(3) Oxyfuel Gas Welding

- Oxyfuel gas welding (OFW) is the term used to describe the group of fusion welding (FW) operations that burn various fuels mixed with oxygen to perform welding.
- The OFW processes employ several types of gases, which is the primary distinction among the members of this group.
- Oxyfuel gas is also commonly used in cutting torches to cut and separate metal plates and other parts.
- The most important OFW process is oxyacetylene welding.

(a) Oxyacetylene Welding

- Oxyacetylene welding (OAW) is a fusion-welding process performed by a high-temperature flame from combustion of acetylene and oxygen.
- The flame is directed by a welding torch.
- A filler metal is sometimes added, and pressure is occasionally applied in OAW between the contacting part surfaces.
- A typical OAW operation is sketched in Figure (5-27).

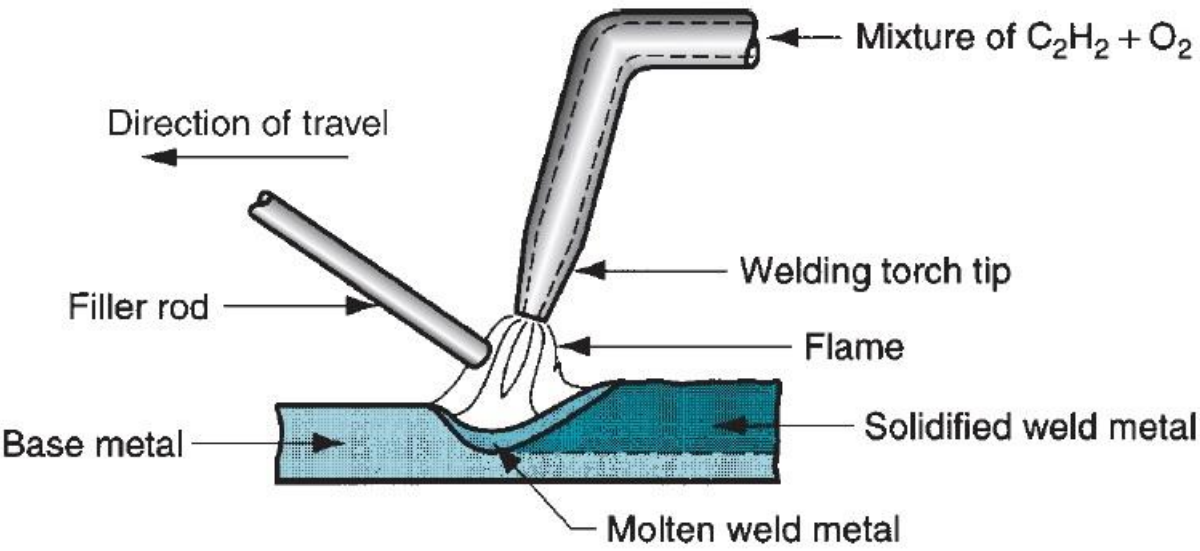

Figure (5-27) A typical oxyacetylene welding operation (OAW).

- When filler metal is used, it is typically in the form of a rod with diameters ranging from 1.6 to 9.5 mm.
- Composition of the filler must be similar to that of the base metals.

- The filler is often coated with a flux that helps to clean the surfaces and prevent oxidation, thus creating a better weld joint.
- Acetylene (C_2H_2) is the most popular fuel among the OFW group because it is capable of higher temperatures than any of the others - up to 3480 °C.
- The flame in OAW is produced by the chemical reaction of acetylene and oxygen in two stages.
- The first stage is defined by the reaction:

$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + heat$$

The products of which are both combustible, which leads to the second-stage reaction:

$$2CO + H_2 + 1.5O_2 \rightarrow 2CO_2 + H_2O + heat$$

- When the mixture of acetylene and oxygen is in the ratio 1:1, as described in above equations, the resulting neutral flame is shown in Figure (5-28).

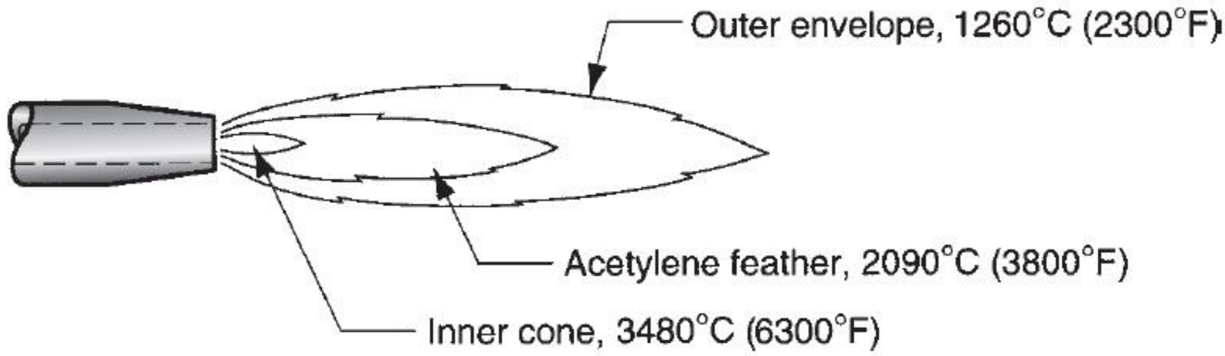

Figure (5-28) The neutral flame from an oxyacetylene torch, indicating temperatures achieved.

- The first-stage reaction is seen as the inner cone of the flame (which is bright white), while the second-stage reaction is exhibited by the outer envelope (which is nearly colorless but with tinges ranging from blue to orange).
- The maximum temperature of the flame is reached at the tip of the inner cone; the second-stage temperatures are somewhat below those of the inner cone.
- During welding, the outer envelope spreads out and covers the w.p. surfaces being joined, thus shielding them from the surrounding atmosphere.

Example (9):

An oxyacetylene torch supplies 0.3 m^3 of acetylene per hour and an equal volume rate of oxygen for an OAW operation on 4.5-mm-thick steel. Heat generated by combustion is transferred to the w.p. surface with a heat transfer factor $f_1 = 0.2$. If 75% of the heat from the flame is concentrated in a circular area on the w.p. surface that is 9 mm in diameter, find (a) rate of heat liberated during combustion, (b) rate of heat transferred to the w.p. surface, and (c) average power density in the circular area.

Solution:

(a) The rate of heat generated by the torch is the product of the volume rate of acetylene times the heat of combustion:

$$R_H = \left(0.3\frac{m^3}{hr}\right)\left(\frac{55(10^6)J}{m^3}\right) = \frac{16.5(10^6)J}{hr} = 4583 J/s$$ **Answer**

(b) With a heat transfer factor $f_1 = 0.2$, the rate of heat received at the work surface is: $f_1 R_H = 0.2(4583) = 917$ J/s **Answer**

(c) The area of the circle in which 75% of the heat of the flame is concentrated is

$$A = \left(\frac{\pi 9^2}{4}\right) = 63.6\, mm^2$$

The power density in the circle is found by dividing the available heat by the area of the circle:

$$PD = \left(\frac{0.75(917)}{63.6}\right) = 10.8\, W/mm^2$$ **Answer**

Characteristics of OAW:

- The combination of acetylene and oxygen is highly flammable, and the environment in which OAW is performed is therefore hazardous.
- OAW equipment is relatively inexpensive and portable.
- It is therefore an economical, versatile process that is well suited to low-quantity production and repair jobs.
- It is rarely used to weld sheet and plate stock thicker than 6.4 mm because of the advantages of arc welding in such applications.
- Although OAW can be mechanized, it is usually performed manually and is hence dependent on the skill of the welder to produce a high-quality weld joint.

(b) Alternative Gases for Oxyfuel Welding

- Several members of the OFW group are based on gases other than acetylene.
- Most of the alternative fuels are listed as follows:

Gases used in oxyfuel welding and/or cutting, with flame temperatures and heats of combustion.				
Fuel	**Temperature**		**Heat of Combustion**	
	°C	°F	MJ/m^3	Btu/ft^3
Acetylene (C_2H_2)	3087	5589	54.8	1470
MAPP (C_3H_4): methylacetylene-propadiene	2927	5301	91.7	2460
Hydrogen (H_2)	2660	4820	12.1	325
Propylenec (C_3H_6)	2900	5250	89.4	2400
Propane (C_3H_8)	2526	4579	93.1	2498
Natural gas	2538	4600	37.3	1000

- The fuel that competes most closely with acetylene in burning temperature and heating value is MAPP methylacetylene-propadiene.
- When hydrogen is burned with oxygen as the fuel, the process is called oxyhydrogen welding (OHW).
- Propane (C_3H_8) is more closely associated with brazing, soldering, and cutting operations than with welding.
- Natural gas consists mostly of ethane (C_2H_6) and methane (CH_4). When mixed with oxygen it achieves a high temperature flame and is becoming more common in small welding shops.

- ***Pressure Gas Welding PGW***: this is a special OFW process, distinguished by type of application rather than fuel gas.
- **PGW** is a fusion-welding process in which coalescence is obtained over the entire contact surfaces of the two w.ps. by heating them with an appropriate fuel mixture (usually oxyacetylene gas) and then applying pressure to bond the surfaces.
- A typical application is illustrated in Figure (5-29).
- W.ps. are heated until melting begins on the surfaces.
- The heating torch is then withdrawn, and the parts are pressed together and held at high pressure while solidification occurs. No filler metal is used in PGW.

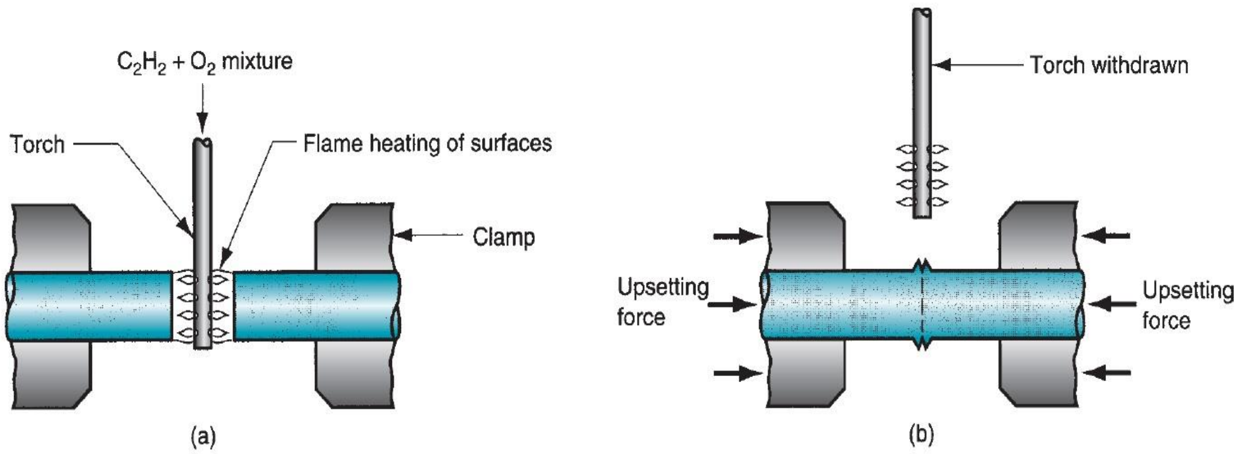

Figure (5-29) An application of pressure gas welding: (a) heating of the two parts, and (b) applying pressure to form the weld.

(4) Other Fusion Welding Processes

(a) Electron-Beam Welding (EBW):

- It is a fusion-welding process in which the heat for welding is produced by a highly focused, high-intensity stream of electrons impinging against the w.p. surface.
- The equipment is similar to that used for electron-beam machining.
- The electron beam gun operates at high voltage to accelerate the electrons (e.g., 10–150 kV typical), and beam currents are low (measured in milliamps).
- The power in EBW is not exceptional, but power density is.
- High power density is achieved by focusing the electron beam on a very small area of the w.p. surface, so that the power density PD is based on:

$$PD = \frac{f_1 EI}{A}$$

PD: power density, W/mm^2 (W/in^2, which can be converted to Btu/sec-in^2 by dividing by 1055);
f_1: heat transfer factor (typical values for EBW range from 0.8–0.95);
E: accelerating voltage, V;
I: beam current, A;
A: the work surface area on which the electron beam is focused, mm^2.
Typical weld areas for EBW range from 13x10^{-3} to 2000x10^{-3} mm^2.

- Previously, this process had to be carried out in a vacuum chamber to minimize the disruption of the electron beam by air molecules.
- This requirement was, and still is, a serious inconvenience in production, due to the time - pump-down time nearly take one hour- required to evacuate the chamber prior to welding.
- Today, EBW technology has progressed to where some operations are performed without a vacuum. Three categories can be distinguished:
  (1) high-vacuum welding (EBW-HV), in which welding is carried out in the same vacuum as beam generation;
  (2) medium-vacuum welding (EBW-MV), in which the operation is performed in a separate chamber where only a partial vacuum is achieved;
  (3) nonvacuum welding (EBW-NV), in which welding is accomplished at or near atmospheric pressure.

- In the latter two operations, the equipment must include one or more vacuum dividers (very small orifices that impede air flow but permit passage of the electron beam) to separate the beam generator (which requires a high vacuum) from the work chamber.
- Also, in nonvacuum EBW, the w.p. must be located close to the orifice of the electron beam gun, approximately 13 mm or less.
- Finally, the lower vacuum processes cannot achieve the high weld qualities and depth-to-width ratios accomplished by EBW-HV.

- **Advantages of EBW**

(1) Any metals that can be arc welded can be welded by EBW, as well as certain refractory and difficult-to-weld metals that are not suited to AW.
(2) W.P. sizes range from thin foil to thick plate.
(3) EBW is applied mostly in the automotive, aerospace, and nuclear industries.
(4) In the automotive industry, EBW assembly includes aluminum manifolds, steel torque converters, catalytic converters, and transmission components.
(5) Mostly, electron-beam welding is noted for high-quality welds with deep and/or narrow profiles, limited heat-affected zone, and low thermal distortion.
(6) Welding speeds are high compared to other continuous welding operations.
(7) No filler metal is used, and no flux or shielding gases are needed.

- **Disadvantages of EBW**

(1) high equipment cost, need for precise joint preparation and alignment.
(2) Limitations associated with performing the process in a vacuum.
(3) There are safety concerns because EBW generates X-rays from which humans must be shielded.

(b) Laser-Beam Welding (LBM):

- It is a fusion-welding process in which coalescence is achieved by the energy of a highly concentrated, coherent light beam focused on the joint to be welded.
- This same technology is used for laser-beam machining.
- LBW is normally performed with shielding gases (e.g., helium, argon, nitrogen, and carbon dioxide) to prevent oxidation.
- Filler metal is not usually added.

- **Advantages of EBW**

(1) LBW produces welds of high quality, deep penetration, and narrow heat-affected zone.
(2) These features are similar to those in EBW.
(3) No vacuum chamber is required than EBW.
(4) No X-rays are emitted than EBW.
(5) Laser beams can be focused and directed by optical lenses and mirrors than EBW.

- **Disadvantages of EBW**

(1) LBW does not possess the capability for the deep welds and high depth-to-width ratios than EBW.
(2) Maximum depth in LBW is about 19 mm, whereas in EBW can be used for weld depths of 50 mm or more.
(3) The depth-to-width ratios in LBW are typically limited to around 5:1.
(4) Because of the highly concentrated energy in the small area of the laser beam, the process is often used to join small parts.

(c) Electroslag Welding (ESW)

- This process uses the same basic equipment as in some arc-welding operations, and it utilizes an arc to initiate welding.
- However, it is not an AW process because an arc is not used during welding.
- **ESW** is a fusion-welding process in which coalescence is achieved by hot, electrically conductive molten slag acting on the base parts and filler metal.
- ESW is shown in Figure (5-30), the general configuration of ESW is similar to electro gas welding.
- It is performed in a vertical orientation (shown here for butt welding), using water-cooled molding shoes to contain the molten slag and weld metal.
- At the start of the process, granulated conductive flux is put into the cavity.
- The consumable electrode tip is positioned near the bottom of the cavity, and an arc is generated for a short while to start melting the flux.

- Once a pool of slag has been created, the arc is extinguished and the current passes from the electrode to the base metal through the conductive slag, so that its electrical resistance generates heat to maintain the welding process.
- Since the density of the slag is less than that of the molten metal, it remains on top to protect the weld pool.
- Solidification occurs from the bottom, while additional molten metal is supplied from above by the electrode and the edges of the base parts.
- The process gradually continues until it reaches the top of the joint.

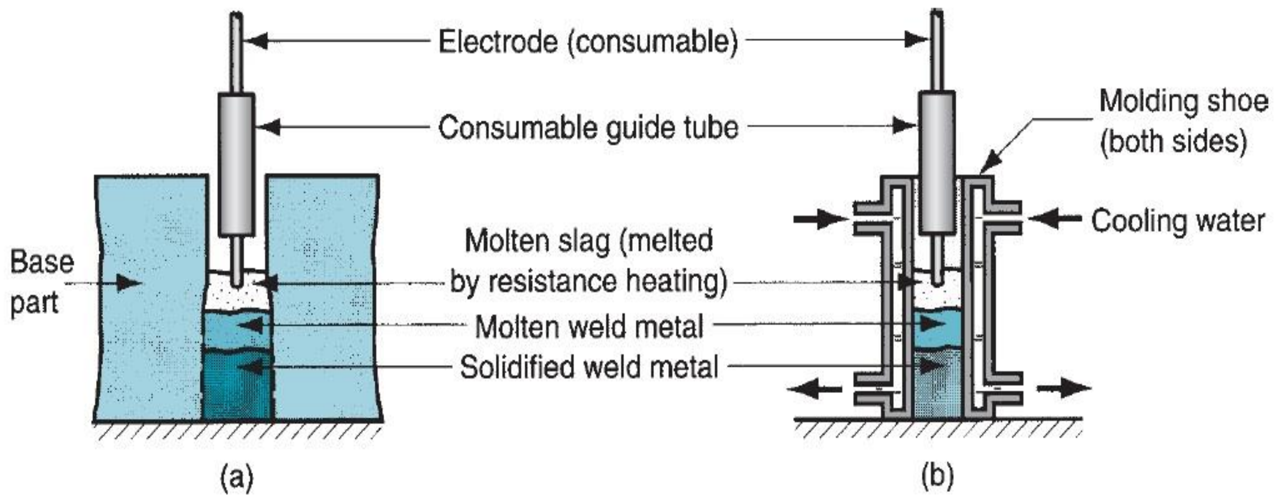

Figure (5-30) Electroslag welding (ESW): (a) front view with molding shoe removed for clarity; (b) side view showing schematic of molding shoe. Setup is similar to electrogas welding Figure (5-13) except that resistance heating of moltenslag is used to melt the base and filler metals.

(d)Thermit Welding (TW)

- Thermit is a trademark name for thermite, a mixture of aluminum powder and iron oxide that produces an exothermic reaction when ignited.
- It is used in incendiary bombs and for welding.
- As a welding process, the use of Thermit dates from around 1900.
- Thermit welding (TW) is a fusion-welding process in which the heat for coalescence is produced by superheated molten metal from the chemical reaction of Thermit.
- Filler metal is obtained from the liquid metal; and although the process is used for joining, it has more in common with casting than it does with welding.
- Finely mixed powders of aluminum and iron oxide (in a 1:3 mixture), when ignited at a temperature of around 1300^{o} C, produce the following chemical reaction:

$$8Al + 3Fe_3O_4 \rightarrow 9Fe + 4Al_2O_3 + heat$$

- The temperature from the reaction is around 2500 ° C, resulting in superheated molten iron plus aluminum oxide that floats to the top as a slag and protects the iron from the atmosphere.
- In Thermit welding, the superheated iron (or steel if the mixture of powders is formulated accordingly) is contained in a crucible located above the joint to be welded, as indicated in Figure (5-31).
- After the reaction is complete (about 30 s, irrespective of the amount of Thermit involved), the crucible is tapped and the liquid metal flows into a mold built specially to surround the weld joint.
- Because the entering metal is so hot, it melts the edges of the base parts, causing coalescence upon solidification.
- After cooling, the mold is broken away, and the gates and risers are removed by oxyacetylene torch or other method.
- The surface of the weld in these applications is often sufficiently smooth so that no subsequent finishing is required.

- **Thermit Welding Applications**
  (1) In joining of railroad rails (as pictured in our figure),
  (2) Repair of cracks in large steel castings and forgings such as ingot molds, large diameter shafts, frames for machinery, and ship rudders.

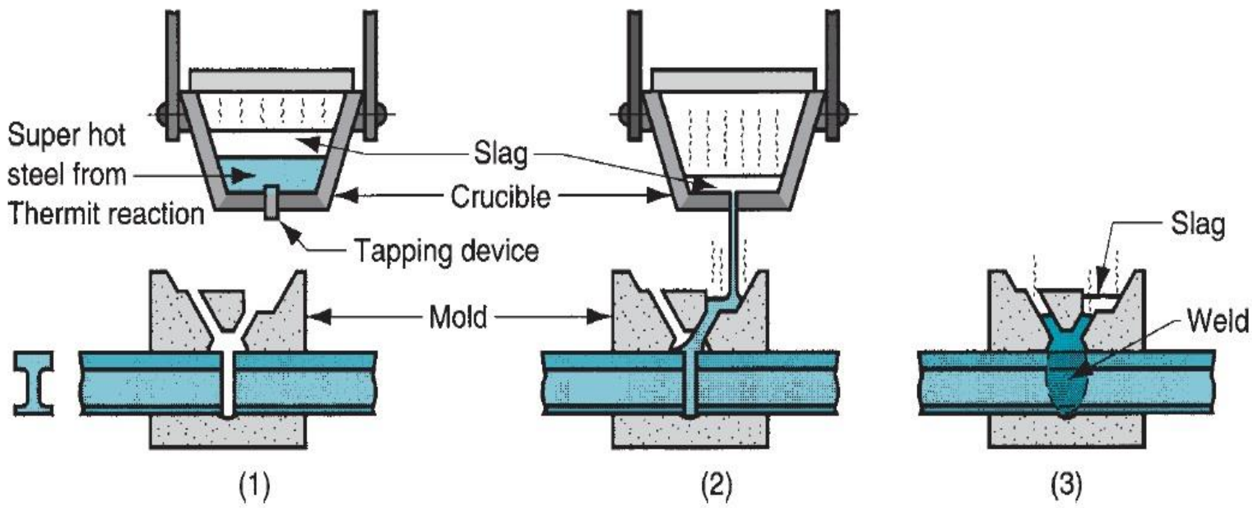

Figure (5-31) Thermit welding: (1) Thermit ignited; (2) crucible tapped, superheated metal flows into mold; (3) metal solidifies to produce weld joint.