UNIT 3: WELDING

Definition:
Welding is a process of joining similar or dissimilar materials by the application of heat and/or pressure.

Principle of welding:

If two surfaces are brought together in such a way that nothing but the grain boundaries separate them then the two bodies with adhere with a very large force resulting in what we called welding.

Types of welding:

Types of Welding
Welding processes differ with respect to the procedures through which temperature & pressure are combined & applied. They can be divided into two groups:
1. Fusion Welding Processes
2. Solid State Welding Processes

1. Fusion Welding Processes.
Fusion welding refers to the welding process that rely upon melting to join the materials. These processes involve high temperature during welding.

2. Solid State Welding
It refers to the welding process in which two workpieces are join under pressure without melting. An intimate contact is provided b/w the materials at a temperature below the melting point of the base ~~k~~ material.

Fusion Welding Processes
Fusion welding is a joining process that uses fusion of the base metal to make the weld. The three major types of fusion welding processes are as follows:

1. **Gas welding**: Oxyacetylene welding (OAW)

2. **Arc welding**:
Shielded metal arc welding (SMAW)
Gas–tungsten arc welding (GTAW)
Gas–metal arc welding (GMAW)
Submerged arc welding (SAW)

3. **High-energy beam welding**:
Laser beam welding (LBW)
Electron Beam Welding (EBW)

OXYACETYLENE WELDING

The Process
Gas welding is a welding process that melts and joins metals by heating them with a flame caused by the reaction between a fuel gas and oxygen. Oxyacetylene welding (OAW), shown in Figure 1, is the most commonly used gas welding process because of its high flame temperature. A flux may be used to deoxidize and cleanse the weld metal. The flux melts, solidifies, and forms a slag skin on the resultant weld metal. Figure 2 shows three different types of flames in oxyacetylene welding: neutral, reducing, and oxidizing (4), which are described next.

Three Types of Flames
A. Neutral Flame This refers to the case where oxygen (O_2) and acetylene (C_2H_2) are mixed in equal amounts and burned at the tip of the welding torch.
A short inner cone and a longer outer envelope characterize a neutral flame (Figure 2*a*). The inner cone is the area where the primary combustion takes place through the chemical reaction between O_2 and C_2H_2, as shown in Figure 3. The heat of this reaction accounts for about two-thirds of the total heat generated. The products of the primary combustion, CO and H_2, react with O_2 from the surrounding air and form CO_2 and H_2O. This is the secondary combustion, which accounts for about one-third of the total heat generated. The area where this secondary combustion takes place is called the outer envelope. It is also called the protection envelope since CO and H_2 here consume the O_2 entering from the surrounding air, thereby protecting the weld metal from oxidation. For most metals, a neutral flame is used.

B. Reducing Flame When excess acetylene is used, the resulting flame is called a reducing flame. The combustion of acetylene is incomplete. As a result, a greenish acetylene feather between the inert cone and the outer envelope characterizes a reducing flame (Figure 2*b*). This flame is reducing in nature and is desirable for welding aluminum alloys because aluminum oxidizes easily. It is also good for welding high-carbon steels (also called carburizing flame in this case) because excess oxygen can oxidize carbon and form CO gas porosity in the weld metal.
C. Oxidizing Flame When excess oxygen is used, the flame becomes oxidizing because of the presence of unconsumed oxygen. A short white inner cone characterizes an oxidizing flame

(Figure 2*c*). This flame is preferred when welding brass because copper oxide covers the weld pool and thus prevents zinc from evaporating from the weld pool.

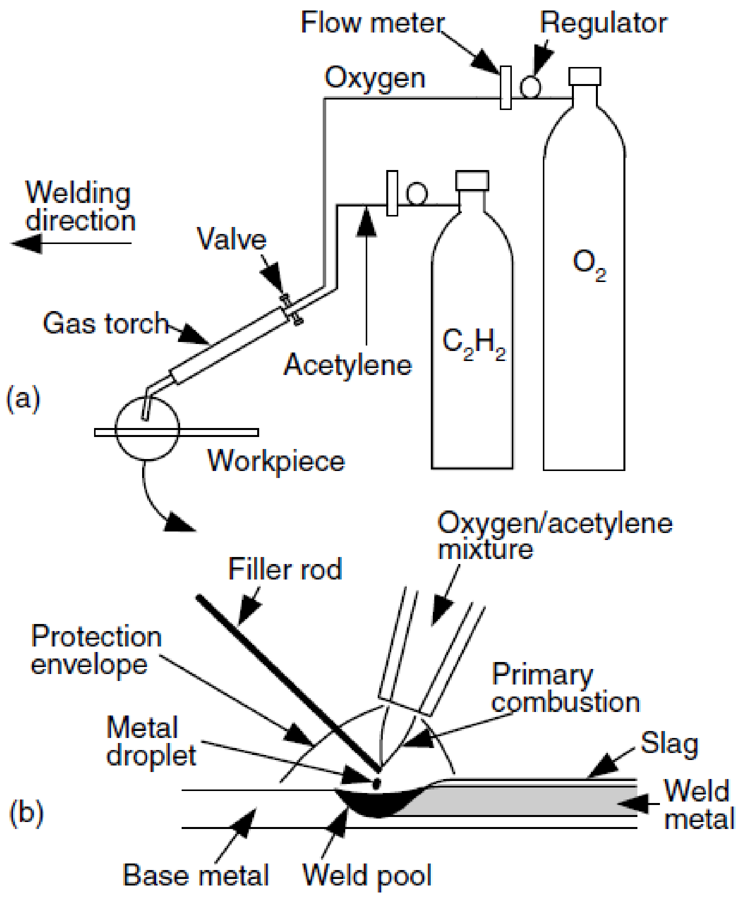

Figure 3.1 Oxyacetylene welding: (*a*) overall process; (*b*) welding area enlarged.

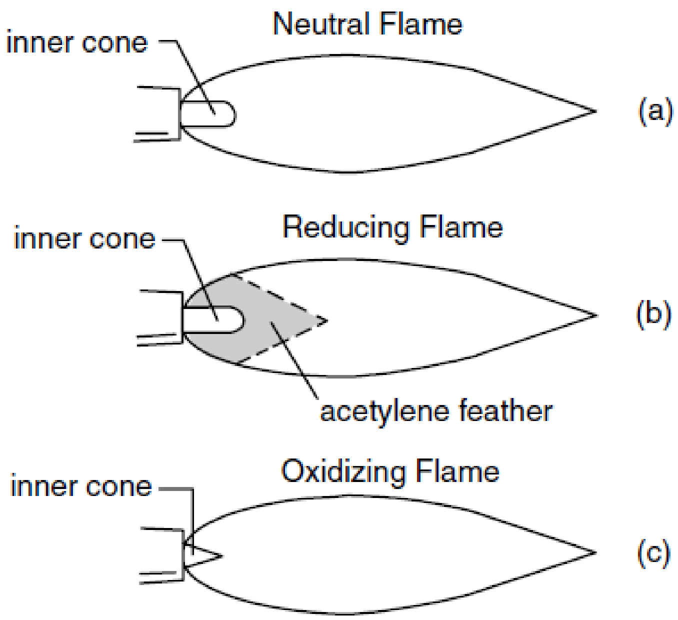

Figure 3.2 Three types of flames in oxyacetylene welding.

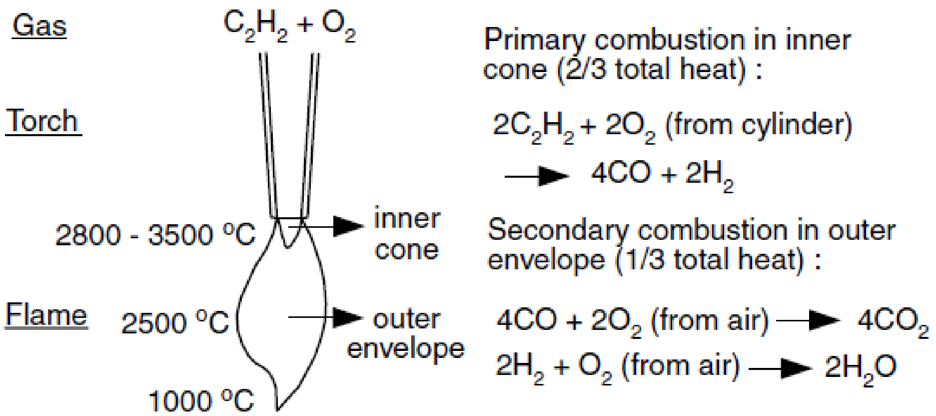

Figure 3.3 Chemical reactions and temperature distribution in a neutral oxyacetylene flame.

Advantages and Disadvantages of Gas welding

The main advantage of the oxyacetylene welding process is that the equipment is simple, portable, and inexpensive. Therefore, it is convenient for maintenance and repair applications. However, due to its limited power density, the welding speed is very low and the total heat input per unit length of the weld is rather high, resulting in large heat-affected zones and severe distortion.The oxyacetylene welding process is not recommended for welding reactive metals such as titanium and zirconium because of its limited protection power.

SHIELDED METAL ARC WELDING

The Process

Shielded metal arc welding (SMAW) is a process that melts and joins metals by heating them with an arc established between a sticklike covered electrode and the metals, as shown in Figure 4. It is often called *stick welding*. The electrode holder is connected through a welding cable to one terminal of the power source and the workpiece is connected through a second cable to the other terminal of the power source (Figure 4*a*). The core of the covered electrode, the core wire, conducts the electric current to the arc and provides filler metal for the joint. For electrical contact, the top 1.5 cm of the core wire is bare and held by the electrode holder. The electrode holder is essentially a metal clamp with an electrically insulated outside shell for the welder to hold safely.

The heat of the arc causes both the core wire and the flux covering at the electrode tip to melt off as droplets (Figure 4*b*). The molten metal collects in the weld pool and solidifies into the weld metal.The lighter molten flux, on the other hand, floats on the pool surface and solidifies into a slag layer at the top of the weld metal.

Functions of Electrode Covering

The covering of the electrode contains various chemicals and even metal powder in order to perform one or more of the functions described below.

A. Protection It provides a gaseous shield to protect the molten metal from air. For a *cellulose*-type electrode, the covering contains cellulose, $(C_6H_{10}O_5)x$. A large volume of gas mixture of H_2, CO, H_2O, and CO_2 is produced when cellulose in the electrode covering is heated and decomposes. For a *limestone*-($CaCO_3$) type electrode, on the other hand, CO_2 gas and CaO slag form when the limestone decomposes. The limestone-type electrode is a *low-hydrogen* type electrode because it produces a gaseous shield low in hydrogen. It is often used for welding metals that are susceptible to hydrogen cracking, such as high-strength steels.

B. Deoxidation It provides deoxidizers and fluxing agents to deoxidize and cleanse the weld metal. The solid slag formed also protects the already solidified but still hot weld metal from oxidation.

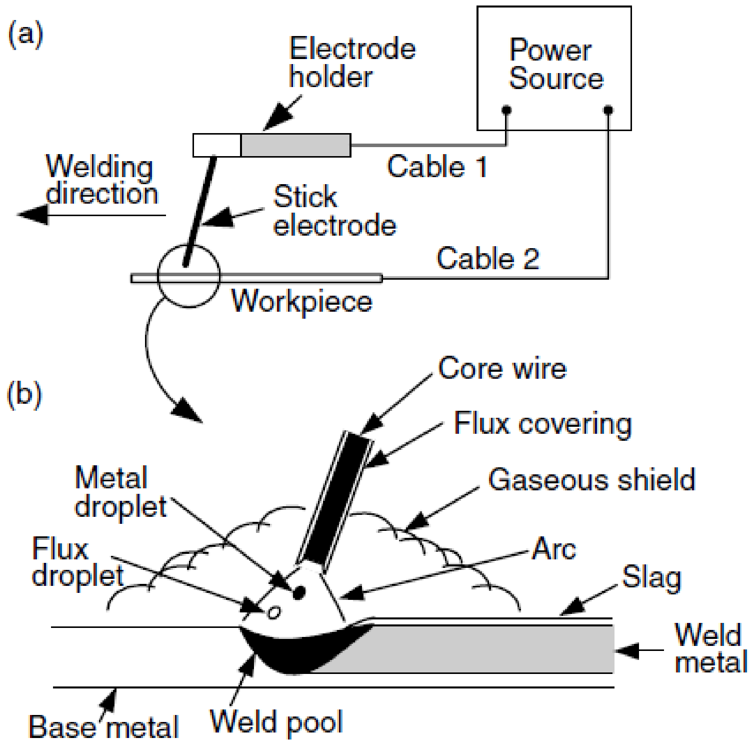

Figure 3.4 Shielded metal arc welding: (*a*) overall process; (*b*) welding area enlarged.

C. Arc Stabilization It provides arc stabilizers to help maintain a stable arc. The arc is an ionic gas (a plasma) that conducts the electric current. Arc stabilizers are compounds that decompose readily into ions in the arc, such as potassium oxalate and lithium carbonate. They increase the electrical conductivity of the arc and help the arc conduct the electric current more smoothly.

D. Metal Addition It provides alloying elements and/or metal powder to the weld pool. The former helps control the composition of the weld metal while the latter helps increase the deposition rate.

Advantages and Disadvantages of SMAW

The welding equipment is relatively simple, portable, and inexpensive as compared to other arc welding processes. For this reason, SMAW is often used for maintenance, repair, and field construction. However, the gas shield in SMAW is not clean enough for reactive metals such as aluminum and titanium. The deposition rate is limited by the fact that the electrode covering tends to overheat and fall off when excessively high welding currents are used. The limited length of the electrode (about 35 cm) requires electrode changing, and this further reduces the overall production rate.

GAS–TUNGSTEN ARC WELDING

The Process

Gas–tungsten arc welding (GTAW) is a process that melts and joins metals by heating them with an arc established between a nonconsumable tungsten electrode and the metals, as shown in Figure 5. The torch holding the tungsten electrode is connected to a shielding gas cylinder as well as one terminal of the power source, as shown in Figure 5*a*. The tungsten electrode is usually in contact with a water-cooled copper tube, called the contact tube, as shown in Figure 5*b*, which is connected to the welding cable (cable 1) from the terminal. This allows both the welding current from the power source to enter the electrode and the electrode to be cooled to prevent overheating. The workpiece is connected to the other terminal of the power source through a different cable (cable 2). The shielding gas goes through the torch body and is directed by a nozzle toward the weld pool to protect it from the air. Protection from the air is much better in GTAW than in SMAW because an inert gas such as argon or helium is usually used as the shielding gas and because the shielding gas is directed toward the weld pool. For this reason, GTAW is also called *tungsten–inert gas* (TIG) welding. However, in special occasions a noninert gas can be added in a small quantity to the shielding gas. Therefore, GTAW seems a more appropriate name for this welding process. When a filler rod is needed, for instance, for joining thicker materials, it can be fed either manually or automatically into the arc.

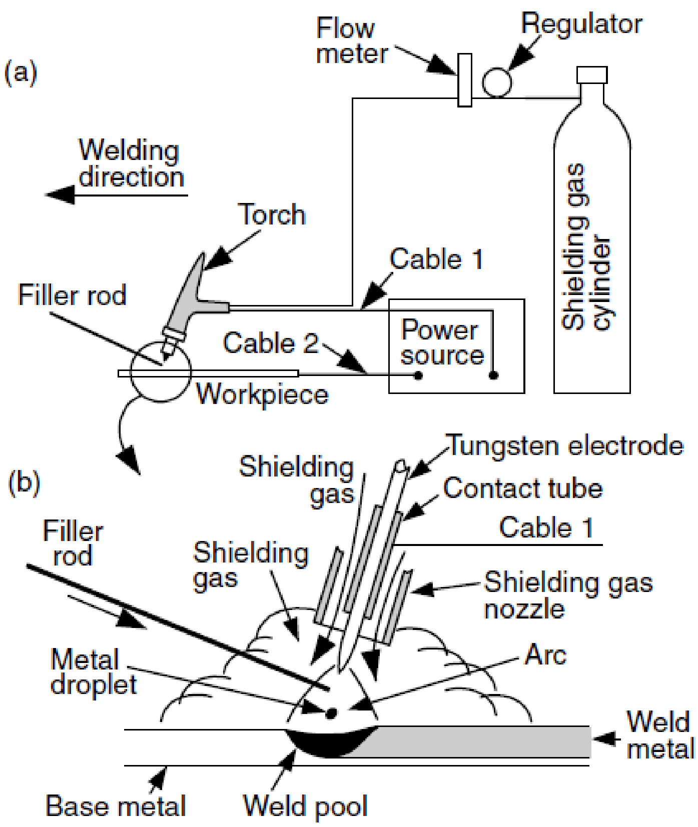

Figure 3.5. Gas–tungsten arc welding: (*a*) overall process; (*b*) welding area enlarged.

Polarity

Figure 6 shows three different polarities in GTAW, which are described next.

A. Direct-Current Electrode Negative (DCEN) This, also called the *straight polarity*, is the most common polarity in GTAW. The electrode is connected to the negative terminal of the power supply. As shown in Figure 6a, electrons are emitted from the tungsten electrode and accelerated while traveling through the arc. A significant amount of energy, called the work function, is required for an electron to be emitted from the electrode. When the electron enters the workpiece, an amount of energy equivalent to the work function is released. This is why in GTAW with DCEN more power (about two-thirds) is located at the work end of the arc and less (about one-third) at the electrode end. Consequently, a relatively narrow and deep weld is produced.

B. Direct-Current Electrode Positive (DCEP) This is also called the *reverse polarity*. The electrode is connected to the positive terminal of the power source. As shown in Figure 6b, the heating effect of electrons is now at the tungsten electrode rather than at the workpiece. Consequently, a shallow weld is produced. Furthermore, a large-diameter, water-cooled electrodes must be used in order to prevent the electrode tip from melting. The positive ions of the shielding gas bombard the workpiece, as shown in Figure 7, knocking off oxide films and producing a clean weld surface. Therefore, DCEP can be used for welding thin sheets of strong oxide-forming materials such as aluminium and magnesium, where deep penetration is not required.

C. Alternating Current (AC) Reasonably good penetration and oxide cleaning action can both be obtained, as illustrated in Figure 6c. This is often used for welding aluminum alloys.

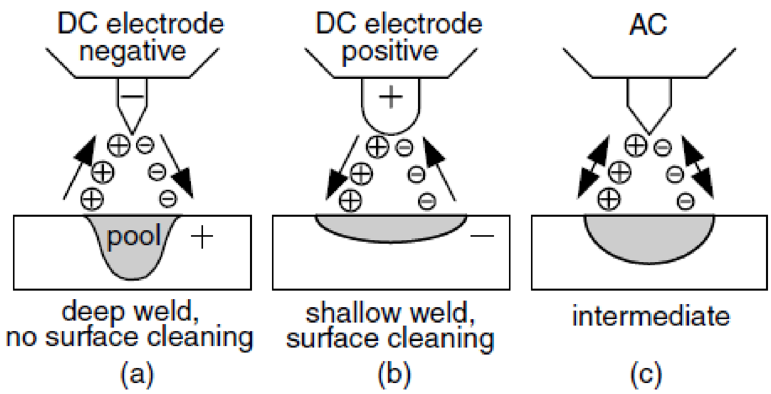

Figure 3.6 Three different polarities in GTAW.

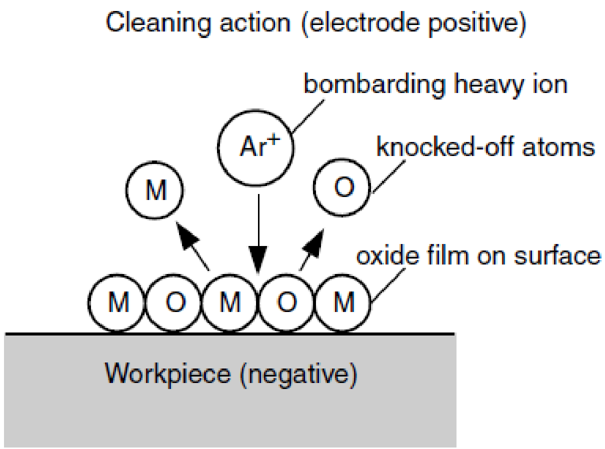

Figure 3.7 Surface cleaning action in GTAW with DC electrode positive

Electrodes

Tungsten electrodes with 2% cerium or thorium have better electron emissivity, current-carrying capacity, and resistance to contamination than pure tungsten electrodes (3). As a result, arc starting is easier and the arc is more stable. The electron emissivity refers to the ability of the electrode tip to emit electrons. A lower electron emissivity implies a higher electrode tip temperature required to emit electrons and hence a greater risk of melting the tip.

Shielding Gases

Both argon and helium can be used. Table 1 lists the properties of some shielding gases (6). As shown, the *ionization potentials* for argon and helium are 15.7 and 24.5 eV (electron volts), respectively. Since it is easier to ionize argon than helium, arc initiation is easier and the voltage drop across the arc is lower with argon. Also, since argon is heavier than helium, it offers more effective shielding and greater resistance to cross draft than helium. With DCEP or AC, argon also has a greater oxide cleaning action than helium. These advantages plus the lower cost of argon make it more attractive for GTAW than helium.

Because of the greater voltage drop across a helium arc than an argon arc, however, higher power inputs and greater sensitivity to variations in the arc length can be obtained with helium. The former allows the welding of thicker sections and the use of higher welding speeds. The latter, on the other hand, allows a better control of the arc length during automatic GTAW.

Advantages and Disadvantages

Gas–tungsten arc welding is suitable for joining thin sections because of its limited heat inputs. The feeding rate of the filler metal is somewhat independent of the welding current, thus allowing a variation in the relative amount of the fusion of the base metal and the fusion of the filler metal. Therefore, the control of dilution and energy input to the weld can be achieved without changing the size of the weld. It can also be used to weld butt joints of thin sheets by fusion alone, that is, without the addition of filler metals or *autogenous* welding. Since the GTAW process is a very clean welding process, it can be used to weld reactive metals, such as titanium and zirconium, aluminum, and magnesium.

However, the deposition rate in GTAW is low. Excessive welding currents can cause melting of the tungsten electrode and results in brittle tungsten inclusions in the weld metal. However, by using preheated filler metals, the deposition rate can be improved.

TABLE 3.1 Properties of Shielding Gases Used for Welding

Gas	Chemical Symbol	Molecular Weight (g/mol)	Specific Gravity with Respect to Air at 1 atm and 0°C	Density (g/L)	Ionization Potential (eV)
Argon	Ar	39.95	1.38	1.784	15.7
Carbon dioxide	CO_2	44.01	1.53	1.978	14.4
Helium	He	4.00	0.1368	0.178	24.5
Hydrogen	H_2	2.016	0.0695	0.090	13.5
Nitrogen	N_2	28.01	0.967	1.25	14.5
Oxygen	O_2	32.00	1.105	1.43	13.2

GAS–METAL ARC WELDING

The Process

Gas–metal arc welding (GMAW) is a process that melts and joins metals by heating them with an arc established between a continuously fed filler wire electrode and the metals, as shown in Figure 8. Shielding of the arc and the molten weld pool is often obtained by using inert gases such as argon and helium, and this is why GMAW is also called the *metal–inert gas* (MIG) welding process. Since noninert gases, particularly CO2, are also used, GMAW seems a more appropriate name. This is the most widely used arc welding process for aluminum alloys.

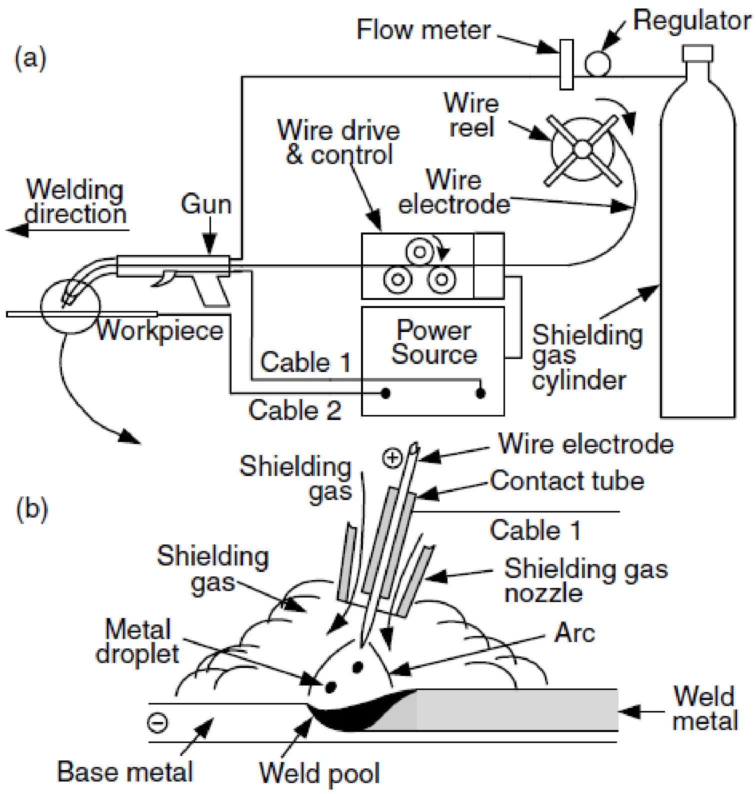

Figure 3.8 Gas–metal arc welding: (*a*) overall process; (*b*) welding area enlarged.

Modes of metal transfer: Modes of metal transfer significantly affect the depth of penetration, stability of weld pool and amount of spatter loss. Various forces cause the transfer of metal into the weld pool. The mode of transfer depends on the intersection of these forces and governs the ability of welding in different positions. The major forces which take part in this process are those due to (i) gravity, (ii) surface tension, (iii) electromagnetic interaction

1. Metal transfer under the influence of gravity: The force due to gravity may be retaining or detaching force, depending on whether the electrode is pointing upward or downward.
2. Metal droplet under the action of surface tension: Surface tension always tends to retain the liquid drop at the tip of the electrode. This force depends on the radius of the electrode and the density of the liquid metal.
3. Metal transfer under the action of electromagnetic force: The electromagnetic force, known as Lorenz force, is setup due to the interaction of the electric current with its own magnetic field. This force acts in the direction of the current when the cross section

of the conductor is increasing in the direction of the current. Similarly, the force acts in the direction opposite to that of the current if the cross section of the conductor is reducing in the direction of current. The hydrostatic pressure is created due to the magnetic force. As a result, the liquid drop is projected along the line of the electrode, independent of gravity.

All these forces interact in a complicated manner and give rise to two broad classes of metal transfer.

1. Free flight transfer. (a) Globular, (b) spray transfer.
2. Short circuit transfer.

(A). Globular transfer: Discrete metal drop close to or larger then electrode diameter travel across the arc gap under the influence of gravity. Globular transfer often is not smooth and produce spatter at relatively low welding current. G T occurs regardless of the type of shielding gases.

(b). Spray Transfer: Above a critical current level small discrete metal drops travel across the arc gap under the action of electromagnetic force at much higher frequency and speed than in globular mode. Metal transfer is much more stable and spatter free.

(c) Short circuit transfer: In Short circuit transfer the liquid drop at the tip of the electrode gets in contact with the weld pool before being detached from the electrode. Thus, the arc is momentarily short circuited. However, due to the surface tension and the electromagnetic force, the drop is pulled into the weld pool and the contact with the electrode is broken. Short-circuiting transfer encompasses the lowest range of welding currents and electrode diameters. It produces a small and fast freezing weld pool that is desirable for welding thin sections and overhead position welding.

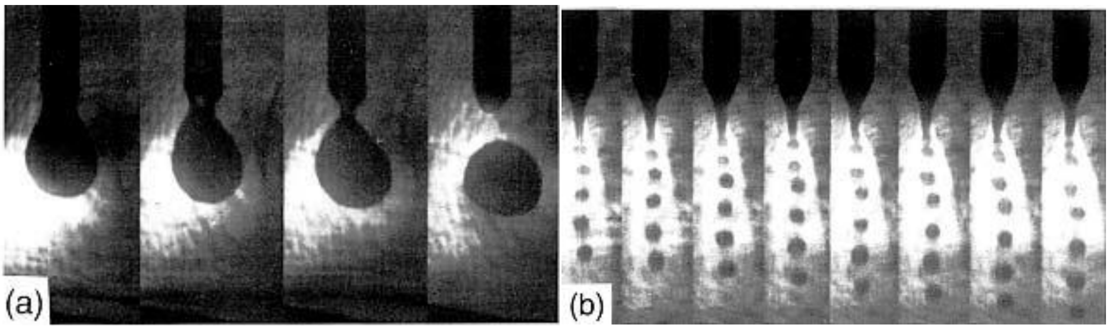

Figure 3.9: Modes of metal transfer (a) Globular (b) Spray

Advantages and Disadvantages

Like GTAW, GMAW can be very clean when using an inert shielding gas. The main advantage of GMAW over GTAW is the much higher deposition rate, which allows thicker workpieces to be welded at higher welding speeds. The dual-torch and twin-wire processes further increase the deposition rate of GMAW (12). The skill to maintain a very short and yet stable arc in GTAW is not required. However, GMAW guns can be bulky and difficult-to-reach small areas or corners.

SUBMERGED ARC WELDING

The Process

Submerged arc welding (SAW) is a process that melts and joins metals by heating them with an arc established between a consumable wire electrode and the metals, with the arc being shielded by a molten slag and granular flux, as shown in Figure 10. This process differs from the arc welding processes discussed so far in that the arc is submerged and thus invisible.The flux is supplied from a hopper (Figure 10*a*), which travels with the torch. No shielding gas is needed because the molten metal is separated from the air by the molten slag and granular flux (Figure 10*b*). Direct-current electrode positive is most often used. However, at very high welding currents (e.g., above 900A) AC is preferred in order to minimize arc blow. Arc blow is caused by the electromagnetic (Lorentz) force as a result of the interaction between the electric current itself and the magnetic field it induces.

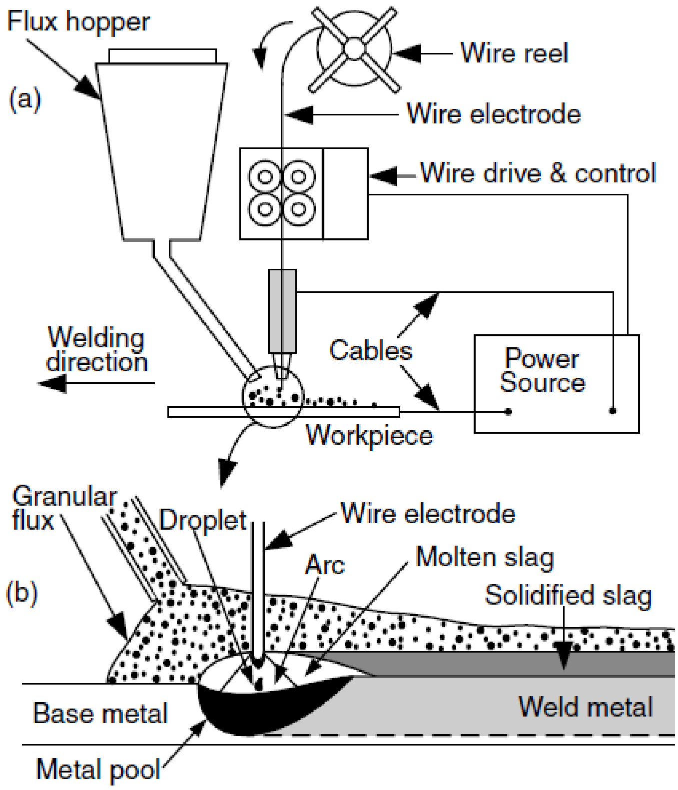

Figure 3.10 Submerged arc welding: (*a*) overall process; (*b*) welding area enlarged.

Advantages and Disadvantages

The protecting and refining action of the slag helps produce clean welds in SAW. Since the arc is submerged, spatter and heat losses to the surrounding air are eliminated even at high welding currents. Both alloying elements and metal powders can be added to the granular flux to control the weld metal composition and increase the deposition rate, respectively. Using two or more electrodes in tandem further increases the deposition rate. Because of its high deposition rate, workpieces much thicker than that in GTAW and GMAW can be welded by SAW. However, the relatively large volumes of molten slag and metal pool often limit SAW to flat-position welding and circumferential welding (of pipes). The relatively high heat input can reduce the weld quality and increase distortions.

LASER BEAM WELDING

The Process

Laser beam welding (LBW) is a process that melts and joins metals by heating them with a laser beam. The laser beam can be produced either by a solid- state laser or a gas laser. In either case, the laser beam can be focused and directed by optical means to achieve high power densities. In a solid-state laser, a single crystal is doped with small concentrations of transition elements or rare earth elements. For instance, in a *YAG laser* the crystal of yttrium– aluminum–garnet (YAG) is doped with neodymium. The electrons of the dopant element can be selectively excited to higher energy levels upon exposure to high-intensity flash lamps, as shown in Figure 11*a*.

Lasing occurs when these excited electrons return to their normal energy state, as shown in Figure 11*b*.The power level of solid-state lasers has improved significantly, and continuous YAG lasers of 3 or even 5 kW have been developed. In a *CO2 laser*, a gas mixture of CO2, N2, and He is continuously excited by electrodes connected to the power supply and lases continuously. Higher power can be achieved by a CO2 laser than a solid-state laser, for instance, 15kW. Figure 12*a* shows LBW in the keyholing mode. Figure 12*b* shows a weld in a 13-mm-thick A633 steel made with a 15-kW CO2 laser at 20mm/s (18). Besides solid-state and gas lasers, semiconductor-based *diode lasers* have also been developed. Diode lasers of 2.5kW power and 1mm focus diameter have been demonstrated (19). While keyholing is not yet possible, conduction mode (surface melting) welding has produced full-penetration welds with a depth–width ratio of 3 : 1 or better in 3-mm-thick sheets.

Reflectivity

The very high reflectivity of a laser beam by the metal surface is a well-known problem in LBW. As much as about 95% of the CO2 beam power can be reflected by a polished metal surface. Reflectivity is slightly lower with a YAG laser beam. Surface modifications such as roughening, oxidizing, and coating can reduce reflectivity significantly (20). Once keyholing is established, absorption is high because the beam is trapped inside the hole by internal reflection.

Advantages and Disadvantages

Like EBW, LBW can produce deep and narrow welds at high welding speeds, with a narrow heat-affected zone and little distortion of the workpiece. It can be used for welding dissimilar metals or parts varying greatly in mass and size. Unlike EBW, however, vacuum and x-ray shielding are not required in LBW. However, the very high reflectivity of a laser beam by the metal surface is a major drawback, as already mentioned. Like EBW, the equipment cost is very high, and precise joint fit-up and alignment are required.

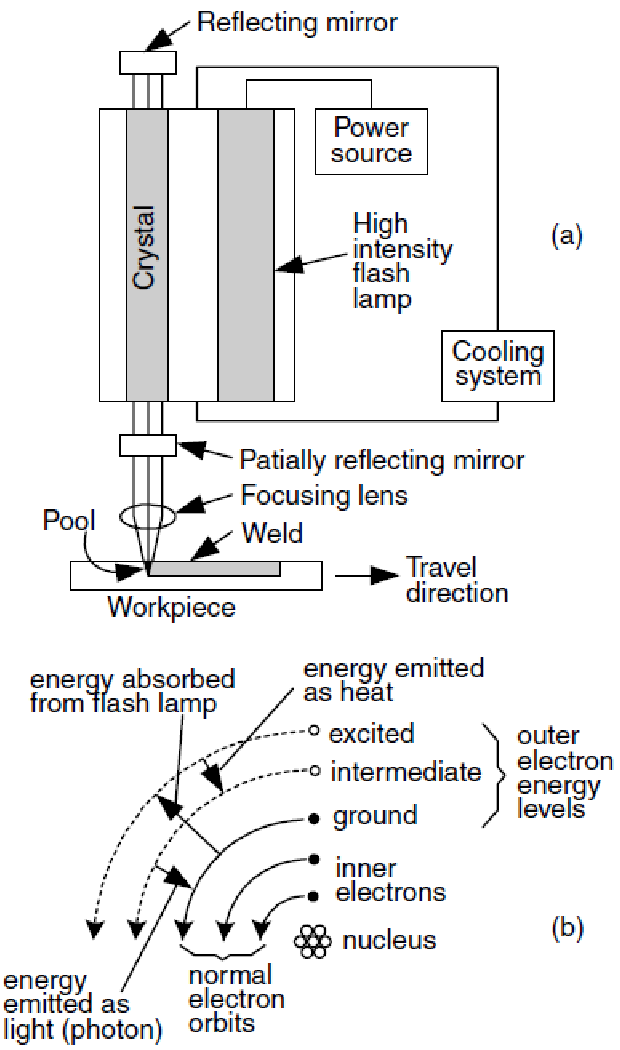

Figure 3.11 Laser beam welding with solid-state laser: (*a*) process; (*b*) energy absorption and emission during laser action.

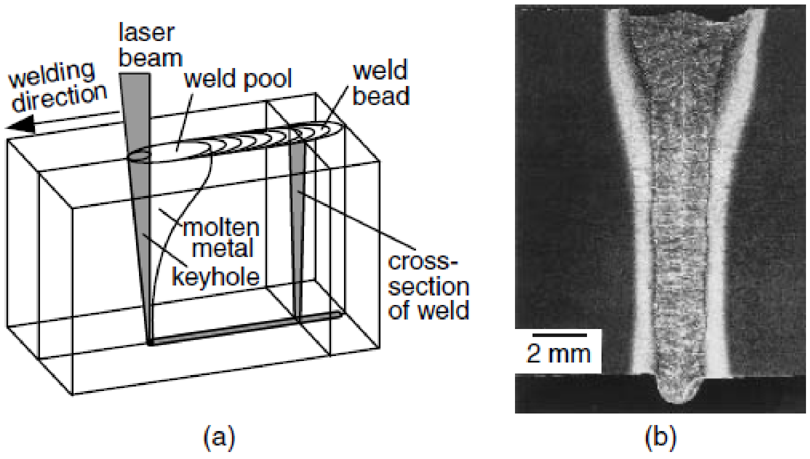

Figure 3.12 Laser beam welding with CO2 laser: (*a*) process; (*b*) weld in 13-mm-thick A633 steel.

ELECTRIC RESISTANCE WELDING

The electric resistance welding is commonly used. It can be applied to any metals. Electric current passes through the materials being joined. The resistance offered to the flow of current results in raising the temperature of the two metal pieces to melting point at their junction. Mechanical pressure is applied at this moment to complete the weld. Two copper electrodes of low resistance are used in a circuit.

The mechanical pressure or force required after the surfaces are heated to a plastic temperature is approximately 0.3 N/m2 at the welded surface.

This method of welding is widely used in modern practice for making welded joints in sheet metal parts, bars and tubes etc.

Parameter Affecting Resistance Welding

Successful application of Resistance welding process depends upon correct application and proper control of the following factors.

1. Current: Enough current is needed to bring the metal to its plastic state of welding.

2. Pressure: Mechanical pressure is applied first to hold the metal pieces tightly between the electrodes, while the current flows through them called **weld pressure**, and secondly when the metal has been heated to its plastic state, to forge the metal pieces together to form the weld, called **forge pressure**.

3. Time of Application: It is the cyclic time and the sum total of the following time period allowed during different stages of welding

a. Weld Time Time period during which the welding current flow through the metal pieces to raise their temp.

b. Forge Time Time period during which the forge pressure is applied to the metal pieces.

c. Hold Time Time period during which the weld to be solidify.

d. Off Time The period of time from the release of the electrodes to the start of the next weld cycle.

4. Electrode contact area: The weld size depends on the contact area of the face of the Electrodes

TYPES OF RESISTANCE WELDING

1. Spot welding 2. Seam welding, 3. Projection welding

Spot Welding

Spot welding is used to lap weld joints in thin metallic plates (up to 12.7 mm thick) for mechanical
strength and not for tightness.

The metallic plates are overlapped and held between two copper electrodes. A high current, depending upon plate thickness, at a very low volt-age (4-12 volts), is passed between the electrodes. The contact resistance of the plates causes to heat rapidly to a plastic state. Mechanical pressure is applied. Supply is cut-off for the metal to regain strength. The pressure is released. The process is repeated at another portion of the plates.

Thus, spot joints at regular interval depending upon the strength required are obtained. The electrodes are water cooled to avoid overheating and softening of the tips. Spot welding is mainly used in the manufacture of automobile parts refrigerators, metallic toys, racks, frames, boxes, radio chassis, etc.

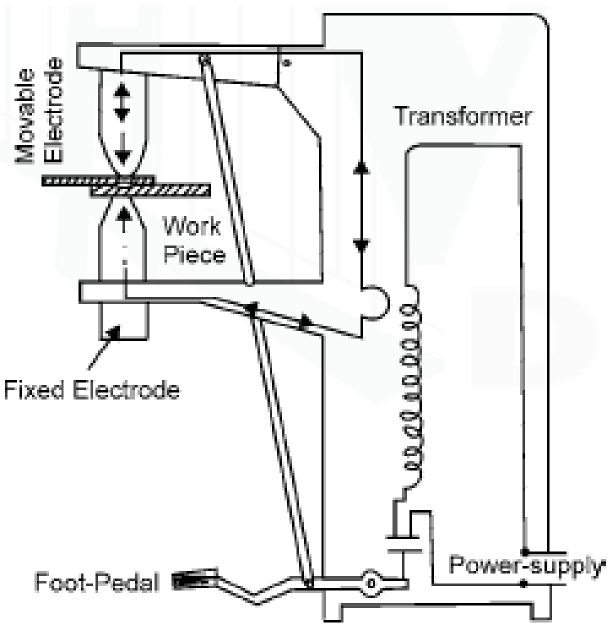

Figure 3.13 (a) Spot Welding

<u>Seam Welding</u>

The metallic plates are held by two copper roller electrodes with one roller driven by motor so that the plates are moved between the rollers at a suitable speed. The high current is passed between the electrodes holding metallic plates pressed together with suitable force and pushes together to travel between the revolving electrodes as showing in Fig. 7.29. The plates between the electrodes get heated to welding (fusion) heat and welded continuously under constant pressure of rotating electrodes. This is a quicker operation than spot welding and gives a stronger joint. The process is employed for pressure tight joints on oil drums, tanks and boiler water pipes, refrigeration parts, motorcar body, utensils, stoves, etc

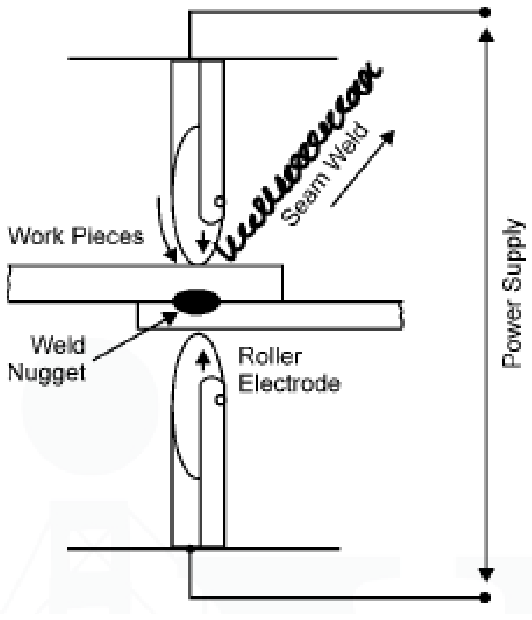

Figure 3.13 (b): Seam welding

<u>Projection Welding</u>

There are raised projections in the workpiece at all points where a weld is desired as shown in Fig. 13 (c). As the current is switched on the projection are melted and the workpieces pressed together to complete the weld. The melted projections form the welds. This method enables production of several spot welds simultaneously.

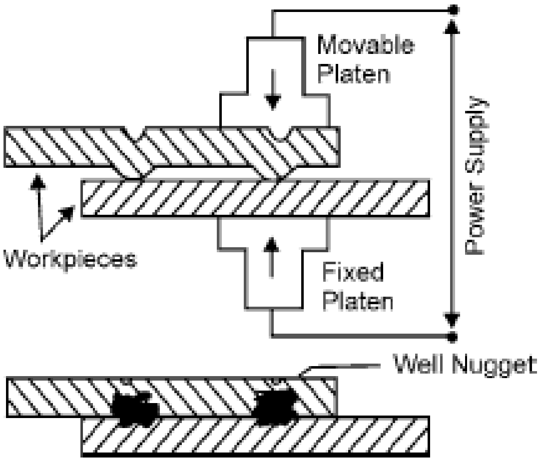

Figure 3.13 (c): Projection welding

<u>ULTRASONIC WELDING</u>

The basic principle of ultrasonic welding is diagrammatically shown in Figure 3.14. It can be seen that the core of ultrasonic vibrations generator is connected to the work through a horn having a suitable shape welding tip to which moderate pressure is applied from the top. The combination of ultrasonic vibrations (15–60 kHz) and moderate pressure causes the formation of a spot weld or a seam weld (with modified apparatus). The deformation caused is less than 5 per cent.

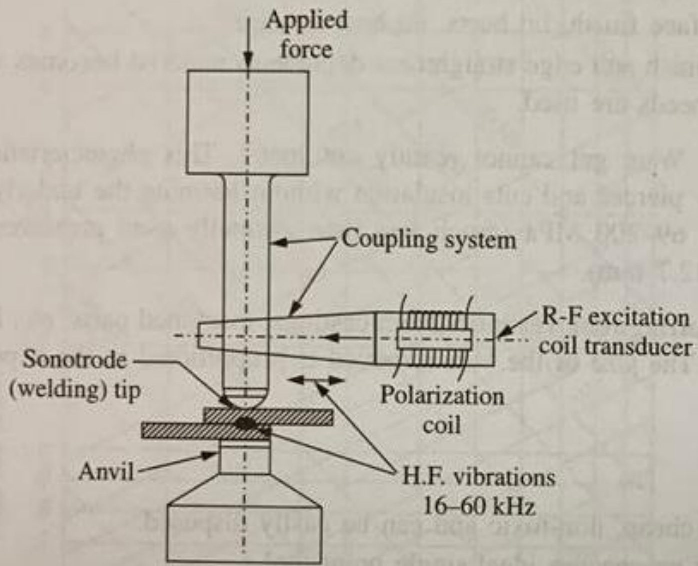

Figure 3.14 Ultrasonic welding equipments.

Interface surfaces move relative to each other. The resulting friction between the interface surfaces causes the removal of surface contaminants and oxide films exposing the clean metallic surfaces in contact with each other which weld together due to the applied pressure. Weld produced is as strong as the parent metal. Some local heating may occur and some grains may cross the interface but no melting or bulk heating occurs.

The process is briefly discussed in the following paragraphs.

It is a solid state joining process for joining similar (or dissimilar) metal in the form of thin strip or foils to produce (generally) lap joints. H.F. (16–60 kHz) vibratory energy gets into the weld area in a plane parallel to the weldment surface producing oscillating shear stress at the weld interface, breaking and expelling surface contaminant and oxides. This interfacial movement results into a metal-to-metal contact.

The machine is set before welding for a applied force, time and power input overlapping plates to be weld are put on the anvil, sonotrode tip is then lowered and clamping force built to the desired amount (a few newtons to several hundred newtons) and the ultrasonic power of adequate intensity is then introduced. Power varies from a few watts for foils to several thousand watts for heavy and hard materials and is applied through the sonotrod tip for a pre-set time.

Power is then automatically cut off and the weldment is released, time taken is less than 1 second. Ultrasonic welding of continuous seam can also be performed using disc type rotary sonotrode and plane anvil. Parameters of the machine are chosen to suit the material and thickness combination.

Applications and advantages of the process are as follows.

The process is excellent for joining foils and thin sheets (up to 3 mm thickness). Local plastic deformation and mechanical mixing result into sound welds. Continuous ring type weld can be made for hermetic sealing of containers. The process finds applications in electrical and electronic industries, sealing and packaging, aircraft, missiles, and in the fabrication of nuclear reactor components. The process can be used to join thin sheets and foils of ferrous metals, alluminium, copper, nickel, titanium, zirconium and their alloys, and a variety of dissimilar metal combinations.

Applications include almost all commonly used armatures, slotted commuters, starter motor armatures, joining of braded brush wires, brush plates, and a wide variety of wire terminals. With newly developed solid state frequency converters, more than 90% of the line power is delivered electrically as high frequency power to the transducer. In the case of ceramic transducer as much as 65–70% of the input electrical line power may be delivered to the weld metal as acoustical power.

Energy required to weld

To weld a given material the energy required increases with material hardness and thickness. This relation for spot welding is given by

$$E_a = 63\ H^{3/2}\ t^{1.5}$$

where E_a = acoustical energy in joules

H = Vickers micro hardness number

t = material thickness adjacent to active tip in inches

This equation is valid for aluminum, steel, and copper for thickness up to 0.81 mm.

Weld Defects

Welding is now finding applications in the fabrication of critical components where the failure may result into a catastrophy. Inspection methods and acceptance standards have now become very stringent. Acceptance standards specify the minimum weld quality and are based upon the test of welded specimens containing some degrees of discontinuities. A safety factor is usually added to establish the final acceptance standard.

The weld discontinuities commonly observed in the welds, their causes, remedies and their significance will now be discussed. Small imperfections, which cause some variation in the normal average properties of the weld-metal are called discontinuities. When the discontinuity becomes large enough to affect the functioning of the joint it is termed a *defect*.

In practice the standard codes do permit limited level of defects based on fracture mechanics principles, taking into consideration the service requirements of the product. With all this in place the fabricator must try to prevent the occurrence of weld defects and to rectify them if they do occur. There are a variety of defects. For our purpose we shall discuss the most important ones shown in Figure 3.15. These are undercuts, cracks, porosity, slag inclusions, lack of fusion and lack of penetration. These defects will now be discussed in a little detail.

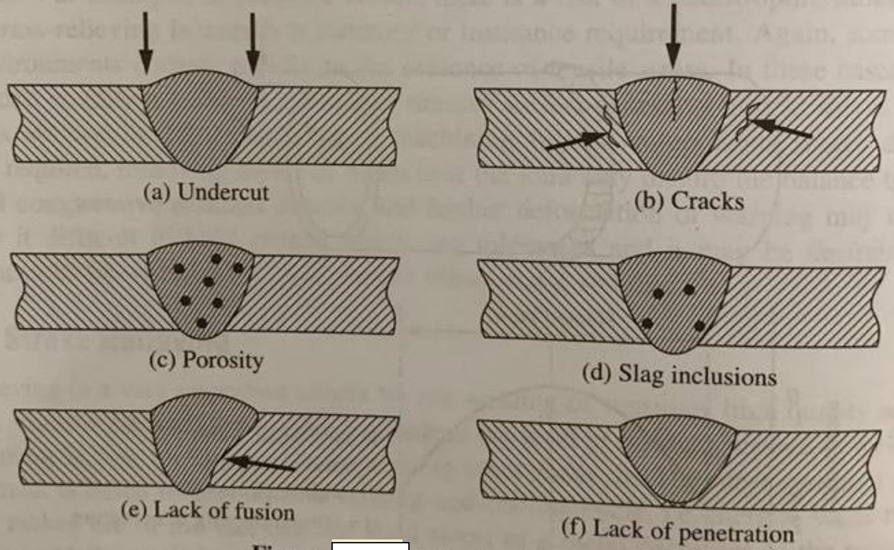

Figure 3.15 Typical weld defects.

Undercuts

An undercut is a groove melted into the base metal adjacent to the toe of a weld and left unfilled by the deposited weld-metal. It also describes the melting away of the sidewall of a welding groove at the edge of a bead. This melting away of the groove forms a sharp recess in the sidewall in the area in which the next layer or bead must fuse, (slag if not removed may become entrapped in the subsequent weld deposit). An undercut, therefore, is a groove that may vary in depth, with sharpness at its root and is as harmful as a crack.

Cracks

Cracks are defined as linear ruptures of metal-under stress. Although sometimes wide, they are often very narrow separations in the weld or adjacent base metal. Usually, little deformation is apparent. There are major classes of cracks which generally recognised: hot cracks, cold cracks, and macrofissures.

All types can occur in the weld or base metal. These are caused by (a) High [illegible] nal stresses, (b) Different amounts of contractions in different weld areas, (c) Embrittlement [illegible] the grain boundaries, and (d) Hydrogen embrittlement. Hot cracks occur while the metal is still hot and cold cracks occur after the weld metal gets solidified.

Figure 3.16 illustrates a variety of cracks including underbead cracks, toe cracks, crater cracks, longitudinal cracks, transverse cracks and microfissures. The underbead crack, limited mainly to steel, is a base metal crack which is usually associated with hydrogen. Toe cracks in steel can be similar in origin. In other metals (including stainless steel), cracks at the toe are often termed *edge of weld cracks*, attributable to hot cracking near the fusion line. Crater cracks are shrinkage cracks which result from stopping the arc suddenly. Cracks between the dendrites and cracks at the centreline where dendrites meet occur during solidification of aluminium alloys and stainless steels. These cracks can be eliminated by changing weld design, process parameters, welding procedure, sequence, preheat and avoiding rapid cooling.

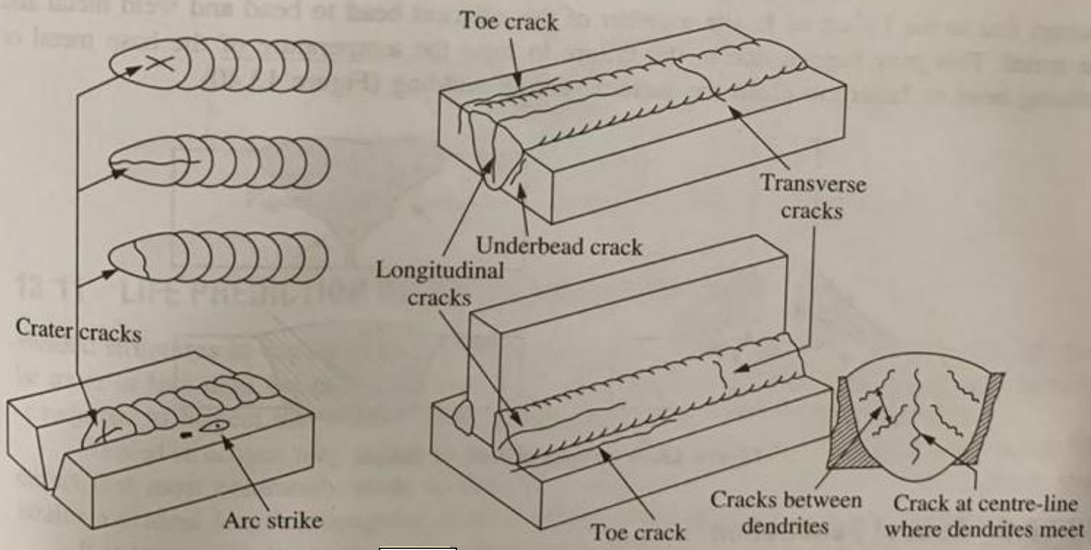

Figure 3.16 Types of cracks in welded joints.

Porosity

Porosity is the presence of a group of gas pores in a weld deposit. It is caused by the entrapment of gas during solidification (when solidification is too rapid). They are small spherical cavities, scattered or clustered locally. Sometimes, the entrapped gas may form a single large cavity which is termed a *blow hole*.

Causes

1. Deoxidisers are inadequate.
2. Sulphur content in base metal is high.
3. Surface contaminants like oil, grease, moisture or mill scale on the joint surface.
4. Moisture content in the flux is high.
5. Gas shielding is insufficient.
6. Long arc or low energy input to the weld.
7. Weld deposit solidification rate is rapid.

Slag Inclusion

During SMA welding using covered electrodes, slag forms on the top of the weld surface. If this is not cleaned properly, it may get entrapped in-between the bead and the subsequent bead or between the weld-bead and the base plate. The chances of slag inclusion are more in multilayered welding operations, if there is failure to remove the slag between passes. It can be prevented by proper groove preparation before each bead is deposited and correcting the contours that will be difficult to penetrate fully with successive passes.

Lack of Fusion

It occurs due to the failure of fusing together of the adjacent bead to bead and weld metal and base metal. This may happen due to the failure to raise the temperature of the base metal or adjoining bead or failure to clean the surfaces before welding (Figure 3.17).

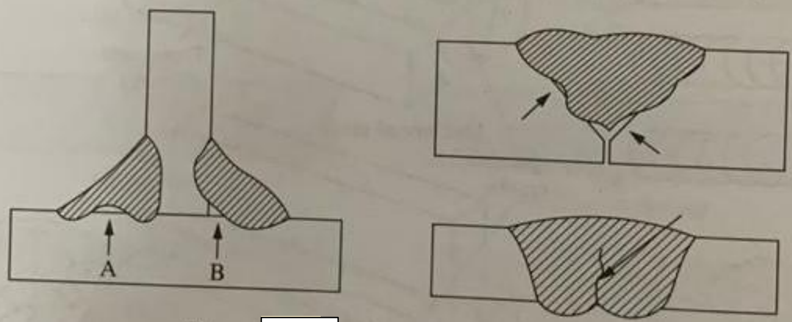

Figure 3.17 Types of lack of fusion.

Lack of Penetration

This defect, occurs when the weld metal deposited fails to reach the root of the joint or fails to fuse the root faces completely. It is caused by using incorrect welding electrode size with respect to the form of the joint, low welding current, inadequate joint design and fit-up. It usually occurs more often in vertical and overhead welding positions. It can be eliminated by: (a) raising base metal temperature, (b) cleaning prior to welding (c) increasing heat input, (d) lowering welding speed, and (e) changing the joint design.