IPE-1101
Manufacturing Process-I

Metal Joining Processes

Motorcycles, computers, washing machines, power tools, air-planes, and how their numerous components are assembled and joined so that they can function reliably. A typical automobile has 15,000 components, a few of which are shown in the following figures; all of them must be assembled, using several joining methods. A Boeing 747-400 aircraft has more than 6 million parts.

Metal Joining Processes

Joining is an all-inclusive term, covering processes such as welding, brazing, soldering, adhesive bonding, and mechanical fastening. These processes are important for the following reasons:

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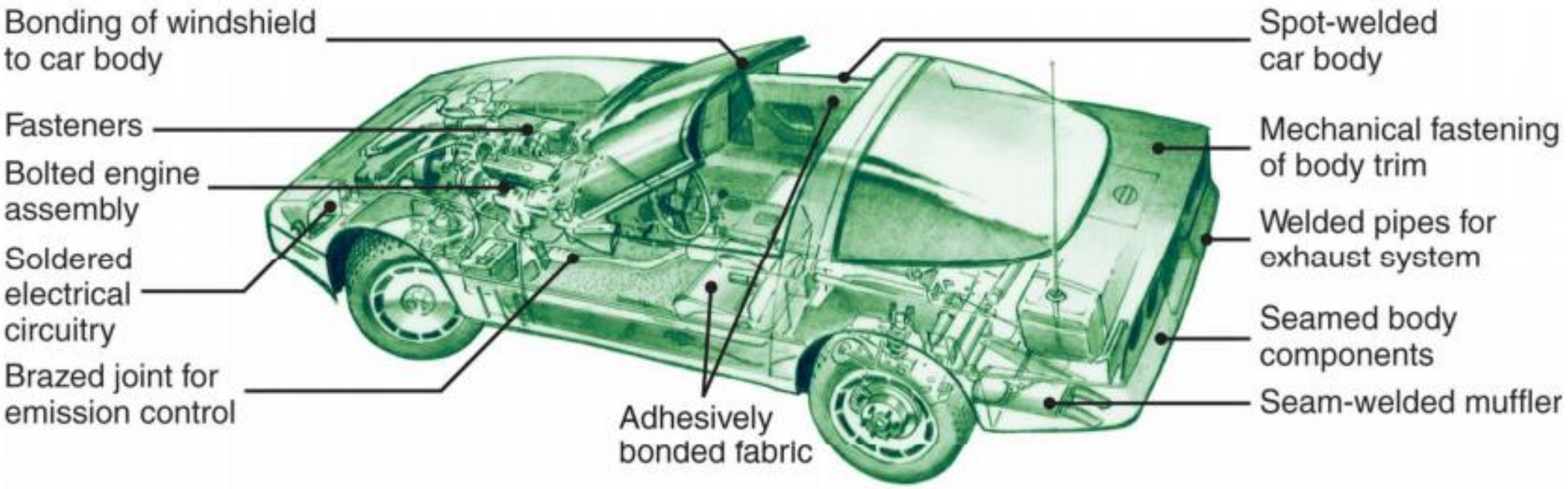


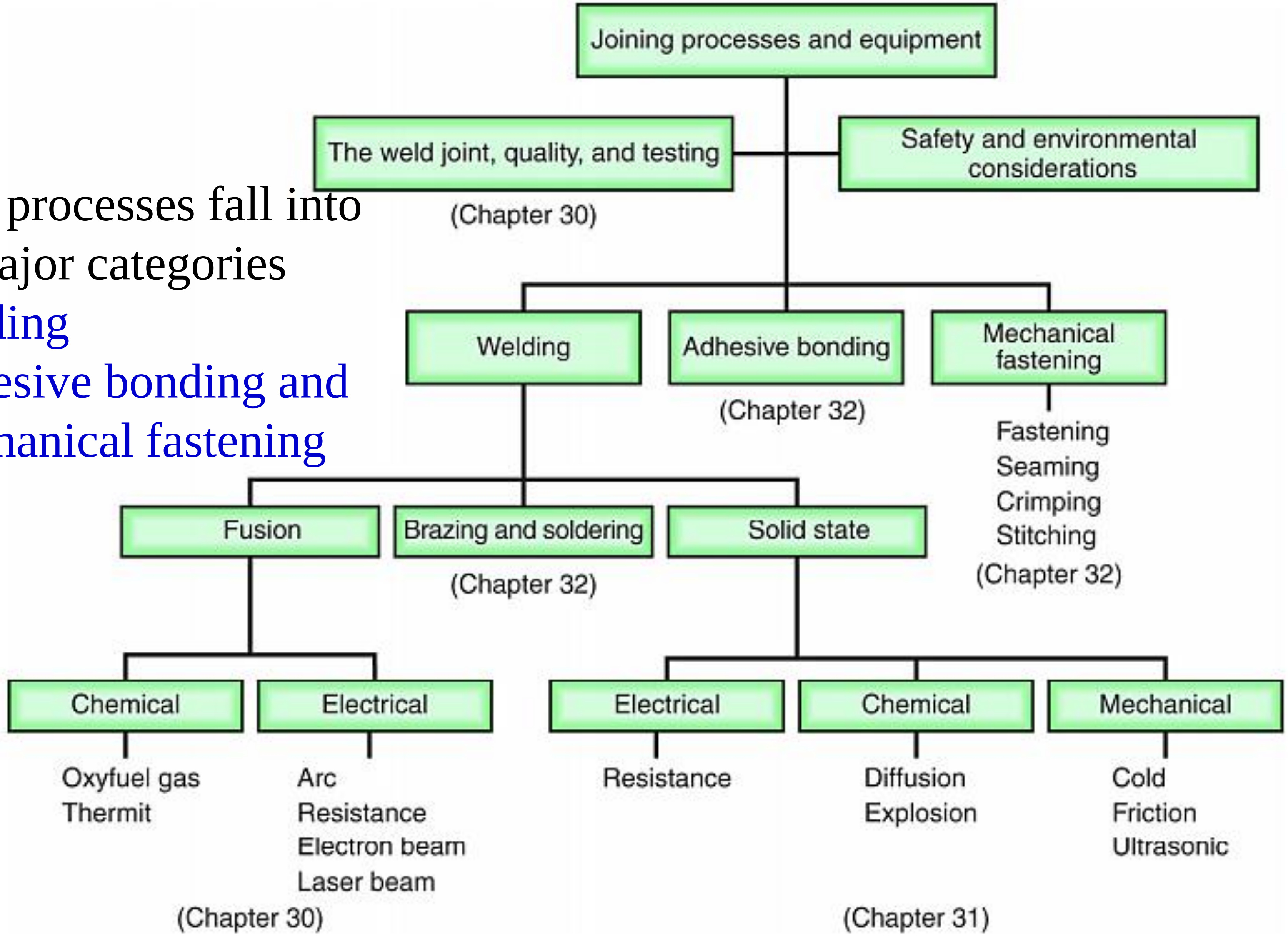
Metal Joining Processes

Joining processes fall into three major categories

(a)Welding

(b)Adhesive bonding and

(c)Mechanical fastening



Comparison of Various Joining Methods

TABLE VI.1

Comparison of Various Joining Methods

	Characteristics								
Method	Strength	Design	Small parts	Large parts	Tolerances	Reliability	Ease of manufacture	Ease of inspection	Cost
Arc welding	1	2	3	1	3	1	2	2	2
Resistance welding	1	2	1	1	3	3	3	3	1
Brazing	1	1	1	1	3	1	3	2	3
Bolts and nuts	1	2	3	1	2	1	1	1	3
Riveting	1	2	3	1	1	1	3	1	2
Fasteners	2	3	3	1	2	2	2	1	3
Seaming and crimping	2	2	1	3	3	1	3	1	1
Adhesive bonding	3	1	1	2	3	2	3	3	2

Note: 1 = very good; 2 = good; 3 = poor. For cost, 1 is the lowest.

Welding

Welding processes can be divided into three basic categories: (a) fusion welding (b) solid-state welding and (c) brazing and soldering

Fusion welding is defined as the melting and coalescing of materials by means of heat (usually supplied by chemical or electrical means); filler metals may or may not used. This process constitutes a major category of welding; it comprises consumable or no consumable electrode arc welding and high-energy-beam welding processes. The welding joint undergoes important metallurgical or physical changes which, in turn, have major effect on the properties and performance of the welded component or structure.

Solid-state welding

In solid-state welding, joining takes place without fusion; consequently, there is no liquid (molten) phase in the joint. The basic categories are diffusion bonding and cold, ultrasonic, friction, resistance, and explosion welding. Diffusion bonding, combined with superplastic forming, has become an important manufacturing process for complex shapes.

Brazing and soldering use filler metals and involve lower temperatures than welding; the heat required is supplied externally.

Differences between fusion welding and solid-state welding

Fusion welding	Solid-state welding
Heat must be applied for welding. Heat can be supplied by various means such as electric arc, fuel-gas flame, resistance heating, laser beam, etc.	No external heat source is required but pressure may be applied externally for welding.
Filler material can be applied easily.	Usually no filler is applied.
Mechanical properties of parent materials are affected by intense heating.	Mechanical properties usually remain unaltered.
Dissimilar metal joining by fusion welding is challenging task, especially if the duo have substantially different melting point and coefficient of thermal expansion.	Joining dissimilar metal is comparatively easier as processes don’t involve melting and solidification.
Examples of fusion welding processes: Arc welding (SMAW, GMAW, TIG, SAW, FCAW, ESW, etc.), Gas welding (AAW, OAW, OHW, PGW) Resistance welding (RSW, RSEW, PW, PEW, FW, etc.) Intense energy beam welding (PAW, EBW, LBW)	Examples of solid-state welding processes: Cold Welding (CW), Roll Welding (ROW), Pressure Welding (PW), Diffusion Welding (DFW), Friction Welding (FRW), Friction Stir Welding (FSW) Forge Welding (FOW), etc.

Adhesive bonding

Adhesive bonding has been developed into an important technology because of its several advantages; it has unique applications requiring strength, sealing, insulating, vibration damping, and resistance to corrosion between dissimilar metals.

Mechanical fastening involves traditional methods of various fasteners, bolts, nuts, and rivets.

Joining plastics can be accomplished by adhesive bonding, fusion by various external or internal heat, and mechanical fastening.

Choice of joining process

The choice of joining process depends on the following factors:

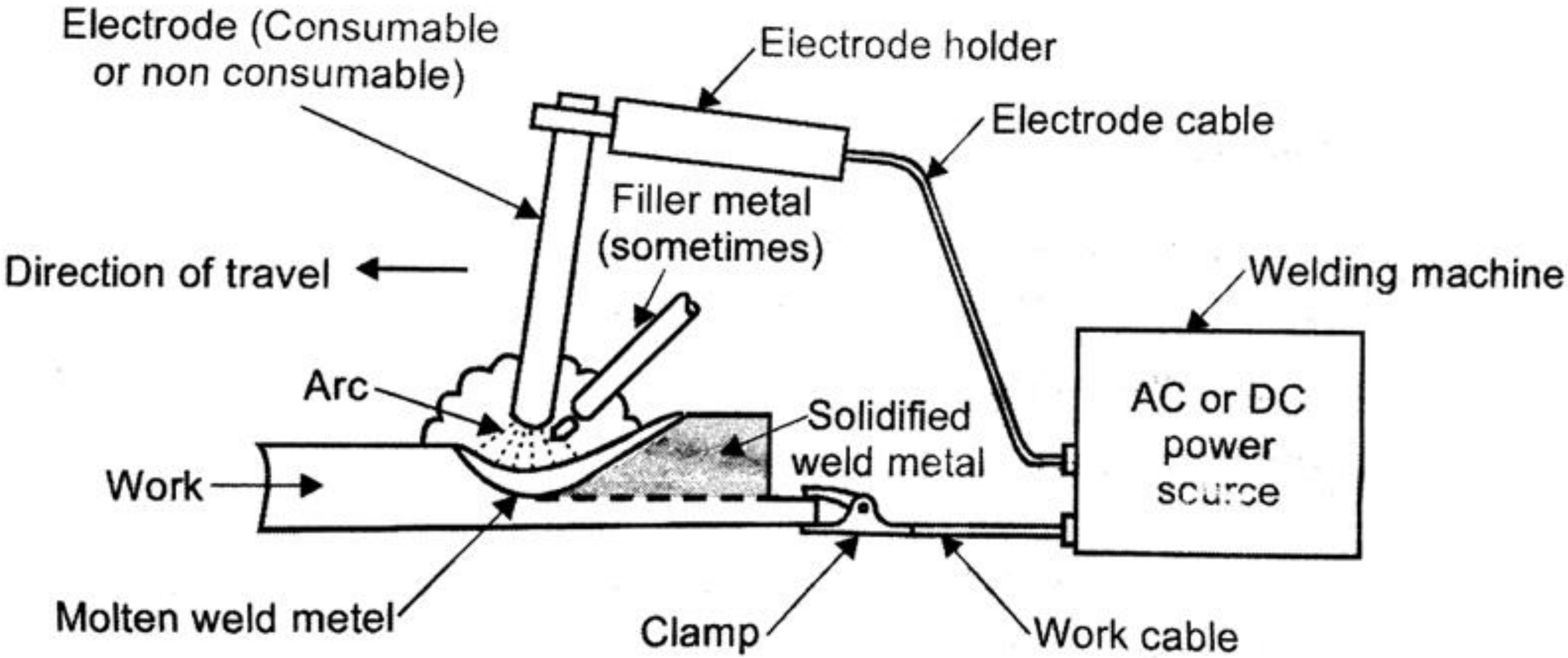
(a) The applications

(b) The joint design

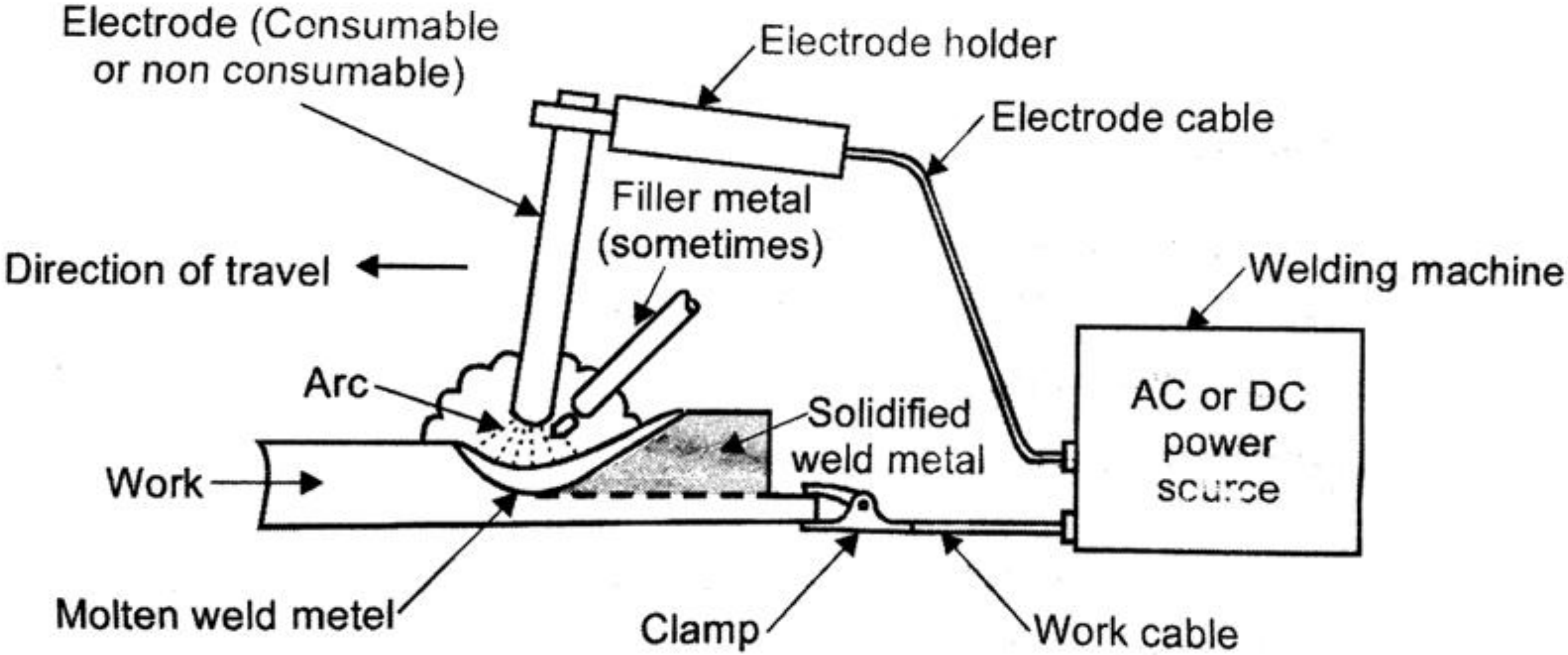
(c) The materials involved and

(d) The shape of the components to be joint

Metal Joining



Arc welding



Electrode (Consumable or non consumable)
Electrode holder
Electrode cable
Filler metal (sometimes)
Direction of travel
Welding machine
Arc
Solidified weld metal
AC or DC power source
Work
Molten weld metel
Clamp
Work cable

27.1 Fusion-Welding Processes

Fusion welding is defined as melting together and coalescing materials by means of heat. The thermal energy required for these welding operations is usually supplied by *Electrical or Chemical means*. Filler metals, which are metal added to the weld area during welding, may or may not be used. Fusion welds made without the addition of filler metals are known as *Autogenous welds.*

Fusion welding process includes *oxyfuel, arc, and high energy beam* (electron-beam and laser-beam) welding processes that have important and unique applications in modern manufacturing.

27.2 Oxyfuel Gas Welding

Oxyfuel gas welding (OFW) is a general term used to describe any welding process that uses a fuel gas combined with ***oxygen*** to produce flame. ***This flame is the source of heat*** that is used to melt the metals at the joint. The most common gas-welding process uses ***acetylene fuel***; it is known as oxyacetylene welding and is used typically for ***structural sheet metal fabrication, automotive bodies, and various other repair works.***

The heat is generated in accordance with a pair chemical reactions. The primary combustion process, which occurs in the ***inner core*** of the flame , runs as follows:

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

This reaction dissociates the acetylene into carbon monoxide and hydrogen; it produces about ***1/3*** of the total heat generated in the flame.

27.2 Oxyfuel Gas Welding

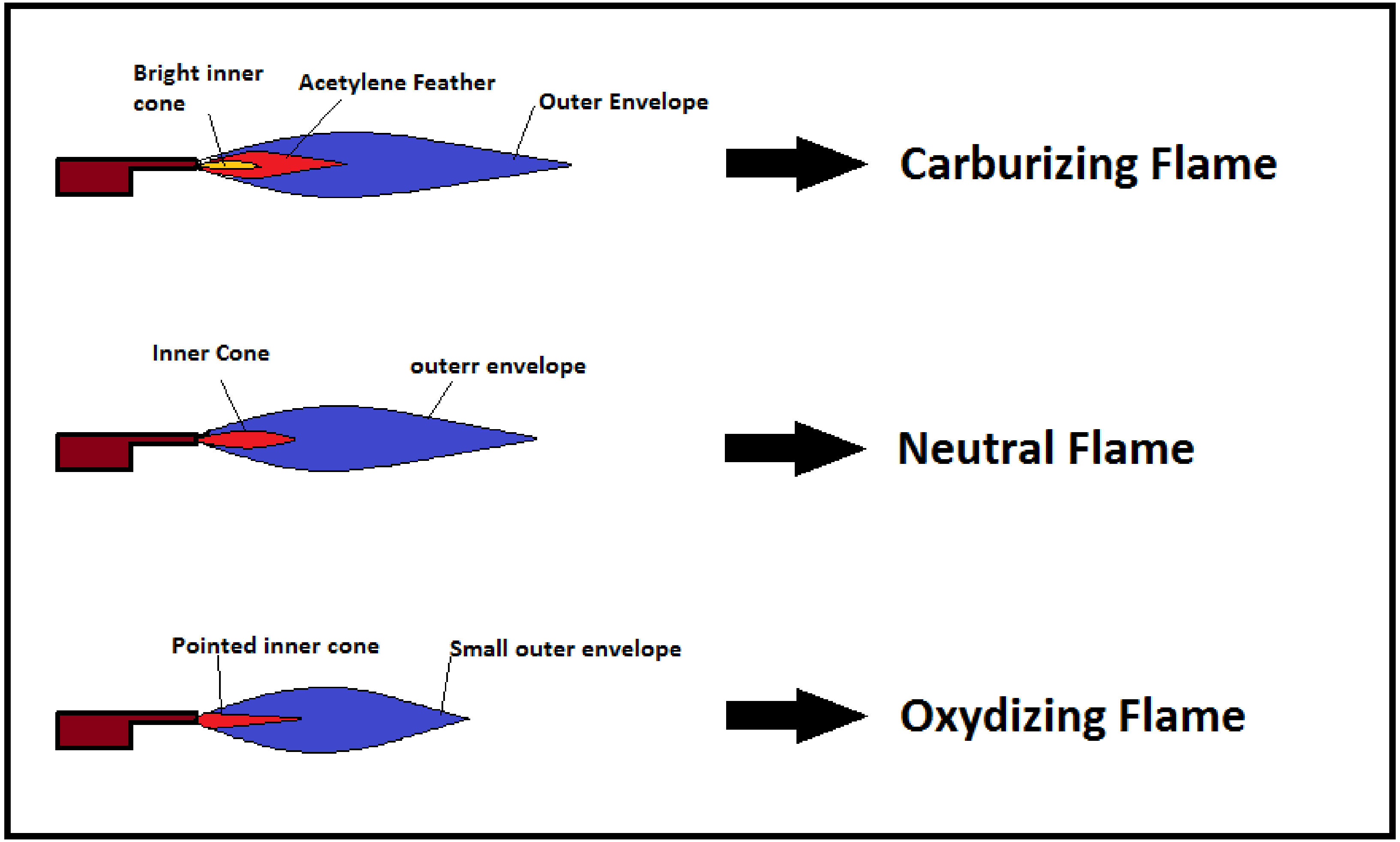
The secondary combustion process is

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

This reactions consists of the ***further burning of the hydrogen*** and ***the carbon monoxide.*** This second reaction produces about ***2/3*** of the total heat. The temperatures developed in the flame as a result of these reactions can reach 3000^0C (6000^0F). Note that the reaction of hydrogen with oxygen ***produces water vapor.***

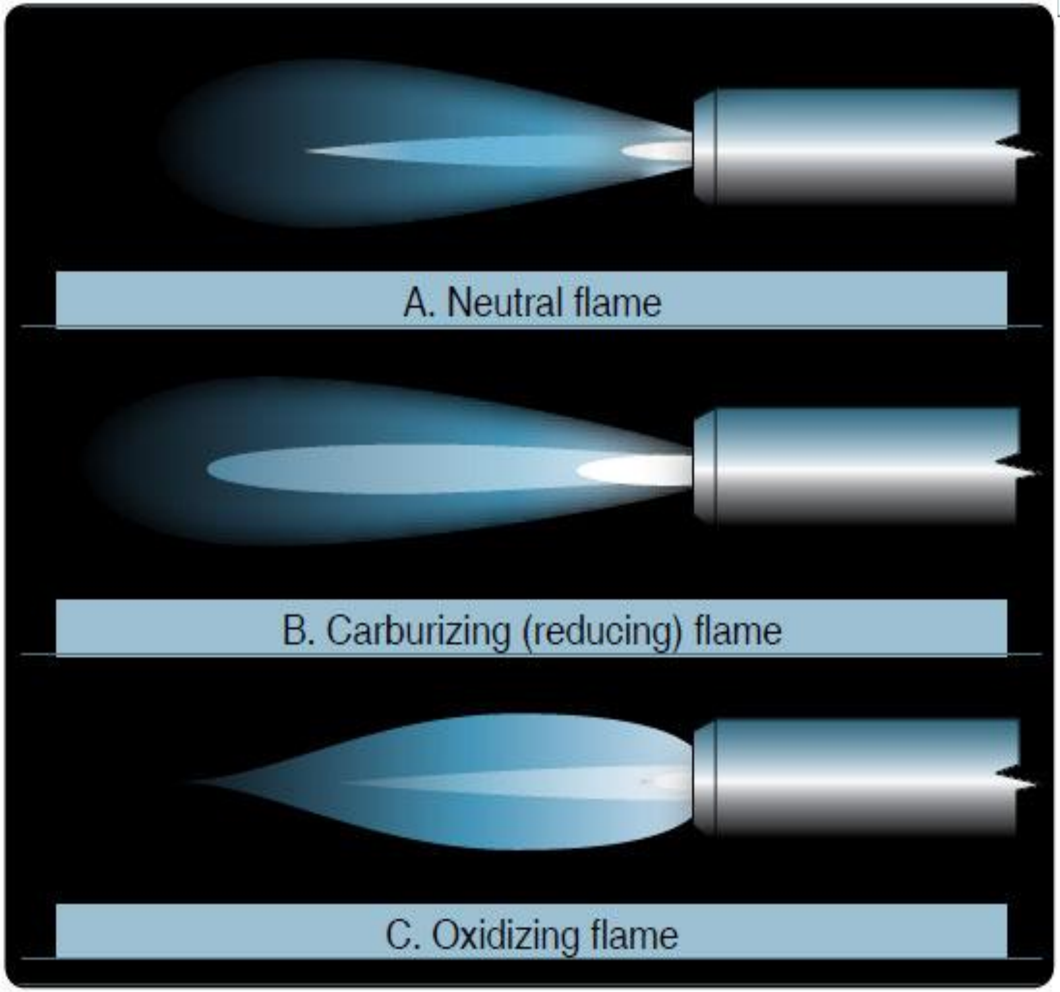
27.2 Oxyacetylene flames

Three basic types of oxyacetylene flames used in oxyfuel-gas welding and cutting operations.



27.2 Oxyacetylene flames

Three basic types of oxyacetylene flames used in oxyfuel-gas welding and cutting operations.



Oxyacetylene Flames Used in Welding

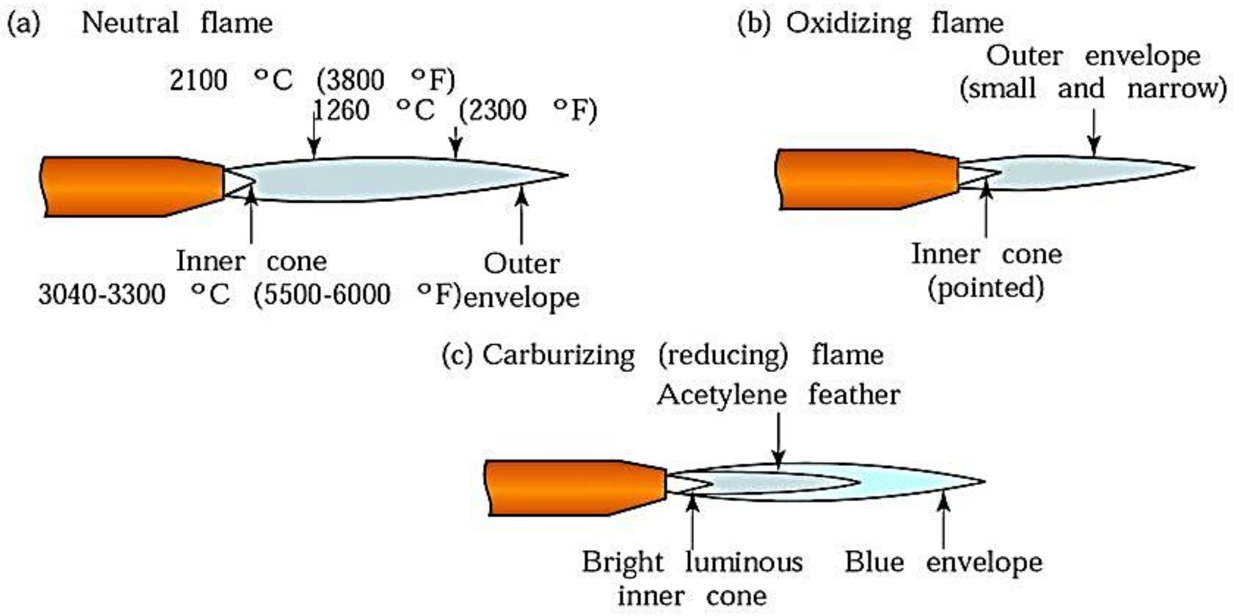


Figure : Three basic types of oxyacetylene flames used in oxyfuel-gas welding and cutting operations: (a) neutral flame; (b) oxidizing flame; (c) carburizing, or reducing, flame. The gas mixture in (a) is basically equal volumes of oxygen and acetylene.

27.2.1 Types of flames

Neutral flame- acetylene : oxygen = 1:1

Oxidizing flame- oxygen > acetylene : This flame is harmful for steels. Because it oxidizes the steel. Only in the ***welding of copper and copper-based alloys*** is an oxidizing flame desirable, because in those cases a thin protective layer of slag forms over the molten metal.

Carburizing/reducing flame- oxygen < acetylene: ***The temperature of a reducing flame is lower***, so it is suitable for applications requiring low heat, such as ***brazing, soldering, and flame-hardening***.

27.2.2 Filler metals

A **filler metal** is a metal added in the making of a joint through welding, brazing, and soldering.

- Filler metals are alloys or unalloyed metals which, when heated, liquefy and melt to flow into the space between two close fitting parts, creating a brazed or soldered joint. ***A filler metal has suitable melting and flow properties to permit distribution by capillary attraction in properly prepared joints.*** Filler metals produce joints that meet service requirements, such as strength and corrosion resistance. They also meet the specifications of the American Welding Society (AWS), The American Society for Testing Materials (ASTM), and in nearly all cases, ISO standards as well.

- Standard filler metals include ***tin, lead, silver, copper, aluminum, nickel, and jewelers gold***. Filler metals are found in solid form (such as rings and wire, slugs, washers, powder), as well as paste. Fusion filler metals are atomized into powder form and mixed with flux into a paste composition.

27.2.2 Filler metals & Flux

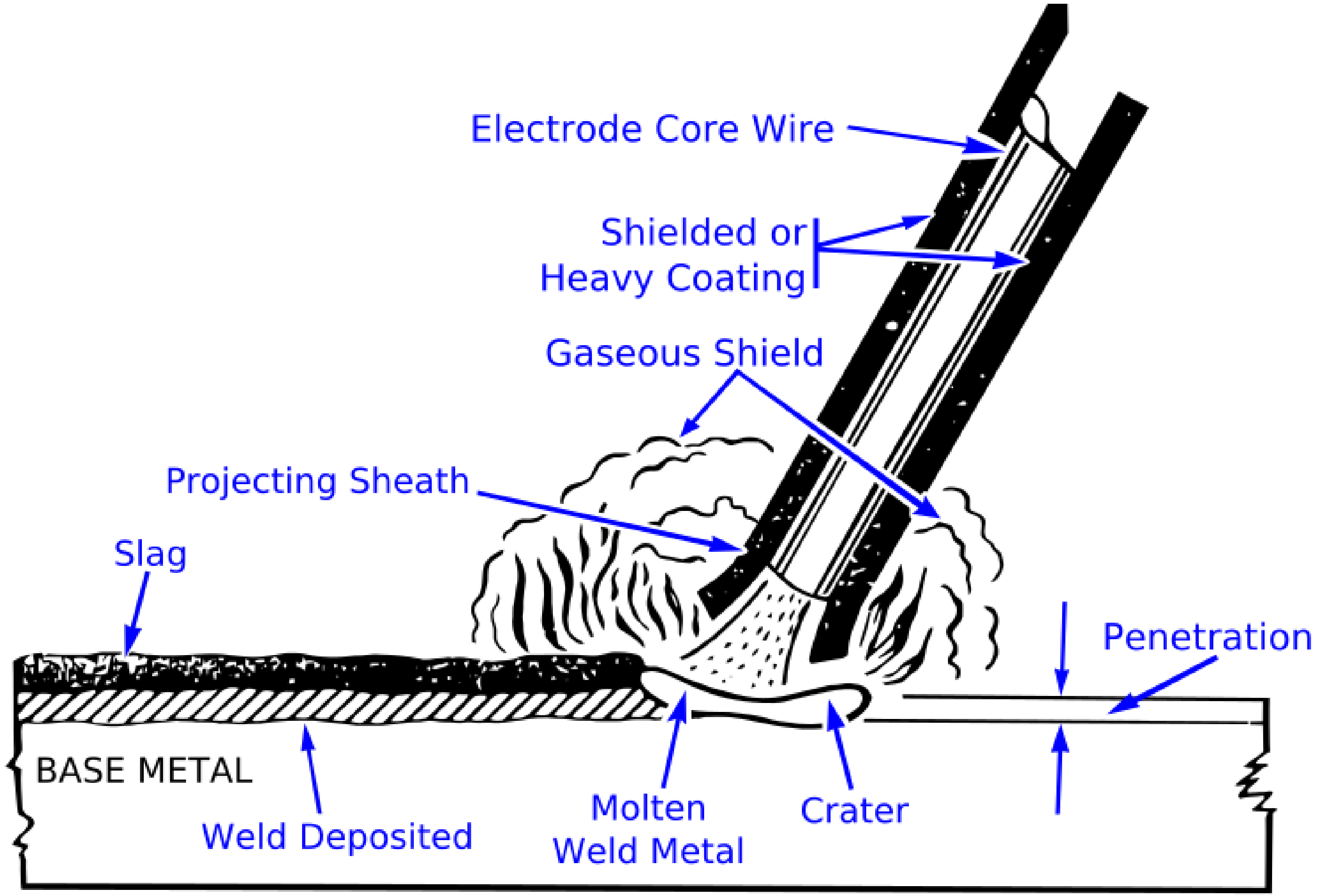
OxyFuel Gas Welding:

- Filler Metals
  - Filler rods or Wire, Copper alloy filler rods and fluxes enable the joining of many base metals. They are especially useful on steel and cast iron.

- Flux
  - The flux is to retard oxidation of the surface of the parts being welding by generating a gaseous shield

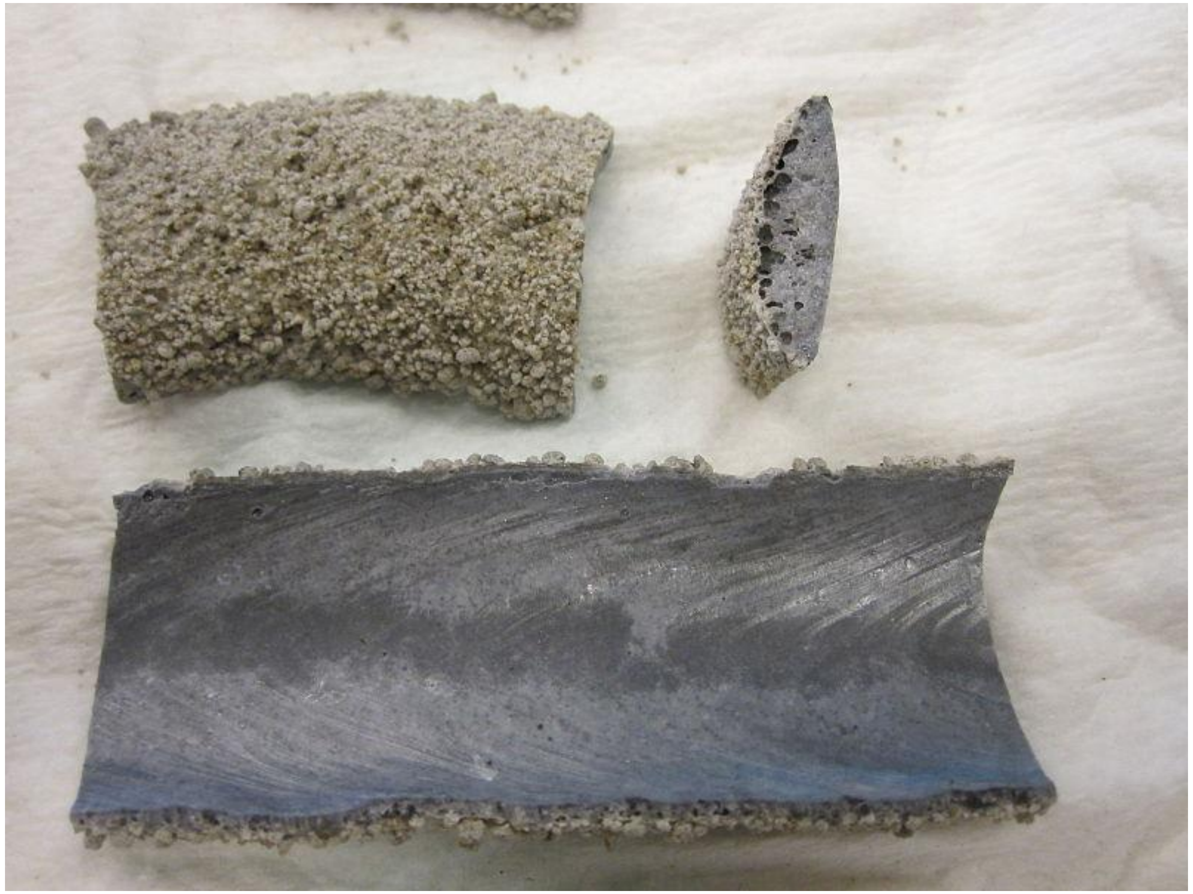
27.2.2 How does flux prevent oxidation?

- Welding flux is a combination of *carbonate and silicate materials* used in welding processes *to shield the weld from atmospheric gases.* When the heat of the weld zone reaches the flux, the flux melts and outgasses. The produced gases push the atmospheric gas back, preventing oxidation (and reactions with nitrogen).
- Flux materials may also contribute to metal behavior in the molten metal, with physical or chemical alterations to the molten metal.
- The flux cover also helps thermally insulate the weld and reduce the cooling rate.



27.2.2 Welding slag

Welding slag is a form of slag, or vitreous material produced as a byproduct of some arc welding processes, most specifically *shielded metal arc welding* (also known as stick welding), *submerged arc welding*, and *flux-cored arc welding*. Slag is formed when flux, the solid shielding material used in the welding process, melts in or on top of the weld zone.

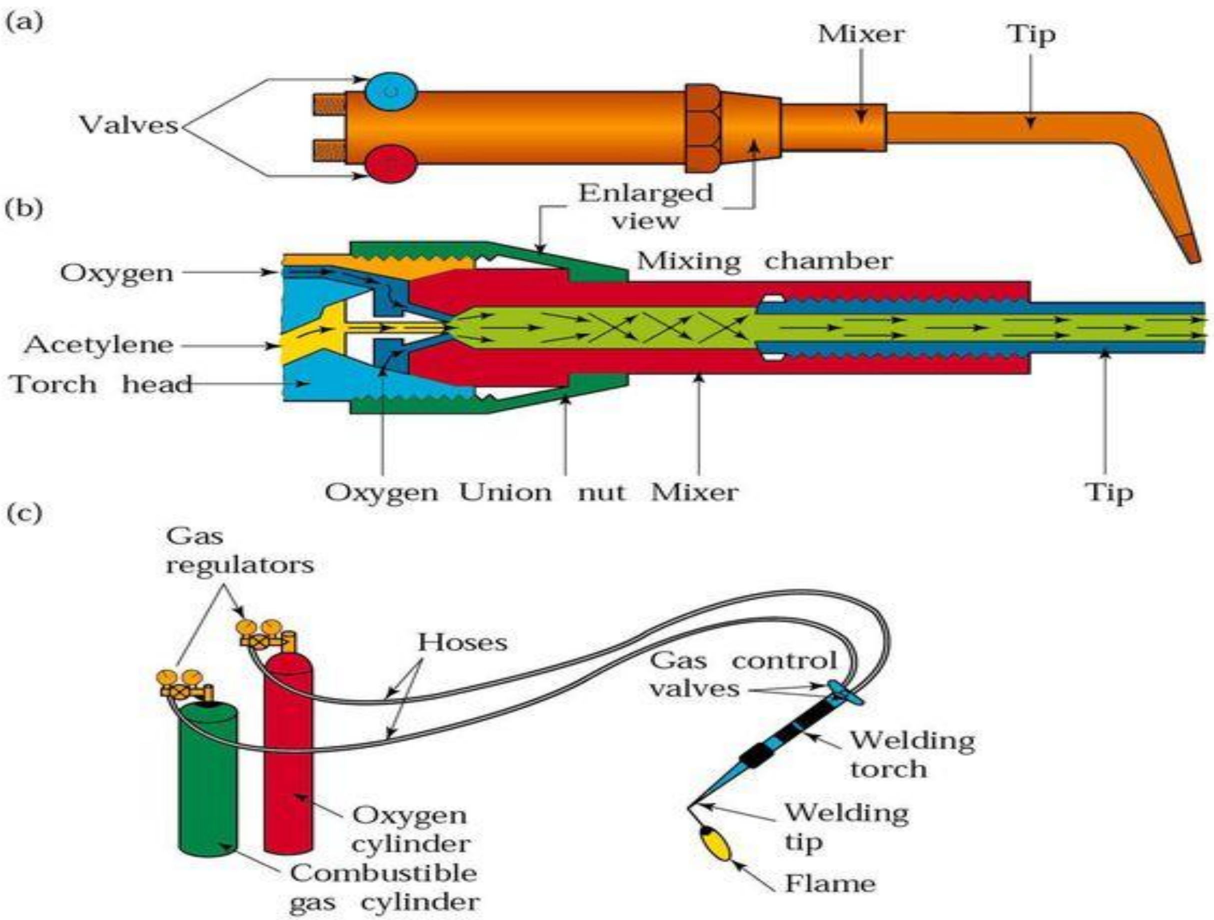


Slag is the solidified remaining flux after the weld area cools.

27.2.3 Welding Practice and Equipment

Torch Used in Oxyacetylene Welding

Figure : (a) General view of and (b) cross-section of a torch used in oxyacetylene welding. The acetylene valve is opened first; the gas is lit with a spark lighter or a pilot light; then the oxygen valve is opened and the flame adjusted. (c) Basic equipment used in oxyfuel-gas welding. To ensure correct connections, all threads on acetylene fittings are left-handed, whereas those for oxygen are right-handed. Oxygen regulators are usually painted green, acetylene regulators red.

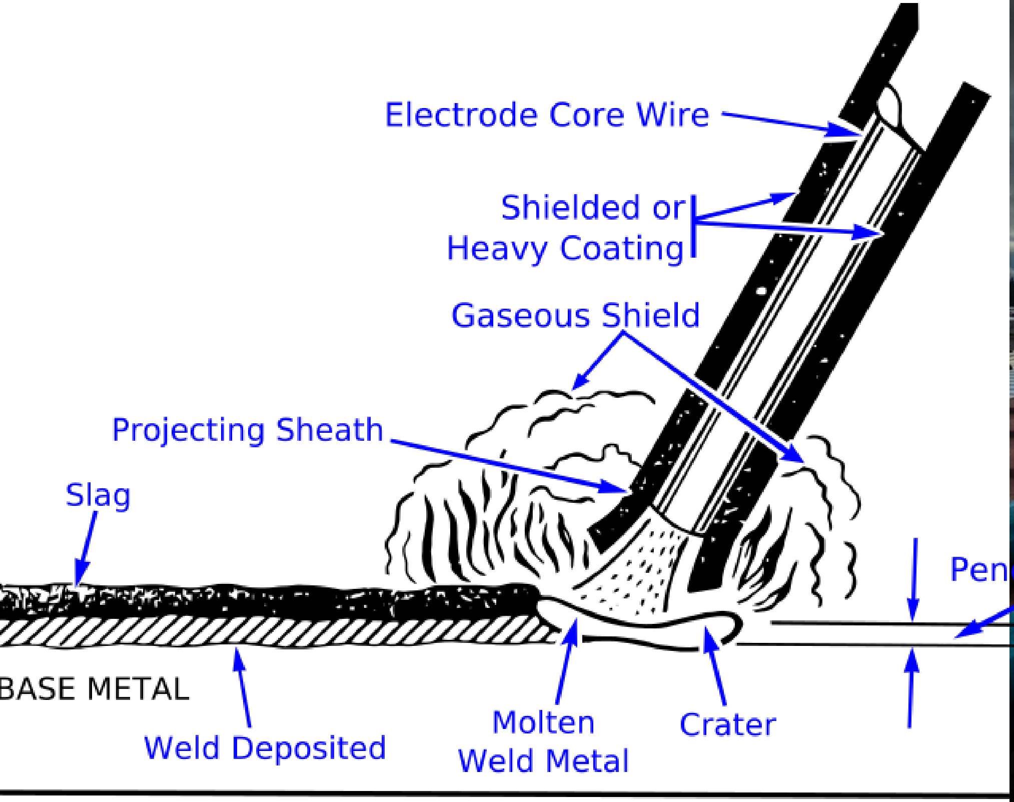


27.2.3 Welding Practice and Equipment

Basic steps of oxyfuel gas welding:

1. Prepare the edges to be joined, and establish and maintain their proper position by the use of clamps and fixtures.
2. Open the acetylene valve, and ignite the gas of the torch. Open the oxygen valve, and adjust the flame for the particular operation.
3. Hold the torch at about 45^0 from the plane of the workpiece, with the inner flame near the workpiece and the filler rod about $30^0 - 40^0$.
4. Touch the filler rod to the joint and control its movement along the joint length by observing the rate of melting and filling of the joint.

27.3.1 Shielded Metal-Arc Welding

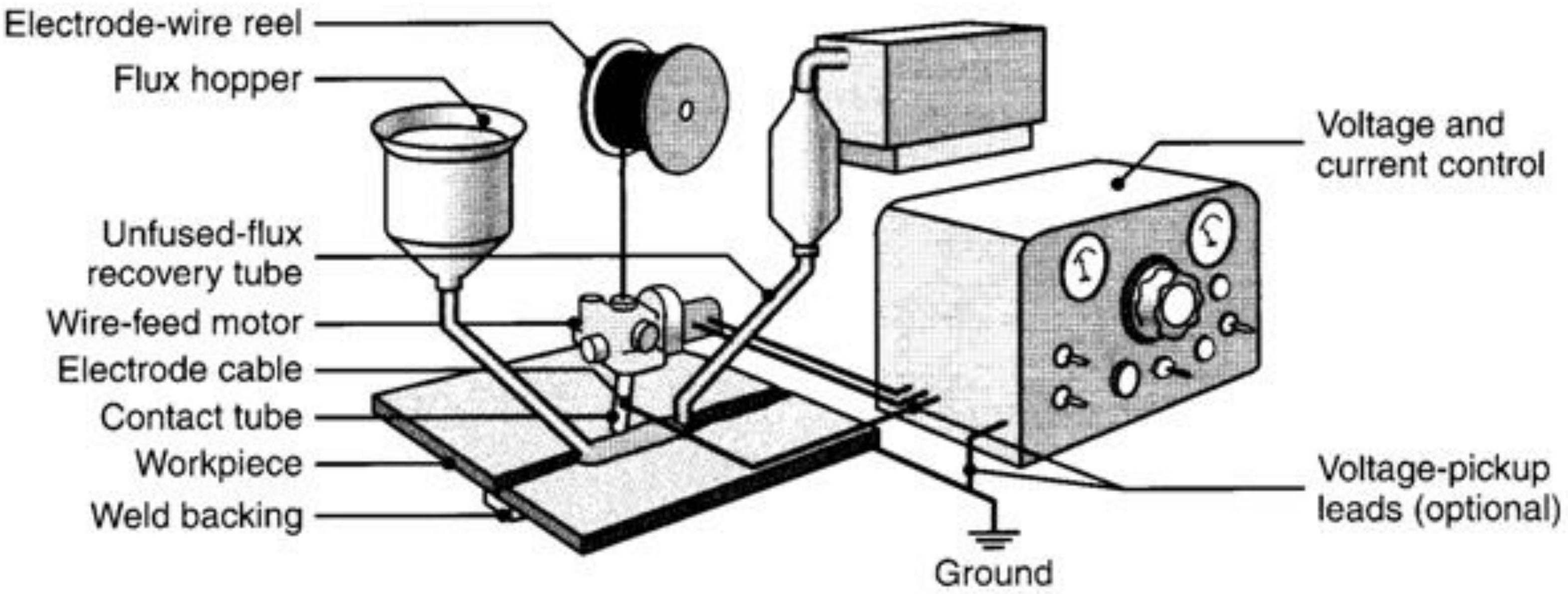


27.3.1 Shielded Metal-Arc Welding

Shielded metal-arc welding (SMAW) is one of the oldest, simplest, and most versatile joining processes. About 50% of all industrial and maintenance welding is currently performed by this process. The electric arc is generated by touching the tip of a coated electrode against the workpiece and then withdrawing it quickly to a distance sufficient to maintain the arc. The electrodes are in the shape of a thin, long stick, so this process is also known as *stick welding.*

The electrode coating deoxidizes the weld area and provides a shielded gas to *protect it from oxygen* in the environment.

27.3.2 Submerged Arc Welding

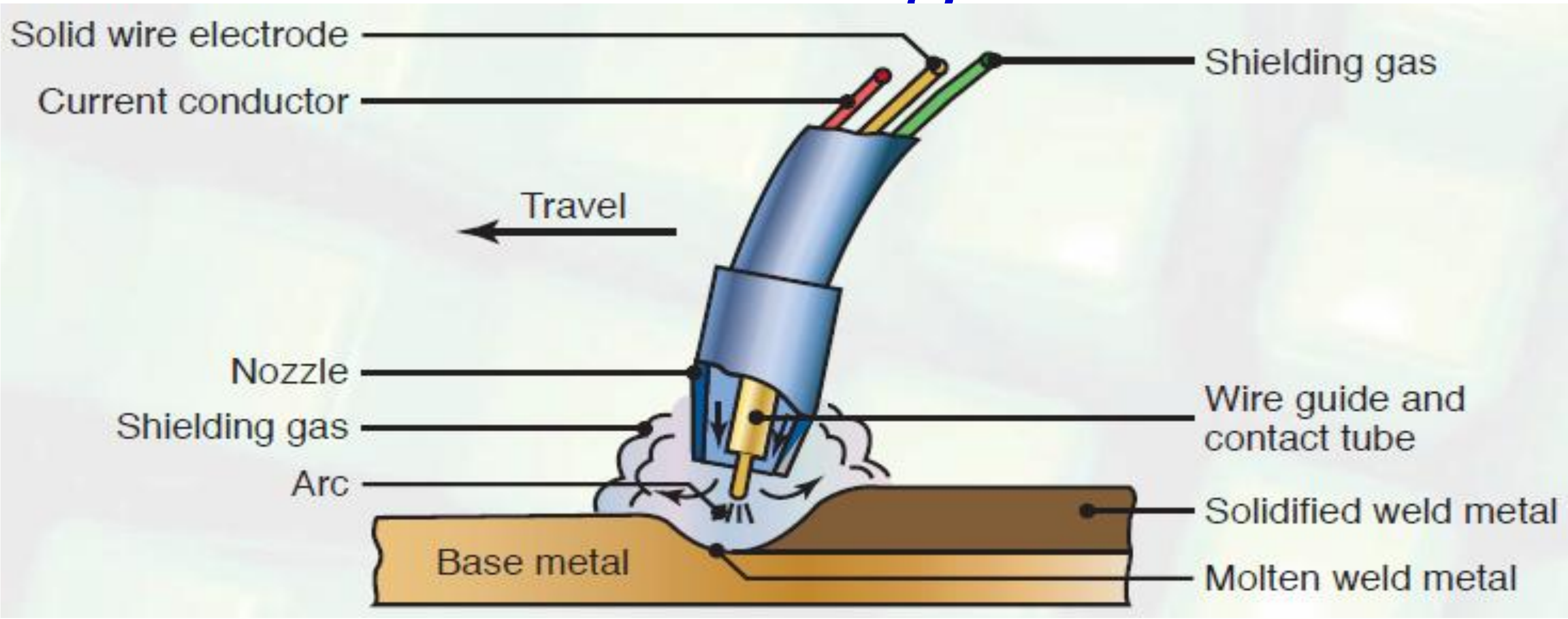


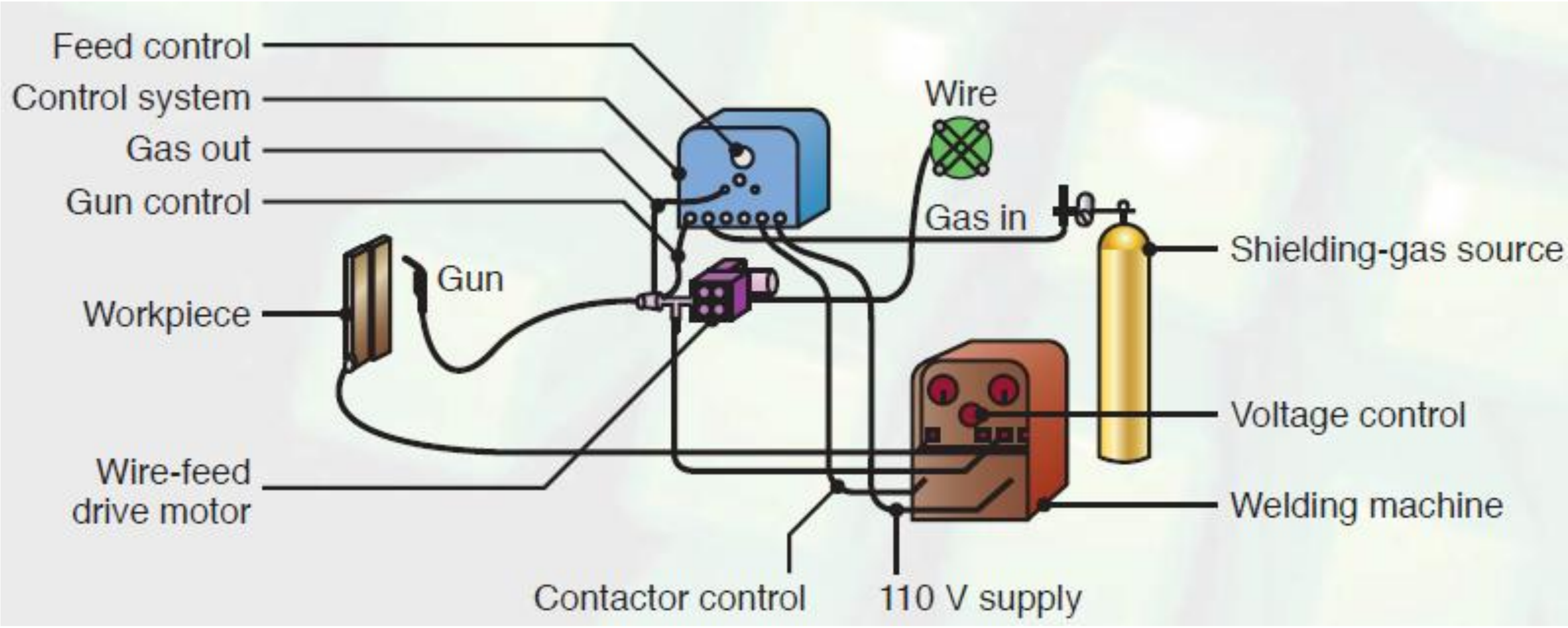
In *submerged arc welding (SAW)*, the weld arc is shielded by *granular flux*, consisting of lime, silica, magnetic oxide, calcium fluoride, and other compounds. The flux is fed into the weld zone by gravity flow through a nozzle. The thick layer of flux completely covers the molten metal; it prevents spatter & sparks and suppresses the intense ultra violation radiation and fumes characteristics of the SMAW process. The flux also acts as a thermal insulator, promoting deep penetration of heat into the workpiece.

27.3.3 Gas Metal-Arc Welding

In gas metal-arc welding (GMAW), developed in the 1950s and formerly called metal inert-gas (MIG), the weld area is shielded by an effectively inert atmosphere of *argon, helium, carbon dioxide or various gas mixtures*. The consumable bare wire is fed automatically through a nozzle into the weld arc.

In order to prevent oxidation of the molten weld puddle, inert shielding gases (*argon, helium, carbon dioxide or various gas mixtures*) are used.





27.3.4 Flux-Cored Arc Welding (FCAW)

The *flux-cored arc welding* (FCAW) is similar to gas metal arc welding, with the exception that the electrode is tabular in shape and is filled with flux (hence the term 'flux-cored'). Cored electrodes produce more stable arc, improve weld contour, and produce better mechanical properties of the weld metal.

Tabular electrode contains powdered metal (that melts and joins the welding zone), vapor/gas forming materials (produces shielded gas zone), deoxidizers and scavengers.

These electrodes do not require external gas shielding, because they contain emissive fluxes that shield the weld area against the surrounding atmosphere.

It is used for welding a variety of joints, mainly on steels, stainless steels, and nickel alloys.

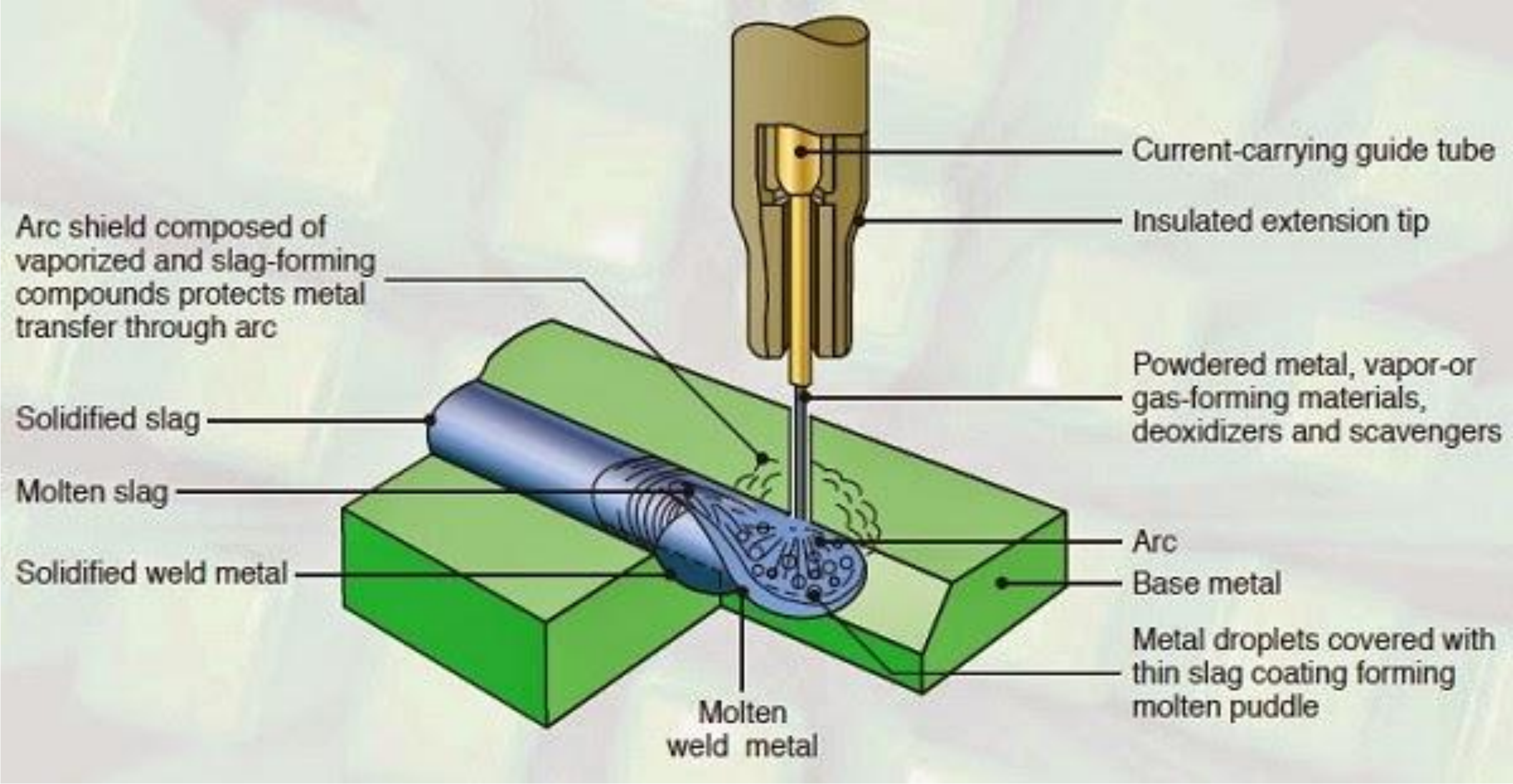


TABLE 27.2 Designations for Mild Steel Coated Electrodes

The prefix "E" designates arc welding electrode.

The first two digits of four-digit numbers and the first three digits of five-digit numbers indicate minimum tensile strength:

E60XX	60,000 psi minimum tensile strength
E70XX	70,000 psi minimum tensile strength
E110XX	110,000 psi minimum tensile strength

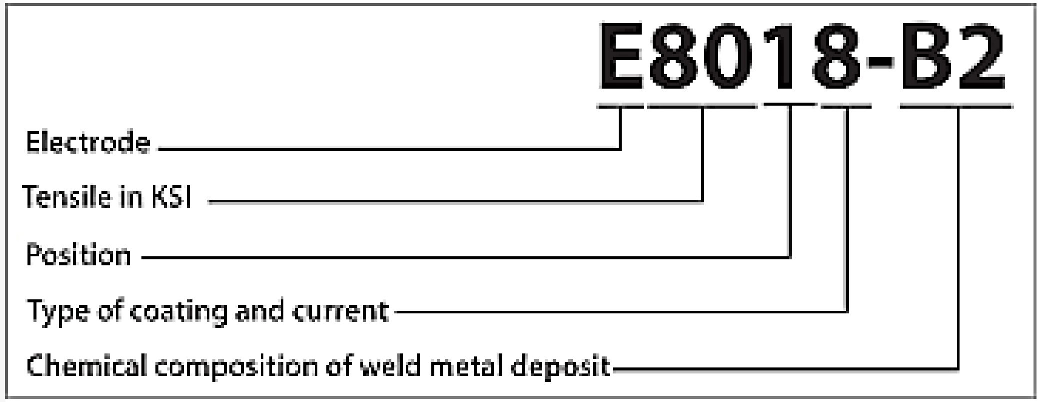
The next-to-last digit indicates position:

EXX1X	All positions
EXX2X	Flat position and horizontal fillets

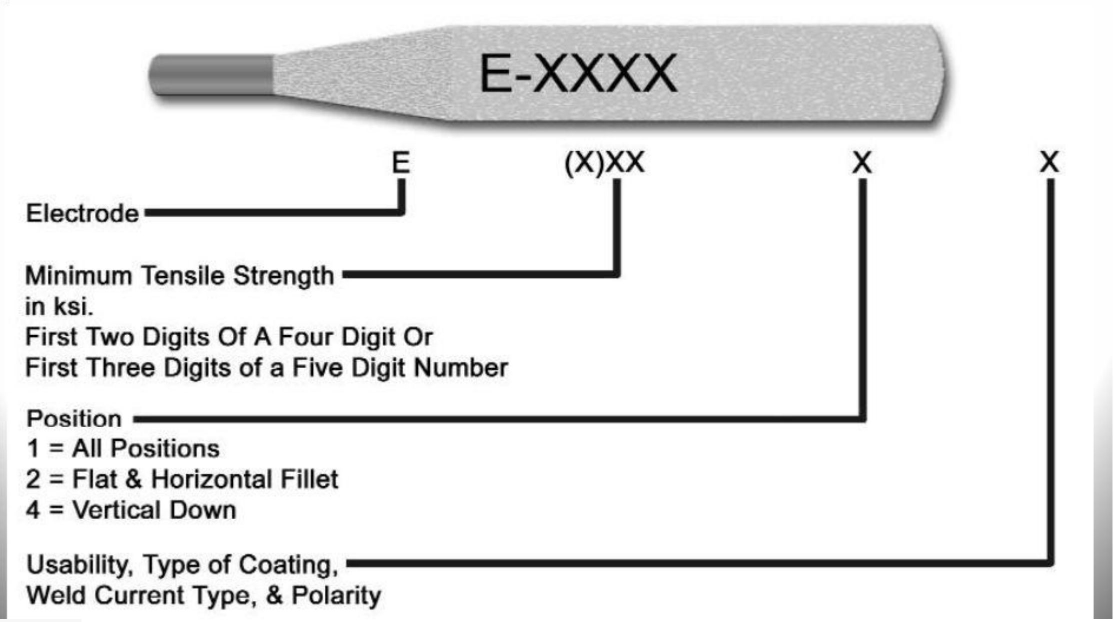
The last two digits together indicate the type of covering and the current to be used.

The suffix (Example: EXXXX-A1) indicates the approximate alloy in the weld deposit

—A1	0.5% Mo
—B1	0.5% Cr, 0.5% Mo
—B2	1.25% Cr, 0.5% Mo
—B3	2.25% Cr, 1% Mo
—B4	2% Cr, 0.5% Mo
—B5	0.5% Cr, 1% Mo
—C1	2.5% Ni
—C2	3.25% Ni
—C3	1% Ni, 0.35% Mo, 0.15% Cr
—D1 and D2	0.25–0.45% Mo, 1.75% Mn
—G	0.5% min. Ni, 0.3% min. Cr, 0.2% min. Mo, 0.1% min. V, 1% min. Mn (only one element required)



AWS Electrode Classification



27.5.1 Gas Tungsten-Arc Welding (GTAW) (Nonconsumable electrode)

In *gas tungsten-arc welding* (GTAW), formerly known as TIG (Tungsten Inert Gas) welding, the filler metal is supplied from a filler wire. Because the tungsten electrode is not consumed in this operation, a constant and stable arc gap is maintained at a constant current level.

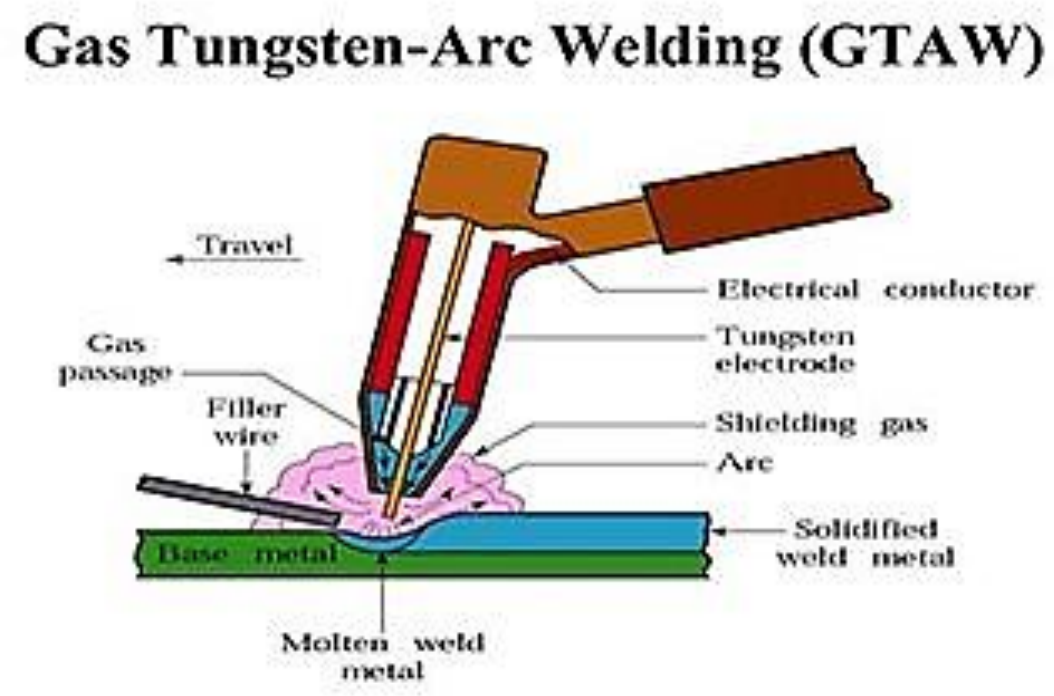
The filler metals are similar to the metals to be welded, and flux is not used.

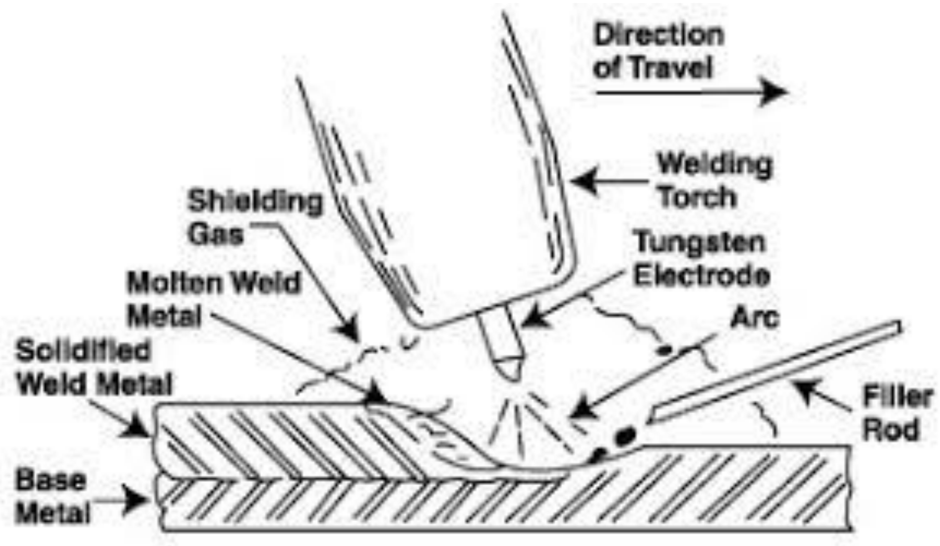
The shielding gas is usually argon or helium (or a mixture of two).

Welding with GTAW may be done without filler metals-for example, in the welding of close-fit joints.

Contamination of the tungsten electrode by the molten metal can be a significant problem, particularly in critical applications, because it can cause discontinuities in the weld.

The GTAW process is used for a wide variety of metals like aluminum, magnesium, titanium, and refractory metals.





27.5.3 Plasma-Arc Welding (Nonconsumable electrode)

In *plasma-arc welding* (PAW), developed in 1960. A concentrated plasma arc is produced and is aimed at the weld area. The arc is stable and reaches temperature as high as $33{,}000^0C$. A plasma is ionized hot gas, composed of nearly equal numbers of electrons and ions.

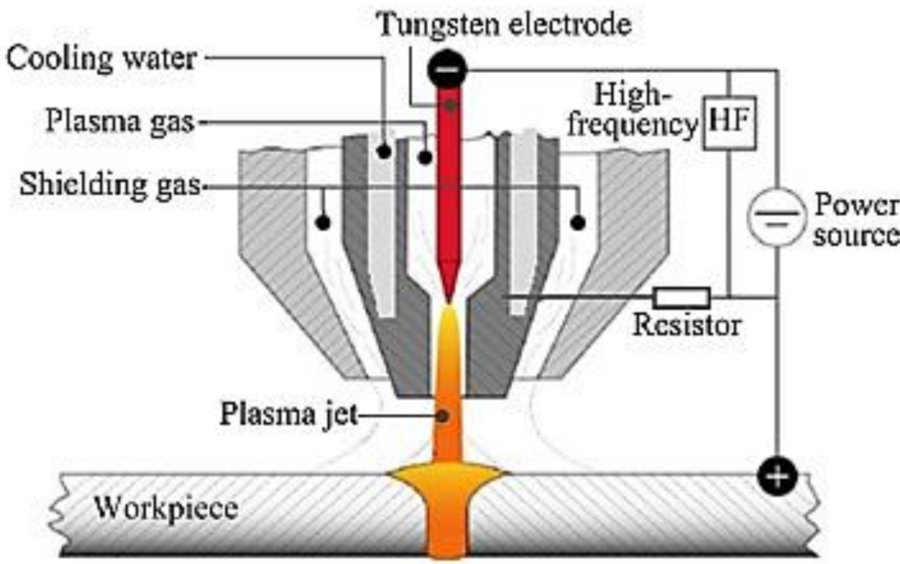
Unlike other processes, the plasma arc is concentrated, because it is forced through a relatively small orifice. Operating currents are usually below 100A, but they can be higher for special applications.

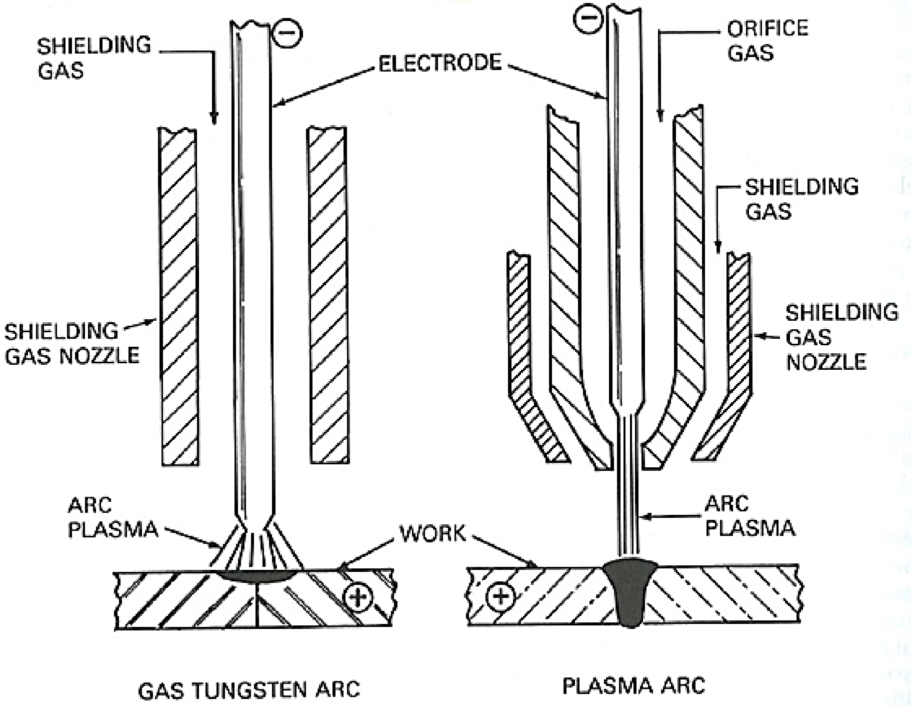
when a filler metal is used, it is fed into the arc, as is done in GTAW.

Arc and weld-zone gas shielding is produced by the use of gases like argon, helium, or mixtures.

Compared to other arc-welding processes, plasma arc welding has higher energy concentration (and so permits deeper and narrower welds), better arc stability, less thermal distortion, higher welding speed (120-1000mm/min).

A variety of metals can be welded, with part thicknesses generally less than 6mm





27.6 Thermit Welding

Thermit welding (TW) gets its name from the compounds named ***thermit***, a name based on the word ***therm***, meaning ***heat***; the word thermit is a registered trademark. The process involves ***exothermic (heat producing)*** reactions between metal oxides and metallic reducing agents. The heat of the reaction is then utilized in welding. This process dates back to the early 1900s.

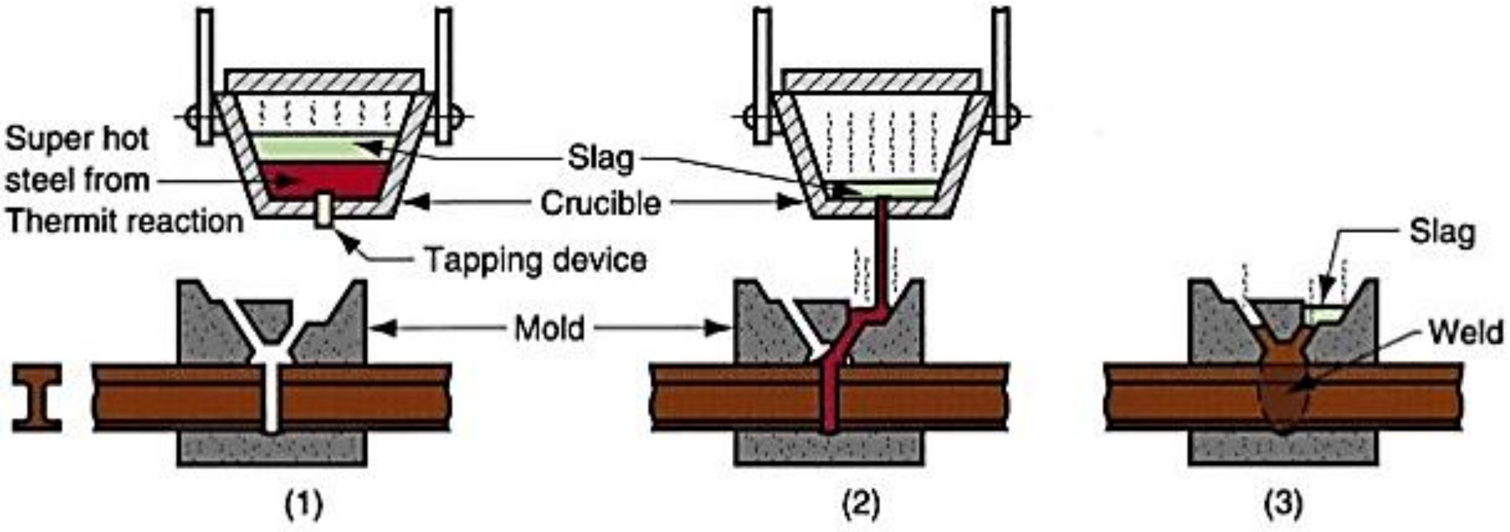
The most common mixture of materials used in welding steel and cast iron is finely divided particles of iron oxides (Fe_3O_4), aluminum oxide (Al_3O_3), iron, and aluminum. This nonexplosive mixture produces a maximum theoretical temperature of from 3200^0C (5800^0F) in less than a minute; however it reaches only about from 2200^0C to 2400^0C.

Thermit welding involves aligning the parts to be joined, but with a gap between them (usually filled with wax), around which a sand or ceramic mold is built. If the parts are thick, the mold cavity may be preheated to improve welding and to dry the mold. Drying the mold is very important; otherwise, superheated steam trapped in the mold can cause explosions.

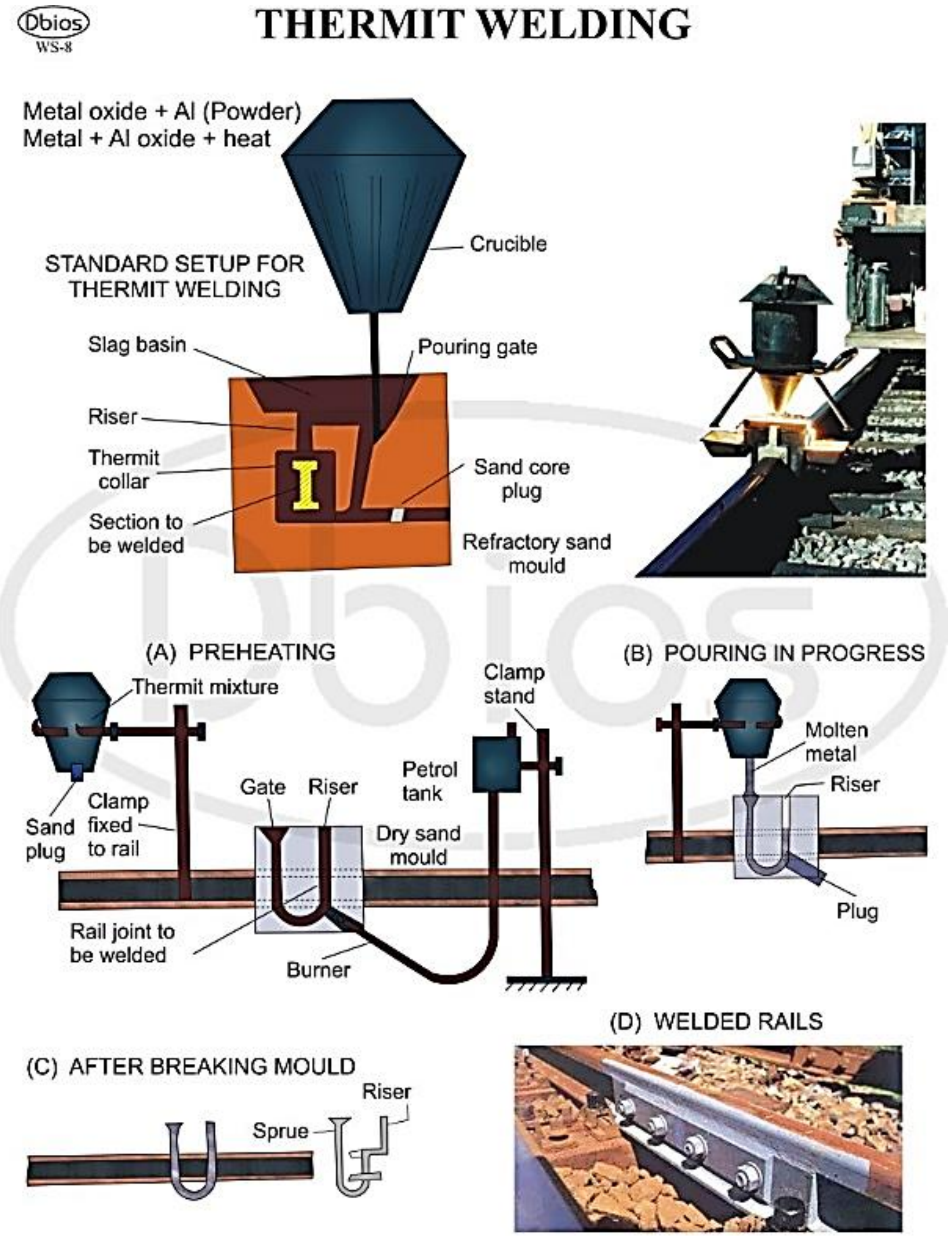
The superheated products of the reaction are allowed to flow into the gap, melting the edges of the parts being joined.

Thermit welding is suitable for welding and repairing large forging and castings, and can also be used to weld thick steel structural sections, rail-road rails, and pipe.

27.6 Thermit Welding



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



27.6 Thermit Welding

27.8 Laser-beam Welding (LBW)

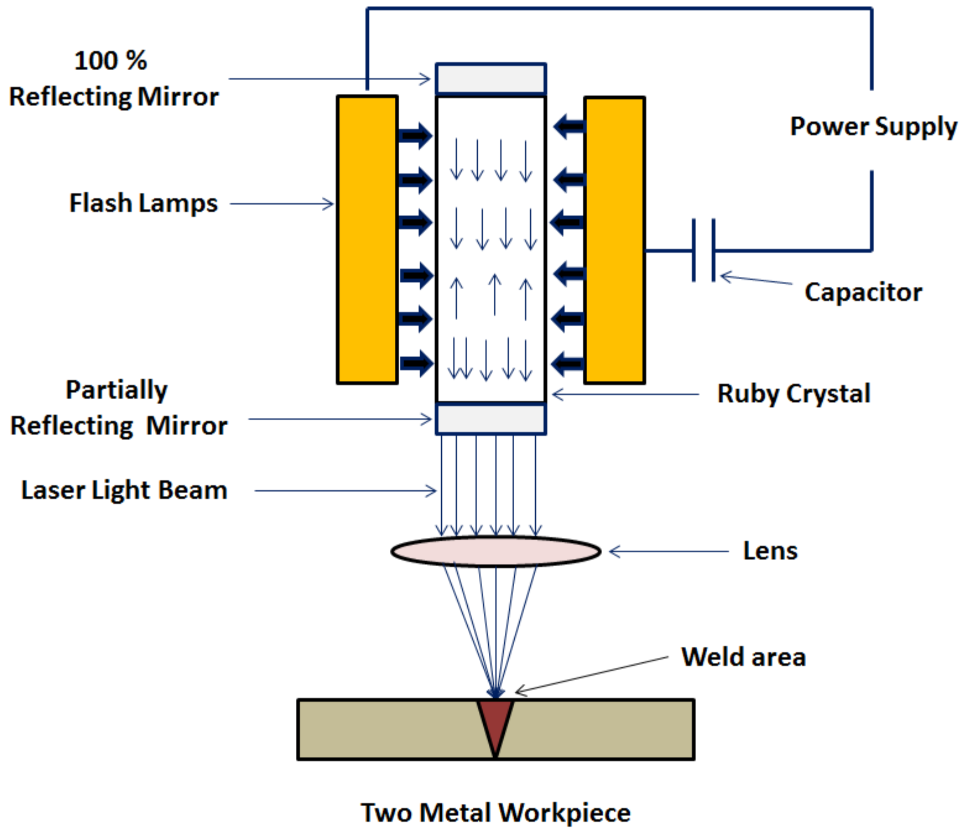
Laser-beam welding (LBW) utilizes a high-power laser beam **as the source of heat**, **to produce a fusion weld**. Because the beam can be focused onto a very small area, it is a high density and, therefore, deep-penetrating capacity.

The beam can be directed, shaped, and focused precisely on the workpiece. Consequently, this process is particularly suitable for welding deep and narrow joints.

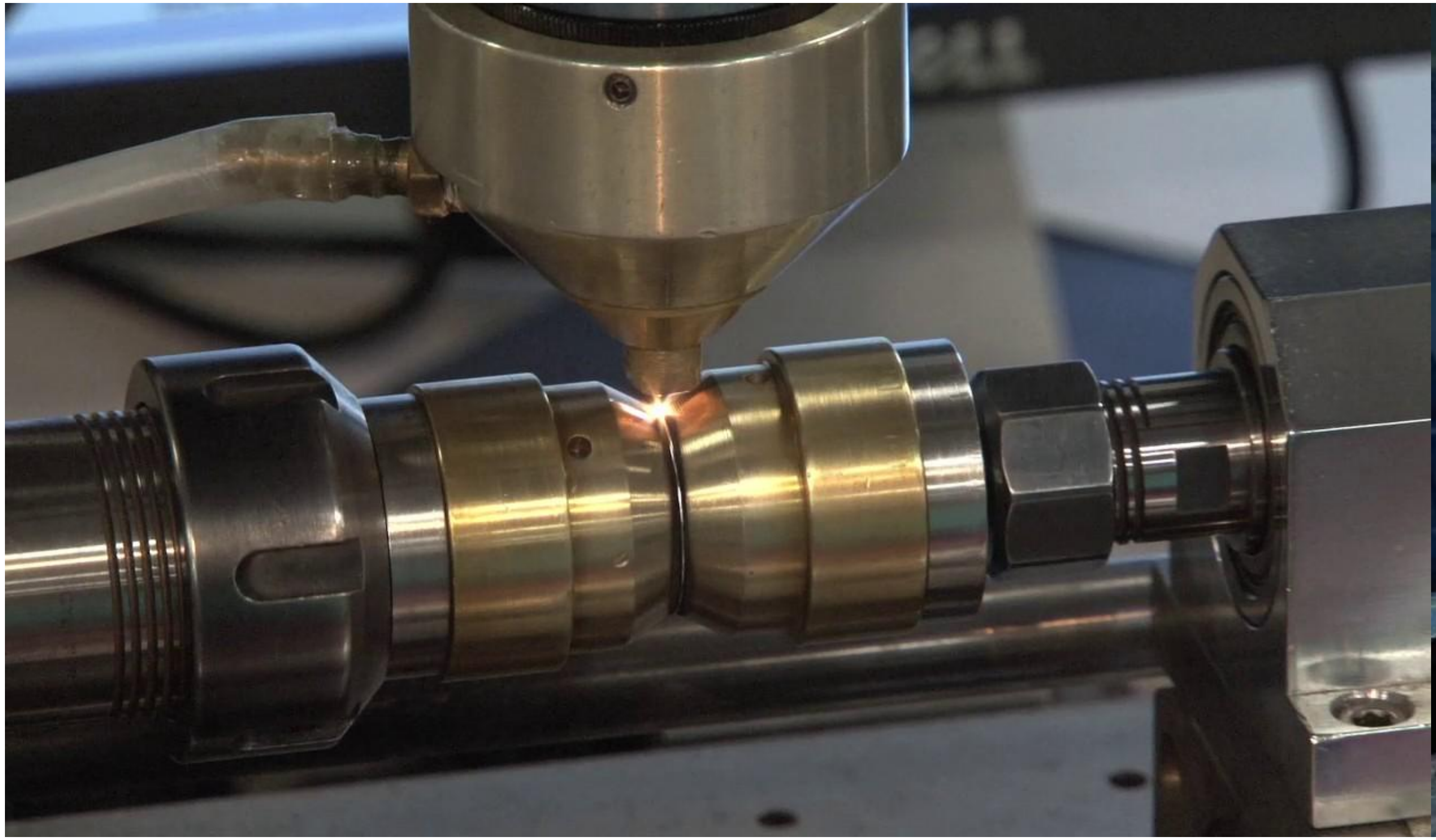
In the automotive industry, welding of transmission components is the most wide-spread application.

The laser beam may be pulsed (in milliseconds) for applications such as spot welding of thin materials, with power levels up to 100kW. Continuous multi-kW laser systems are used for deep welds on thick sections.

Laser beam welding produces welds of good quality, with minimum shrinkage and distortion. The process can be automated so as to be used on a variety of materials with thickness upto 25mm; it is particularly effective on thin workpieces.



27.8 Application of Laser-beam Welding (LBW)



27.9.1 Oxyfuel Gas Cutting

In addition to mechanical means, a piece of materials can be divided into two or more pieces or into various contours by the use of heat source that melts and removes a narrow zone in the workpiece. The sources of heat can be torches, electric arcs, or lasers.

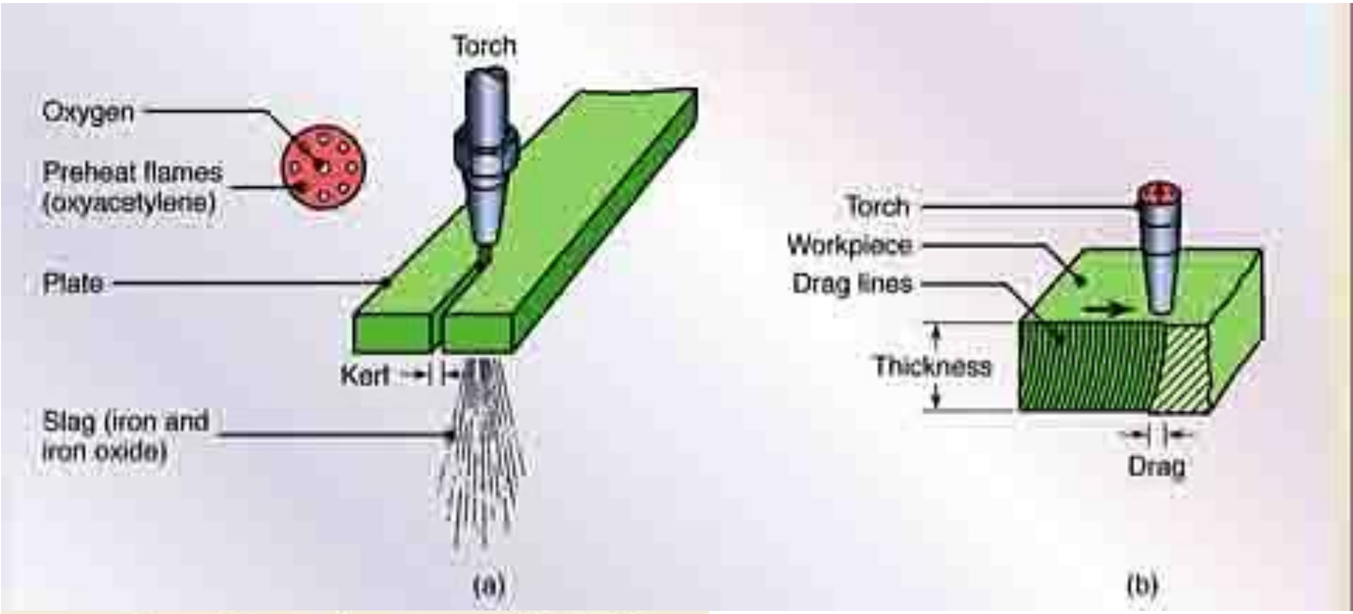
27.9.1 Oxyfuel Gas Cutting: Oxyfuel gas cutting (OFC) is similar to oxyfuel welding, but the heat source is now used to remove a narrow zone from a metal plate or sheet. This process is particularly suitable for steels.

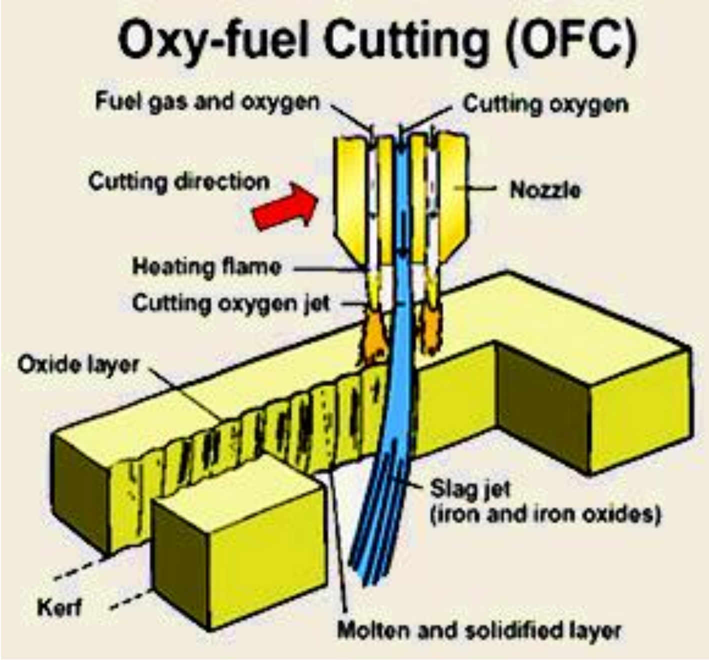
The basic reactions with steel are:

$$\mathrm{Fe} + \mathrm{O} \rightarrow \mathrm{FeO} + \mathrm{Heat} \quad \ldots\ldots\ldots..(27.3)$$

$$3\mathrm{Fe} + 2O_2 \rightarrow Fe_3O_4 + \mathrm{Heat}\ldots\ldots\ldots(27.4)$$

$$\text{and } 4\mathrm{Fe} + 3O_2 \rightarrow 2Fe_2O_3 + \mathrm{Heat} \quad \ldots\ldots(27.5)$$





27.9.1 Oxyfuel Gas Cutting

The greatest heat is generated by ***second reaction***, and it can produce a temperature to about ($\mathbf{870^0}\boldsymbol{C}$). However, this temperature is not sufficiently high to cut steels, so the workpiece is *preheated* with fuel gas, and oxygen is introduced later. The higher the carbon content of the steel is, the higher the preheating temperature must be.

Cutting occurs mainly by the oxidation (burning) of the steel; some melting also takes place. ***Cast irons and steel casting can also be cut by this method.*** The process also generates a kerf similar to that produced by sawing with a saw blade.

The maximum thickness that can be cut by OFC depends mainly on the gases used. With oxyacetylene gas, the maximum thickness is about 300 to 350mm (12 to 14 in.). Kerf widths range from about 1.5mm to 10mm, with reasonably good control of tolerances. The flame leave drag lines on the cut surface, which ends up rougher than surfaces produced by sawing, by blanking, or by other operations using mechanical cutting tools. Distortion caused by uneven temperature distribution can be a problem in OFC.

27.9.1 Oxyfuel Gas Cutting (Applications)

27.9.2 Arc cutting

Arc-cutting processes are based on the same principles as arc-welding processes. A variety of materials can be cut at high speeds by arc cutting.

In air carbon-arc cutting (CAC-A), a carbon electrode is used, and the molten metal is blown away by a high-velocity air jet.

Plasma-arc cutting (PAC) produces the highest temperature. It is used for rapid cutting of nonferrous and stainless-steels plates. The cutting productivity of this process is higher than that of oxyfuel gas methods. It produces good surface finish and narrow kerfs.

27.10 Welding safety

Surroundings. Because of the heat sources, such as open flames, arcs, sparks, and hot metal, used in welding and related operations, fire and explosion hazards are always present in the work area. Thus, welding processes should be carried out away from all combustible materials, including flammable fluids, vapors, gases, fuel, and wood.

Personal danger. Fires and explosions can cause serious injury and even fatality. Protection of the operator's eyes, faces, and body against sparks, spatter, and infrared and ultraviolet radiation is essential. Several types of safety equipment and protective clothing are available; they should be used.

Noise and shock. Excessive and prolonged noise generated by welding or cutting operations can cause temporary or permanent hearing loss. Ear protection devices should be used. Welding and related methods and machinery that use electricity as a source of energy is also present hazards. Proper installation and maintenance of equipment and training of personnel are essential.

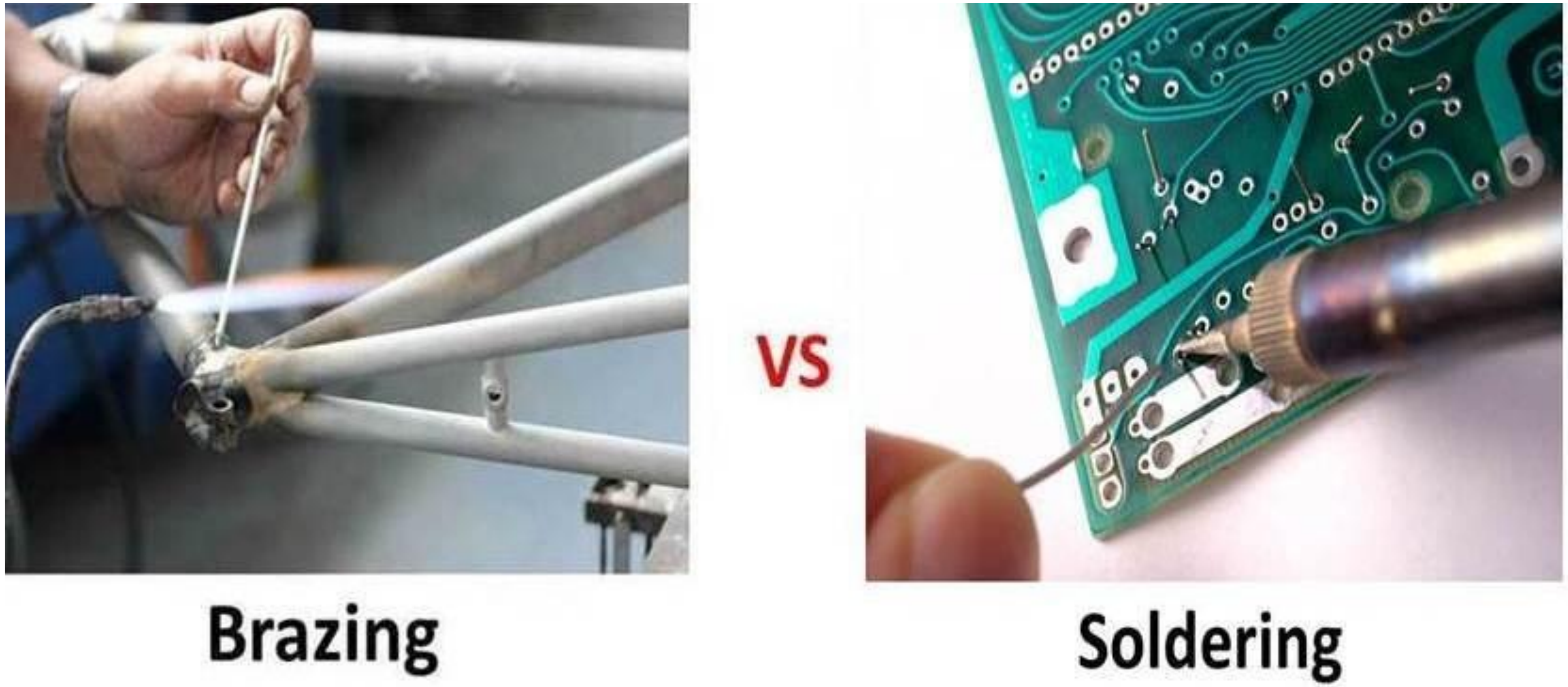
Fumes. Various shielding gases are used during welding operations. Some of these gases are toxic and can be hazardous to health. Consequently, environmental issues are involved in the use of welding processes. Some important factors to be considered follow: the nature of the fumes and gases evolved during welding; the proper disposal of used electrodes, fluxes, and slag.

Soldering, Brazing, and Welding

- Soldering, brazing, and welding are all methods of joining two or more pieces of metal and selected other materials. They are also methods used to fill gaps in metal parts.
- In welding, the two metals (or thermoplastic) must be similar. For example, ***copper cannot be welded to steel***. Welding uses high temperatures to melt and join two metal parts. A filler metal is often used as well. When properly done, the finished weld is as strong as the surrounding metal. But if the process is not carried out and the welder applies too much heat, it can change the metal's properties and weaken the weld. There are several different types of welding, including metal inert gas (MIG), arc, electron beam, laser, and stir friction. Welding is also widely used to slice apart large metal structures by melting through them.

Soldering, Brazing, and Welding

- Brazing joins two metals by heating and melting a filler (alloy) that bonds to the two pieces of metal and joins them. ***The filler obviously must have a melting temperature below that of the metal pieces***. Brazing can join ***dissimilar metals*** such as aluminum, silver, copper, gold, and nickel. ***Flux is often used during brazing***. It is a liquid that promotes wetting, which lets the filler flow over the metal parts to be joined. It also cleans the parts of oxides so that the filler bonds more tightly to the metal parts. In addition, fluxes are used in welding to clean the metal surfaces.
- Properly brazed joints can be stronger than the pieces being joined, but are not as strong as welded joints. Brazing also has ***minimal effects*** on the two metal parts.



Soldering, Brazing, and Welding

- Soldering is a low-temperature analog to brazing. By the American Welding Society's definition, ***soldering takes place with fillers*** (also known as solders) that melt at below 840°F (450°C). Metals that can be soldered include gold, silver, copper, brass, and iron. ***The filler, called solder, melts***. When it solidifies, it is bonded to the metal parts and joins them. ***The bond is not as strong as brazed joint or welded one***. Solder was once made mainly of lead, but environmental concerns are pushing industry to lead-free alternatives.
- ***Flux is used in soldering***, just as it is in brazing and welding to clean the metal surfaces and make it easy for the solder to flow over the pieces to be joined.
- Soldering is also used to join electrical components. The joint is not necessarily strong or structural, but electrically connects the parts with conductive solder.