


GLOBAL MANUFACTURING

ARAUJO, Anna Carla
Sept, 2015
Mechanical Engineering Department – POLI/COPPE/UFRJ

Joining Processes [#11]

Joining x Assembly

- **Joining**: is generally used for welding, brazing, soldering,and adhesive bonding, which form a permanent joint between the parts—a joint that cannot easily be separated.
- **Assembly**: usually refers to mechanical methods of fastening parts together. Some of these methods allow for easy disassembly, while others do not.
- The metallurgical processes of welding, brazing, and soldering are usually used to join metals and often involve the solidification of molten material.
- The use of discrete fasteners (such as bolts and nuts, screws, and rivets) requires the creation of aligned holes and produces stress localization. While the holes may affect performance, disassembly and reassembly can often be performed with relative ease.
- The adhesive bonding has grown with new developments in polymeric materials and is being used extensively in automotive and aircraft production. Any material can be joined to any other material, and the low-temperature joining is particularly attractive for composite materials. Production rates are often low, however, because of the time required for the adhesive to develop full strength.
- From a technical viewpoint, powder metallurgy is another consolidation process, because the end product is built up by the joining of a multitude of individual particles.

Welding

Welding is a materials joining process in which two or more parts are **coalesced** at their contacting surfaces by a suitable application of heat and/or pressure.

Many welding processes are accomplished by

- heat alone, with no pressure applied;
- a combination of heat and pressure;
- Or by pressure alone, with no external heat supplied.

In some welding processes a filler material is added to facilitate coalescence.

(1) fusion welding and

(2) solid-state welding

Welding processes

- **Oxyfuel gas welding (OFW)**
  - Oxyacetylene welding (OAW)
  - Pressure gas welding (PGW)
- **Arc welding (AW)**
  - Shielded metal arc welding (SMAW)
  - Gas metal arc welding (GMAW)
    - Pulsed arc (GMAW-P)
    - Short-circuit arc (GMAW-S)
    - Electrogas (GMAW-EG)
    - Spray transfer (GMAW-ST)*
  - Gas tungsten arc welding (GTAW)
  - Flux-cored arc welding (FCAW)
  - Submerged arc welding (SAW)
  - Plasma arc welding (PAW)
  - Stud welding (SW)
- **Resistance welding (RW)**
  - Resistance spot welding (RSW)
  - Resistance seam welding (RSW)
  - Projection welding (RPW)
- **Solid-state welding (SSW)**
  - Forge welding (FOW)
  - Cold welding (CW)
  - Friction welding (FRW)
  - Ultrasonic welding (USW)
  - Explosion welding (EXW)
  - Roll welding (ROW)
- **Unique processes**
  - Thermit welding (TW)
  - Laser-beam welding (LBW)
  - Electroslag welding (ESW)
  - Flash welding (FW)
  - Induction welding (IW)
  - Electron-beam welding (EBW)

*Not a standard AWS designation

TABLE 30-2 Weldability or Joinability of Various Engineering Materials[a]

Material	Arc Welding	Oxyacetylene Welding	Electron-Beam Welding	Resistance Welding	Brazing	Soldering	Adhesive Bonding
Cast iron	C	R	N	S	D	N	C
Carbon and low-alloy steel	R	R	C	R	R	D	C
Stainless steel	R	C	C	R	R	C	C
Aluminum and magnesium	C	C	C	C	C	S	R
Copper and copper alloys	C	C	C	C	R	R	C
Nickel and nickel alloys	R	C	C	R	R	C	C
Titanium	C	N	C	C	D	S	C
Lead and zinc	C	C	N	D	N	R	R
Thermoplastics	Heated tool R	Hot gas R	N	Induction C	N	N	C
Thermosets	N	N	N	N	N	N	C
Elastomers	N	N	N	N	N	N	R
Ceramics	N	S	C	N	N	N	R
Dissimilar metals	D	D	C	D	D/C	R	R

[a] R, recommended (easily performed with excellent results); C, commonly performed; D, difficult; S, seldom used; N, not used.

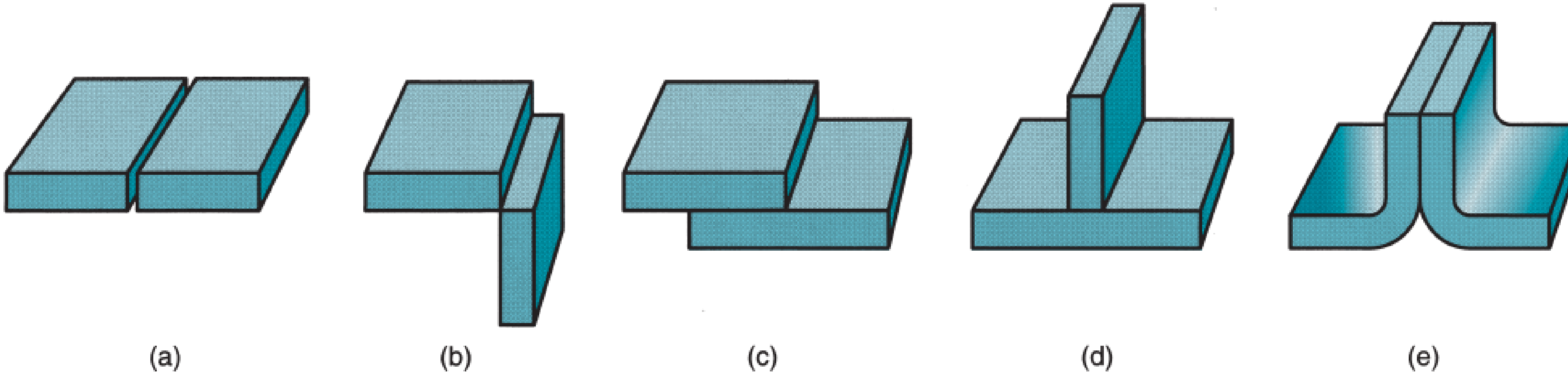
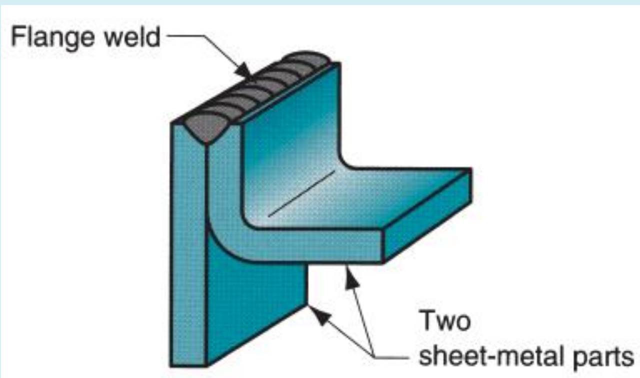
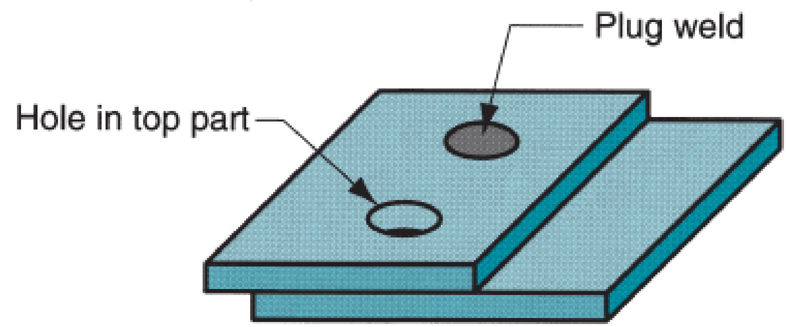
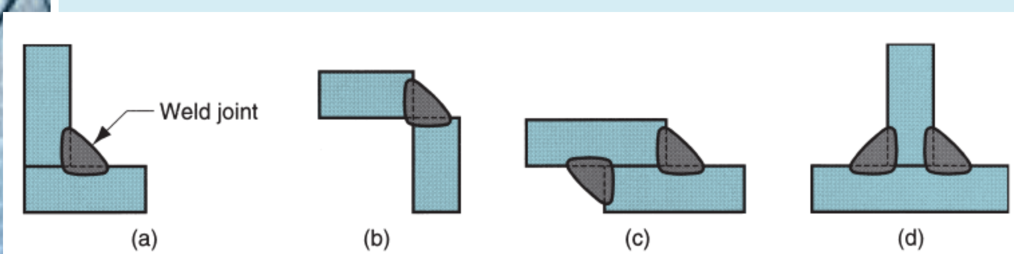
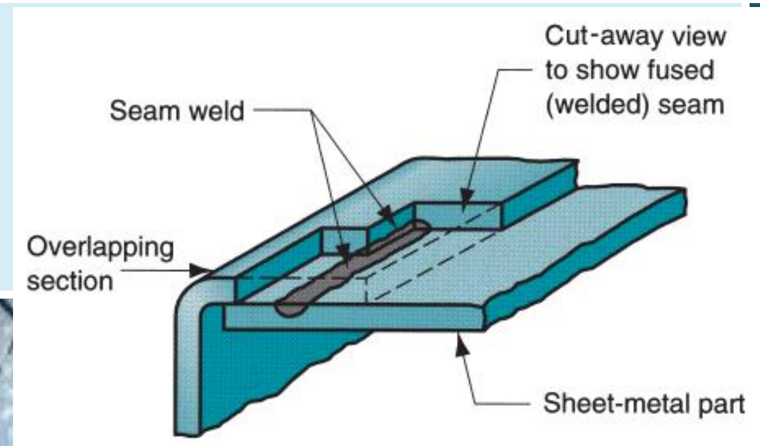


FIGURE 22.2 Five basic types of joints: (a) butt, (b) corner, (c) lap, (d) tee, and (e) edge. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)









Fusion Welding

- Fusion-welding processes use heat to melt the base metals.
- Filler:
  - A filler metal is added to the molten pool to facilitate the process and provide bulk and strength to the welded joint.
  - A fusion-welding operation in which no filler metal is added is referred to as an autogenous weld.

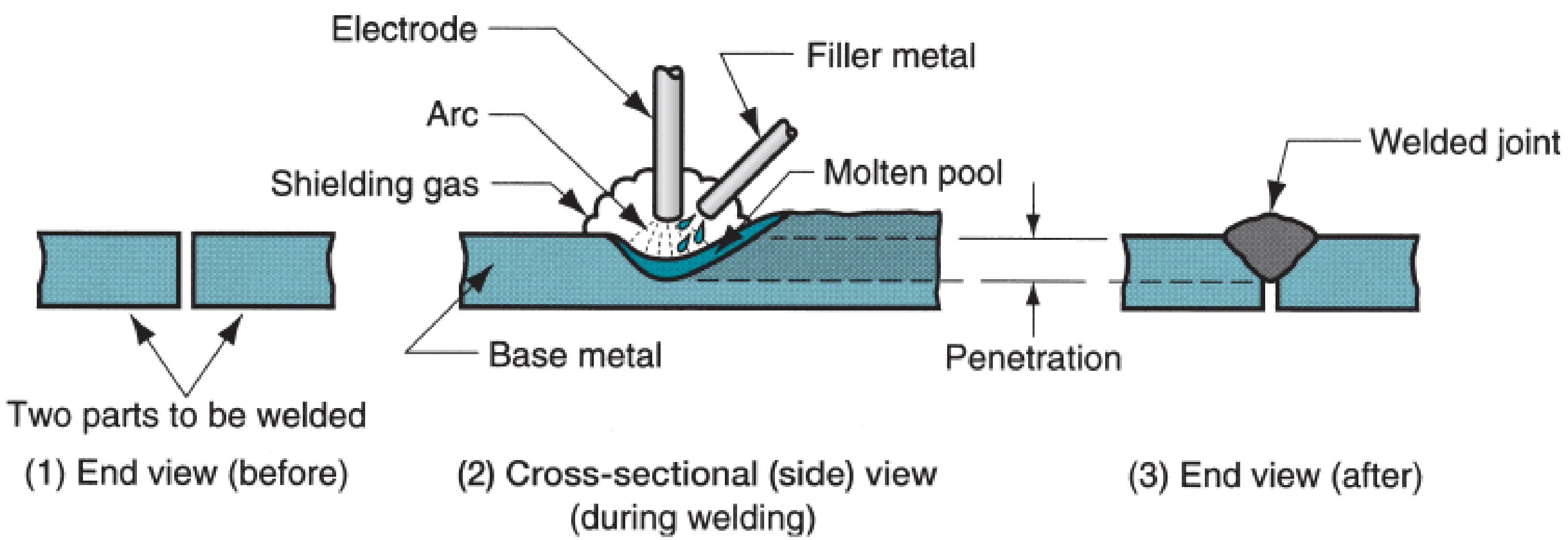


FIGURE 22.1 Basics of arc welding: (1) before the weld; (2) during the weld (the base metal is melted and filler metal is added to the molten pool); and (3) the completed weldment. There are many variations of the arc-welding process. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Physic of Welding – Power Density

Power density can be defined as the **heating power transferred to the work per unit surface area**, W/mm^2. The time to melt the metal is inversely proportional to the power density.

At low power densities, a significant amount of time is required to cause melting. If power density is too low, the heat is conducted into the work as rapidly as it is added at the surface, and melting never occurs.

$$PD = \frac{P}{A}$$

Differences among welding processes in this range are:

(1) the rate at which welding can be performed and/or

(2) The size of the region that can be welded.

TABLE 22.1 Comparison of several fusion-welding processes on the basis of their power densities.

	Approximate Power Density	
Welding Process	**W/mm^2**	**$Btu/sec\text{-}in^2$**
Oxyfuel welding	10	6
Arc welding	50	30
Resistance welding	1000	600
Laser beam welding	9000	5000
Electron beam welding	10,000	6000

Physic of Welding – Heat Balance in Fusion Welding

The quantity of heat required to melt a given volume of metal depends on:

(1) the heat to raise the temperature of the solid metal to its melting point, which depends on the metal's volumetric specific heat,

(2) the melting point of the metal $\mathbf{T_m}$, and

(3) the heat to transform the metal from solid to liquid phase at the melting point, which depends on the metal's heat of fusion.

$$U_m = KT_m^2$$

U_m = the unit energy for melting

K = Conversion Unit Constant

$$H_w = f_1 f_2 H$$

Hw = net Heat

F = factors

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

TABLE 22.2 Melting temperatures on the absolute temperature scale for selected metals.

Metal	Melting Temperature °K[a]	Melting Temperature °R[a]	Metal	Melting Temperature °K[a]	Melting Temperature °R[b]
Aluminum alloys	930	1680	Steels		
Cast iron	1530	2760	Low carbon	1760	3160
Copper and alloys			Medium carbon	1700	3060
Pure	1350	2440	High carbon	1650	2960
Brass, navy	1160	2090	Low alloy	1700	3060
Bronze (90 Cu–10 Sn)	1120	2010	Stainless steels		
Inconel	1660	3000	Austenitic	1670	3010
Magnesium	940	1700	Martensitic	1700	3060
Nickel	1720	3110	Titanium	2070	3730

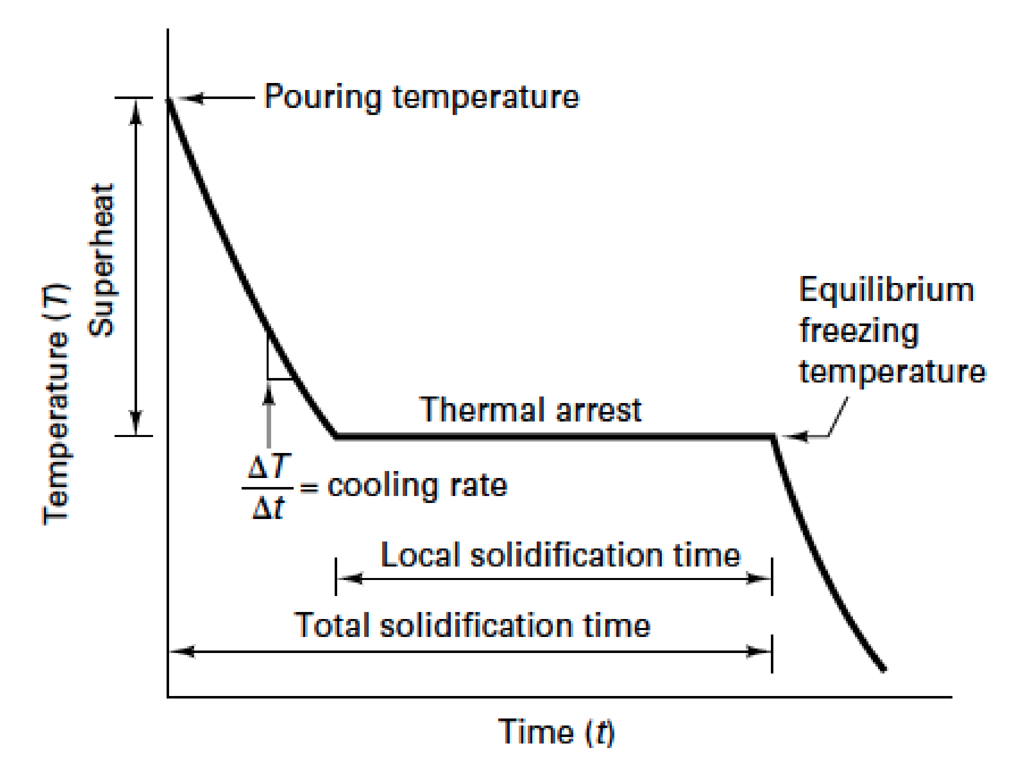
Based on values in [2].

[a]Kelvin scale = Centigrade (Celsius) temperature + 273.

[b]Rankine scale = Fahrenheit temperature + 460.

R_{Hw} = rate of heat energy delivered to the operation for welding

How pure metal solidifies? [CASTING]



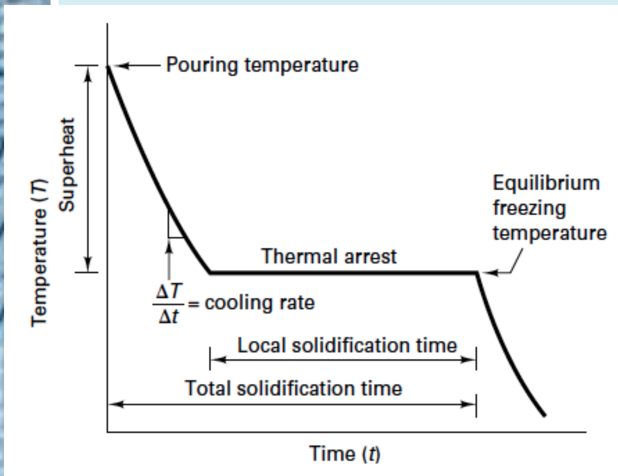
Pouring temperature: the temperature of the liquid metal when it first enters the mold.

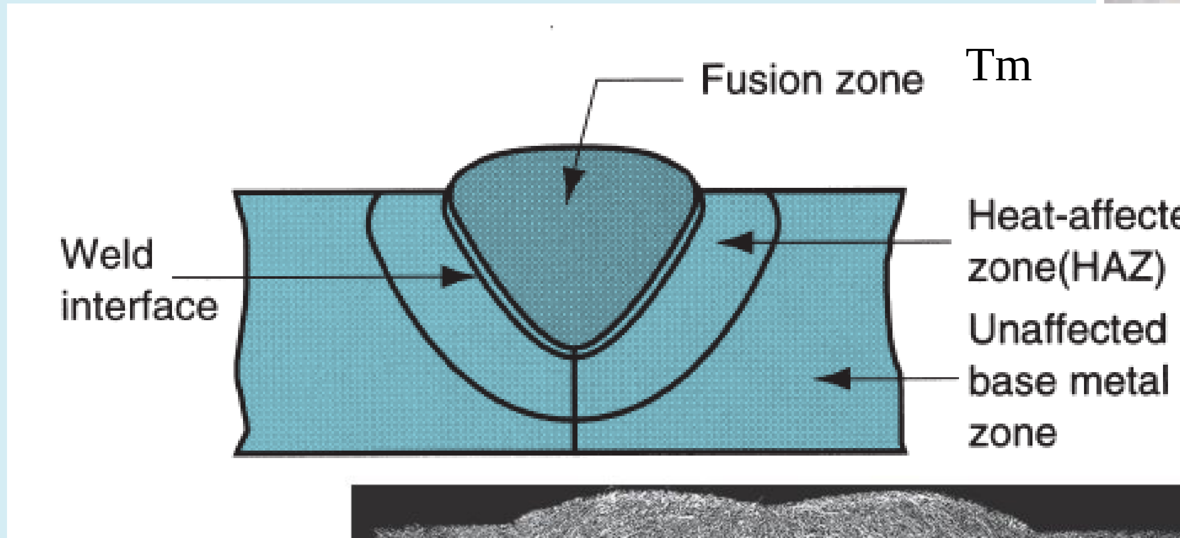
Superheat: is the difference between the pouring temperature and the freezing temperature of the material.

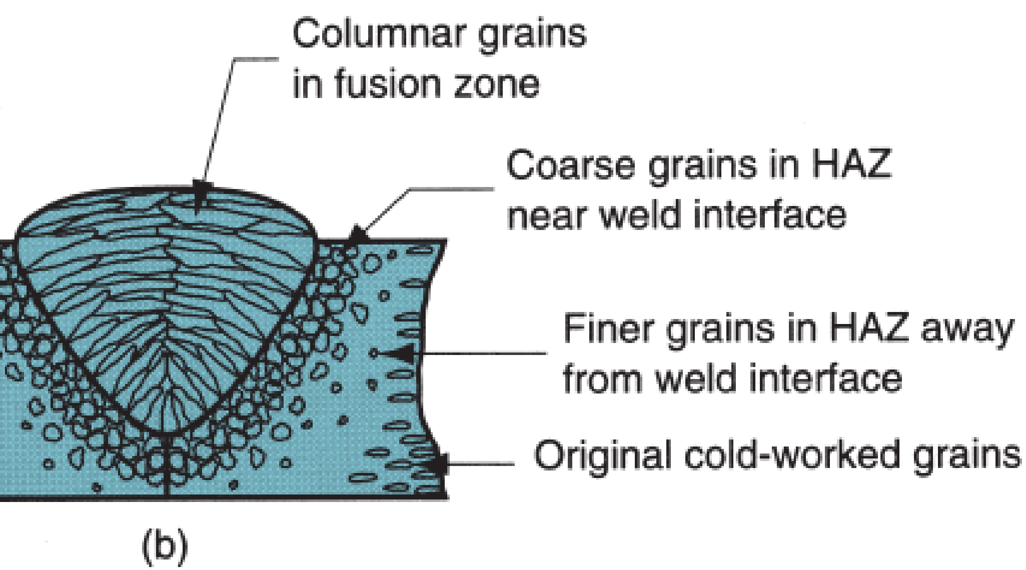
Cooling rate: the rate at which the liquid or solid is cooling and can be viewed as the slope of the cooling curve at any given point.

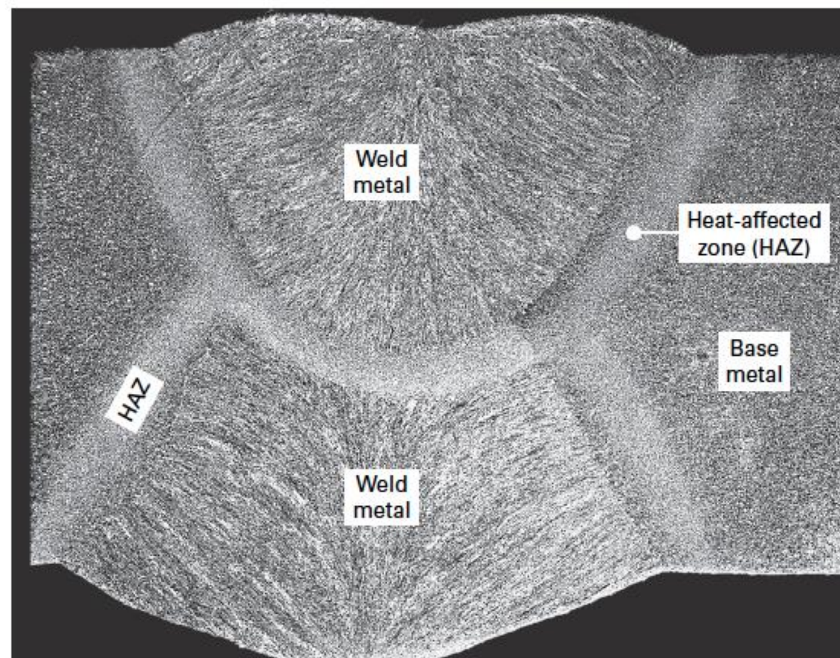
Thermal arrest: is the plateau in the cooling curve that occurs during the solidification of a material with fixed melting point. At this temperature, the energy or heat being removed from the mold comes from the latent heat of fusion that is being released during the solidification process.

Physic of Welding – Microstructure / Solidification









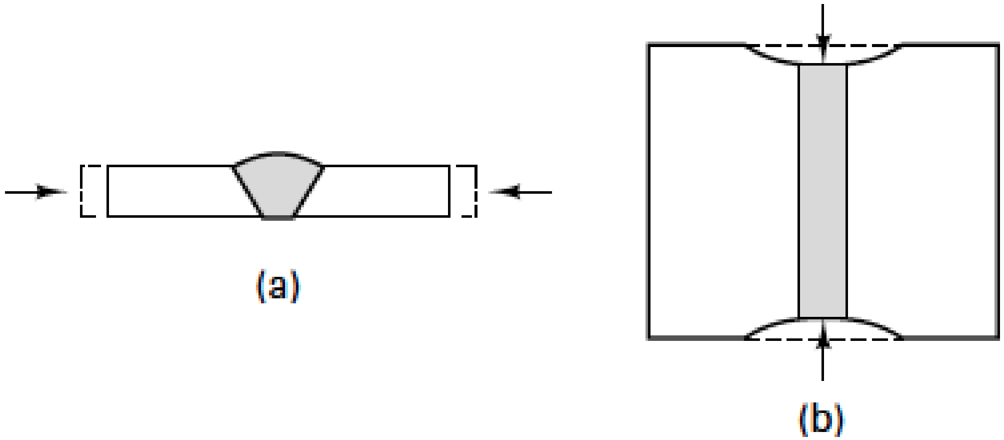


FIGURE 30-15 Shrinkage of a typical butt weld in the transverse (a) and longitudinal (b) directions as the material responds to the induced stresses. Note that restricting transverse motion will place the entire weld in transverse tension.

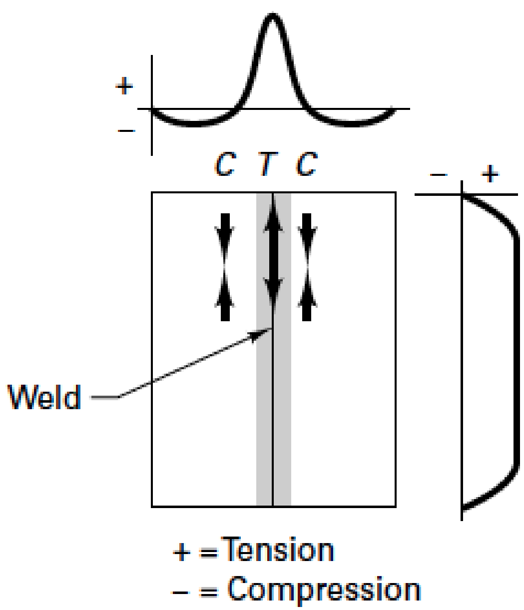
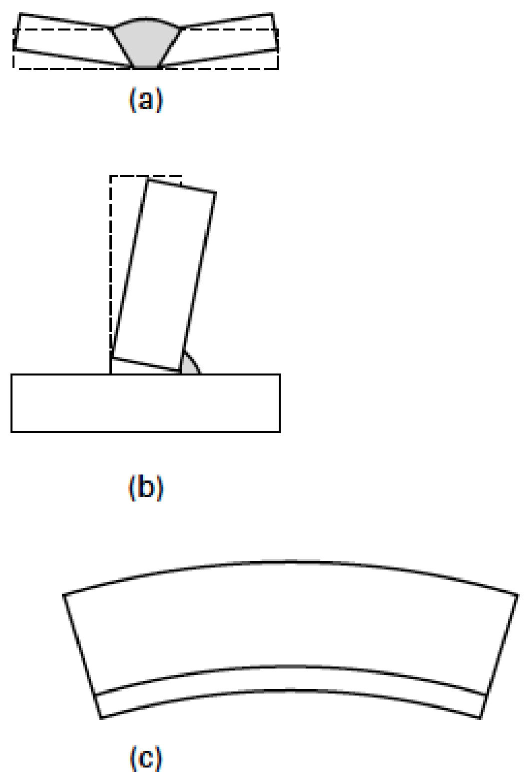
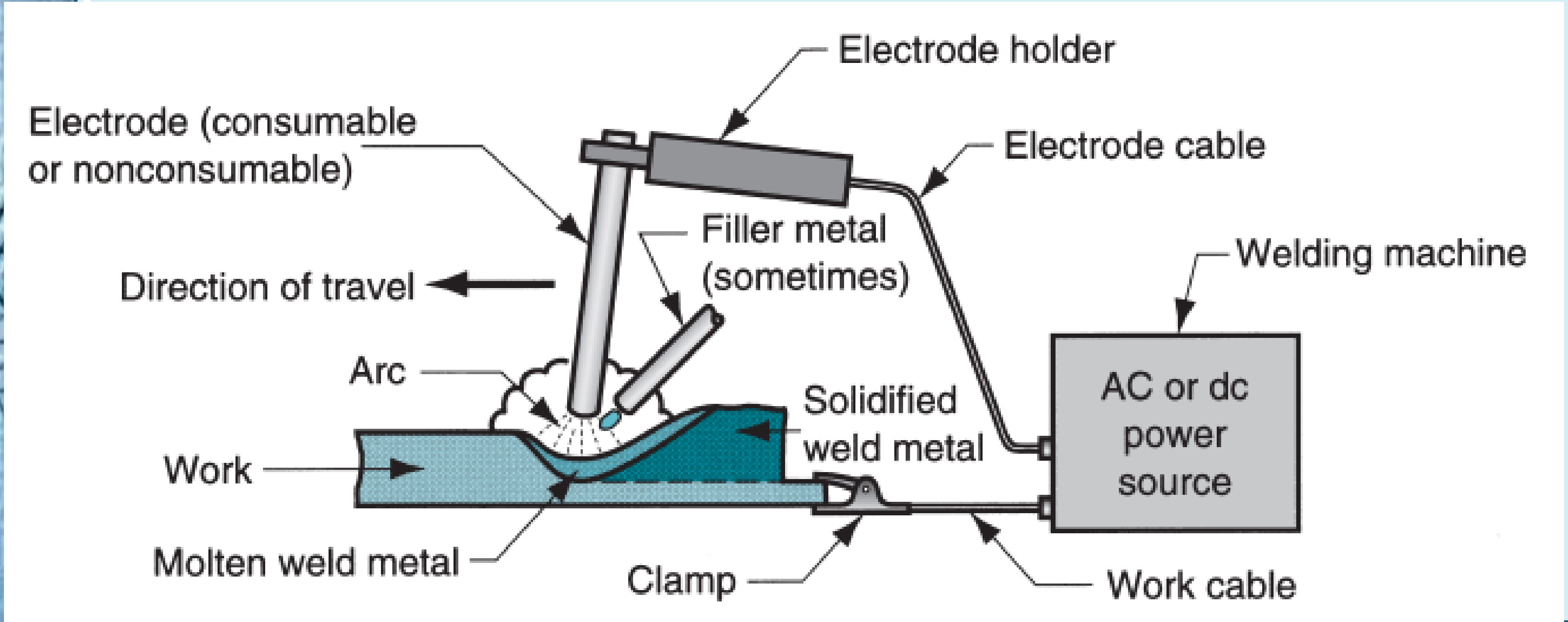


FIGURE 30-14 Schematic of the longitudinal residual stresses in a fusion-welded butt joint.

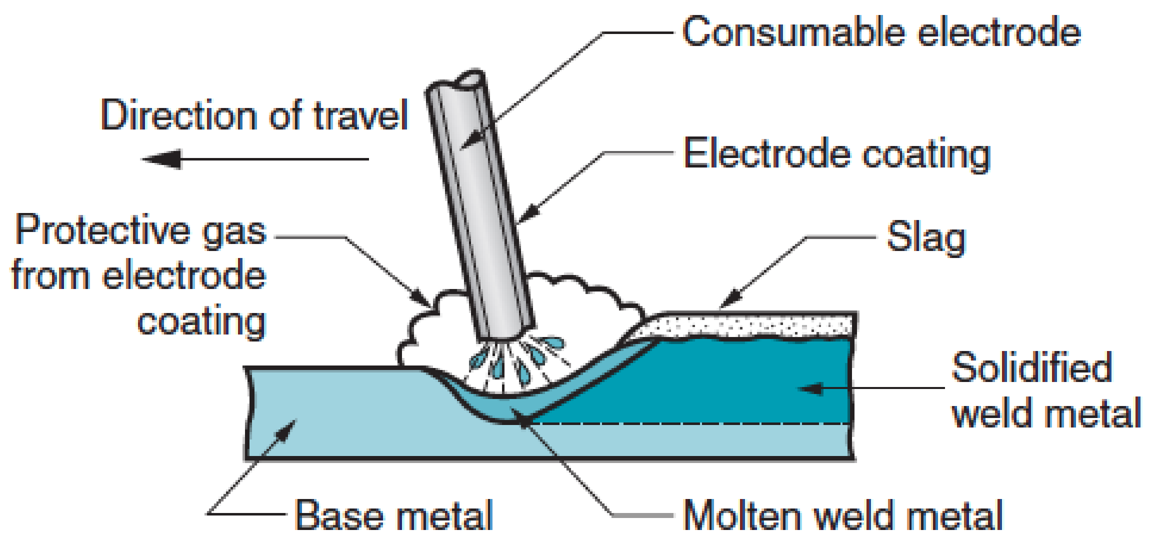


Arc Welding (AW)

- 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 the work. The same basic process is also used in arc cutting.
- 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 the work and then quickly separated from it by a short distance.



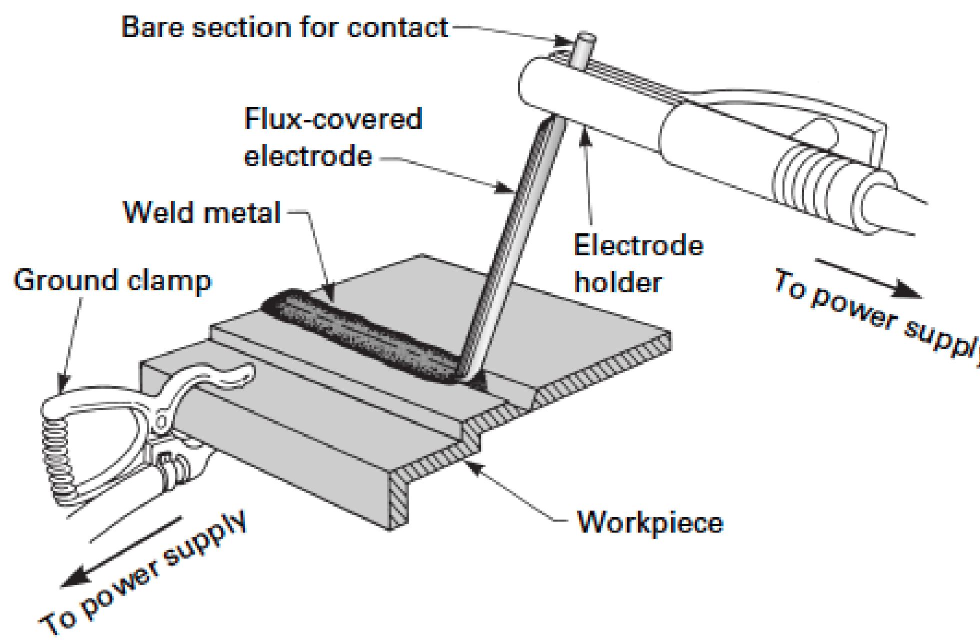
Shielded metal arc welding (SMAW)



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.

TABLE 31-3 Process Summary: Shielded Metal Arc Welding

Heat source	Electric arc
Protection	Slag from flux and gas from vaporized coating material
Electrode	Discontinuous, consumable
Material joined	Best for steel
Rate of heat input	Medium
Weld profile (D/W)	1
Current	<300 amps
Max. penetration	3–6 mm
Assets	Cheap, simple equipment
Limitations	Discontinuous, shallow welds; requires slag removal



E (X) XX X X

Minimum tensile strength, in 1.000 psi, as-deposited weld metal in non-stress-relieved condition.

45
60
70
80
90
100
120

Welding position
1 All
2 Flat and horizontal
3 Flat only

0–8

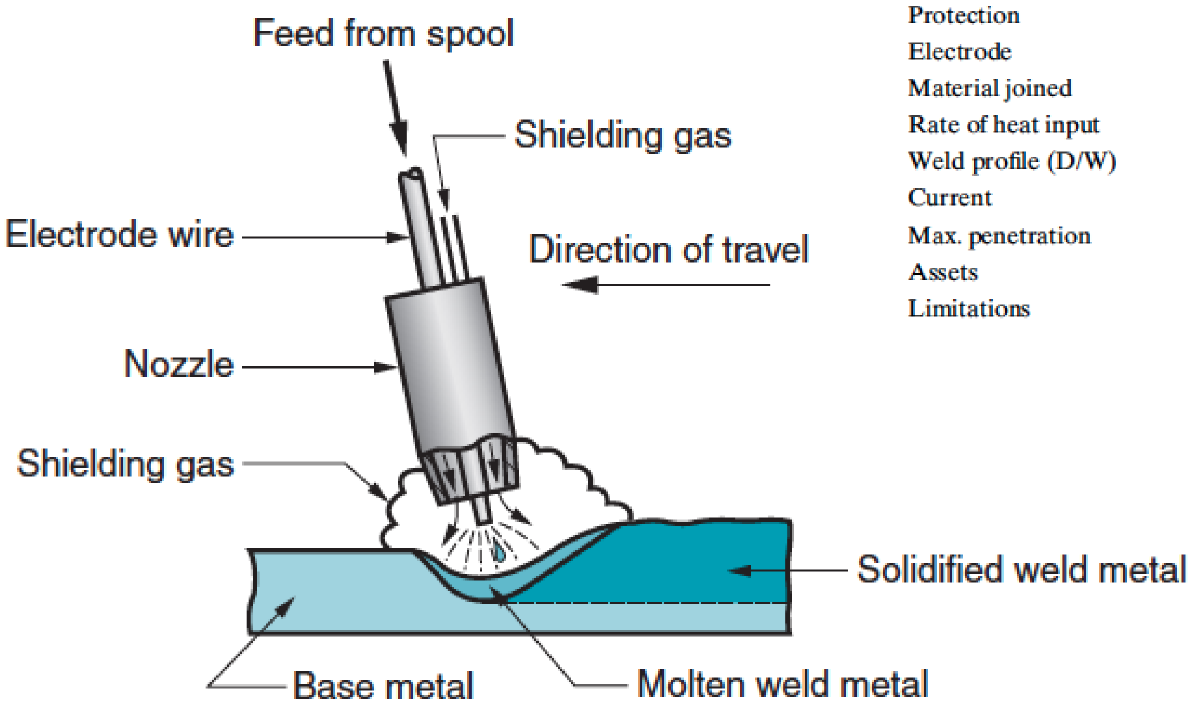
Current	Polarity	Type of coating
AC or DC	Straight or reversed	0 Cellulosic 1 Cellulosic + Ca and K 2 Titania 3 High titania–potassium 4 Titania + iron powder 5 Low hydrogen (lime) 6 Low hydrogen + potassium 7 Cellulosic + iron powder 8 Low hydrogen + iron powder

FIGURE 31-10 Designation system for arc-welding electrodes.

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.

Selection of gases (and mixtures of gases) depends on the metal being welded, as well as other factors. Inert gases are used for welding aluminum alloys and stainless steels, while CO2 is commonly used for welding low and medium carbon steel. (MIG/MAG)

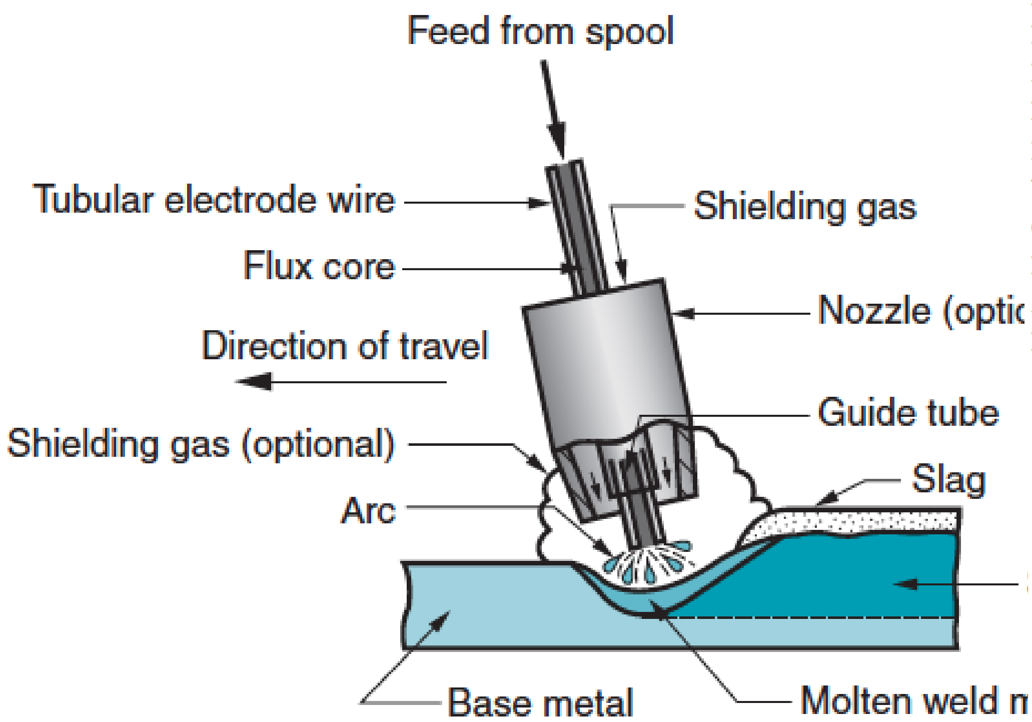


Heat source	Electric arc
Protection	Externally supplied shielding gas
Electrode	Continuous, consumable
Material joined	All common metals
Rate of heat input	Medium
Weld profile (D/W)	1
Current	<500 amps
Max. penetration	6–10 mm
Assets	No slag to remove
Limitations	More costly equipment than SMAW or FCAW

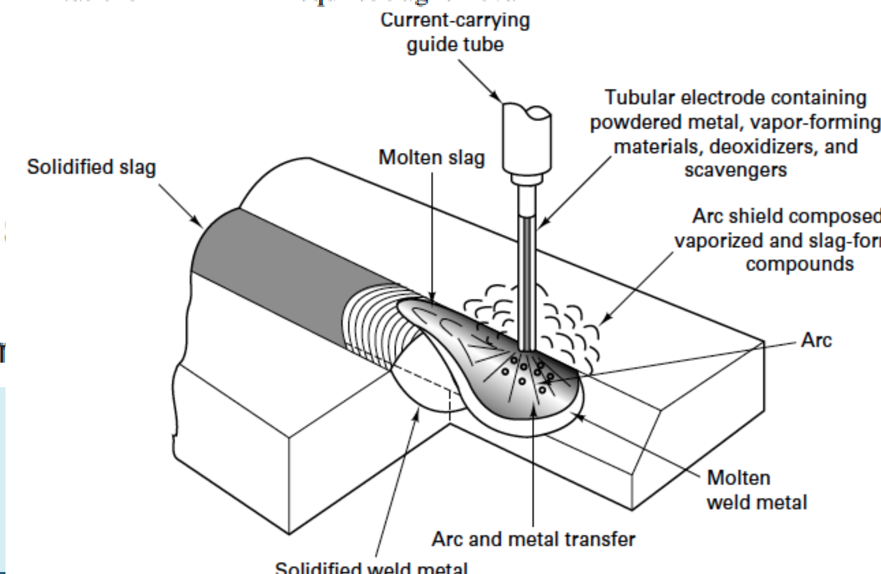
Flux-cored arc welding (FCAW)

Flux-cored arc welding (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.

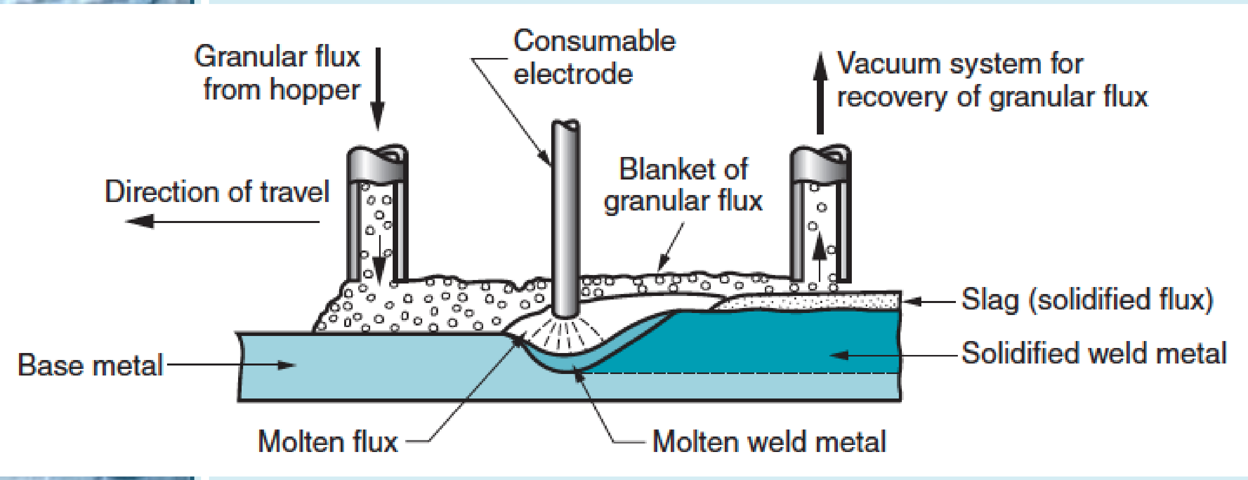
The tubular flux-cored “wire” is flexible and can therefore be supplied in the form of coils to be continuously fed through the arc-welding gun.

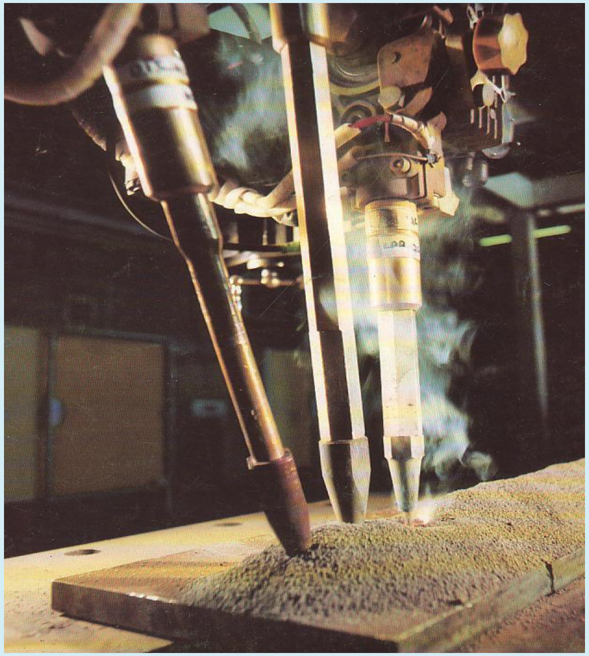


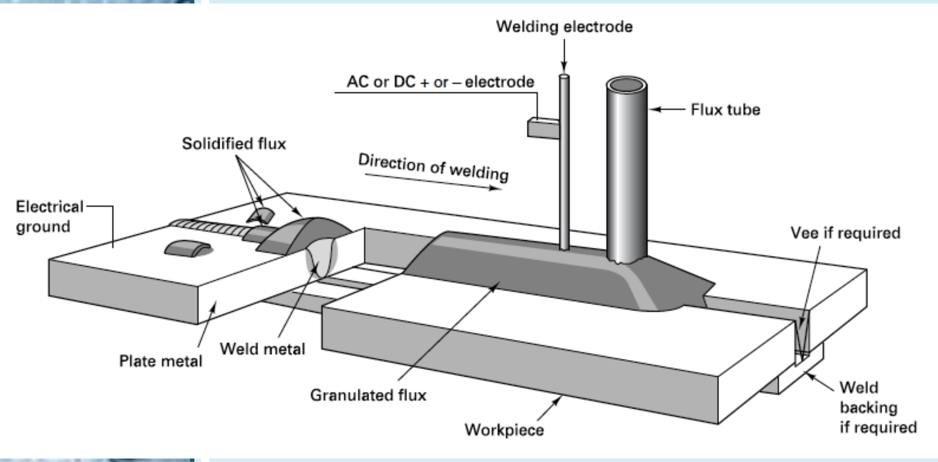
Heat source	Electric arc
Protection	Slag and gas from flux (optional secondary gas shield)
Electrode	Continuous, consumable
Material joined	Best for steel
Rate of heat input	Medium
Weld profile (D/W)	1
Current	<500 amps
Max. penetration	6–10 mm
Assets	Continuous electrode
Limitations	Requires slag removal



Submerged Arc Welding (SAW)



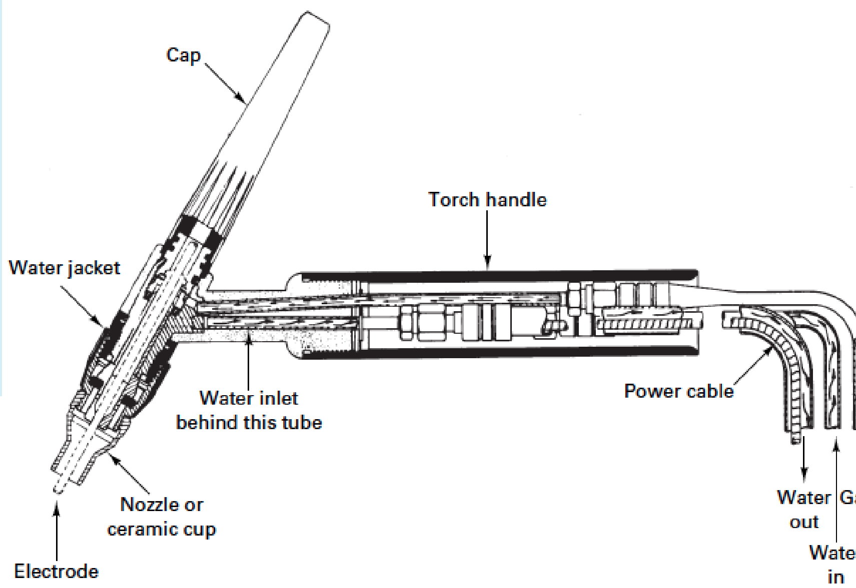


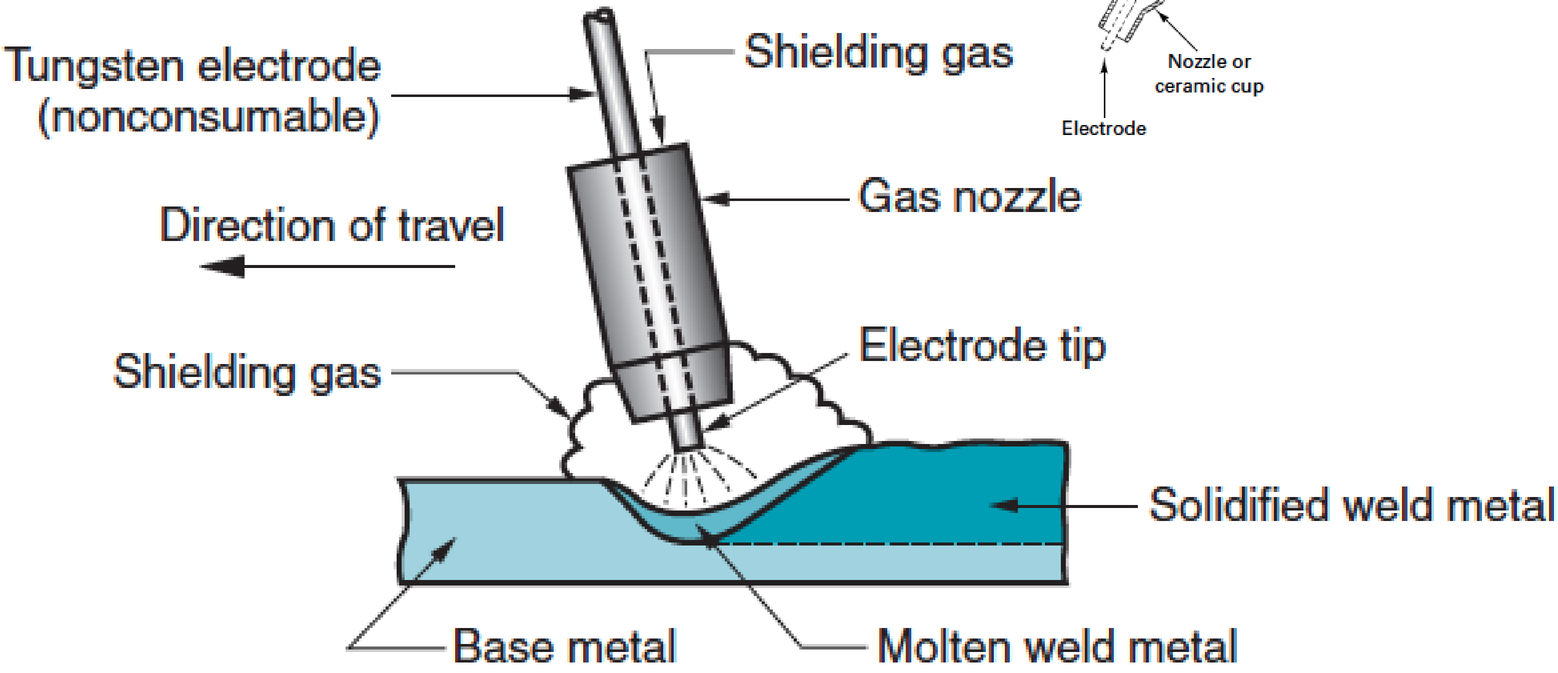


It is an arc-welding process that uses a continuous, consumable bare wire electrode, and arc shielding is provided by a cover of granular flux.

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.

Gas tungsten arc welding (GTAW)

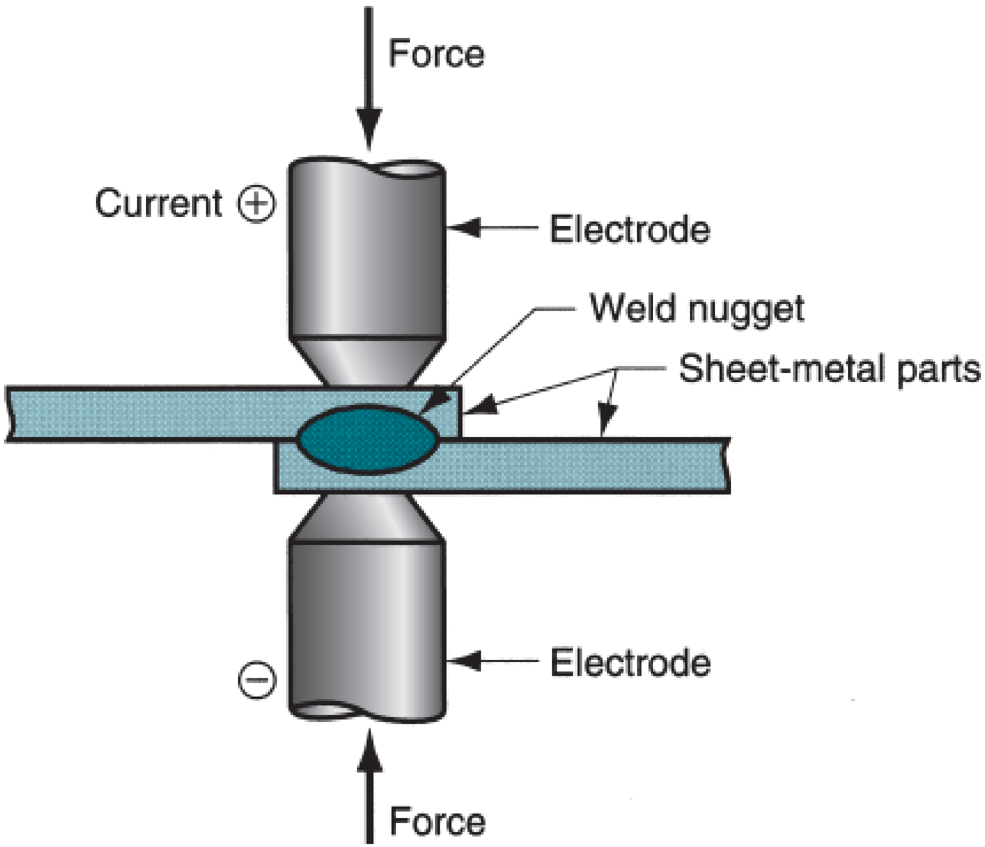


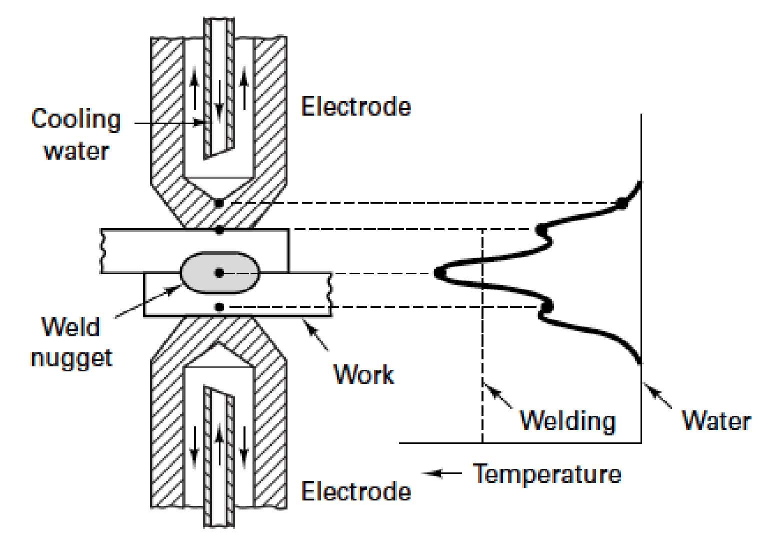


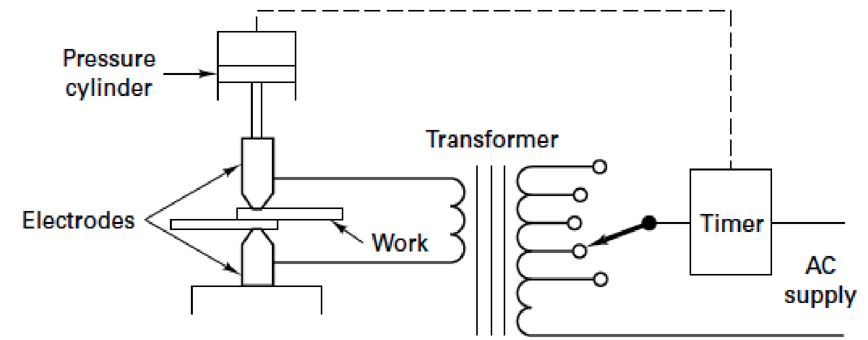
This process uses a nonconsumable tungsten electrode and an inert gas for arc shielding. The term TIG welding (tungsten inert gas welding) is often applied to this process.

Resistence Welding

Resistance welding (RW) is a group of fusion-welding processes that uses a combination of heat and pressure to accomplish coalescence, the heat being generated by electrical resistance to current flow at the junction to be welded.







$$H = I^2 R t$$

H = total heat input in joules
I = current in amperes
R = electrical resistance of the circuit in ohms
t = length of time during which current is flowing in seconds

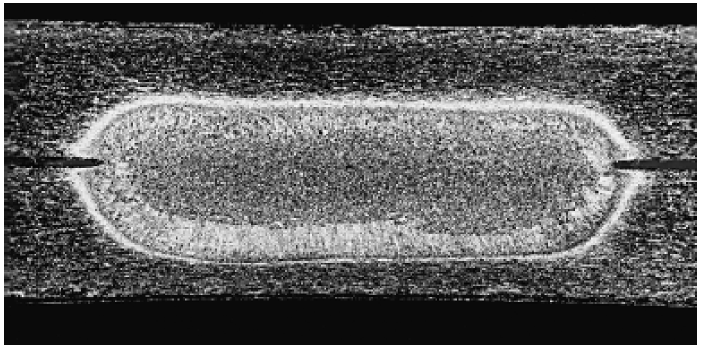


FIGURE 32-5 A spot-weld nugget between two sheets of 1.3-mm (0.05-in.) aluminum alloy. The nugget is not symmetrical because the radius of the upper electrode was greater than that of the lower electrode. *(Courtesy Locheed Martin Corporation, Bethesda, MD)*

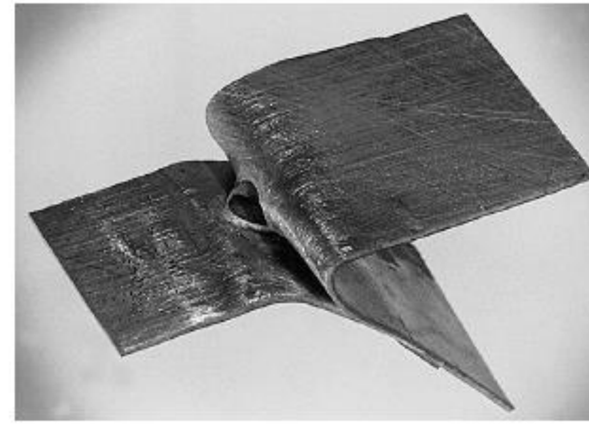


TABLE 32-1 Metal Combinations That Can Be Spot Welded

Metal	Aluminum	Brass	Copper	Galvanized Iron	Iron (Wrought)	Monel	Nichrome	Nickel	Nickel Silver	Steel	Tin Plate	Zinc
Aluminum	x										x	x
Brass		x	x	x	x	x	x	x	x	x	x	x
Copper		x	x	x	x	x	x	x	x	x	x	x
Galvanized Iron		x	x	x	x	x	x	x	x	x	x	
Iron (Wrought)		x	x	x	x	x	x	x	x	x	x	
Monel		x	x	x	x	x	x	x	x	x	x	
Nichrome		x	x	x	x	x	x	x	x	x	x	
Nickel		x	x	x	x	x	x	x	x	x	x	
Nickel Silver		x	x	x	x	x	x	x	x	x	x	
Steel		x	x	x	x	x	x	x	x	x	x	
Tin Plate	x	x	x	x	x	x	x	x	x	x		
Zinc	x	x	x									x

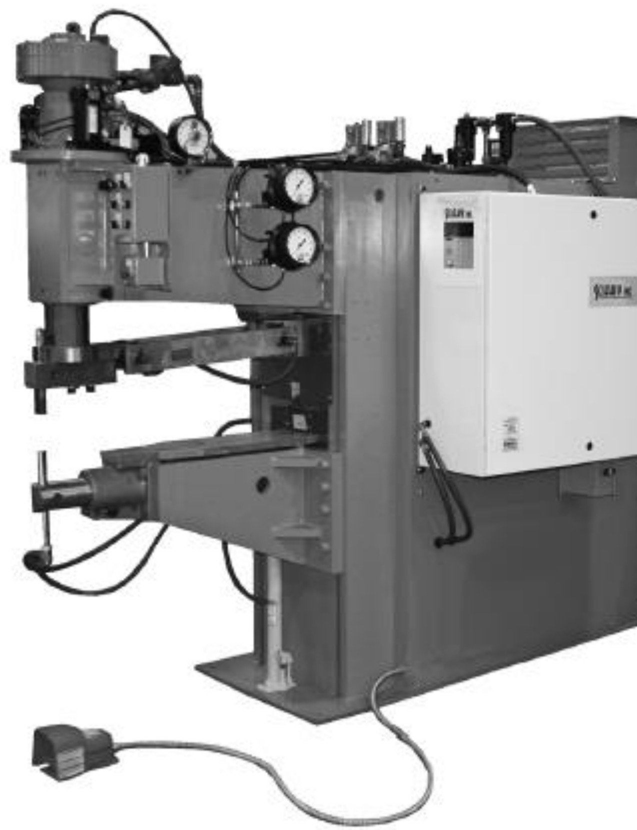
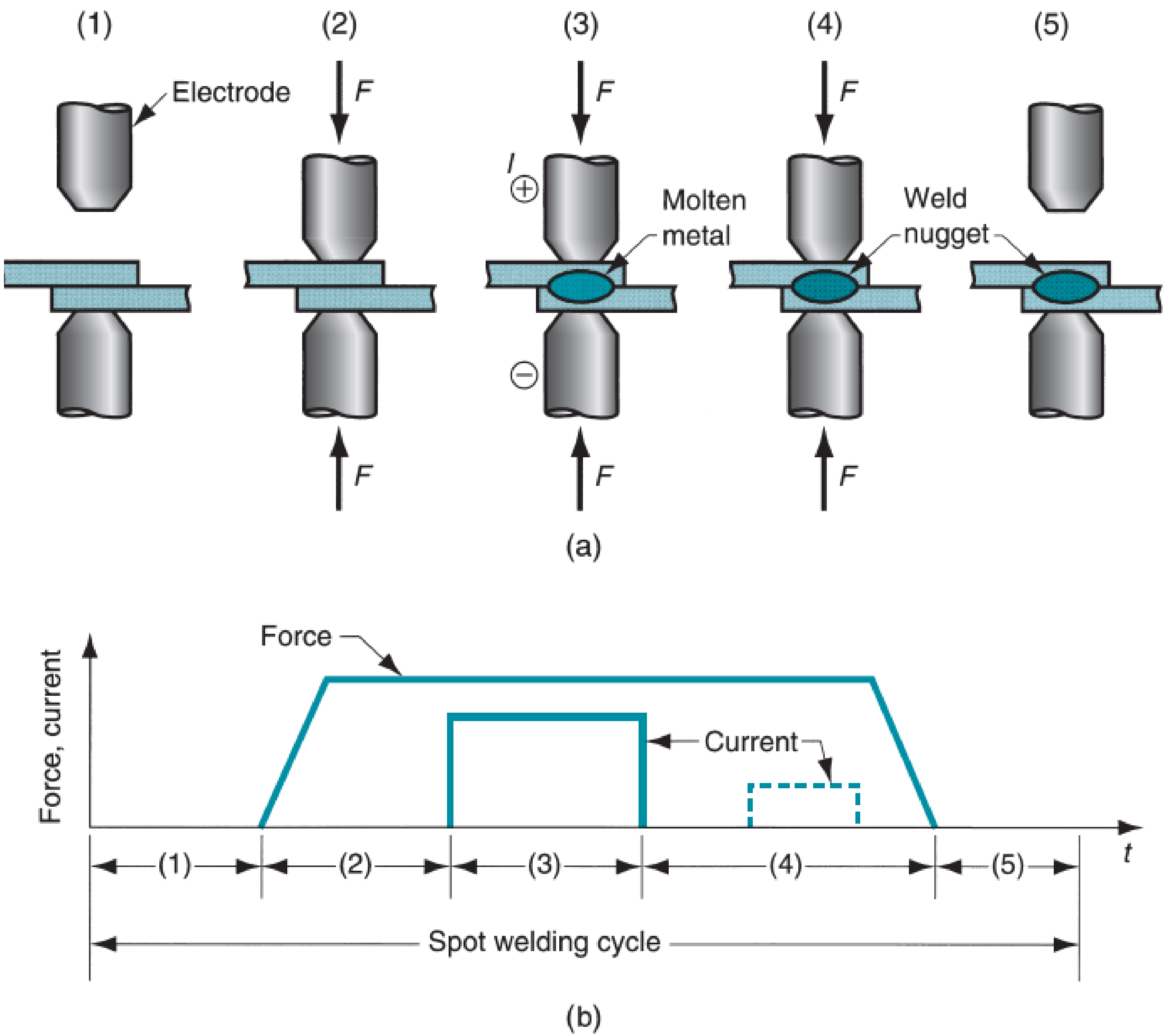
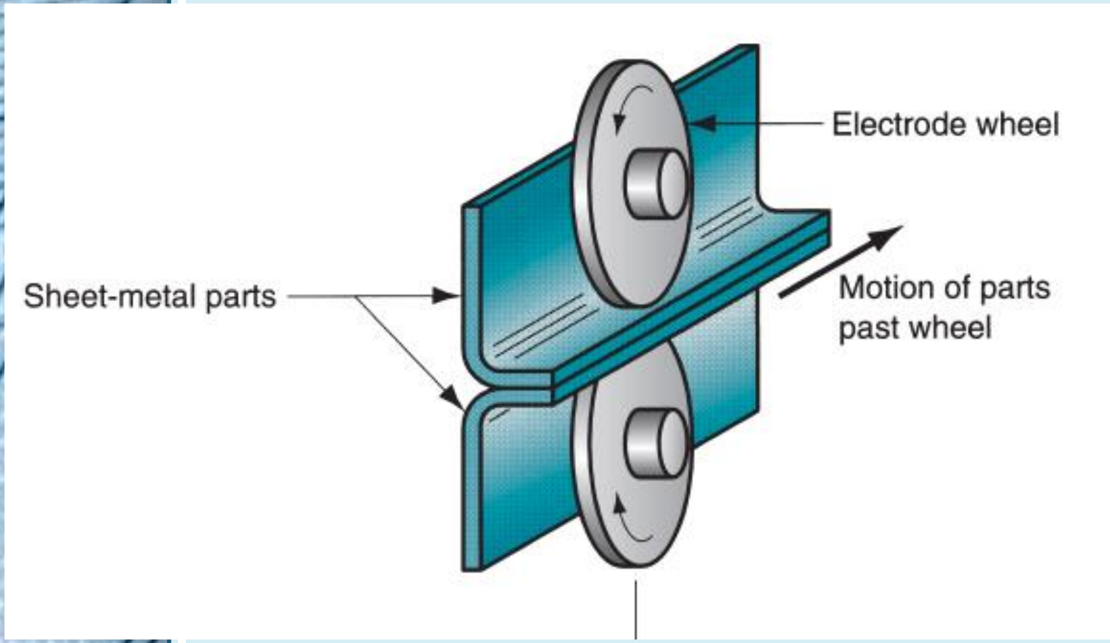
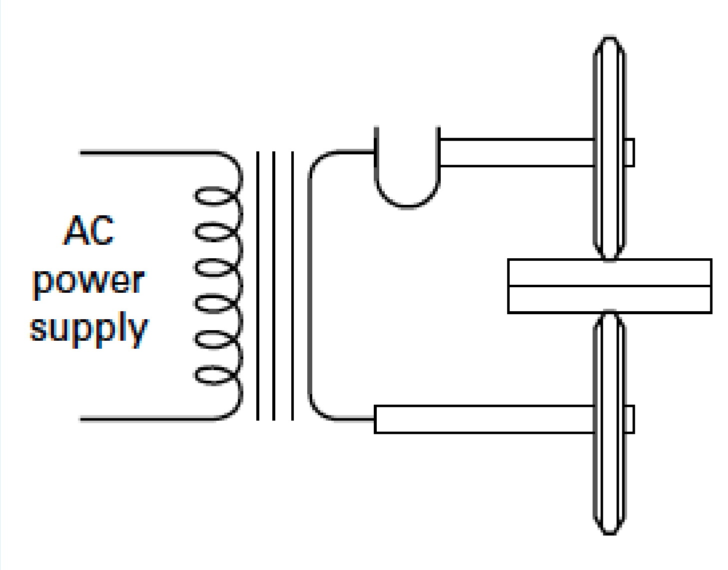


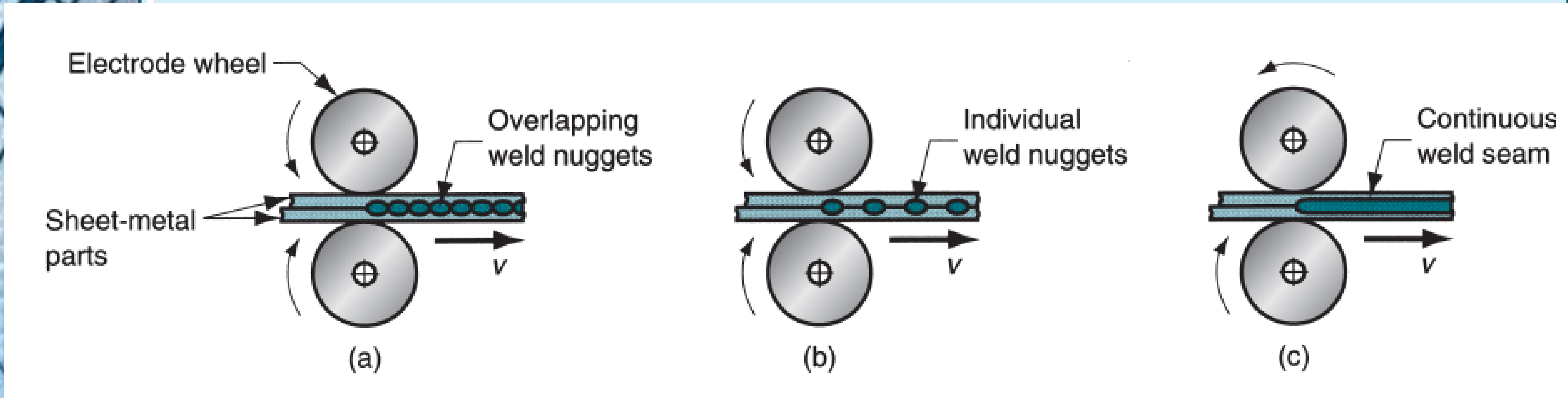
FIGURE 23.11 (a) Steps in a spot-welding cycle, and (b) plot of squeezing force and current during cycle. The sequence is: (1) parts inserted between open electrodes, (2) electrodes close and force is applied, (3) weld time—current is switched on, (4) current is turned off but force is maintained or increased (a reduced current is sometimes applied near the end of this step for stress relief in the weld region), and (5) electrodes are opened, and the welded assembly is removed. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)



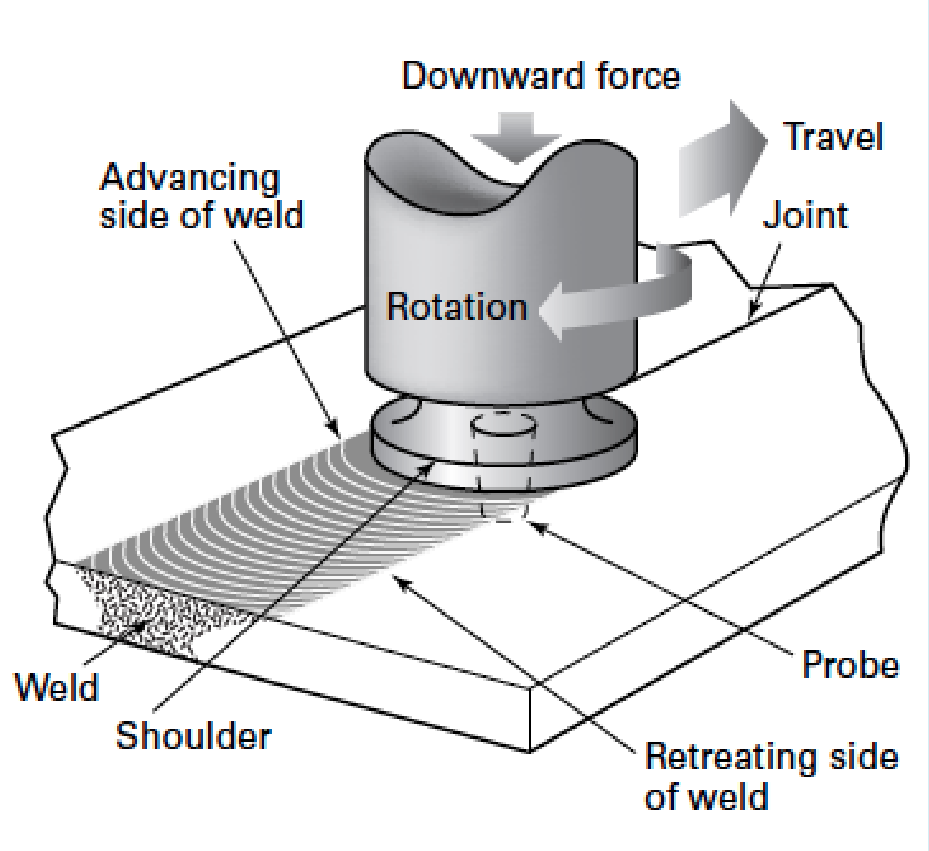
Resistance Seam Welding

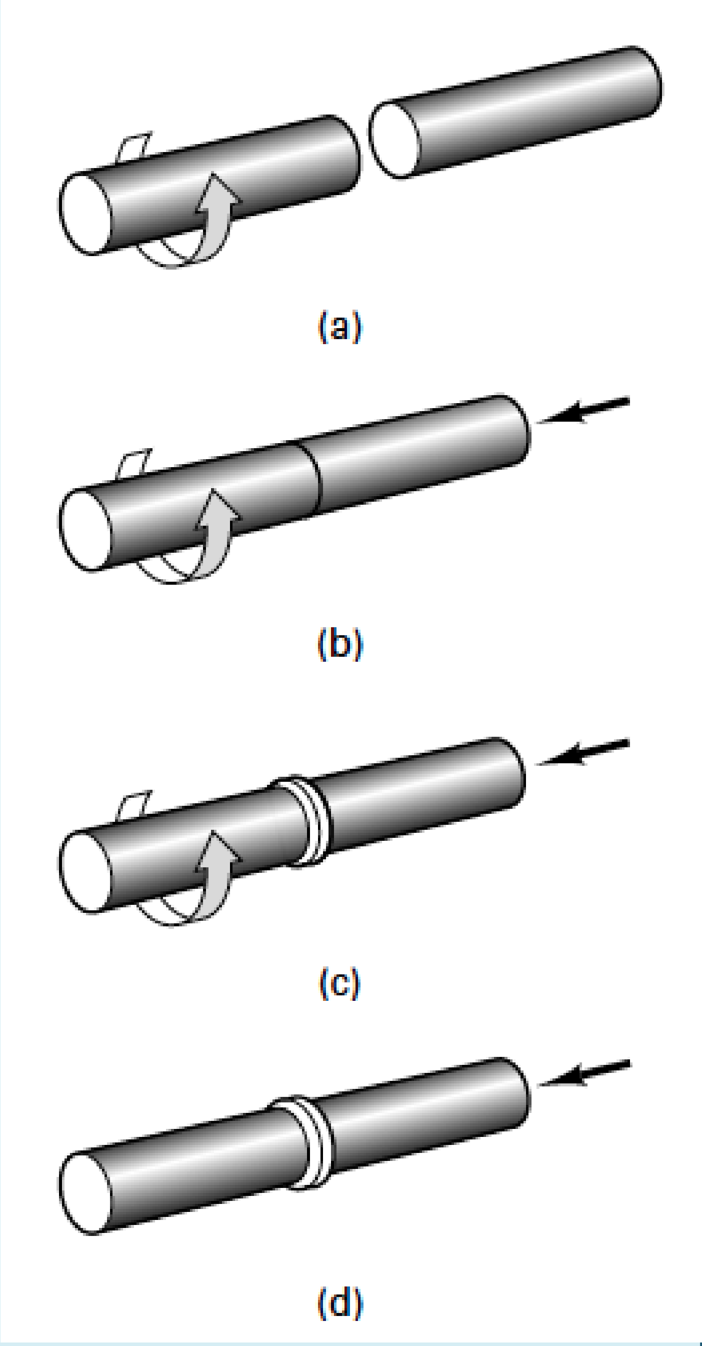






Friction Stir Welding





OXYFUEL GAS WELDING (OXYACETYLENE)

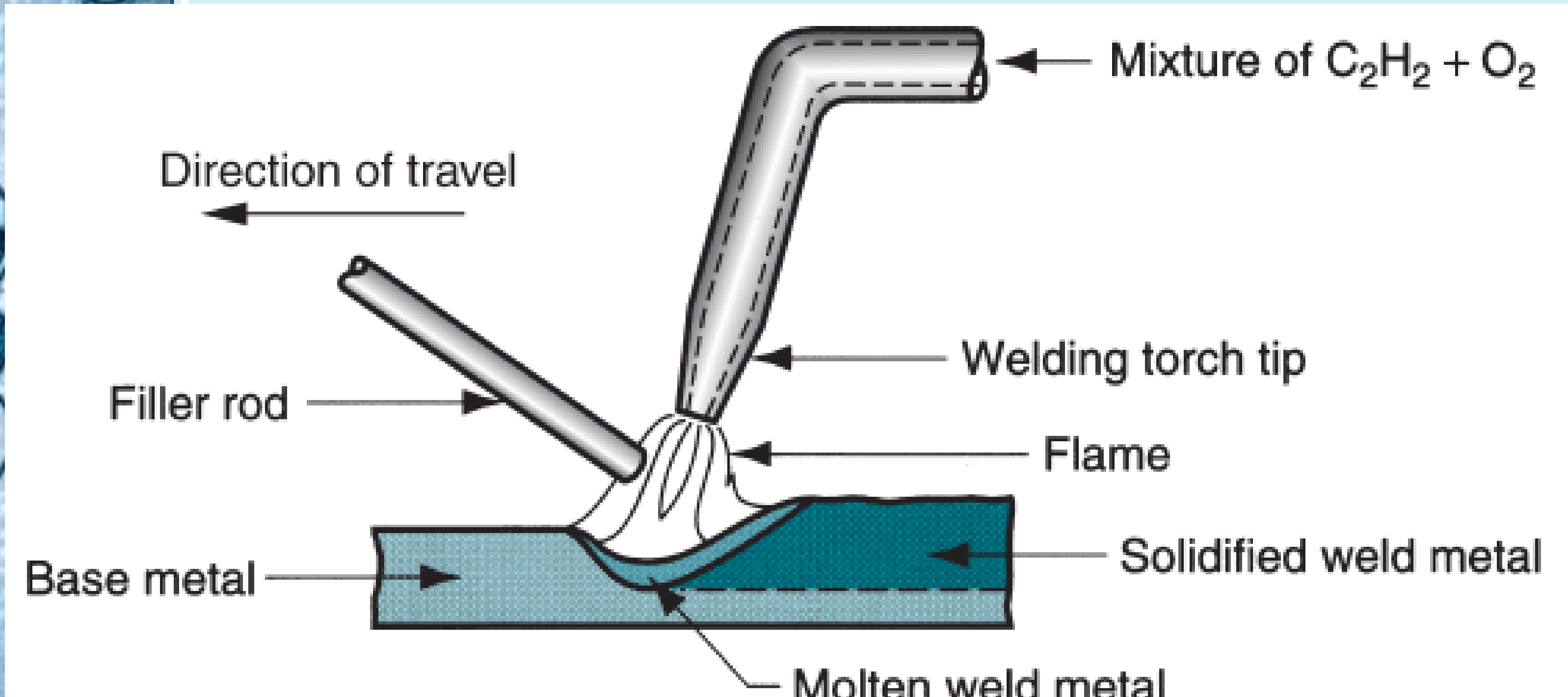
In the first stage, the supplied oxygen and acetylene react to produce carbon monoxide and hydrogen

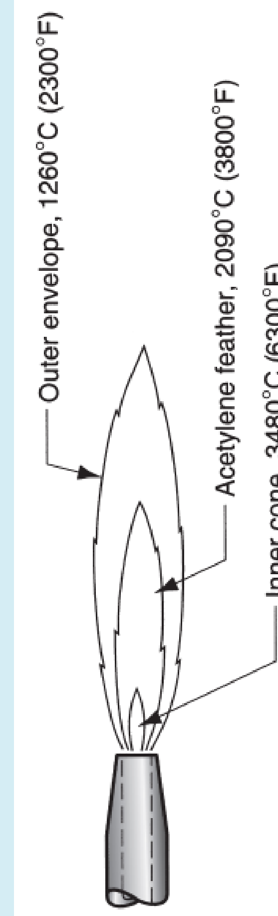
$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + \text{heat}$$

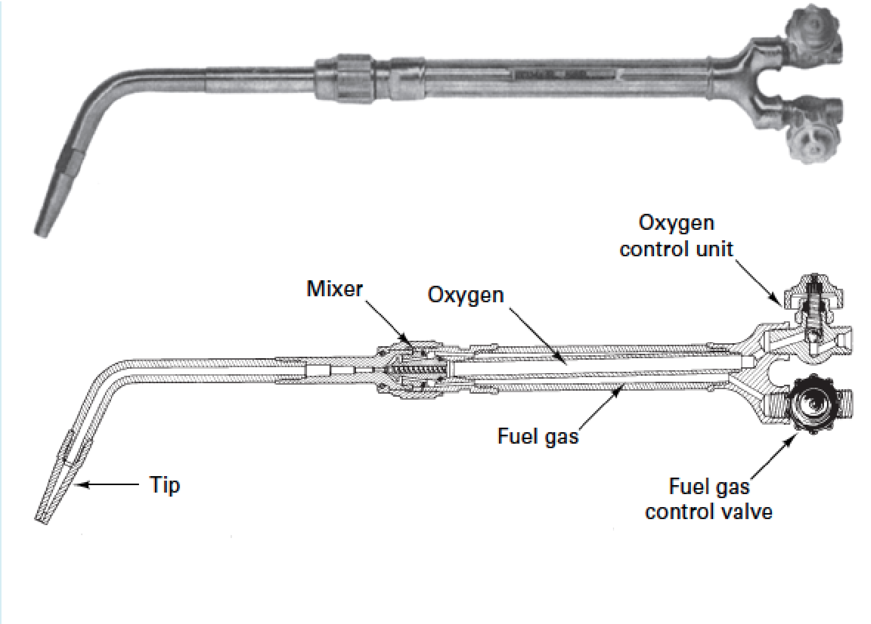
The second stage of the reaction involves the combustion of the CO and H2 and occurs just beyond the first combustion zone.

$$2CO + O_2 \rightarrow 2CO_2 + \text{Heat}$$

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O + \text{Heat}$$



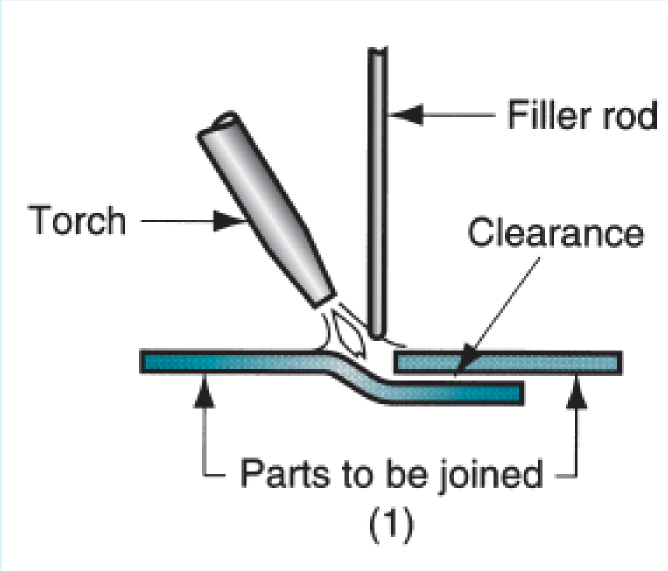


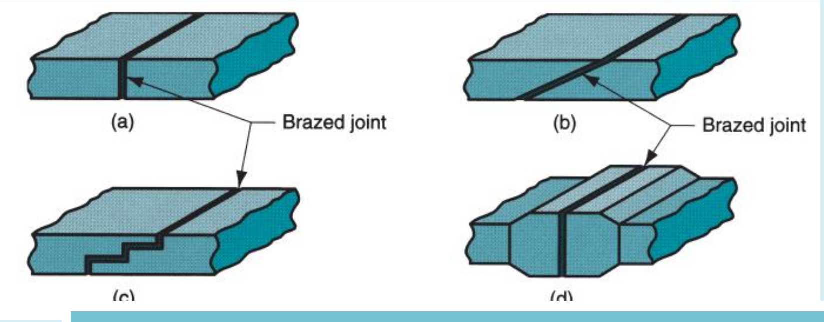

Oxygen
control unit
Mixer
Oxygen
Fuel gas
Tip
Fuel gas
control valve


PPU SOLDA

Brazing

- Brazing is a joining process in which a filler metal is melted and distributed by capillary action between the faying surfaces of the metal parts being joined. No melting of the base metals occurs in brazing; only the filler melts.
- In brazing, the filler metal (also called the brazing metal) has a melting temperature (liquidus) that is above 450C (840F) but below the melting point (solidus) of the base metal.





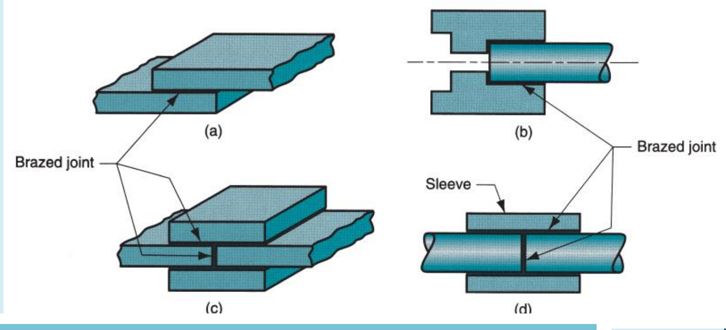


TABLE 24.1 Common filler metals used in brazing and the base metals on which they are used.

Filler Metal	Typical Composition	Approximate Brazing Temperature °C	Approximate Brazing Temperature °F	Base Metals
Aluminum and silicon	90 Al, 10 Si	600	1100	Aluminum
Copper	99.9 Cu	1120	2050	Nickel copper
Copper and phosphorous	95 Cu, 5 P	850	1550	Copper
Copper and zinc	60 Cu, 40 Zn	925	1700	Steels, cast irons, nickel
Gold and silver	80 Au, 20 Ag	950	1750	Stainless steel, nickel alloys
Nickel alloys	Ni, Cr, others	1120	2050	Stainless steel, nickel alloys
Silver alloys	Ag, Cu, Zn, Cd	730	1350	Titanium, Monel, Inconel, tool steel, nickel

Soldering

Soldering is similar to brazing and can be defined as a joining process in which a filler metal with melting point (liquidus) not exceeding 450C (840F) is melted and distributed by capillary action between the faying surfaces of the metal parts being joined.

As inbrazing, no melting of the base metals occurs, but the filler metal wets and combines with the base metal to form a metallurgical bond.

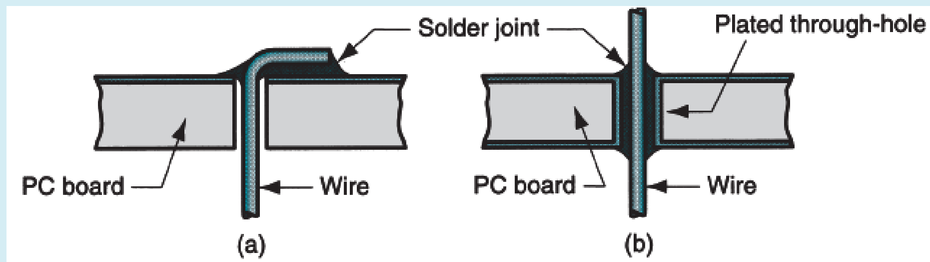
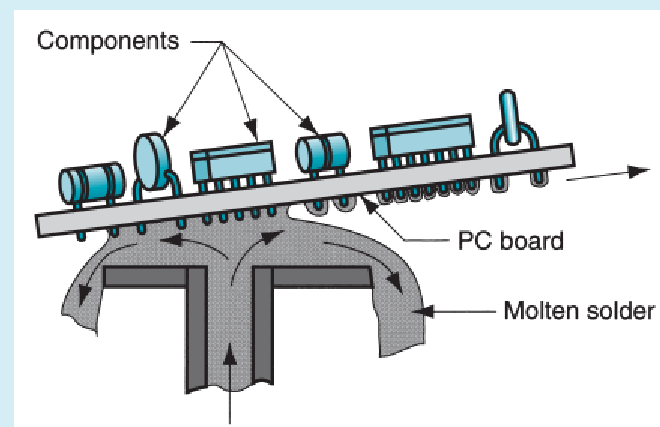


TABLE 24.2 Some common solder alloy compositions with their melting temperatures and applications.

Filler Metal	Approximate Composition	Approximate Melting Temperature °C	Approximate Melting Temperature °F	Principal Applications
Lead-silver	96 Pb, 4 Ag	305	580	Elevated temperature joints
Tin-antimony	95 Sn, 5 Sb	238	460	Plumbing & heating
Tin-lead	63 Sn, 37 Pb	183[a]	361[a]	Electrical/electronics
	60 Sn, 40 Pb	188	370	Electrical/electronics
	50 Sn, 50 Pb	199	390	General purpose
	40 Sn, 60 Pb	207	405	Automobile radiators
Tin-silver	96 Sn, 4 Ag	221	430	Food containers
Tin-zinc	91 Sn, 9 Zn	199	390	Aluminum joining
Tin-silver-copper	95.5 Sn, 3.9 Ag, 0.6 Cu	217	423	Electronics: surface mount technology



Adhesive Bonding

- Adhesive bonding is a joining process in which a filler material is used to hold two (or more) closely spaced parts together by surface attachment. The filler material that binds the parts together is the adhesive. It is a nonmetallic substance—usually a polymer.
- The parts being joined are called adherends. Adhesives of greatest interest in engineering are structural adhesives, which are capable of forming strong, permanent joints between strong, rigid adherends.

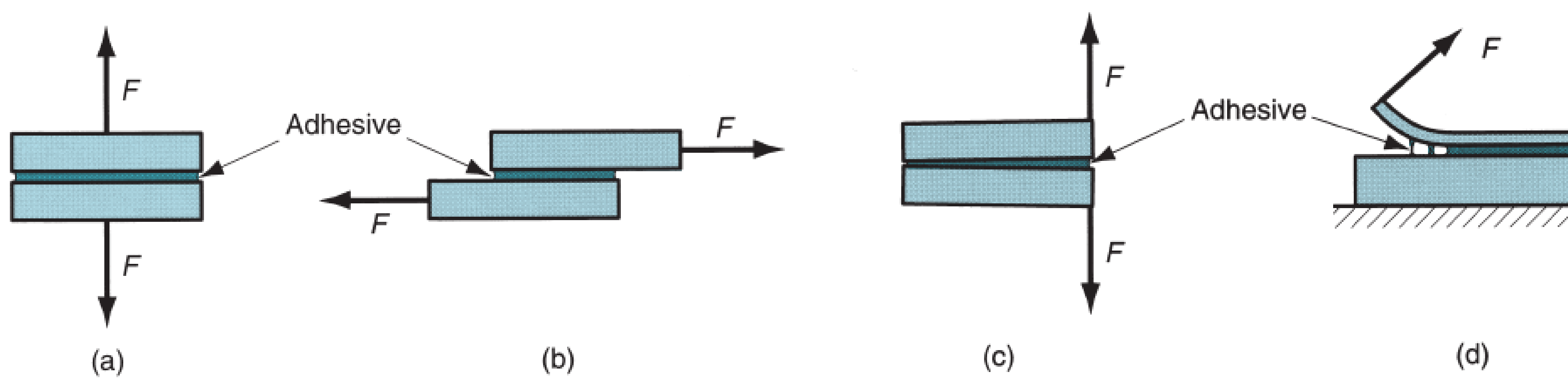


FIGURE 24.9 Types of stresses that must be considered in adhesive bonded joints: (a) tension, (b) shear, (c) cleavage, and (d) peeling. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikell P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Adhesive Types

1. natural, derived from natural sources (e.g., plants and animals), including gums, starch, dextrin, soy flour, and collagen. This category of adhesive is generally limited to low-stress applications, such as cardboard cartons, furniture, and bookbinding; or where large surface areas are involved (e.g., plywood).
2. Inorganic adhesives are based principally on sodium silicate and magnesium oxychloride. Although relatively low in cost, they are also low in strength—a serious limitation in a structural adhesive.
3. Synthetic adhesives constitute the most important category in manufacturing. They include a variety of thermoplastic and thermosetting polymers. They are cured by various mechanisms, such as

   (1) mixing a catalyst or reactive ingredient with the polymer immediately prior to applying,

   (2) heating to initiate the chemical reaction,

   (3) Radiation curing, such as ultraviolet light, and

   (4) curing by evaporation of water from the liquid or paste adhesive.

   In addition, some synthetic adhesives are applied as films or as pressuresensitive coatings on the surface of one of the adherends.

Joining of Plastics

Because the thermoplastics soften and melt at such low temperatures, the heat required to weld these materials is significantly less than that required in the welding of metals.

The processes used to weld plastics can be divided into two groups:

(1) those that utilize mechanical movement and friction to generate heat, such as ultrasonic weld-spin welding, and vibration welding,

(2) those that involve external heat sources, such as hot-plate welding, hot-gas welding, and resistive and inductive implant welding.

In both groups, it is important to control the rate of heating.

Plastics have low thermal conductivity, and it is easy to induce burning, charring or other material degradation before softening has occurred to the desired depth.

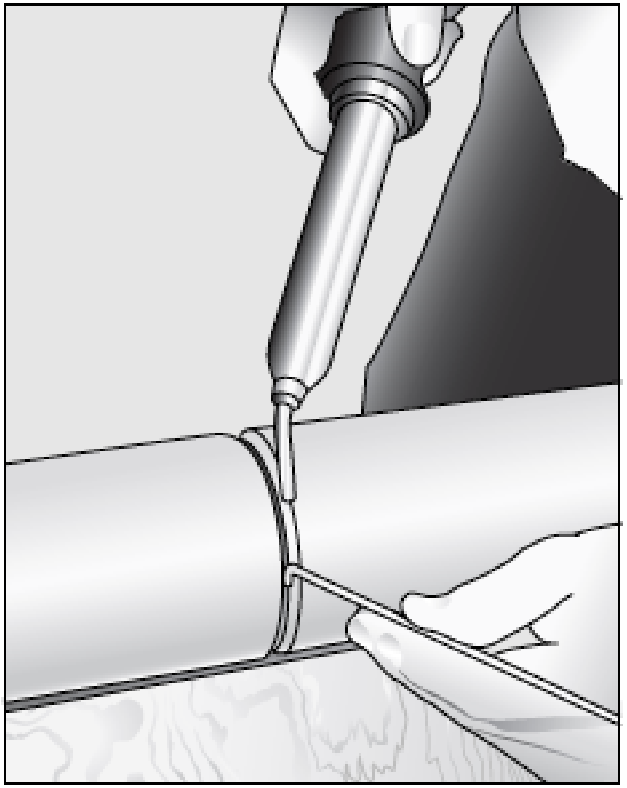


FIGURE 34-9 Using a hot-gas torch to make a weld in plastic pipe.

Joining of Ceramics

When we consider joining operations, the unique properties of ceramics once again introduce fabrication limitations.

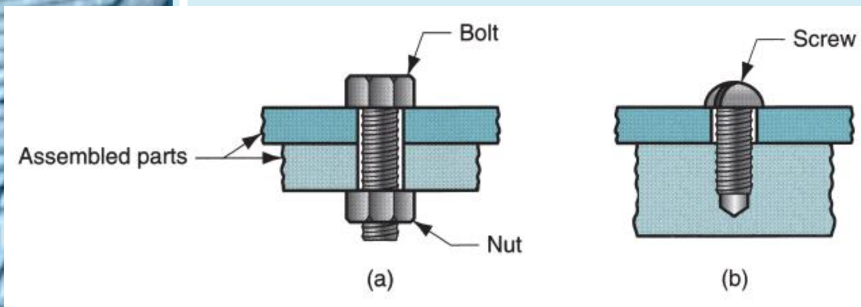
Brittle ceramics cannot be joined by fusion welding or deformation bonding, and threaded assemblies should be avoided whenever possible.

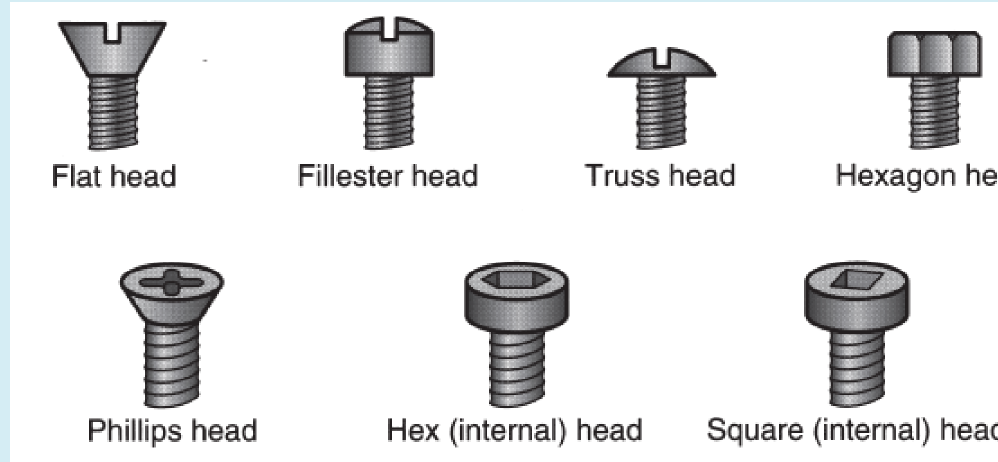
Therefore, most joining utilizes some form of adhesive bonding, brazing, diffusion bonding, or special cements.

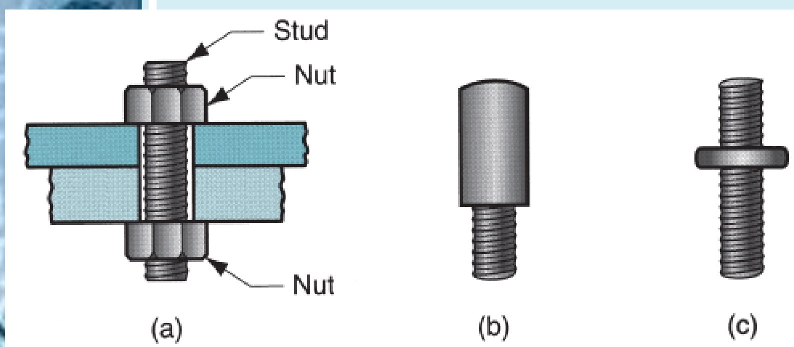
Even with these methods, the stresses that develop on the surfaces can lead to premature failure.

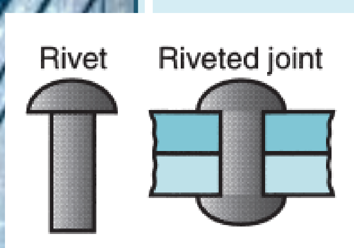
As a result, most ceramic products are designed to be monolithic (single-piece) structures rather than multipart assemblies.

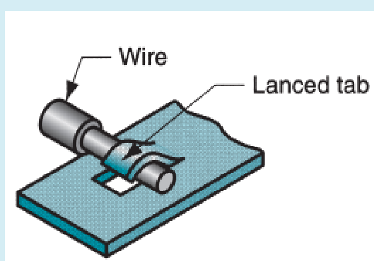
Mechanical Assembly

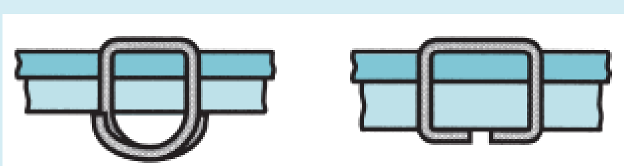












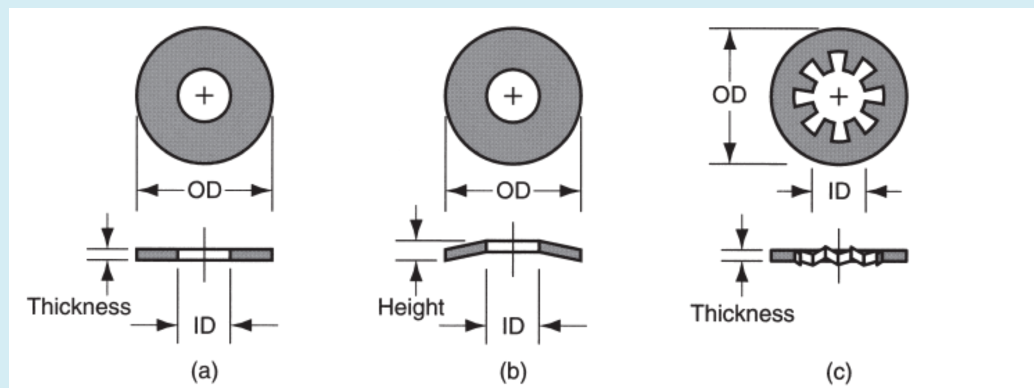


FIGURE 25.7 Types of washers: (a) plain (flat) washers; (b) spring washers, used to dampen vibration or compensate for wear; and (c) lockwasher designed to resist loosenin of the bolt or screw. (Credit: *Fundamentals of Modern Manufacturing*, 4th Edition by Mikel P. Groover, 2010. Reprinted with permission of John Wiley & Sons, Inc.)

Mechanical Assembly and Quality Control

- Next Class