12) illustrates the FCAW process, with the gas (optional) distinguishing between the two types.

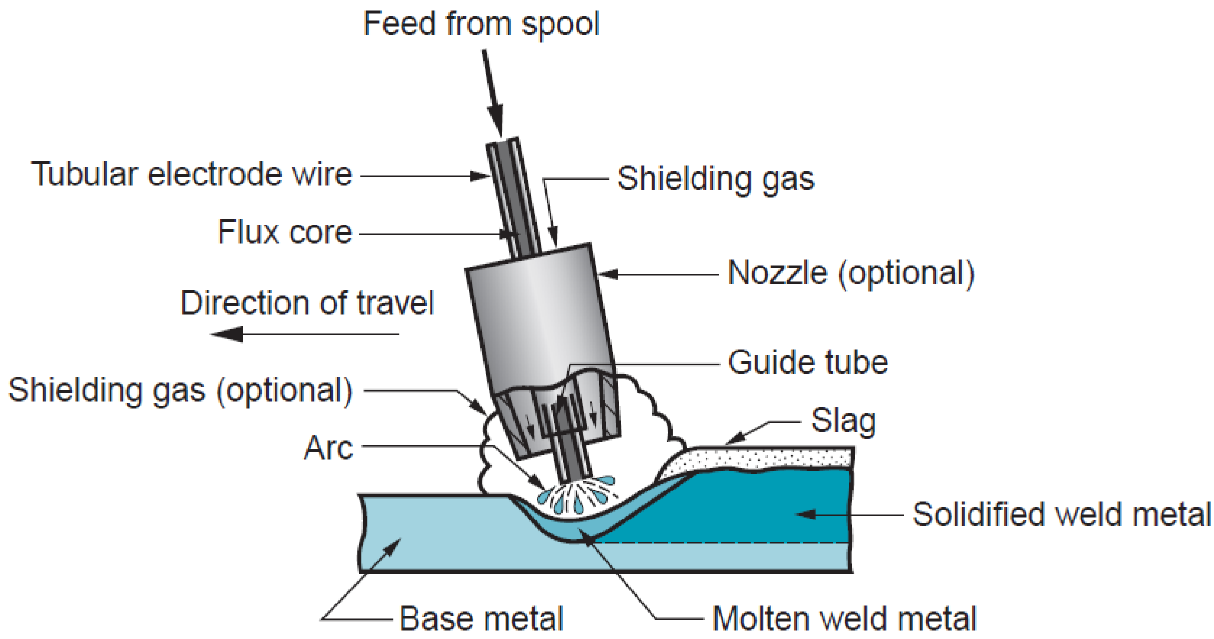

Figure (5-12) Flux-cored arc welding (FCAW). The presence or absence of externally supplied shielding gas distinguishes the two types: (1) self-shielded, in which the core provides the ingredients for shielding; and (2) gas shielded, in which external shielding gases are supplied.

- **FCAW Advantages:**

1- FCAW has advantages similar to GMAW, due to continuous feeding of the electrode.
2- It is used primarily for welding steels and stainless steels over a wide stock thickness range.
3- It is noted for its capability to produce very-high-quality weld joints that are smooth and uniform.

(e) Electrogas Welding (EGW):

- EGW is an AW process that uses a continuous consumable electrode (either flux-cored wire or bare wire with externally supplied shielding gases) and molding shoes to contain the molten metal.
- The process is primarily applied to vertical butt welding, as pictured in Figure (5-13).
- When the flux-cored electrode wire is employed, no external gases are supplied, and it considered a special application of self-shielded FCAW.
- When a bare electrode wire is used with shielding gases from an external source, it is considered a special case of GMAW.
- The molding shoes are water cooled to prevent their being added to the weld pool.

- Together with the edges of the parts being welded, the shoes form a container, almost like a mold cavity, into which the molten metal from the electrode and base parts is gradually added.
- The process is performed automatically, with a moving weld head traveling vertically upward to fill the cavity in a single pass.
- **Principal applications of EGW** welding are: steels (low- and medium-carbon, low-alloy, and certain stainless steels) in the construction of large storage tanks and in shipbuilding.
- Stock thicknesses from 12 to 75 mm (0.5–3.0 in) are within the capacity of EGW.
- In addition to butt welding, it can also be used for fillet and groove welds, always in a vertical orientation.

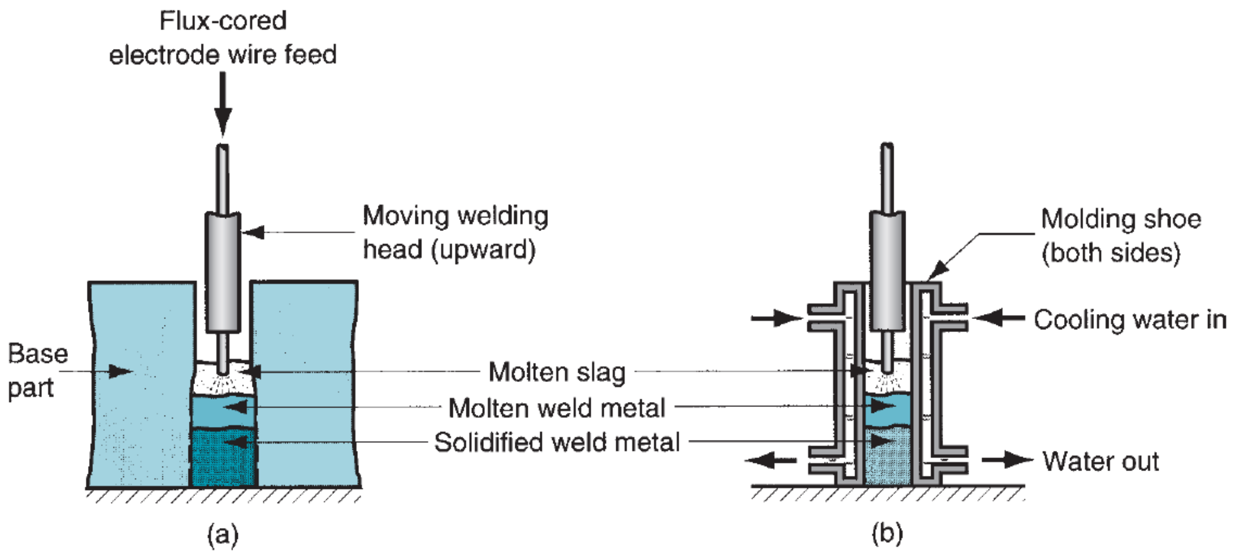

Figure (5-13) Electrogas welding using flux-cored electrode wire: (a) front view with molding shoe removed for clarity, and (b) side view showing molding shoes on both sides.

(f) <u>Submerged Arc Welding (SAW)</u>:

- SAW is an arc-welding process that uses a continuous, consumable bare wire electrode, and arc shielding is provided by a cover of granular flux.
- The electrode wire is fed automatically from a coil into the arc.
- The flux is introduced into the joint slightly ahead of the weld arc by gravity from a hopper, as shown in Figure (5-14).
- The blanket of granular flux completely submerges the welding operation, preventing sparks, spatter, and radiation that are so hazardous in other AW processes.
- Thus, the welding operator in SAW need not wear the somewhat cumbersome face shield (safety glasses and protective gloves are required).

- The portion of the flux closest to the arc is melted, mixing with the molten weld metal to remove impurities and then solidifying on top of the weld joint to form a glasslike slag.
- The slag and unfused flux granules on top provide good protection from the atmosphere and good thermal insulation for the weld area, resulting in relatively slow cooling and a high-quality weld joint, noted for toughness and ductility.
- The unfused flux remaining after welding can be recovered and reused.
- The solid slag covering the weld must be chipped away, usually by manual means.
- **SAW is widely used in steel-low-carbon, low-alloy, and stainless steels- (25-mm-thickness and heavier) fabrication for structural shapes (e.g., welded I-beams); longitudinal and circumferential seams for large diameter pipes, tanks, and pressure vessels; and welded components for heavy machinery.**
- **High-carbon steels, tool steels, and most nonferrous metals are not welded by SAW.**
- Because of the gravity feed of the granular flux, the parts must always be in a horizontal orientation, and a backup plate is often required beneath the joint during the welding operation.

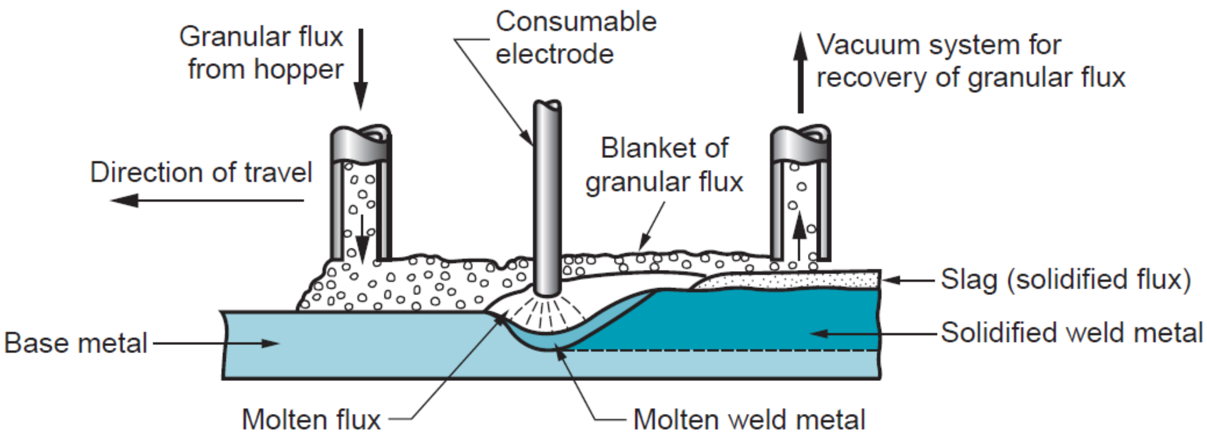

Figure (5-14) Submerged arc welding (SAW).

AW PROCESSES — NONCONSUMABLE ELECTRODES

(a) Gas Tungsten Arc Welding (GTAW):

- Gas tungsten arc welding (GTAW) is an AW process that uses a non-consumable tungsten electrode and an inert gas for arc shielding.
- The term TIG welding (tungsten inert gas welding) is often applied to this process (in Europe, WIG welding is the term—the chemical symbol for tungsten is W, for Wolfram).
- GTAW can be implemented with or without a filler metal.
- Figure (5-15) illustrates the latter case.
- When a filler metal is used, it is added to the weld pool from a separate rod or wire, being melted by the heat of the arc.
- Tungsten is a good electrode material due to its high melting point of 3410 °C.
- Typical shielding gases include argon, helium, or a mixture of these gas elements.
- GTAW is applicable to nearly all metals in a wide range of stock thicknesses.
- It can also be used for joining various combinations of dissimilar metals.

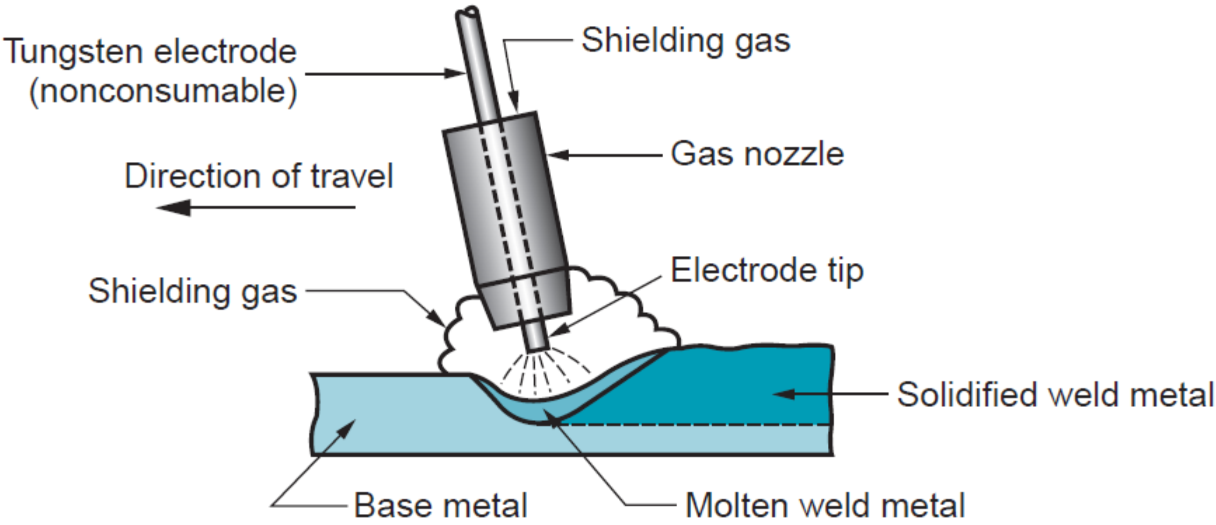

Figure (5-15) Gas tungsten arc welding (GTAW).

- Its most common applications are for aluminum and stainless steel.
- Cast irons, wrought irons, and of course tungsten are difficult to weld by GTAW.
- In steel welding applications, GTAW is generally slower and more costly than the consumable electrode AW processes, except when thin sections are involved and very-high-quality welds are required.
- Filler metal is usually not added when thin sections are welded.
- The process can be performed manually or by machine and automated methods for all joint types.

- **<u>Advantages of GTAW</u>**:

1- High-quality welds.
2- No weld spatter because no filler metal is transferred across the arc.
3- Little or no post weld cleaning because no flux is used.

(b) <u>Plasma Arc Welding (PAW)</u>:

- PAW is a special form of gas tungsten arc welding in which a constricted plasma arc is directed at the weld area.
- In PAW, a tungsten electrode is contained in a specially designed nozzle that focuses a high-velocity stream of inert gas (e.g., argon or argon–hydrogen mixtures) into the region of the arc to form a high velocity, intensely hot plasma arc stream.
- The process is explained in Figure (5-16).

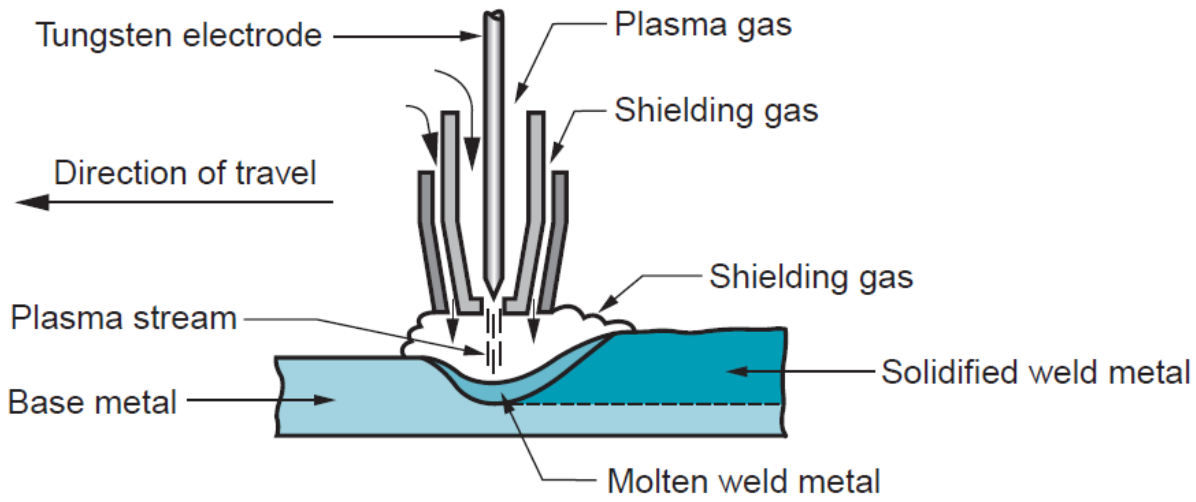

Figure (5-16) Plasma arc welding (PAW).

- Argon, argon–hydrogen, and helium are also used as the arc-shielding gases.
- Temperatures in plasma arc welding reach 17,000 ^{o}C or greater.
- The reason why temperatures are so high in PAW (higher than in GTAW) derives from the constriction of the arc.
- The power levels in PAW are highly concentrated to produce a plasma jet of small diameter and very high-power density.
- PAW can be used in applications such as automobile subassemblies, metal cabinets, door and window frames, and home appliances.
- PAW can be used to weld almost any metal, including tungsten.
- Difficult-to-weld metals such as bronze, cast irons, lead, and magnesium.

- **PAW limitations:**

1- High equipment cost.
2- Larger torch size than other AW operations, which tends to restrict access in some joint configurations.

- **PAW Advantages:**

1- Good arc stability.
2- Better penetration control than most other AW processes.
3- High travel speeds.
4- Excellent weld quality.

Other Arc-Welding and Related Processes

(a) Carbon arc welding (CAW):

- CAW is an arc-welding process in which a non-consumable carbon (graphite) electrode is used.
- CAW is used as a heat source for brazing and for repairing iron castings.
- It can also be used in some applications for depositing wear-resistant materials on surfaces.
- Graphite electrodes for welding have been largely superseded by tungsten (in GTAW and PAW).

(b) Stud welding (SW):

- SW is a specialized AW process for joining studs or similar components to base parts.
- SW operation is illustrated in Figure (5-17), in which shielding is obtained by the use of a ceramic ferrule.
- To begin with, the stud is chucked in a special weld gun that automatically controls the timing and power parameters of the steps shown in the sequence.
- The worker must only position the gun at the proper location against the base w.p. and pull the trigger.
- SW applications include: threaded fasteners for attaching handles to cookware, heat radiation fins on machinery, and similar assembly situations.
- In high-production operations, stud welding usually has advantages over rivets, manually arc-welded attachments, and drilled and tapped holes.

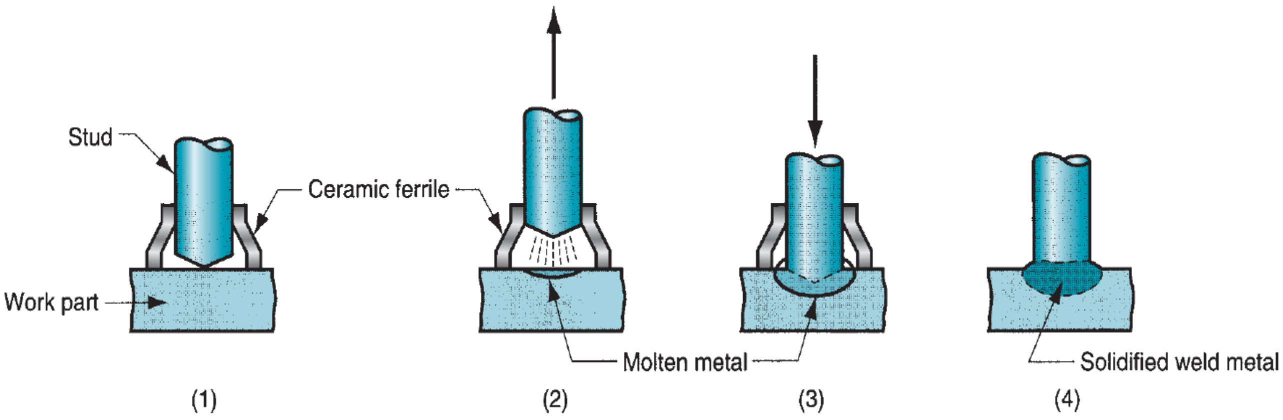

Figure (5-17) Stud arc welding (SW): (1) stud is positioned; (2) current flows from the gun, and stud is pulled from base to establish arc and create a molten pool; (3) stud is plunged into molten pool; and (4) ceramic ferrule is removed after solidification.