Joining

IME 240 Lecture 14

Joining and Assembly

- Most products are assembled from components
- Joining covers assembly processes such as welding, soldering, brazing, adhesive bonding, and mechanical fastening
- Reasons for joining
    - Product is impossible to manufacture in one piece
    - Multiple components are more economical to produce
    - Assembled products can be taken apart for maintenance or repair
    - Components contribute different properties and fulfill functional requirements for the product
    - Transporting components may be less expensive or easier than full products

Assembly Design Considerations

- Application
- Joint design
- Materials
- Shapes of components, including thickness and size
- Location of joint within product
- Number of individual components
- Operator skill required
- Equipment and labor costs

Welding Safety

- Use safety equipment!
  - Goggles with shaded lenses
  - Face shields
  - Gloves
  - Protective clothing
- Properly connect gas lines
- Anchor gas cylinders securely
- Weld away from combustible materials and flammable fluids or vapors
- Noise, shock, and fume hazards exist for personnel

Fusion Welding

- Melting together and coalescing of materials by means of heat from chemical or electrical sources
- Filler metals supply additional material to the weld area
    - Rod or wire that may be coated with flux
    - Flux retards oxidation of welded surfaces by generating a gaseous shield around the weld zone
    - Flux also helps dissolve and remove oxides from the workpiece
- If filler metals are not used, forms autogenous welds
- Includes consumable and non-consumable electric arc welding and high-energy-beam welding
- Can also be used with plastics
- Processes include oxyfuel, arc, and high-energy-beam (electron-beam and laser-beam)

Oxyfuel Gas Welding (OFW)

- Uses a fuel gas combined with oxygen to produce a flame which melts metals at the joint
- Most common process is oxyacetylene welding using acetylene (C_2H_2) fuel
- Used for sheet metal fabrication, automotive bodies, repair work, etc.
- Two chemical reactions:

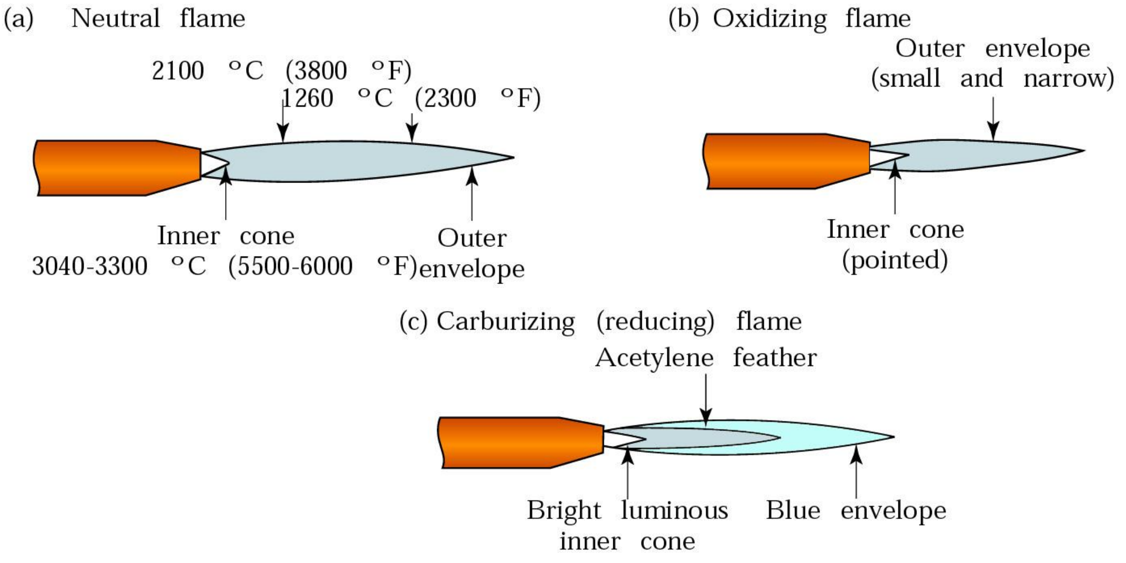
$$C_2H_2 + O_2 \rightarrow 2CO + H_2 + Heat$$

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

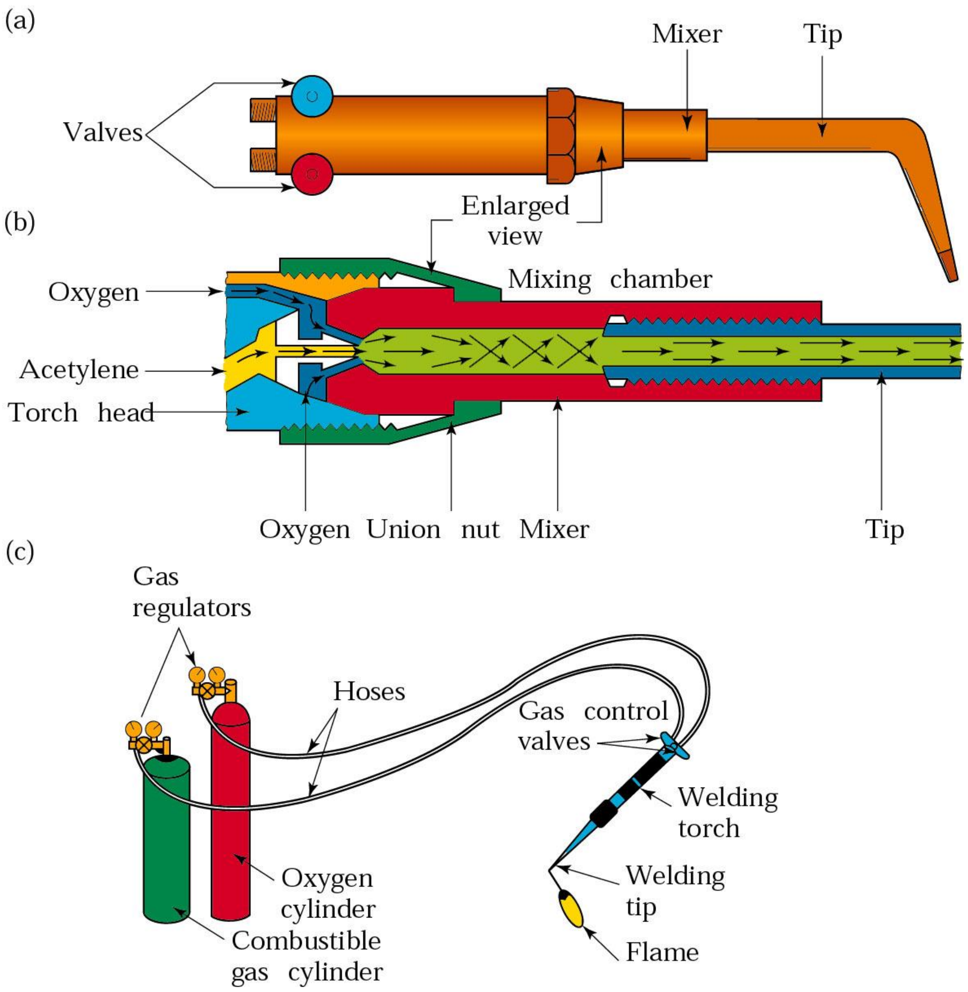
- Flame temperatures can reach 3300°C (6000°F)
- For ferrous and nonferrous metals, usually less than 6 mm thickness

Oxyfuel Gas Welding Flames

- Neutral flame produced by 1:1 ratio of fuel and oxygen
- More oxygen produces an oxidizing flame which is harmful, especially for steels
- Oxidizing flame can be desirable for copper-based alloys because it produces a thin protective layer of slag
- Less oxygen produces a reducing or carburizing flame with less heat, suitable for brazing, soldering, or flame-hardening
- Other fuel (hydrogen, methylacetylene propadiene, etc.) produce lower temperature flames



Oxyfuel Gas Welding Procedures



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.

- Prepare edges of joints (clean with wire brush, etc.) after each pass
- Position components using clamps and fixtures
- Open acetylene valve and ignite gas at tip of torch with spark lighter or pilot light
- Open oxygen valve and adjust flame
- Hold torch 45° from plane of workpiece with inner flame near workpiece
- Touch filler rod to workpiece and move along joint at appropriate rate
- Equipment is <$500 for small units
- Usually a manual process

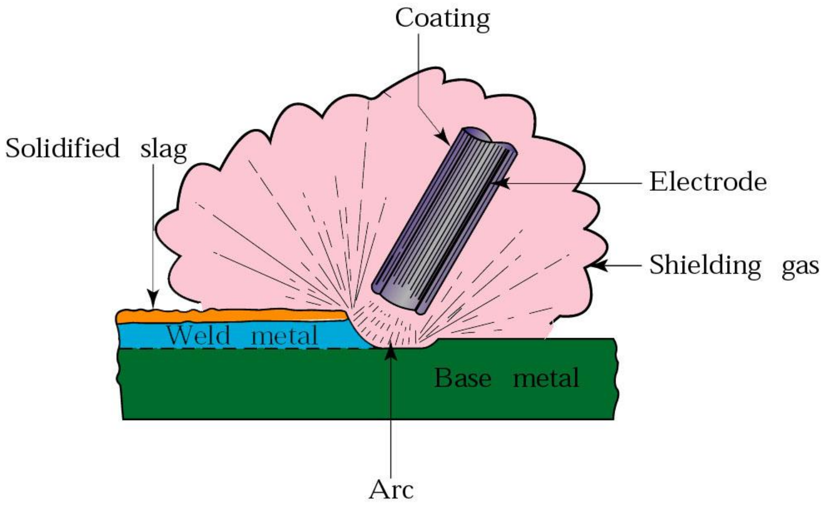
Arc Welding

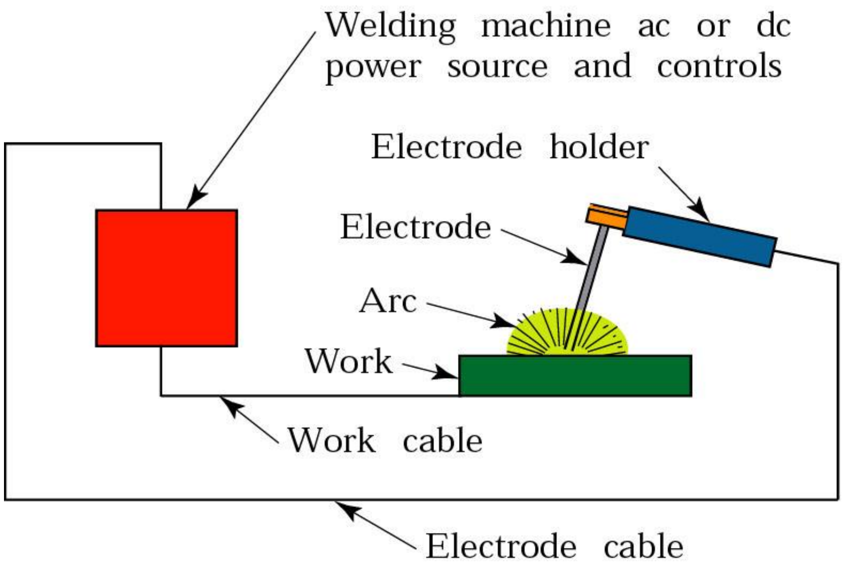
- Heat for welding obtained from electrical sources
- Consumable or non-consumable electrodes
- Arc produced between tip of electrode and workpiece
- AC or DC power supply
- Temperatures of about 30,000°C (54,000°F)
- Consumable
    - SMAW, SAW, GMAW (MIG), FCAW, EGW, ESW
    - Consumable electrodes are classified by strength of deposited metal, current (AC or DC), and coating type
    - Coatings include claylike silicate binders and powdered oxides, carbonates, fluorides, metal alloys, and cellulose
    - Coatings stabilize the arc, generate shielding gases, control electrode melt rate, act as flux to prevent oxidation, and add alloying elements
- Non-consumable: GTAW (TIG), AHW, PAW

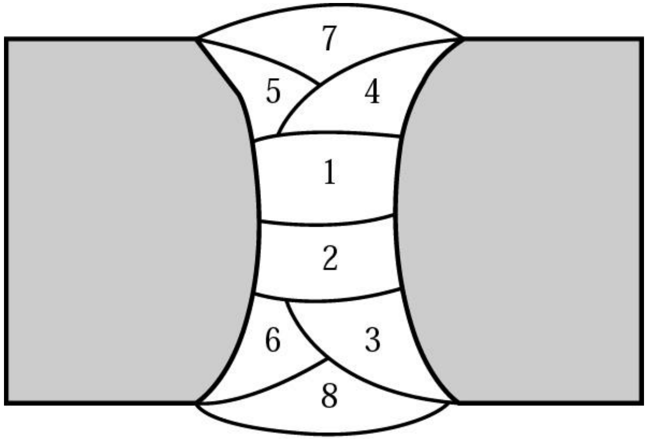
SMAW – Shielded Metal arc Welding

- Oldest, simplest process – used in construction, ship building, etc
- Represents 50% of industrial and maintenance welding
- Also known as stick welding due to shape of electrode
- Coated electrode touches workpiece and removed quickly to a distance that maintains arc
- Tip of electrode, coating, and workpiece surface are melted
- Straight Polarity – workpiece is positive and electrode negative for sheet metals for shallow penetration and very wide gaps
- Reverse polarity – positive electrode for deeper weld penetration
- DC preferred for sheet metal welding due to steady arc
- With AC, arc pulsates rapidly for welding thick sections or using large diameter electrodes at high currents
- Current usually between 50 and 300 A, power less than 10 kW
- Equipment costs typically $1500 and is portable & easily maintained
- Thicknesses of 3-19 mm, unless multiple passes are used

SMAW – Shielded Metal arc Welding







Multiple Pass Weld Formation

SAW – Submerged arc Welding

- Weld arc shielded by a granular flux of lime, silica, manganese oxide, calcium fluoride, etc.
- Flux fed into weld zone by gravity
- Flux prevents spatter and sparks, suppresses UV radiation and fumes present in SMAW
- Flux also insulates, promoting deep penetration of heat into workpiece
- Consumable electrode is coiled wire fed automatically through a welding gun
- Currents 300-2000 A
- Welder must wear gloves and tinted glasses, but face shields not necessary
- Limited to flat or horizontal workpieces with a backup piece
- Pipes can be rotated during welding
- Process can be automated
- High productivity (4-10 times SMAW), but more expensive ($2-10K+)

SAW – Submerged arc Welding

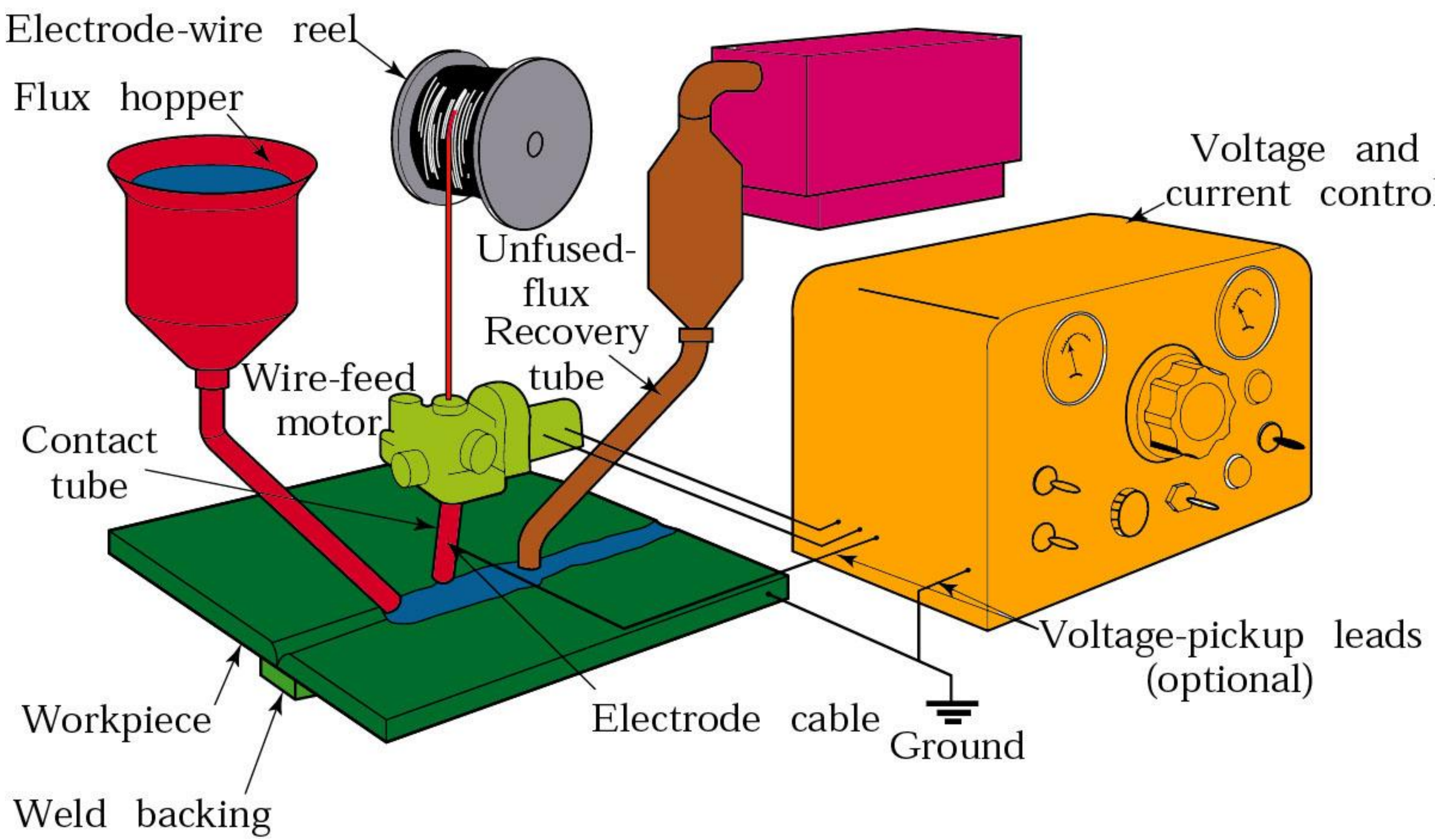
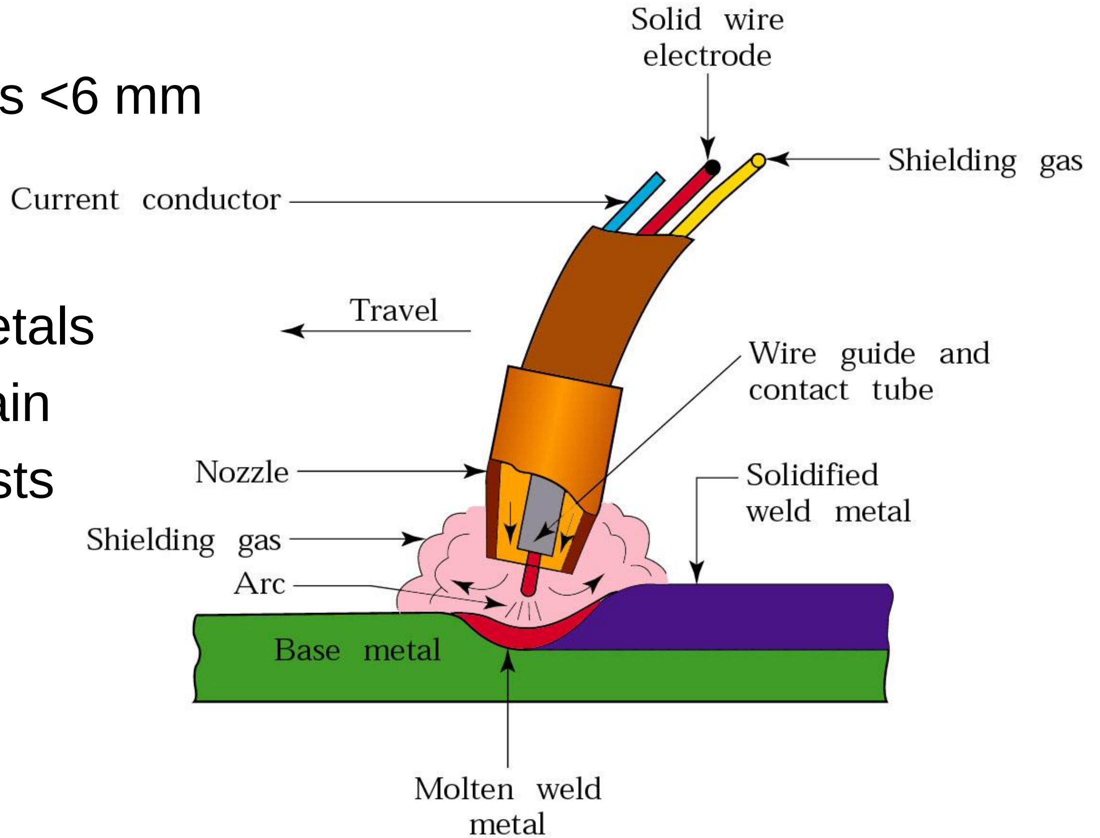


Figure 27.7 Schematic illustration of the submerged-arc welding process and equipment. The unfused flux is recovered and reused. *Source*: American Welding Society.

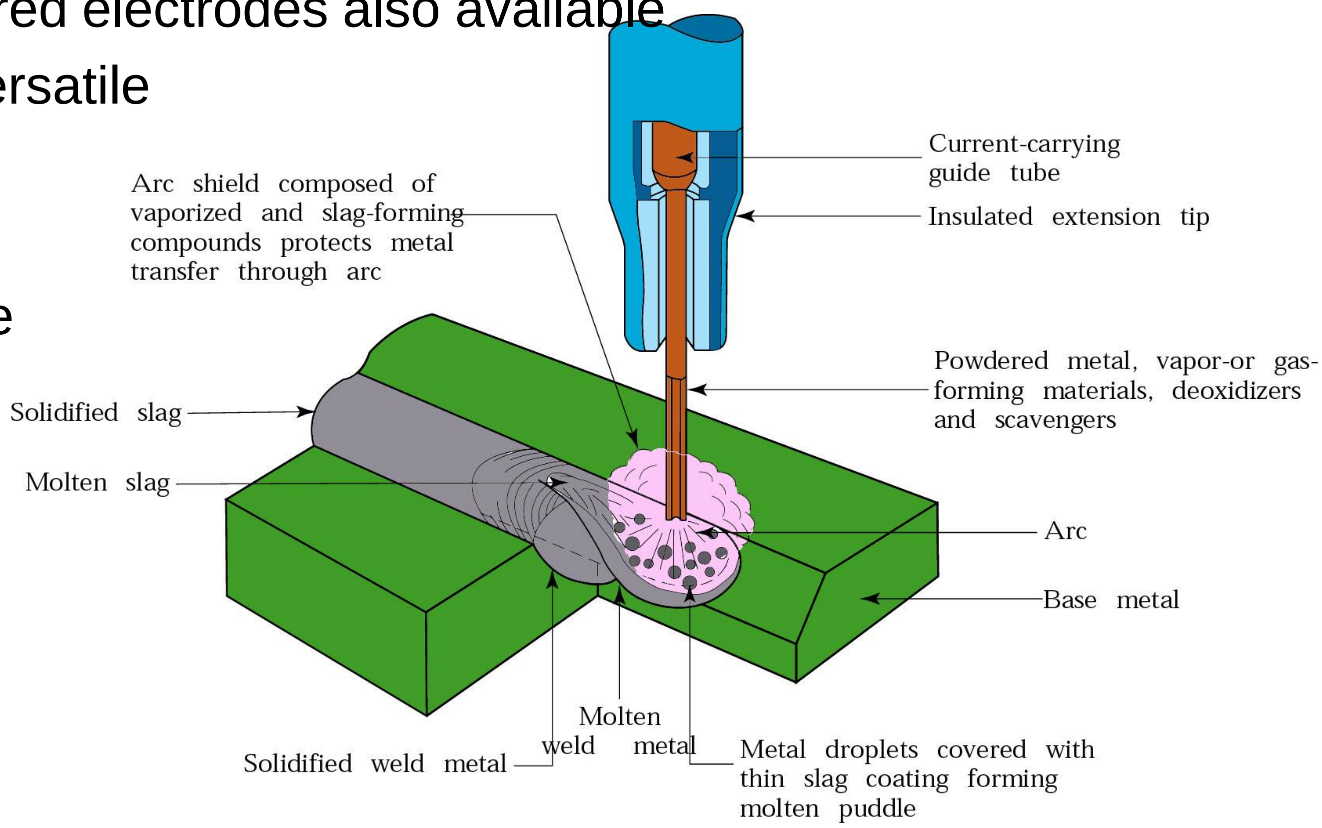
GMAW – Gas Metal-Arc Welding

- Formerly called Metal Inert Gas (MIG) welding
- Weld area shielded by inert gas such as argon, helium, CO_2
- Deoxidizers usually present in electrode metal
- Metal can be deposited by spray transfer, globular transfer, or short-circuiting
- Only suitable for thin sheets <6 mm
- Low temperatures
- Can be automated
- Ferrous and nonferrous metals
- Simple process, easy to train
- $1000-3000 equipment costs



FCAW – Flux Cored Arc Welding

- Electrode is tubular in shape and filled with flux
- Stable arc, improved weld contour and mechanical properties
- Flux is flexible, so electrode can come in long coils
- Alloying elements can be added to flux core
- Self-shielding cored electrodes also available
- Economic and versatile
- Steels and nickel alloys
- Easy to automate
- Power requirement 20kW
- $1000-3000 equipment costs

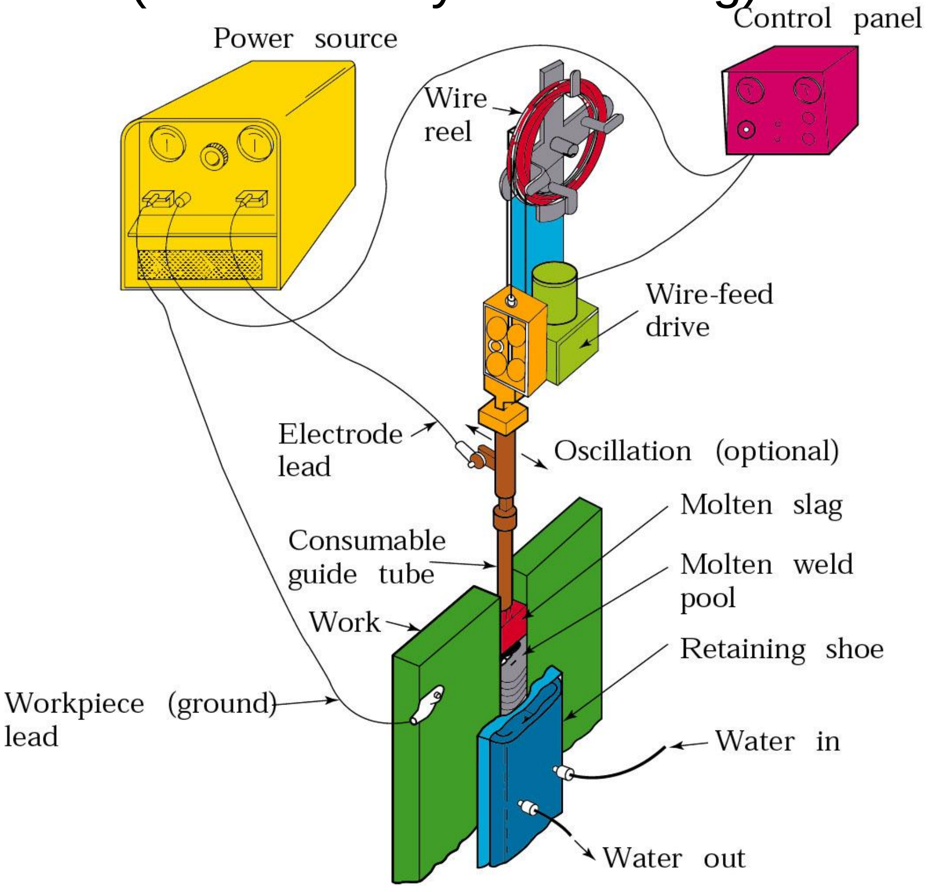


EGW – Electrogas Welding

- For welding edges of sections vertically in one pass to form a butt joint
- Requires special equipment to deposit weld material into a cavity between the two workpieces
- Shielding by inert gases
- Water-cooled dams (shoes) needed to prevent molten slag from running off
- Weld thicknesses from 12-75 mm
- Steels, titanium, aluminum alloys
- Used for bridges, pressure vessels, pipes, storage tanks, ships
- $15,000-$25,000 equipment costs (smaller portable units for $5000)

ESW – Electroslag Welding

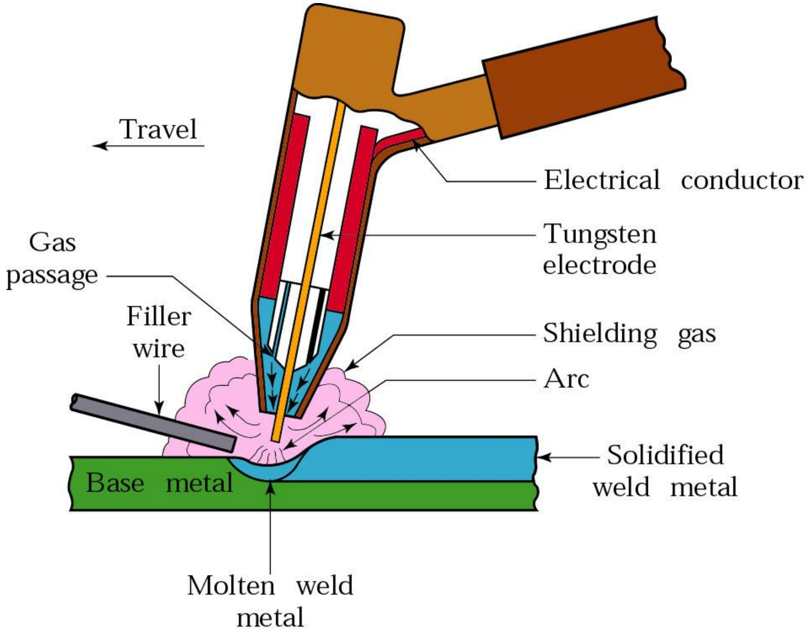
- Similar to EGW but arc is started between the electrode tip and bottom of workpiece
- Flux is added and melted by heat of arc until molten slag reaches tip of electrode, then arc is extinguished (so not strictly arc welding)
- Thickness of 50-900 mm
- Single pass only
- Current 600 A, 40-50 V
- Good weld quality
- Structural steel components, heavy machinery, nuclear reactor vessels
- $15,000-25,000 or more

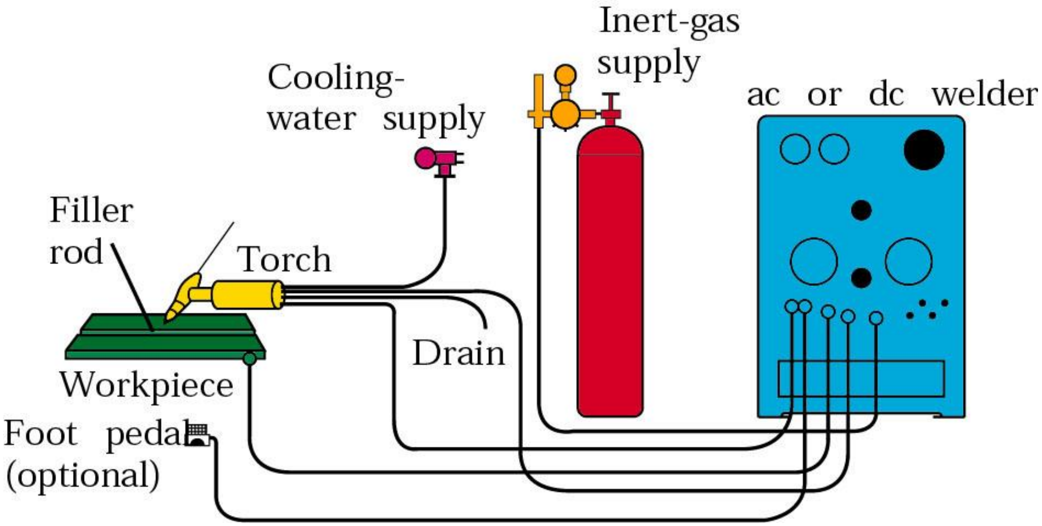


GTAW – Gas Tungsten Arc Welding

- Non consumable electrode made of tungsten
- Formerly know as tungsten inert gas (TIG)
- Filler metal is used from a filler wire, similar to workpiece material
- Filler not needed for close fit joints
- Flux is not used, but inert gas shield is
- Constant and stable arc gap can be maintained
- 200 A DC current, or 500 A AC current
- Power from 8-20 kW
- Contamination of electrode by molten metal can be a problem
- For aluminum, magnesium, titanium
- Good for thin metals
- Produces high quality welds and surface finish
- Portable equipment $1000-5000

GTAW – Gas Tungsten Arc Welding

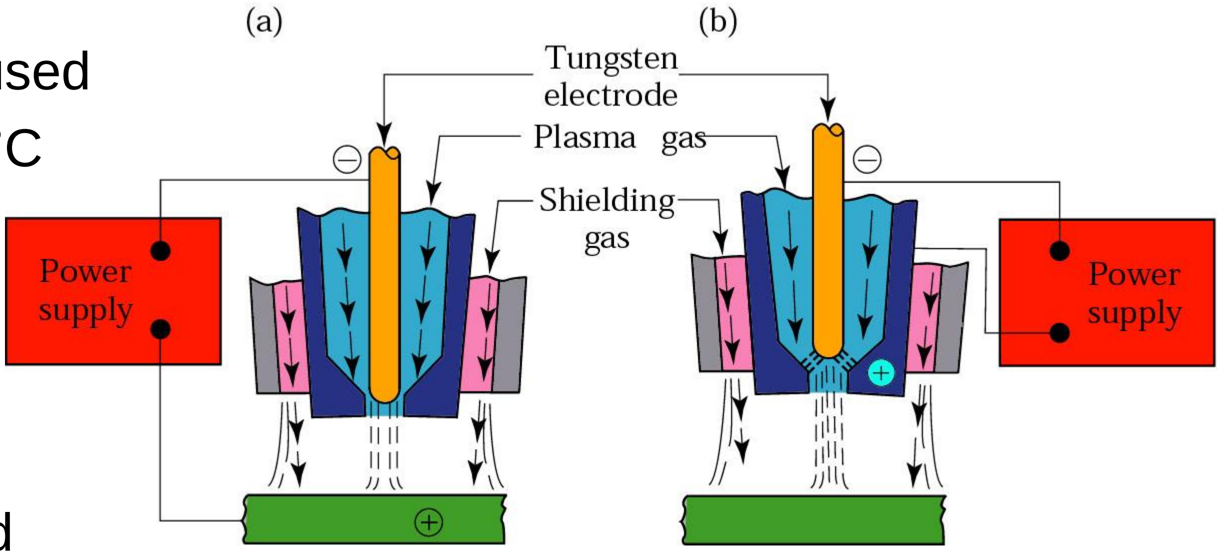




Equipment for gas tungsten-arc welding operations. *Source*: American Welding Society.

PAW – Plasma Arc Welding

- Plasma is ionized hot gas forced through a small orifice and aimed at weld area
- Tungsten electrode used
- Stable arc at 33,000°C
- Currents usually <100A
- Filler metal may be used
- Shielding gases used
- Thicknesses <6 mm
- $3000-6000



Two types of plasma-arc welding processes: (a) transferred, (b) nontransferred. Deep and narrow welds can be made by this process at high welding speeds.

- Often used for butt and lap joints due to higher energy concentration, stability, and welding speeds
- Safety – need to protect against glare, spatter, and noise

TW – Thermit Welding

- Thermite compounds used
- Involves exothermic reaction between metal oxides and metallic reducing agents
- Nonexplosive mixture produces temperatures of 2200-2400 °C
- Parts to be joined are aligned with a gap between them, usually filled with wax
- Sand or ceramic mold build around joint
- Superheated reaction products allowed to flow into gap, melting part edges
- Used for welding and repairing large forgings and castings, railroad rails, pipes, etc

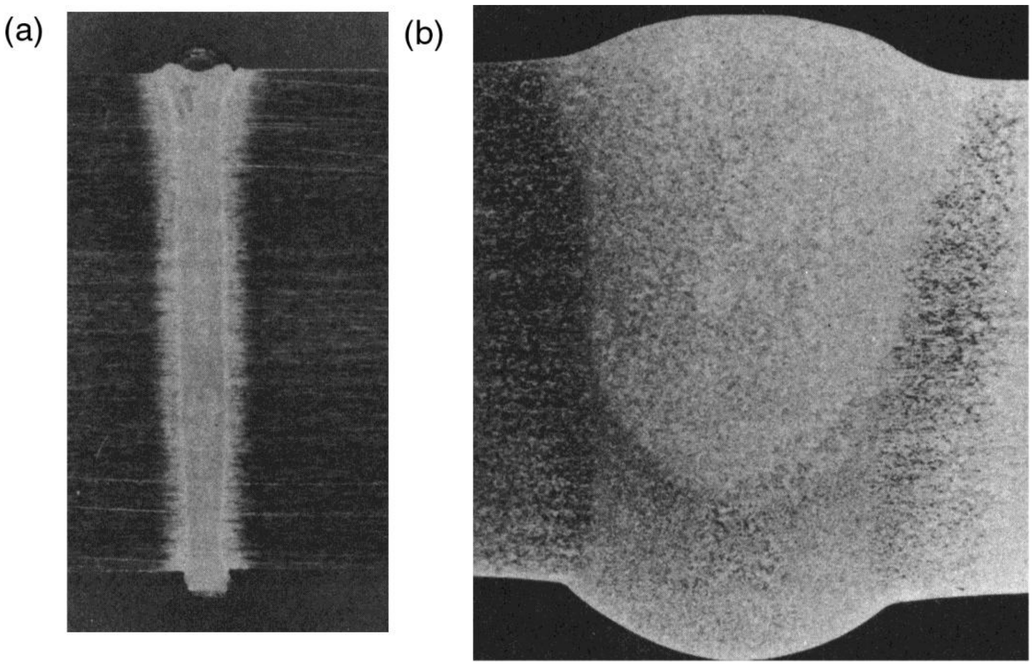
EBW – Electron Beam Welding

- Heat is generated by high-velocity narrow-beam electrons
- Kinetic energy of electrons converted to heat
- Special equipment is required with workpiece in a vacuum
- Energy also capable of producing holes in workpiece
- No flux, filler, or shielding gas needed
- Up to 100kW
- Butt or lap joints with thicknesses up to 150 mm
- Small weld size, minimal distortion and shrinkage in weld area, good quality welds
- Aircrafts, missiles, nuclear, automobile, and electronics
- $75,000-$1M
- Safety considerations of x-ray beams

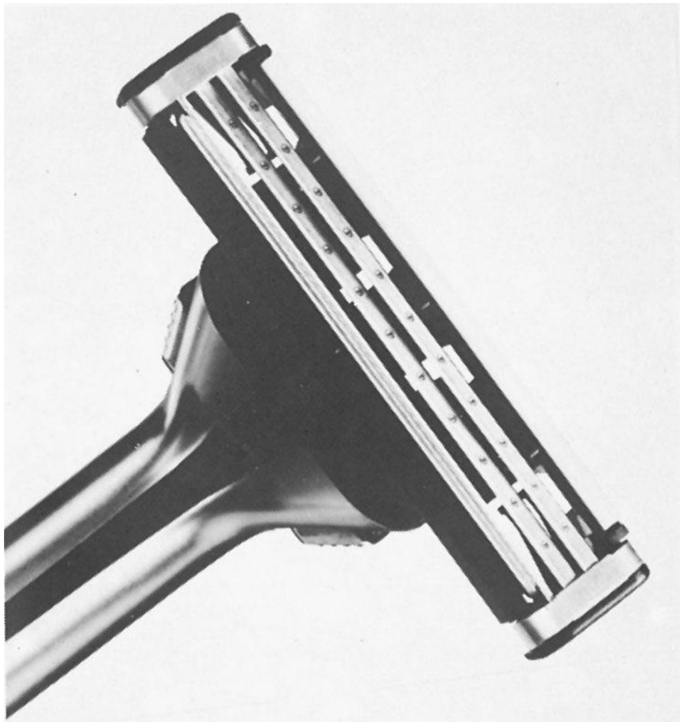
LBW – Laser Beam Welding

- Heat source is high power laser beam
- Beam can be focused on very small area for deep penetration
- Suitable for deep and narrow joints
- Laser may be pulsed or continuous
- Good quality welds with minimum shrinkage or distortion
- Welds with good strength, ductile and free from porosity
- Thicknesses up to 25 mm
- Vacuum not required
- Aluminum, titanium, ferrous metals, copper, etc
- Safety with Nd:YAG laser is important
- Equipment costs of $40,000-$1M

Electron Beam and Laser Beam Welding



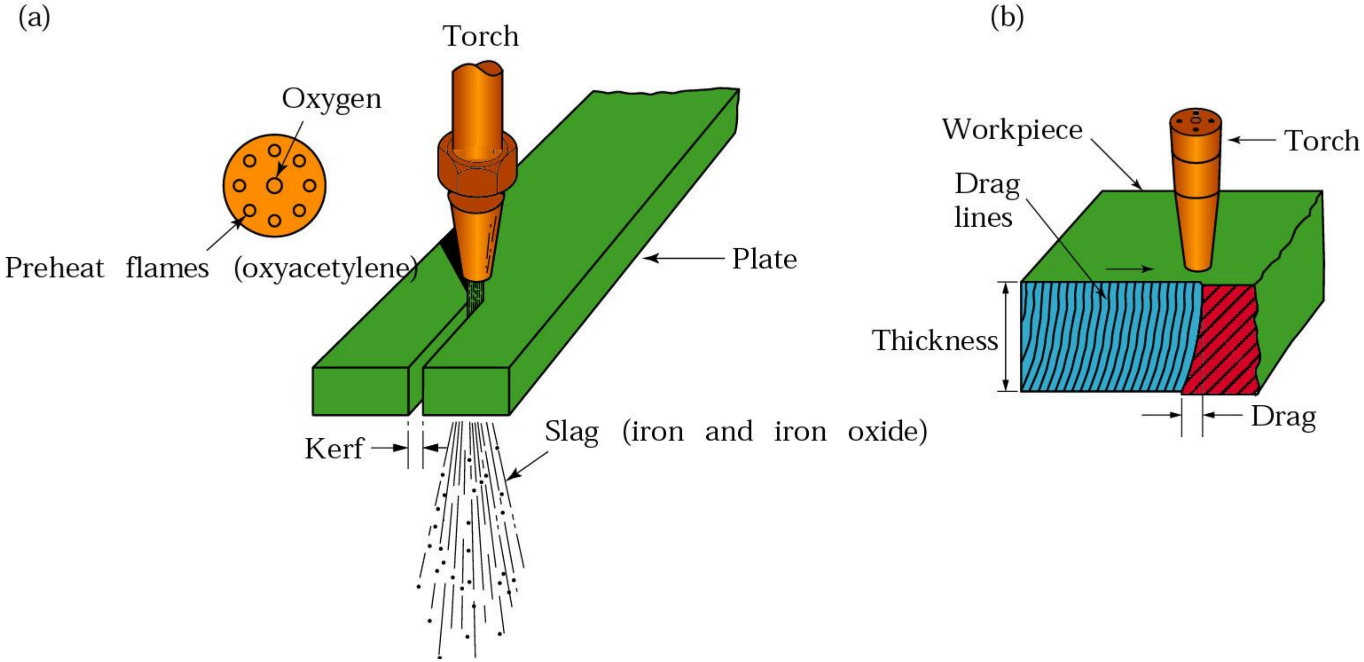
Comparison of the size of weld beads in (a) electron-beam or laser-beam welding to that in (b) conventional (tungsten-arc) welding. *Source*: American Welding Society, *Welding Handbook* (8th ed.), 1991.



Laser welding of razor blades.

Cutting

- Oxyfuel cutting, arc cutting, and laser or electron beam cutting use same heat sources as welding to remove a narrow zone, especially with steel workpieces
- Maximum thickness 300-350 mm
- Kerf widths of 1.5-10 mm
- Flame leaves drag lines on cut surface

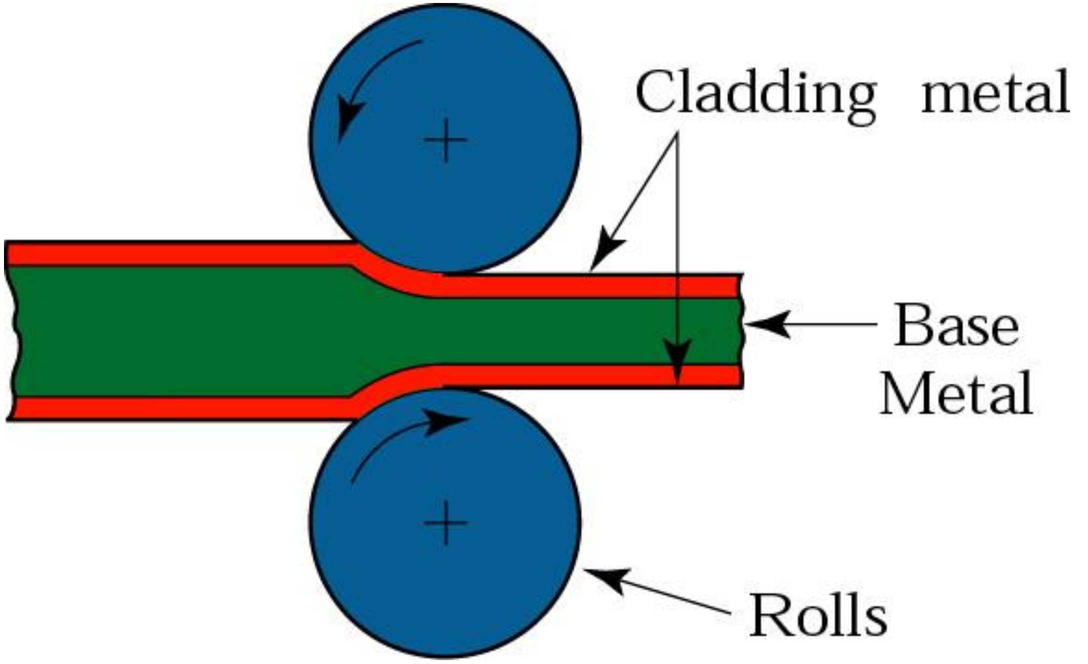


Solid-State Welding

- No liquid or molten state phase occurs in the joint
- Includes cold, ultrasonic, friction, resistance, and explosion bonding
- If two clean surfaces are brought into atomic contact with each other under pressure, they form bonds
- Applying external heat improves the bond by diffusion
- Small interfacial movements between the surfaces breaks up oxide films and generates new clean surfaces to improve bond strength
- Processes include friction, resistance, and explosion welding

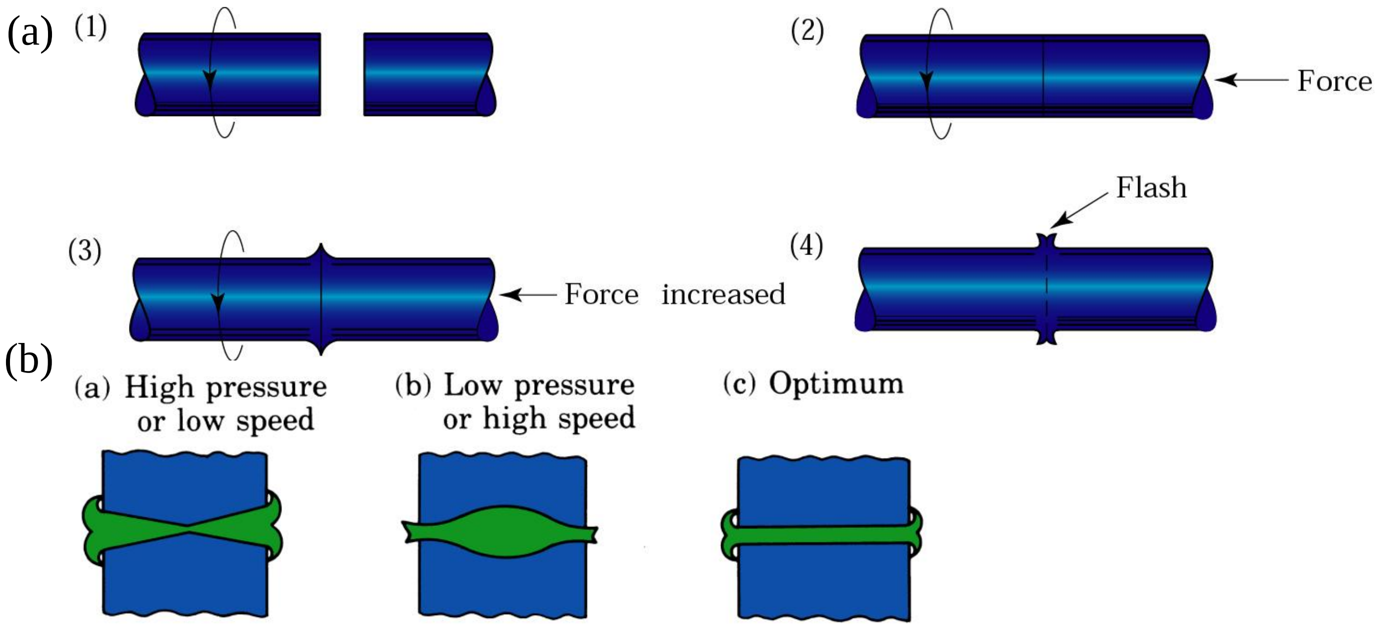
CW – Cold Welding

- Pressure is applied to workpieces by dies or rollers
- Plastic deformation also occurs
- One or both materials should be ductile
- Roll bonding, or cladding, is the process used to make quarters out of copper/nickel alloy and pure copper



FRW – Friction Welding

- Heat is generated by friction between two components being joined
- One piece is stationary while other is rotated against it
- Rotation is quickly stopped while pressure is applied



(a) Sequence of operations in the friction welding process: (1) Left-hand component is rotated at high speed. (2) Right-hand component is brought into contact under an axial force. (3) Axial force is increased; flash begins to form. (4) Left-hand component stops rotating; weld is completed. The flash can subsequently be removed by machining or grinding. (b) Shape of fusion zone in friction welding, as a function of the force applied and the rotational speed.

RW – Resistance Welding

- Heat required for welding is produced by electrical resistance across the two components
- Heat generated, $H = I^2Rt$

  where H is heat in joules,

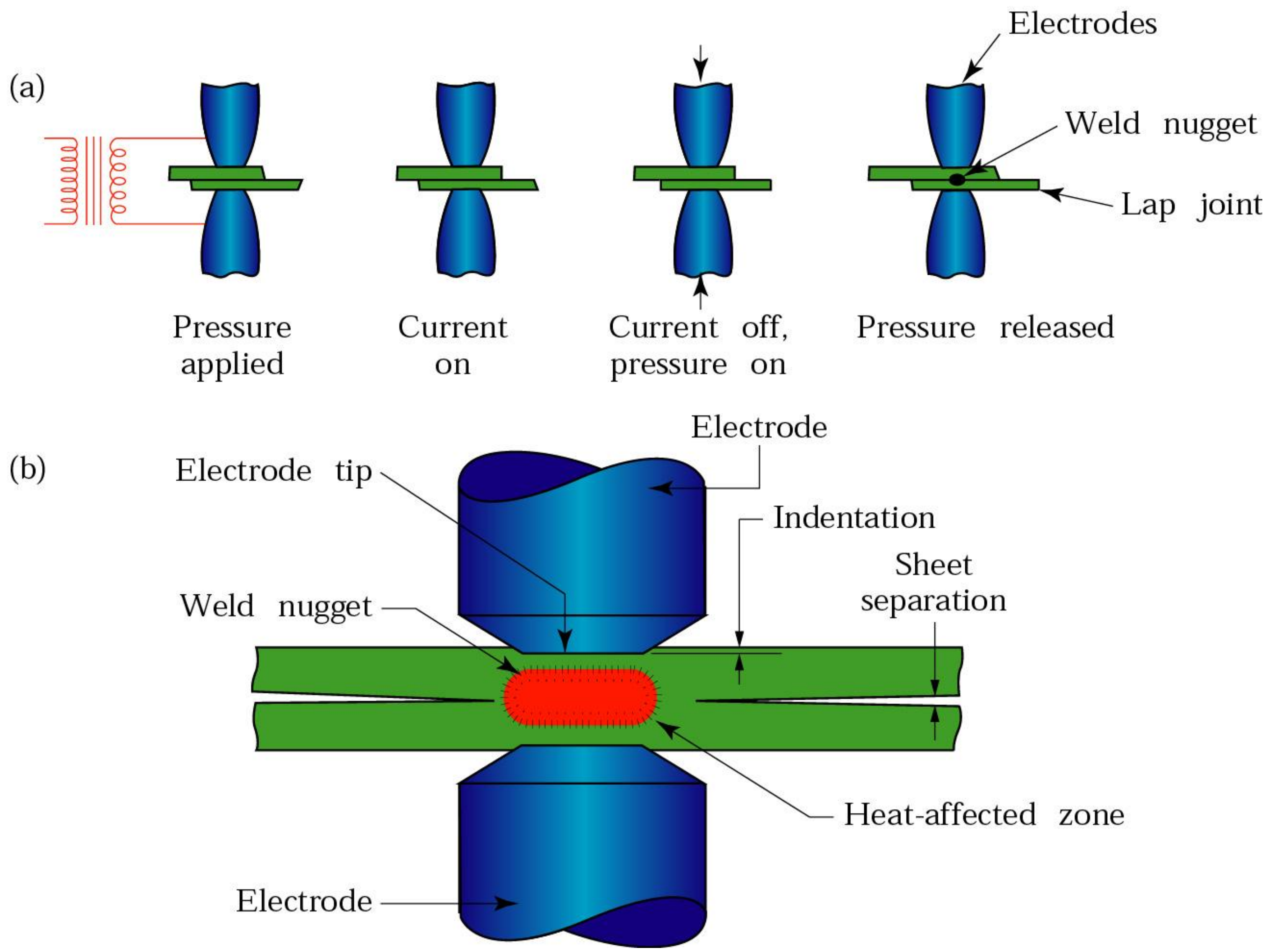
  I is current in Amperes

  R is resistance in ohms

  and t is time in seconds
- Resistance spot welding (RSW) is where the electrodes are on either side of a lap joint to produce a weld nugget, usually 6-10 mm in diameter
- RSW is used extensively in automotive bodies and many other sheet metal applications
- Resistance seam welding (RSEW) has rotating wheel or roller electrodes

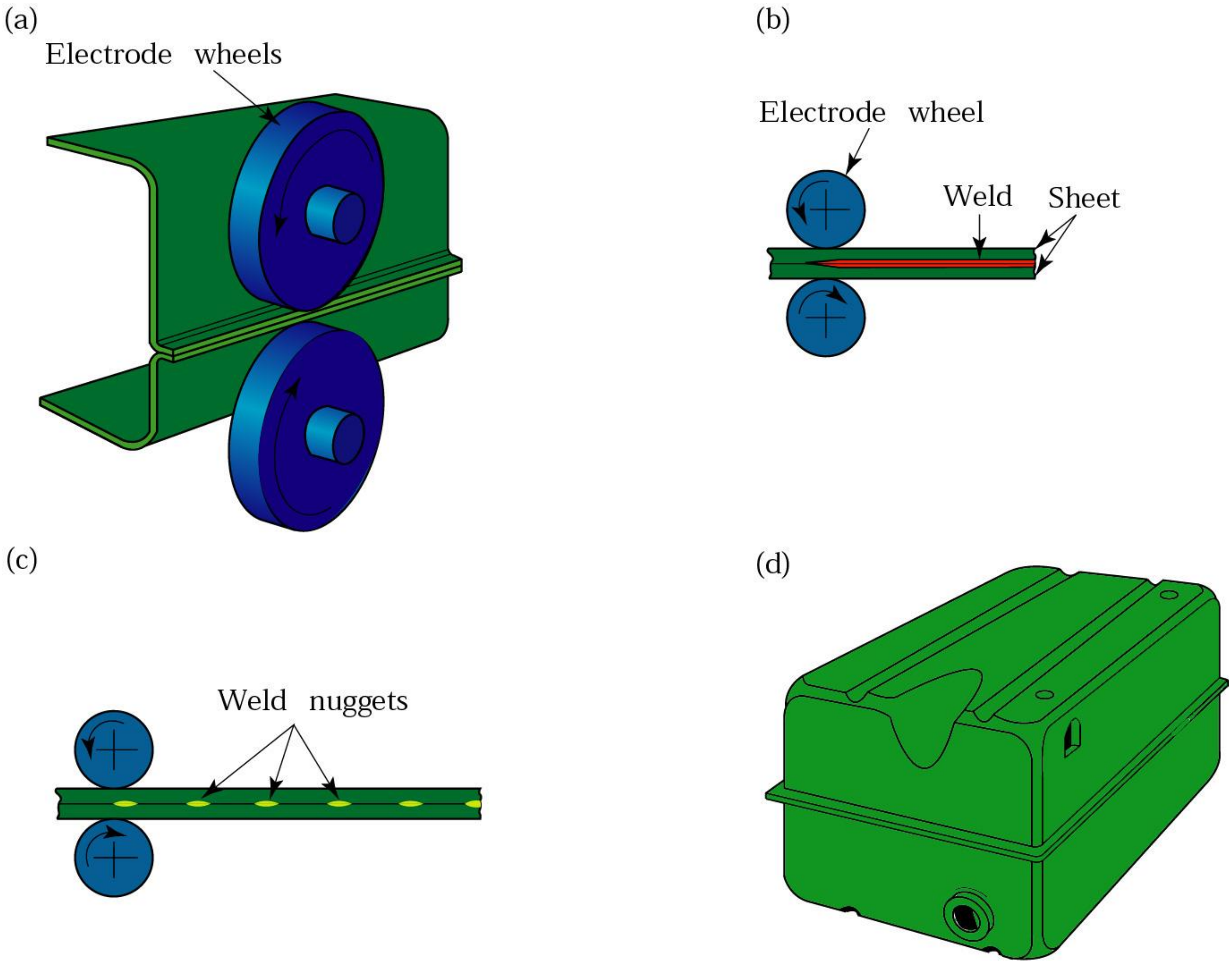
RSW – Resistance Spot Welding

(a) Sequence in resistance spot welding. (b) Cross-section of a spot weld, showing the weld nugget and the indentation of the electrode on the sheet surfaces. This is one of the most commonly used process in sheet-metal fabrication and in automotive-body assembly.



RSEW – Resistance Seam Welding

(a) Seam-welding process in which rotating rolls act as electrodes. (b) Overlapping spots in a seam weld. (c) Roll spot welds. (d) Resistance-welded gasoline tank.



Brazing and Soldering

- Requires lower temperatures than welding
- Uses filler metals, such as alloys of aluminum, magnesium, copper, silver, gold, etc
- Joint design is important:
  - If clearance is too small fill metal will not penetrate
  - If clearance is too large capillary behavior will not occur
  - If area of contact is too small, joint will not withstand loading
- Can be used in combination with mechanical fasteners

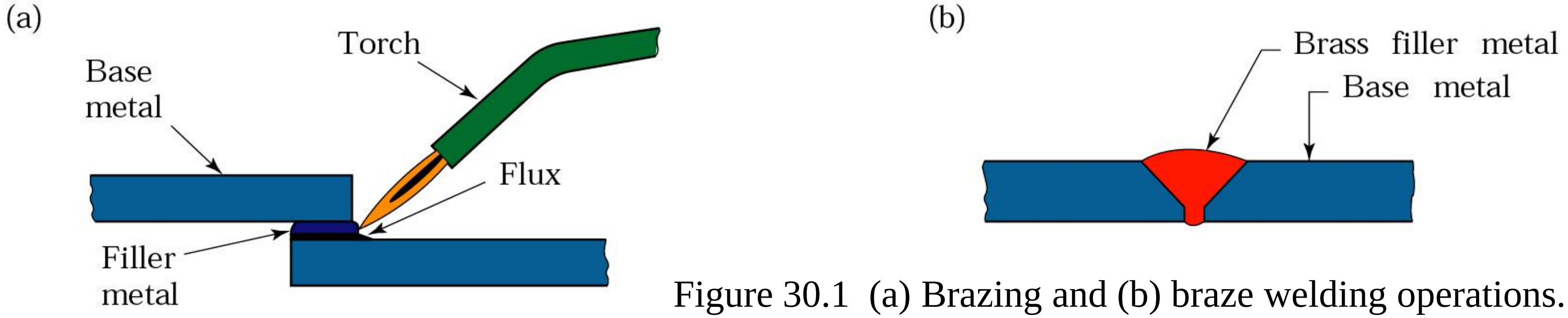
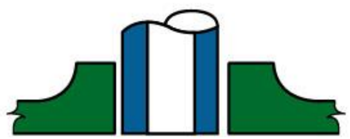
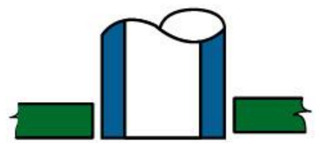
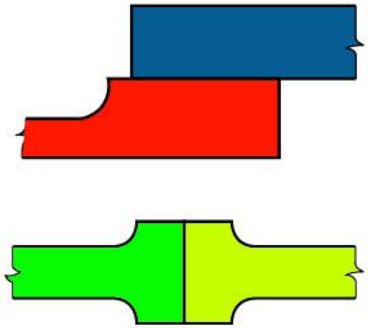
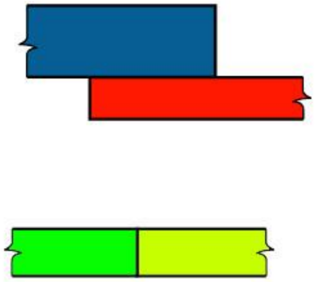
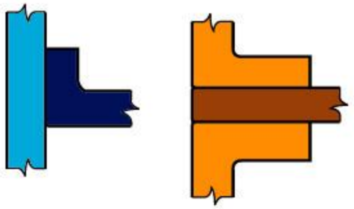
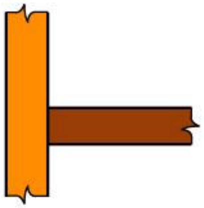


Figure 30.1 (a) Brazing and (b) braze welding operations.

Brazing and Soldering Joint Design

Good	Poor	Comments
		Too little joint area in shear
		Improved design when fatigue loading is a factor to be considered
		Insufficient bonding

Adhesive Bonding

- Can provided strength, sealing, insulating, vibration damping, and corrosion resistance properties
- Can be used with plastics
- Many types:
  - Epoxy – one or two component thermoset
  - Silicon, Urethane, and other thermosets
  - Acrylics – thermoplastic, requires ventilation
  - Cyanoacrylate – “crazy glue”
  - Anaerobic – thermoset, adheres in absence of oxygen
  - Pressure sensitive – tape, labels, stickers
  - Water based glues
- Some may require various forms of curing

Adhesive Bonding Joint Designs

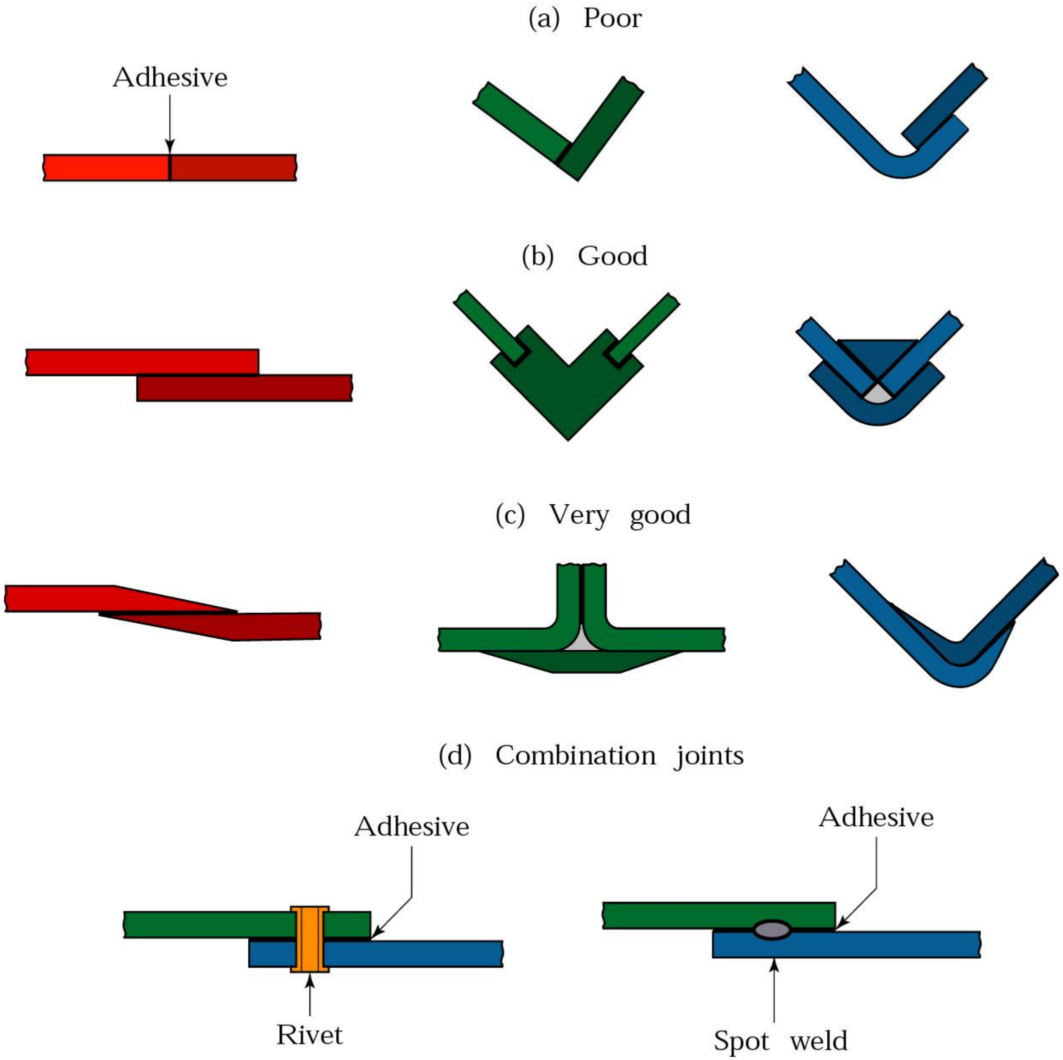
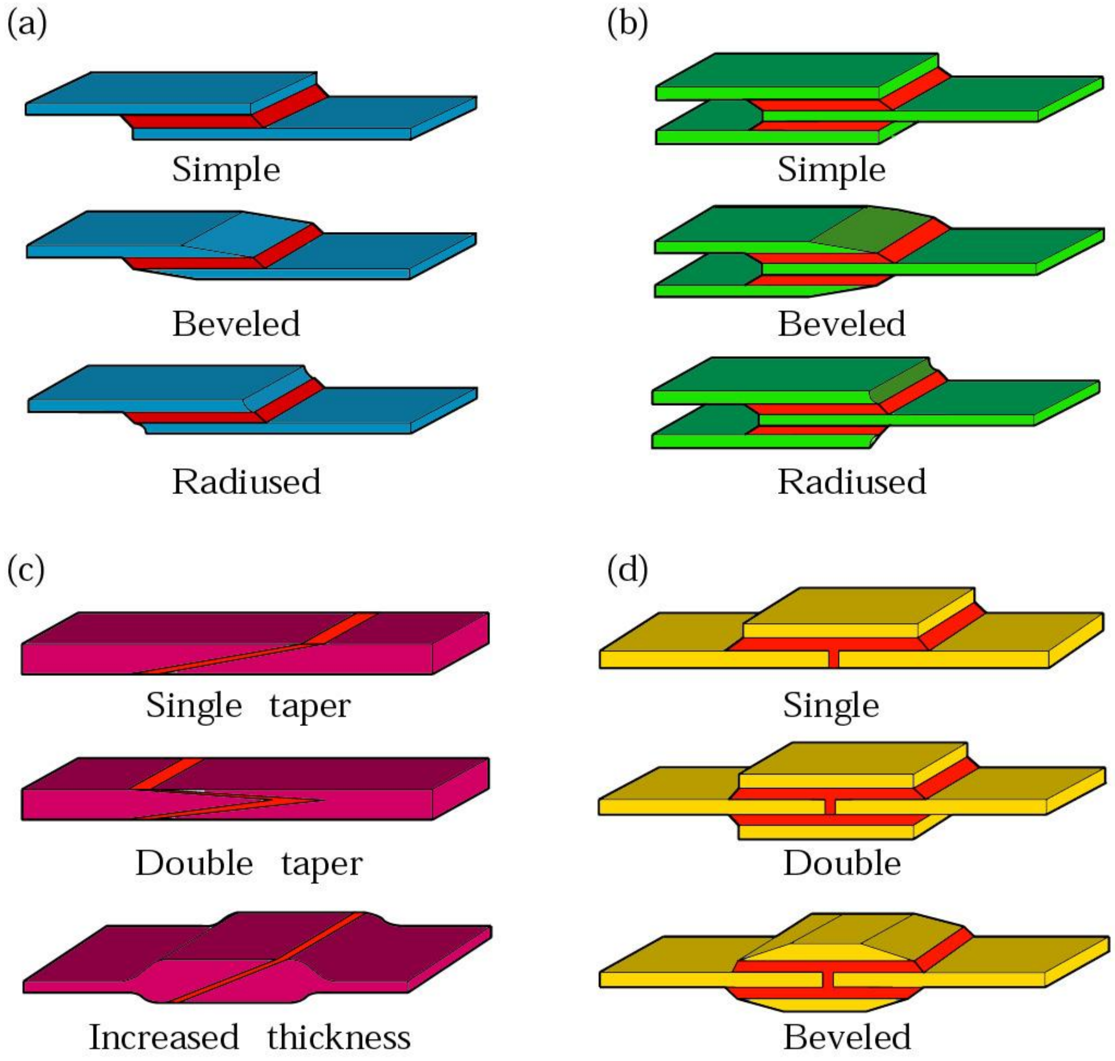


Figure 30.9 Various joint designs in adhesive bonding. Note that good designs require large contact areas between the members to be joined.

- Peel tests can be used to assess strength of bonds

Adhesive Bonding

Figure 30.10 Various configurations for adhesively bonded joints: (a) single lap, (b) double lap, (c) scarf, (d) strap.



Mechanical Fastening

- Traditional components such as bolts, nuts, rivets, etc.
- Can be used with plastics or metals

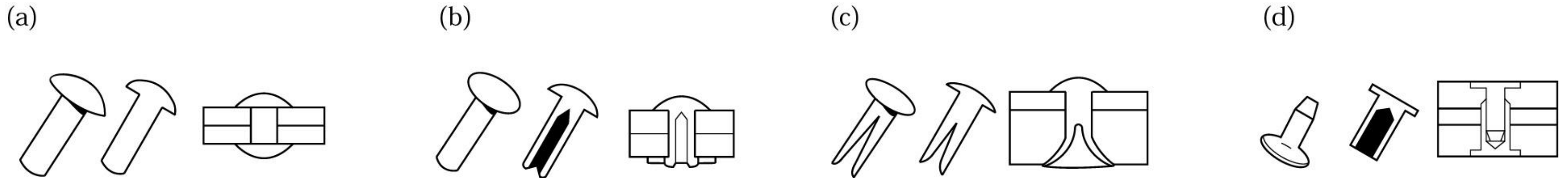


Figure 30.11 Examples of rivets: (a) solid, (b) tubular, (c) split (or bifurcated), (d) compression.

Rivet Design

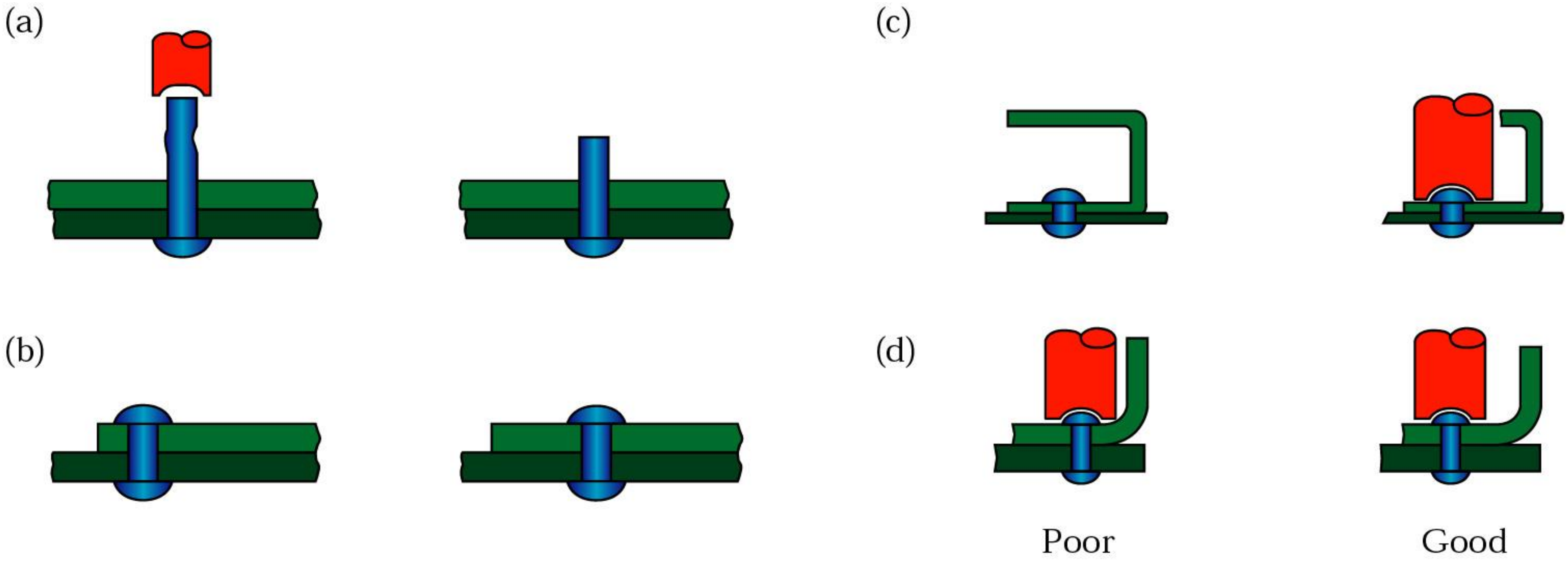
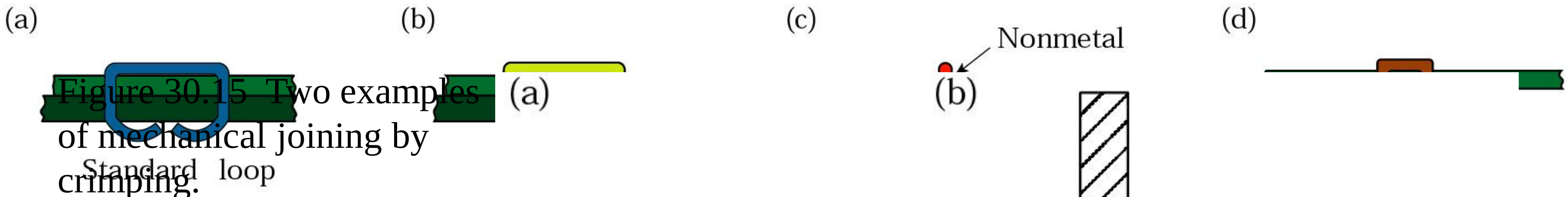


Figure 30.12 Design guidelines for riveting. (a) Exposed shank is too long; the result is buckling instead of upsetting. (b) Rivets should be placed sufficiently far from edges to avoid stress concentrations. (c) Joined sections should allow ample clearance for the riveting tools. (d) Section curvature should not interfere with the riveting process. *Source*: J. G. Bralla.

Mechanical Assembly



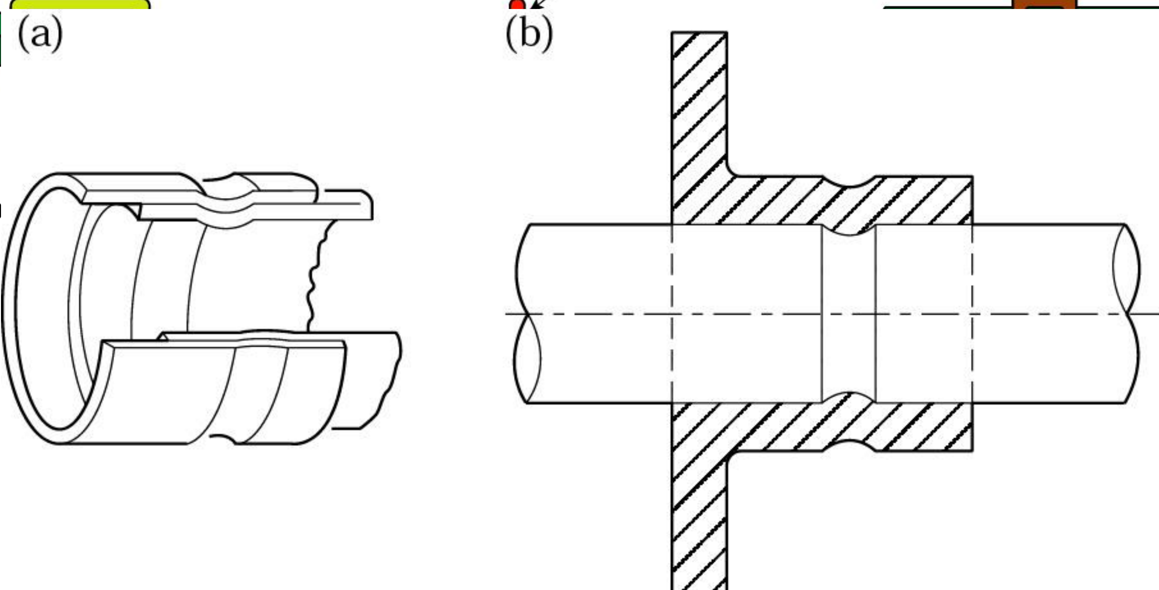


Figure 30.15 Two examples of mechanical joining by crimping.

Figure 30.13 Various examples o

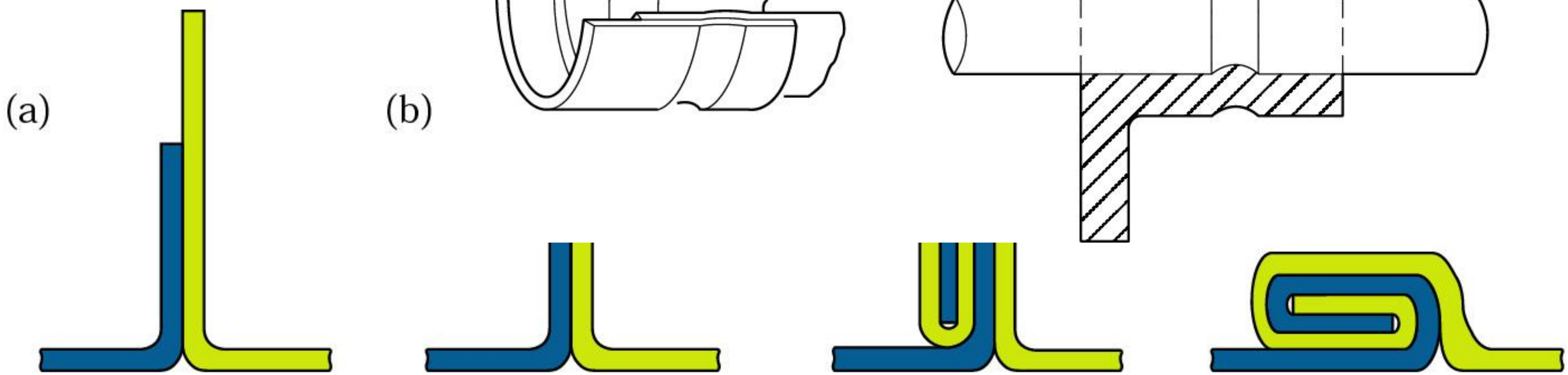
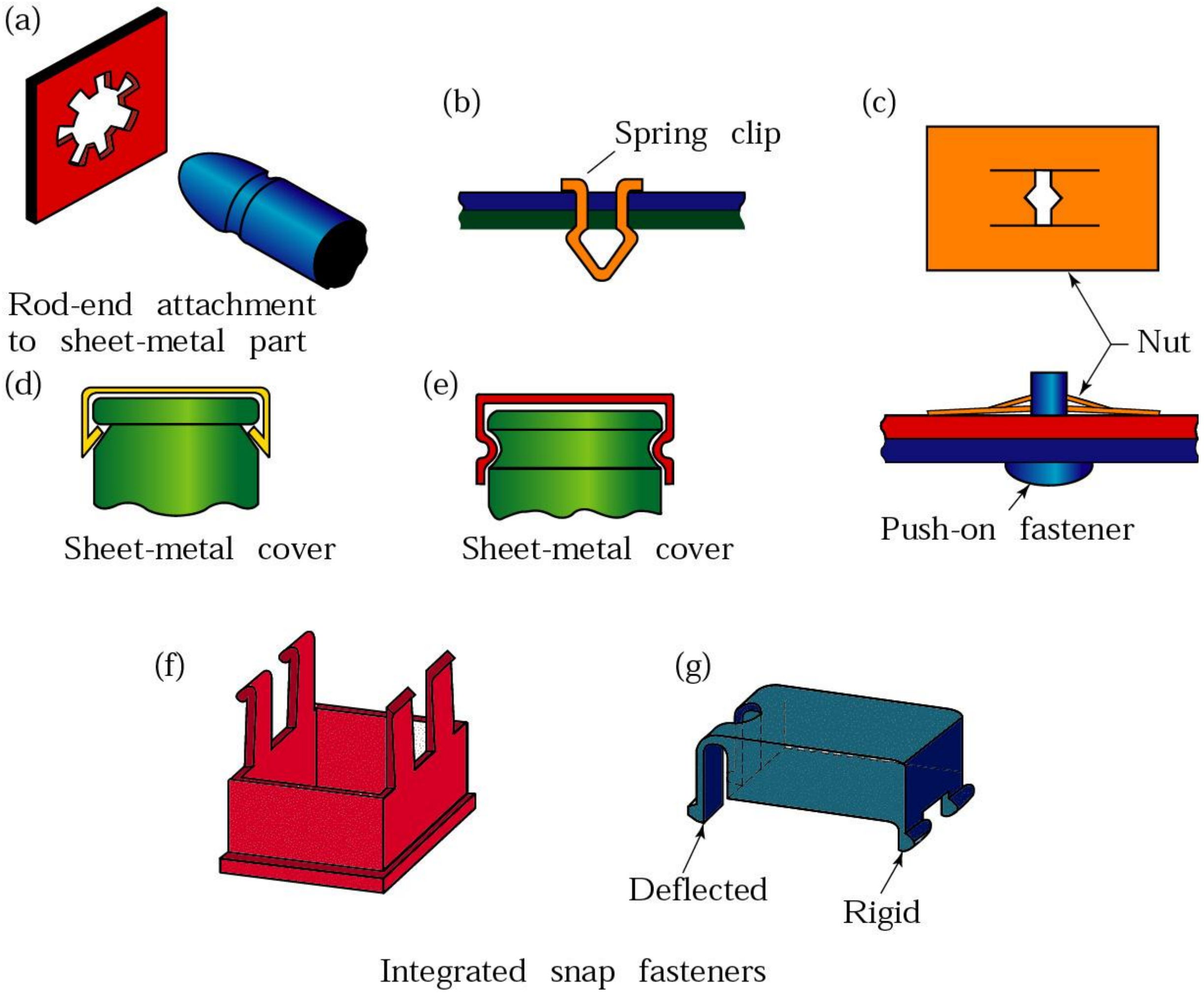


Figure 30.14 Stages in forming a double-lock seam.

Spring and Snap Fits, Crimping



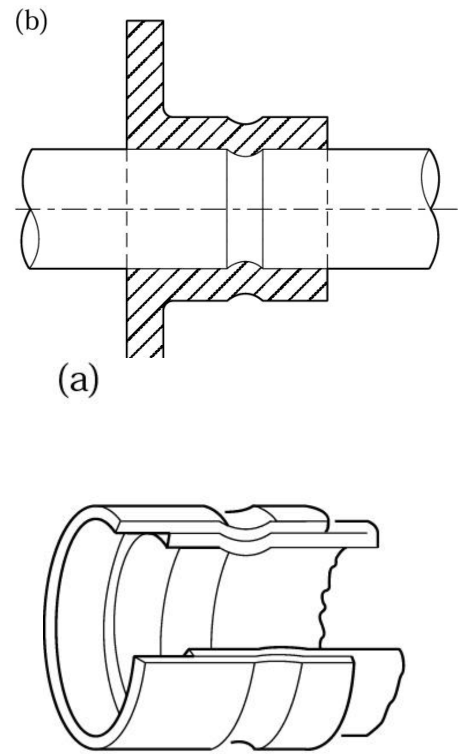


Figure 30.15 Two examples of mechanical joining by crimping.