446.305A MANUFACTURING PROCESSES

Chapter 12. Joining and Fastening Processes

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Introduction (1)

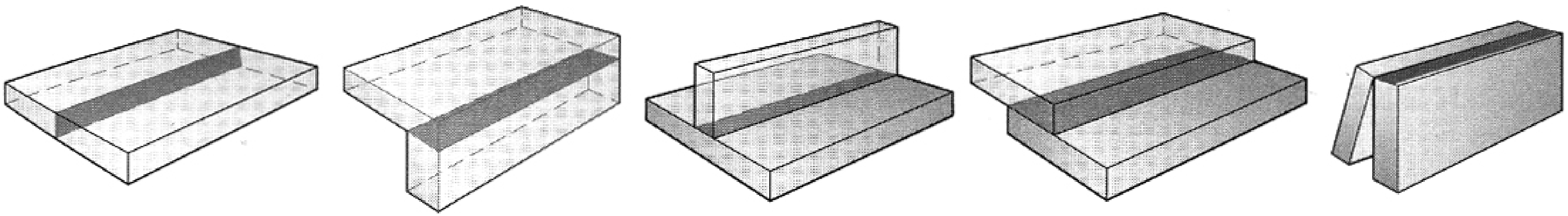
- **Fusion Welding (용접)**
  - Melting together and coalescing materials by means of heat, usually supplied by electrical or high-energy means.
- **Solid-state Welding (고상용접)**
  - Joining takes place without fusion.
- **Adhesive Bonding (접착법)**
- **Mechanical fastening (체결)**
  - Fasteners, bolts, nuts, rivets, etc.

TABLE 12.1

Comparison of Various Joining Methods

	Characteristics								
Method	Strength	Design Variability	Small Parts	Large Parts	Tolerances	Reliability	Ease of Maintenance	Visual 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, 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.



(a) Butt joint (b) Corner joint (c) T joint (d) Lap joint (e) Edge joint

FIGURE 12.1 Examples of joints that can be made through the various joining processes described in Chapter 12.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Introduction (2)

TABLE 12.2

General Characteristics of Joining Processes

Joining Process	Operation	Advantage	Skill Level Required	Welding Position	Current Type	Distortion*	Cost of Equipment
Shielded metal arc	Manual	Portable and flexible	High	All	ac, dc	1 to 2	Low
Submerged arc	Automatic	High deposition	Low to medium	Flat and horizontal	ac, dc	1 to 2	Medium
Gas metal arc	Semiautomatic or automatic	Works with most metals	Low to high	All	dc	2 to 3	Medium to high
Gas tungsten arc	Manual or automatic	Works with most metals	Low to high	All	ac, dc	2 to 3	Medium
Flux-cored arc	Semiautomatic or automatic	High deposition	Low to high	All	dc	1 to 3	Medium
Oxyfuel	Manual	Portable and flexible	High	All	–	2 to 4	Low
Electron beam, laser beam	Semiautomatic or automatic	Works with most metals	Medium to high	All	–	3 to 5	High

* 1, highest; 5, lowest

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Arc-Welding Processes: Consumable Electrode (1)

- **Shielded metal-arc welding (SMAW, 피복금속 아크용접)**
  - 50A ~ 300A (~10kW)

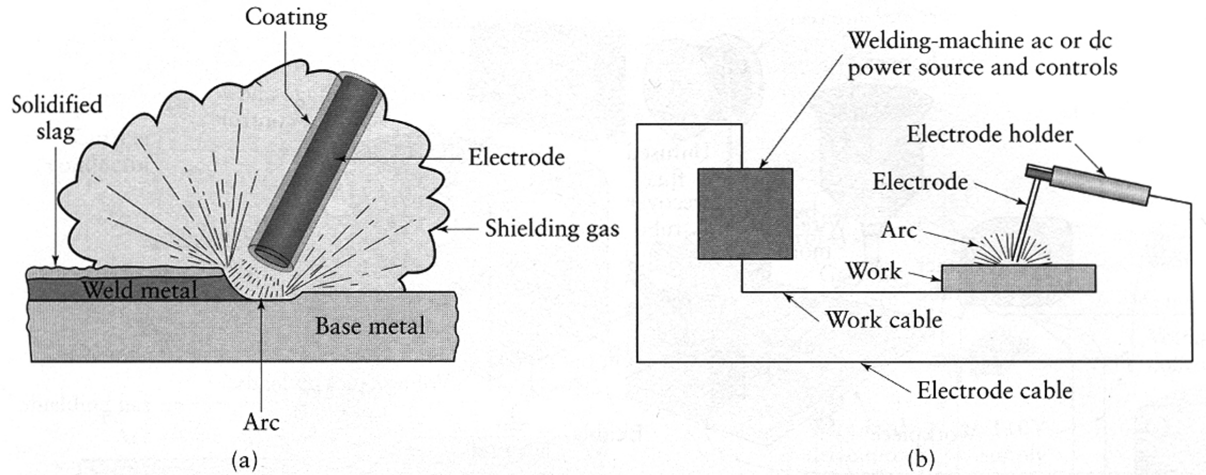


FIGURE 12.2 (a) Schematic illustration of the shielded metal-arc-welding process. About 50% of all large-scale industrial welding operations use this process. (b) Schematic illustration of the shielded metal-arc-welding operation, also known as *stick welding*, because the electrode is in the shape of a stick.

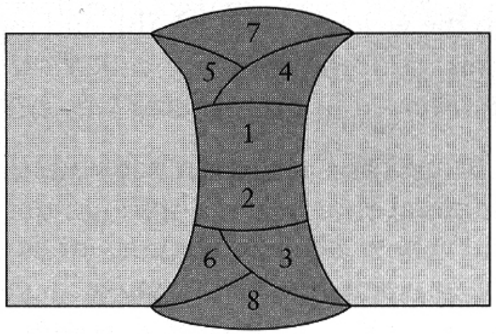


FIGURE 12.3 A weld zone showing the build-up sequence of individual weld beads in deep welds.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Arc-Welding Processes: Consumable Electrode (2)

- **Submerged arc welding (SAW)**
  - Flux - lime, silica, manganese oxide, calcium fluoride.

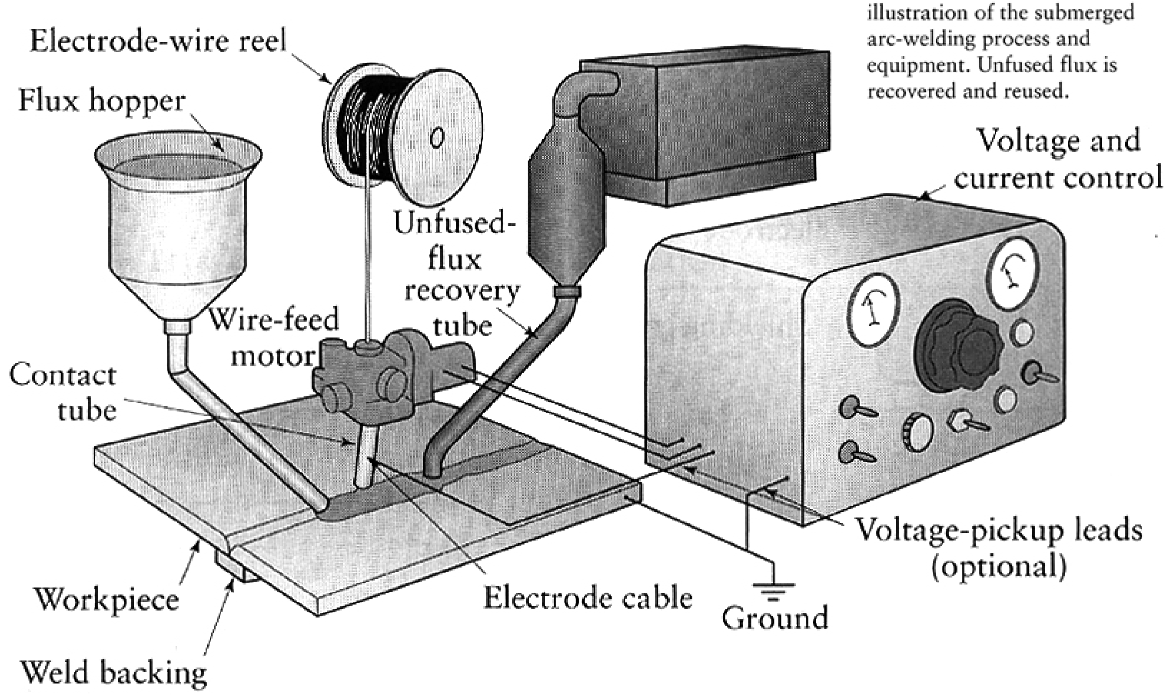


FIGURE 12.4 Schematic illustration of the submerged arc-welding process and equipment. Unfused flux is recovered and reused.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Arc-Welding Processes: Consumable Electrode (3)

- **Gas metal-arc welding (GMAW)**
  - Ar, He, CO_2 (inert gas)
  - Known as metal inert gas welding (MIG)

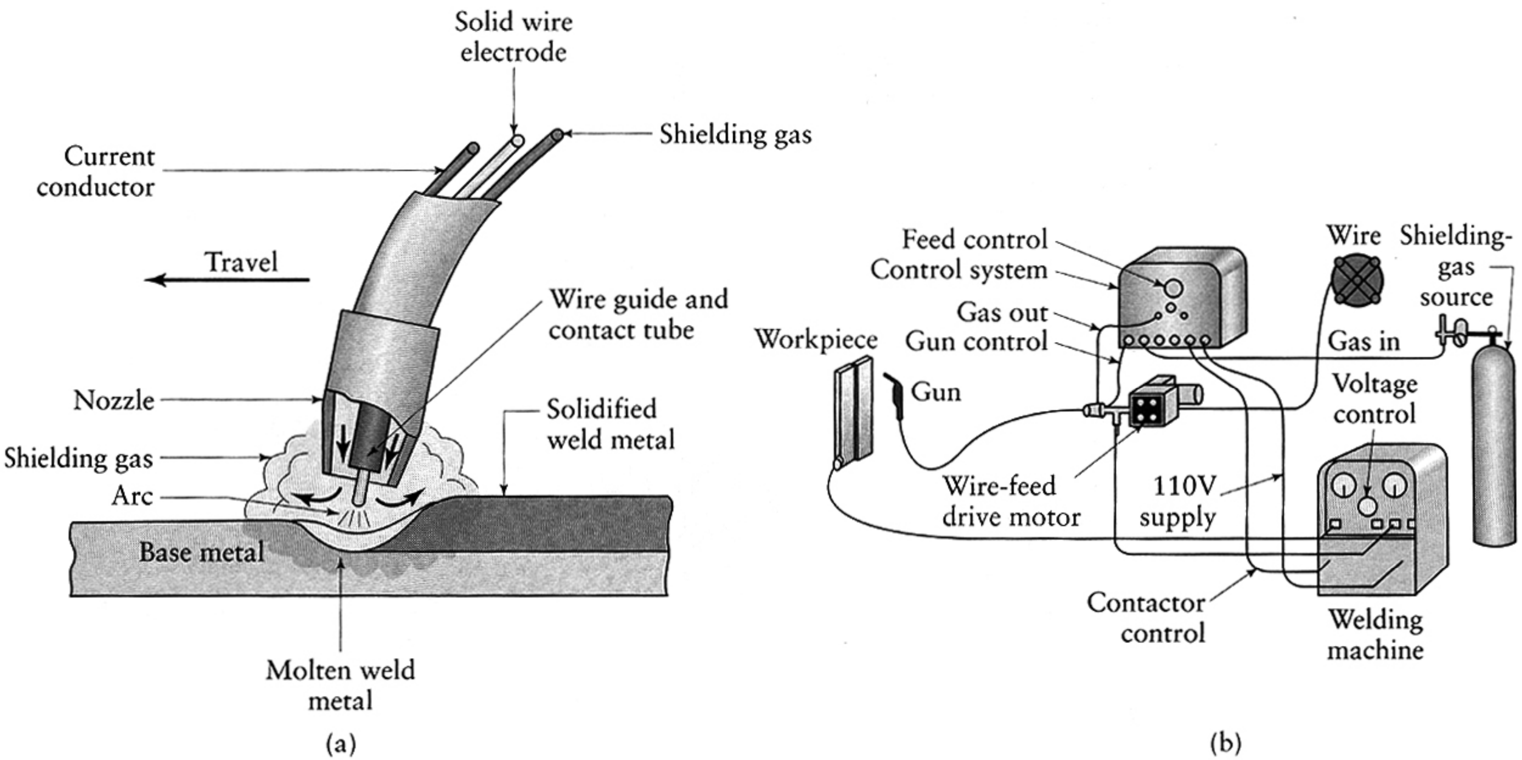


FIGURE 12.5 (a) Gas metal-arc-welding process, formerly known as MIG welding (for *metal inert gas*). (b) Basic equipment used in gas metal-arc-welding operations.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Arc-Welding Processes: Consumable Electrode (4)

- **Flux-cored arc welding (FCAW)**

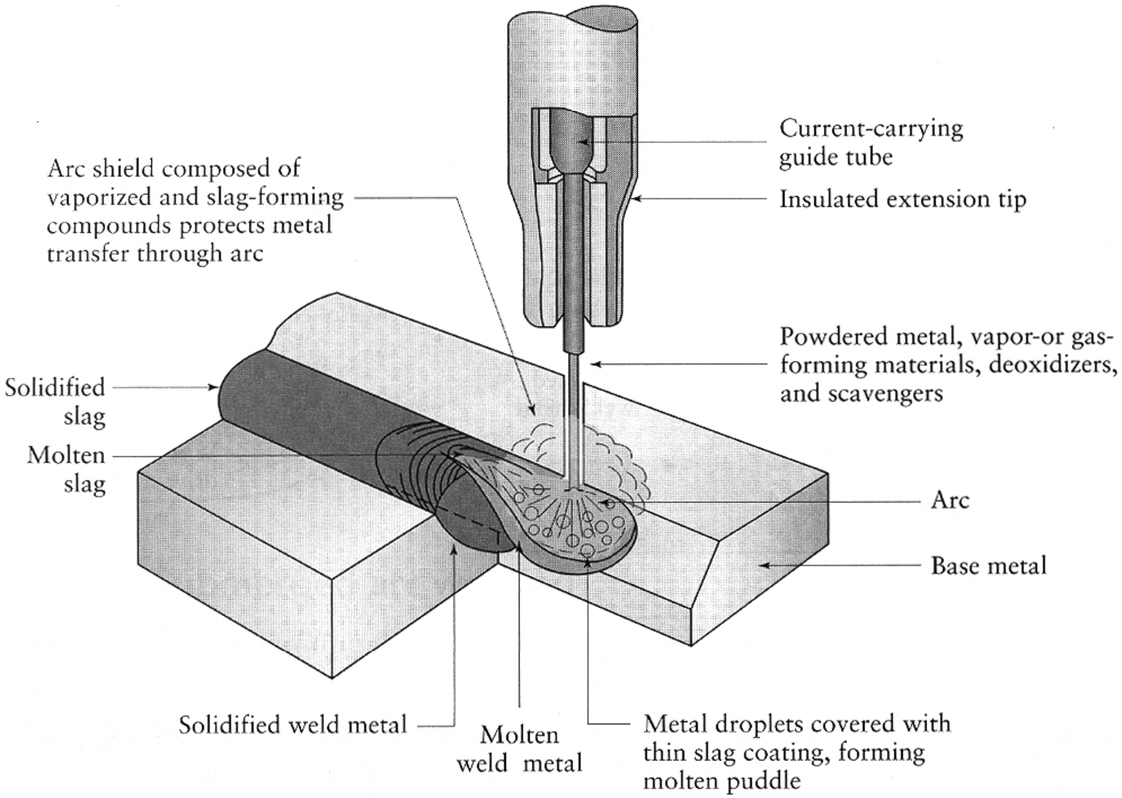


FIGURE 12.6 Schematic illustration of the flux-cored arc-welding process. This operation is similar to gas metal-arc welding, shown in Fig. 12.5.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Arc-Welding Processes: Non-consumable Electrode (1)

- **Gas tungsten-arc welding (GTAW)**
  - Known as TIG (Tungsten inert gas) welding.

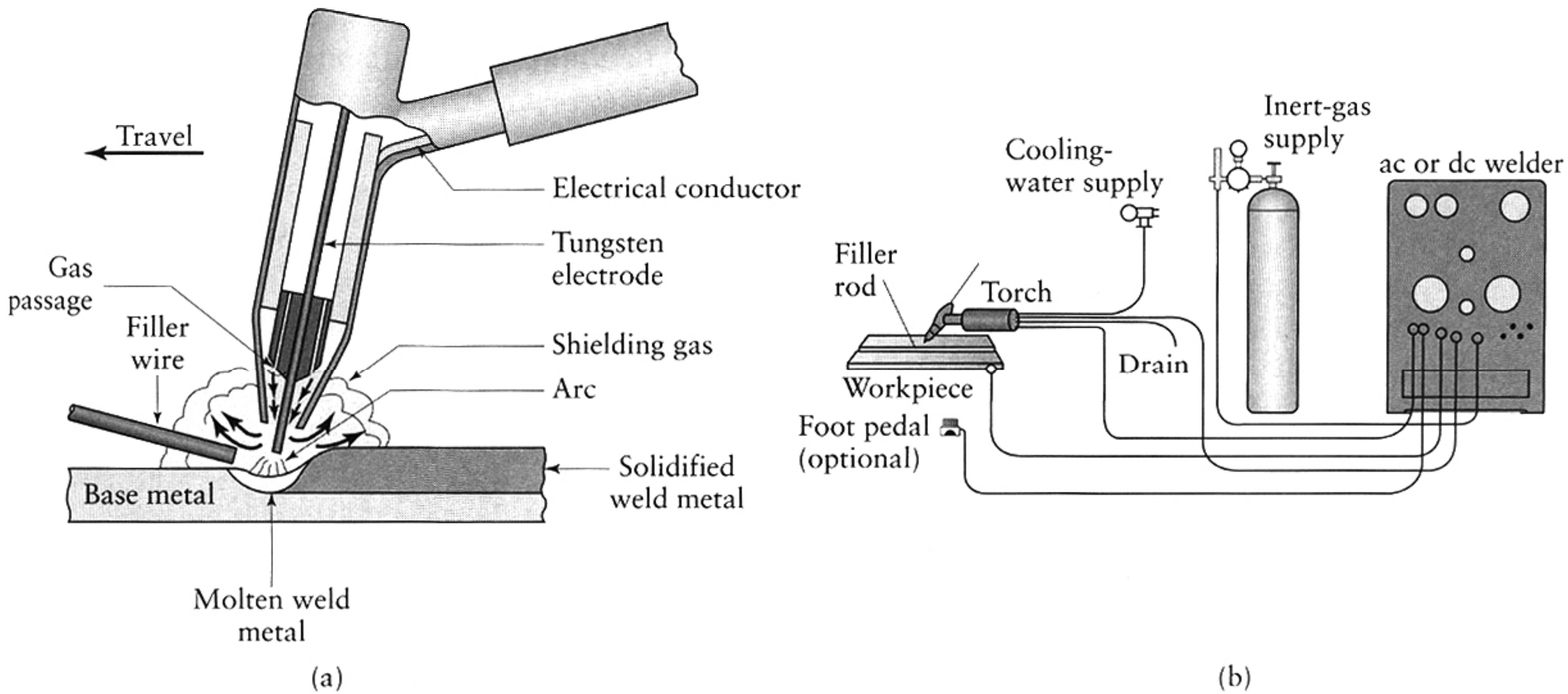


FIGURE 12.9 (a) Gas tungsten-arc-welding process, formerly known as TIG welding (for *tungsten inert gas*). (b) Equipment for gas tungsten-arc-welding operations.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Arc-Welding Processes: Non-consumable Electrode (2)

- **Plasma-arc welding (PAW)**

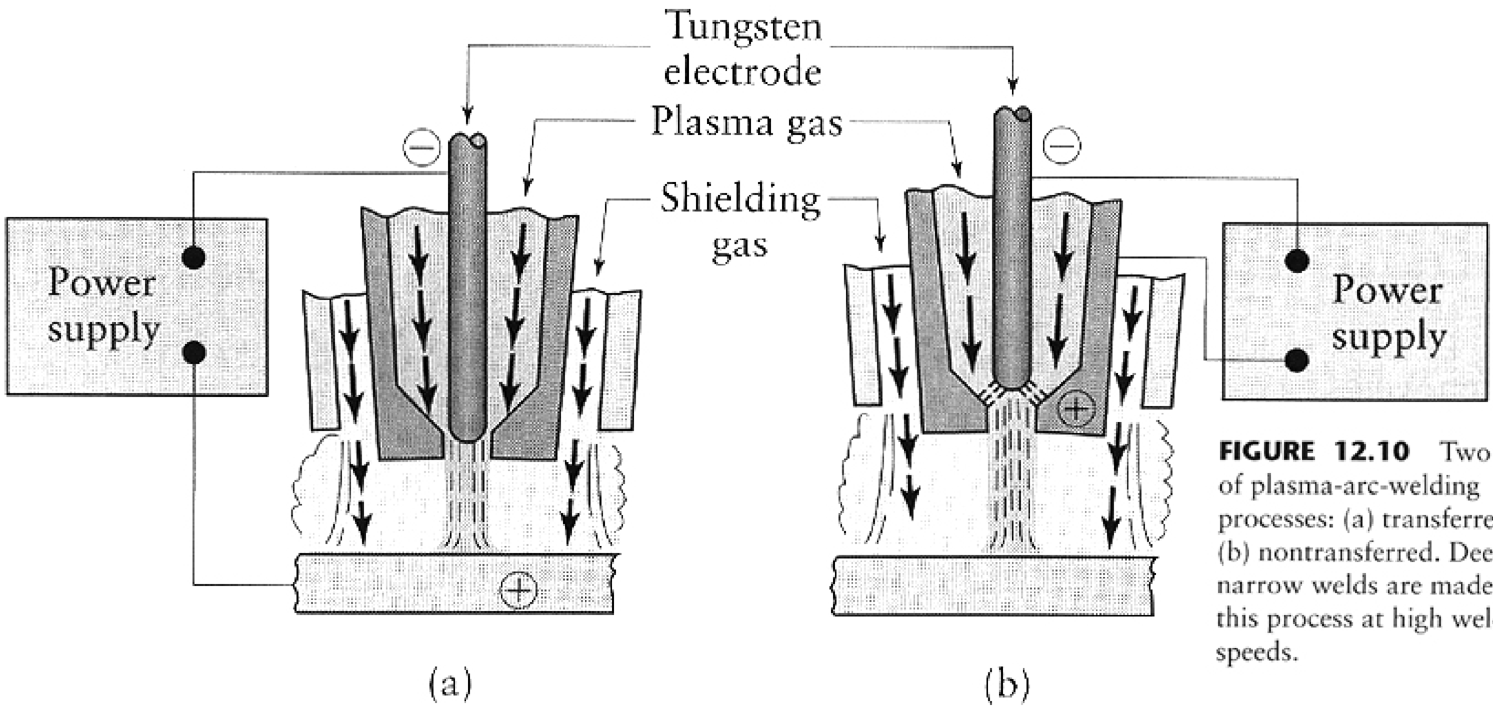
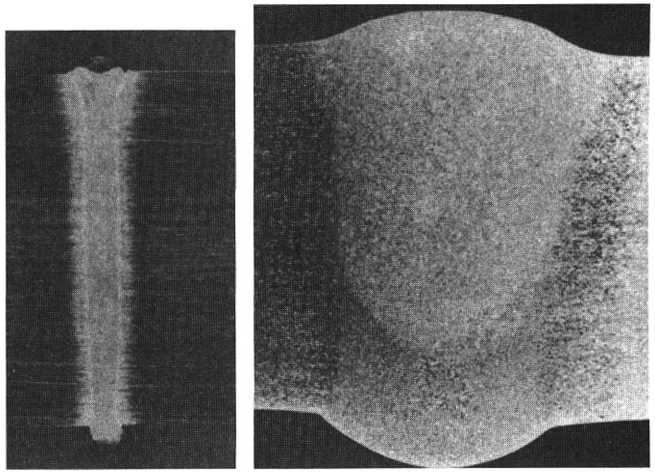


FIGURE 12.10 Two types of plasma-arc-welding processes: (a) transferred and (b) nontransferred. Deep and narrow welds are made by this process at high welding speeds.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

High-Energy-Beam Welding

- **Laser-beam welding (LBW)**
  - Good for high aspect ratio.
  - Vacuum is not required.



(a) (b)

FIGURE 12.11 Comparison of the size of weld beads in (a) electron-beam or laser-beam welding with that in (b) conventional (tungsten-arc) welding. *Source:* American Welding Society, *Welding Handbook*, 8th ed., 1991.

FIGURE 12.12 Gillette Sensor razor cartridge, with laser-beam welds.

Nd:YAG laser with fiber-optic delivery

- **Electron-beam welding (EBW)**
  - Generates X-rays.
  - High welding quality.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Fusion-Welded Joint (1)

- **Base metal**
- **Heat-affected zone (HAZ)**
- **Fusion zone**

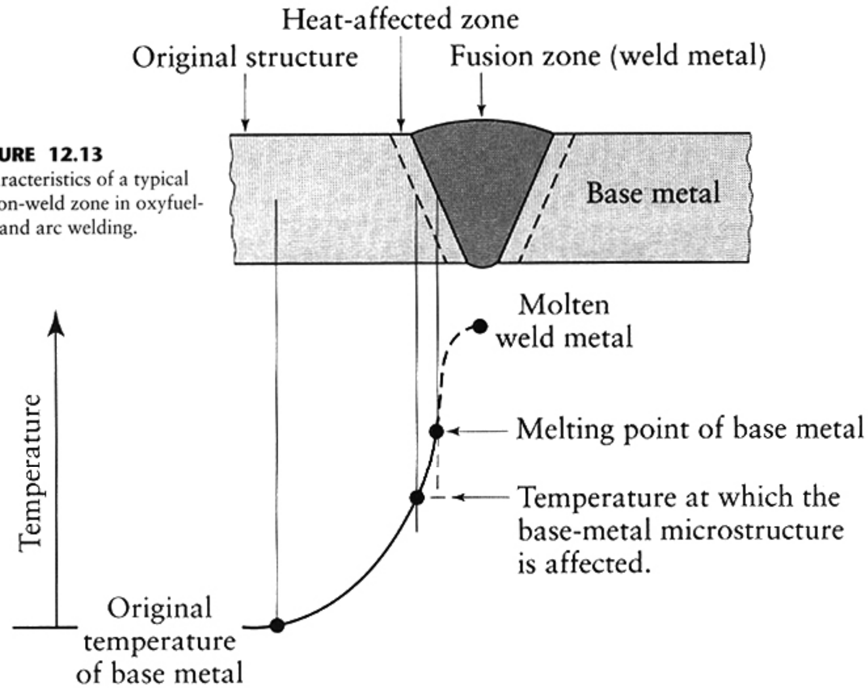


FIGURE 12.13 Characteristics of a typical fusion-weld zone in oxyfuel-gas and arc welding.

- **Note that the grains form parallel to the heat flow.**
    - similar to the dendrite in a cast structure.

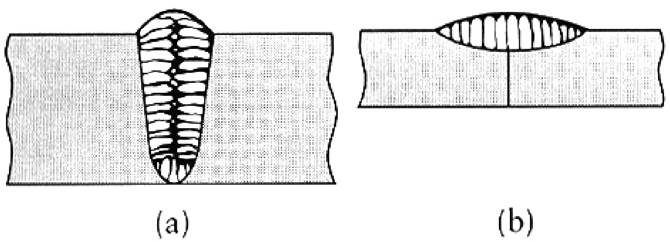


FIGURE 12.14 Grain structure in (a) a deep weld and (b) a shallow weld. Note that the grains in the solidified weld metal are perpendicular to their interface with the base metal. In a good weld, the solidification line at the center in the deep weld shown in (a) has grain migration, thus developing uniform strength in the weld bead.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Fusion-Welded Joint (2)

- **Heat-affected zone**
  - Cold-worked base metal.
  - Heat applied during welding recrystallizes the elongated grains.
  - Grains close to the weld metal grow and this grain growth will result in a region which is softer and has less strength.

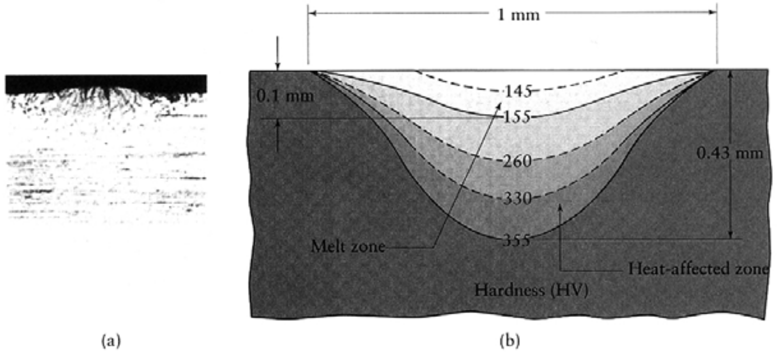


FIGURE 12.15 (a) Weld bead on a cold-rolled nickel strip produced by a laser beam. (b) Microhardness profile across the weld bead. Note the softer condition of the weld bead compared with the base metal. *Source:* IIT Research Institute.

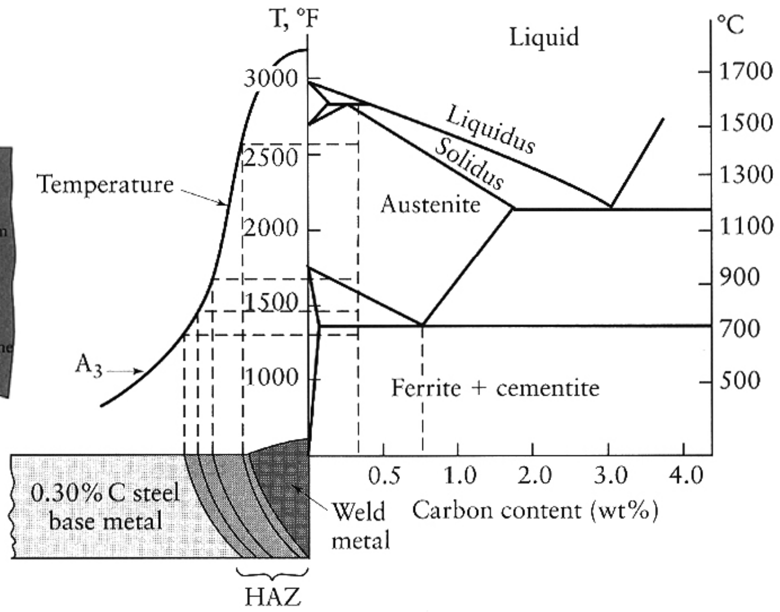


FIGURE 12.16 Schematic illustration of various regions in a fusion-weld zone and the corresponding phase diagram for 0.30% C steel. *Source:* Courtesy of the American Welding Society.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Residual Stresses

- **Stress relieving**
  - Preheating.
  - Lower cooling rate.
  - Lower magnitude of thermal stresses.
    (by reducing the *E* of metals being welded.)
  - Reducing shrinkage & crack.

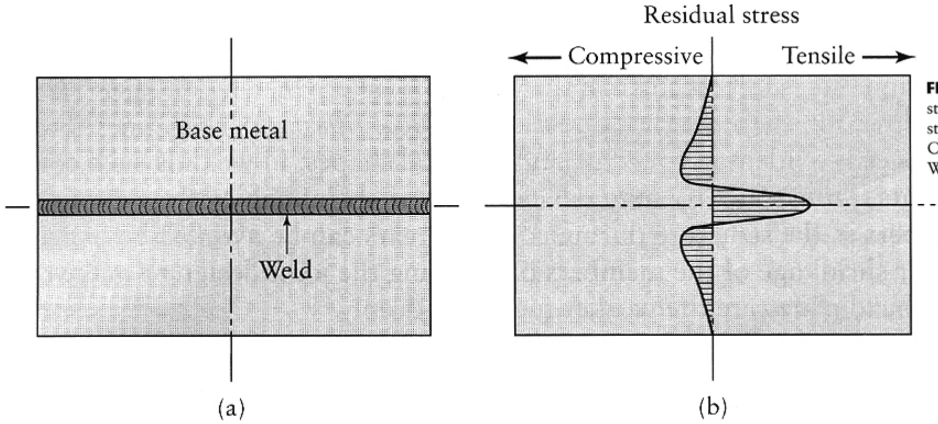


FIGURE 12.23 Residual stresses developed in a straight butt joint. *Source:* Courtesy of the American Welding Society.

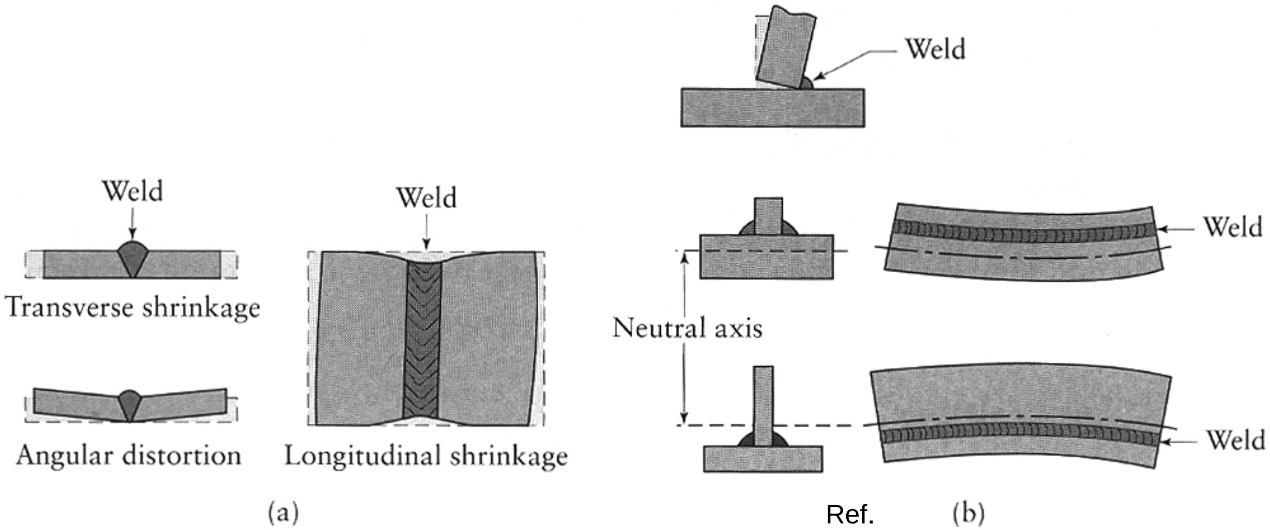


FIGURE 12.22 Distortion of parts after welding: (a) butt joints and (b) fillet welds. Distortion is caused by differential thermal expansion and contraction of different regions of the welded assembly. Warping can be reduced or eliminated by proper weld design and fixturing prior to welding.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Cold Welding & Ultrasonic Welding

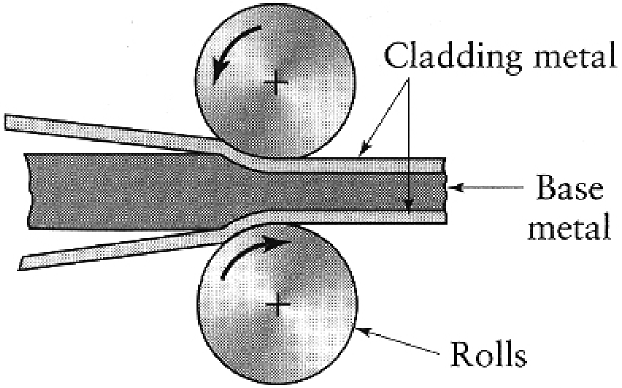
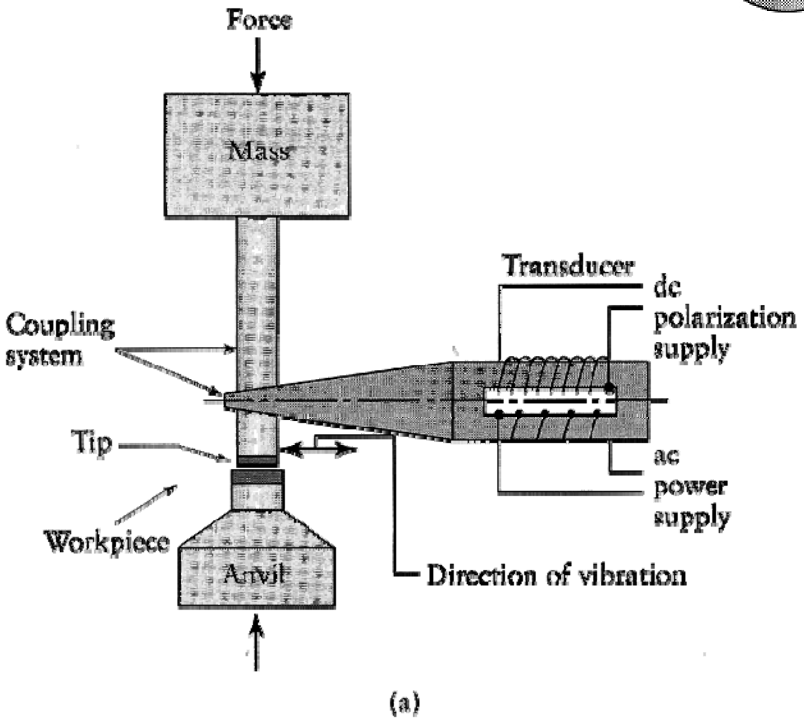


FIGURE 12.26 Schematic illustration of the roll-bonding, or cladding, process.



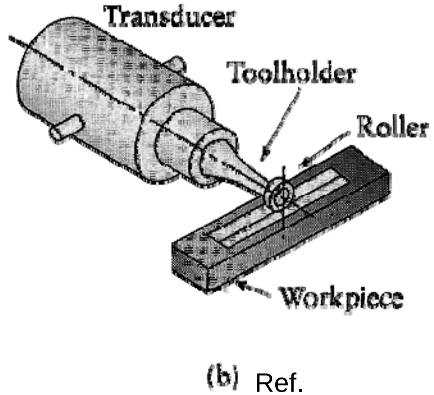


FIGURE 12.27 (a) Components of an ultrasonic-welding machine for lap welds. The lateral vibrations of the tool tip cause plastic deformation and bonding at the interface of the workpieces. (b) Ultrasonic seam welding using a roller.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Friction Welding

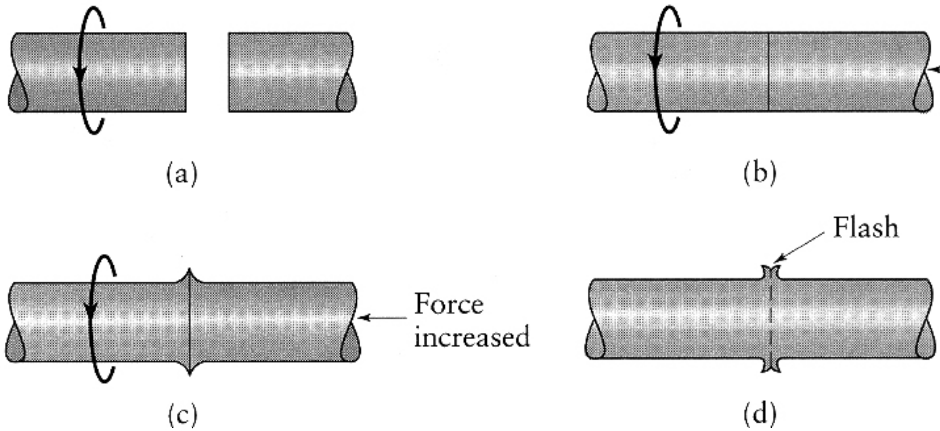


FIGURE 12.28 Sequence of operations in the friction-welding process. (a) The part on the left is rotated at high speed. (b) The part on the right is brought into contact under an axial force. (c) The axial force is increased; flash begins to form. (d) The part on the left stops rotating. The weld is completed. Flash can be removed by machining or grinding.

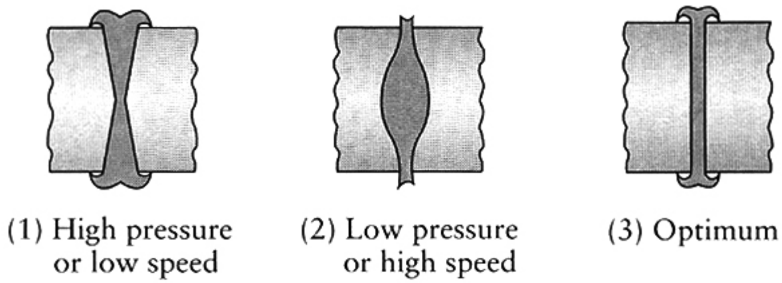
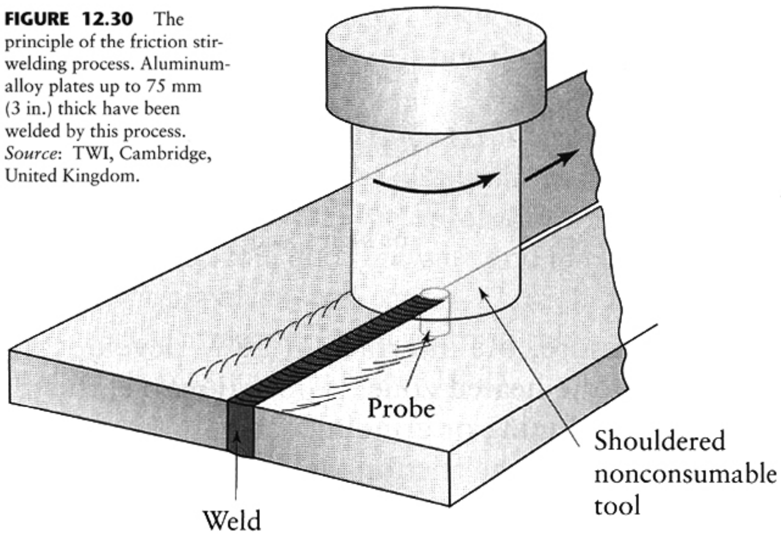


FIGURE 12.29 Shape of the fusion zone in friction welding as a function of the force applied and the rotational speed.

FIGURE 12.30 The principle of the friction stir-welding process. Aluminum-alloy plates up to 75 mm (3 in.) thick have been welded by this process. *Source*: TWI, Cambridge, United Kingdom.



Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Resistance Welding (1)

$$H = I^2 R t$$

H = heat generated (J)

I = current (A)

R = resistance (Ω)

t = flow time of the current (s)

- **Resistance spot welding**

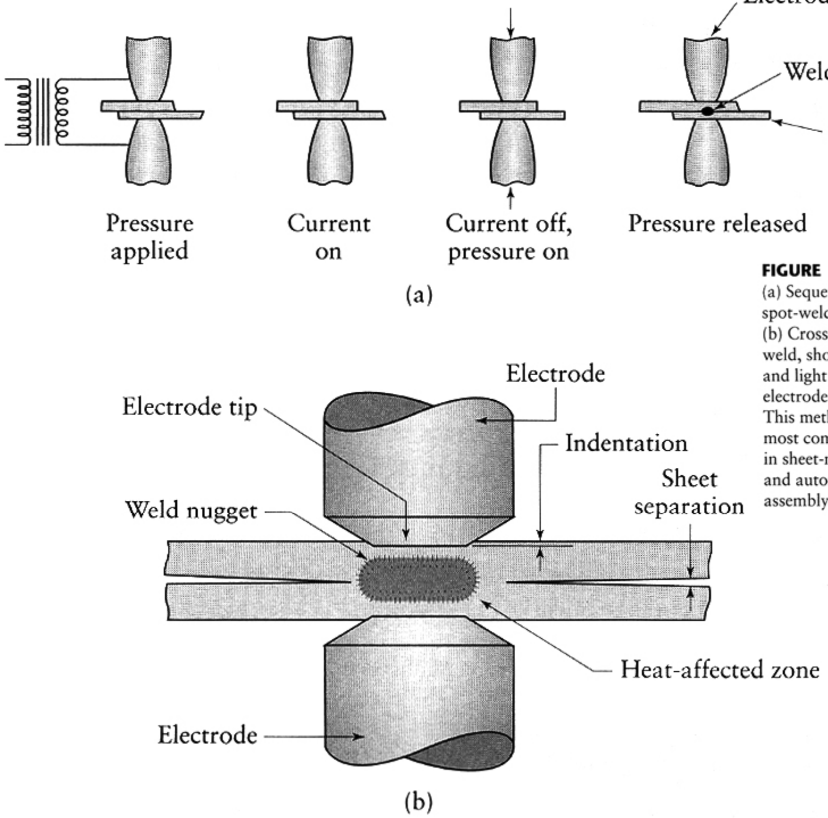


FIGURE 12.31
(a) Sequence in the resistance spot-welding process.
(b) Cross-section of a spot weld, showing weld nugget and light indentation by the electrode on sheet surfaces. This method is one of the most common processes used in sheet-metal fabrication and automotive-body assembly.

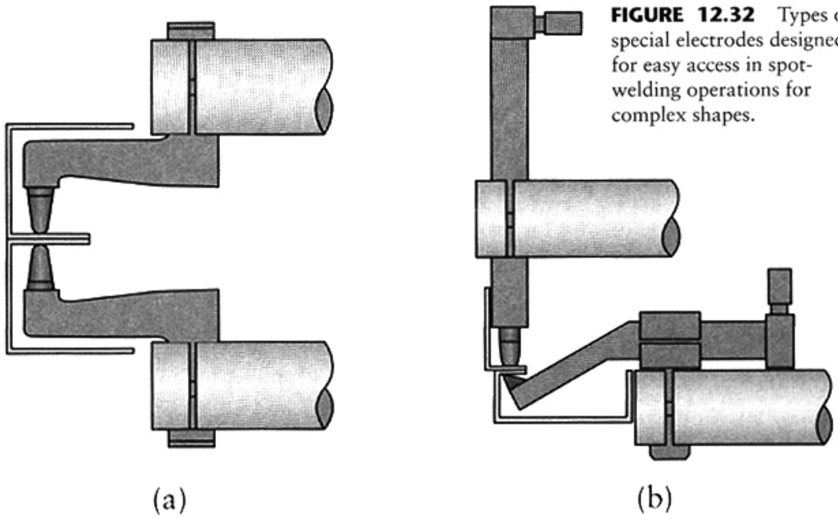


FIGURE 12.32 Types of special electrodes designed for easy access in spot-welding operations for complex shapes.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Resistance Welding (2)

- **Resistance seam welding**

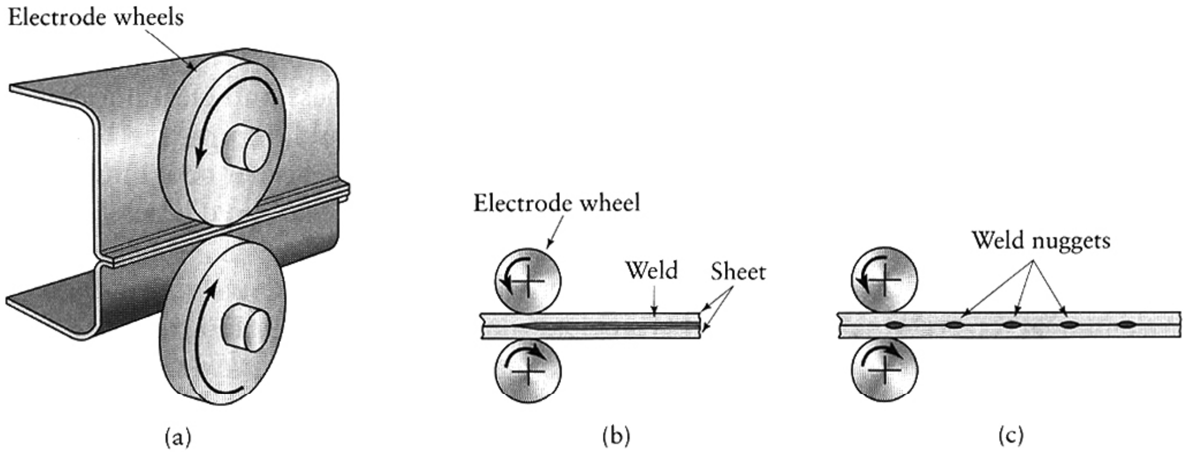


FIGURE 12.33 (a) Seam-welding process, with rolls acting as electrodes. (b) Overlapping spots in a seam weld. (c) Roll spot welds.

- **Resistance projection welding**

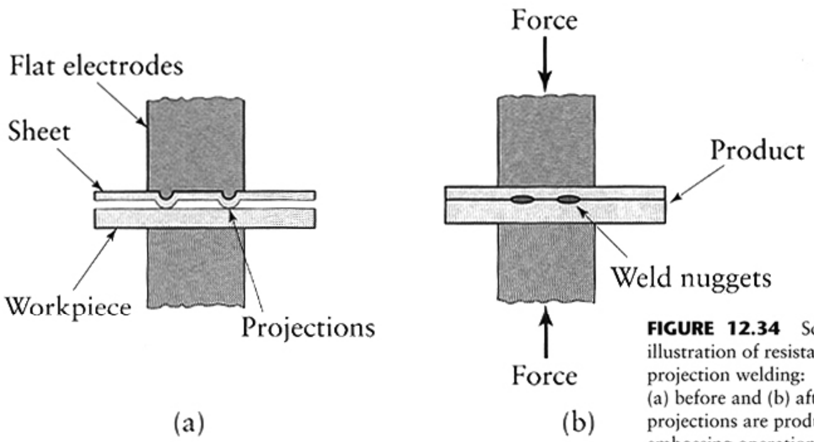


FIGURE 12.34 Schematic illustration of resistance projection welding: (a) before and (b) after. The projections are produced by embossing operations, as described in Section 7.6.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Explosive welding (폭발용접)

- **Joined by high kinetic energy.**
- **Detonation speed : 2400~3600m/s**

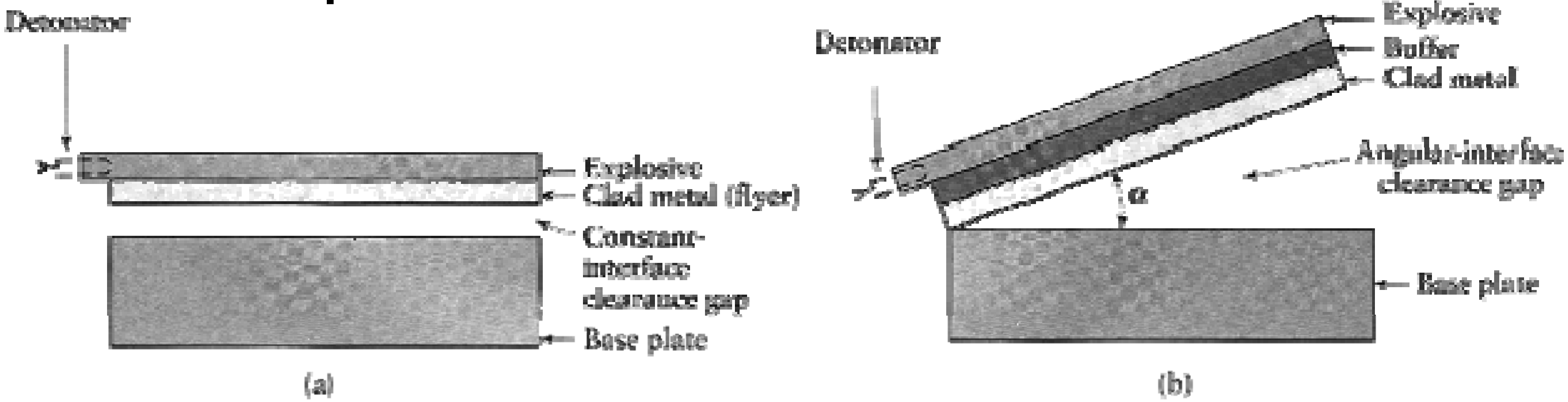


FIGURE 12.37 Schematic illustration of the explosion-welding process: (a) constant-interface clearance gap and (b) angular-interface clearance gap.

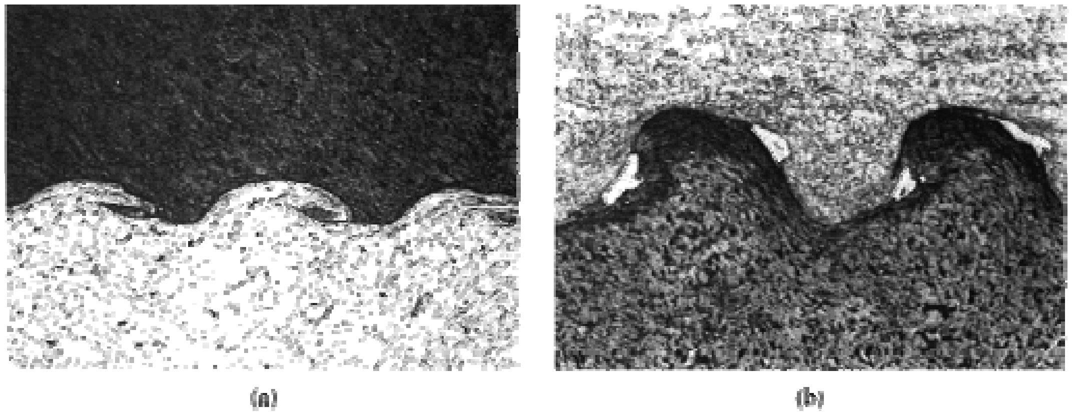


FIGURE 12.38 Cross sections of explosion-welded joints: (a) titanium (top) on low-carbon steel (bottom) and (b) Incoloy 800 (iron-nickel-base alloy) on low-carbon steel. The wavy interfaces shown improve the shear strength of the joint. Some combinations of metals, such as tantalum and vanadium, produce a much less wavy interface. If the two metals have little metallurgical compatibility, an interlayer may be added that has compatibility with both metals. Source: Courtesy of DuPont Company.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Brazing (경납접)

- The temperature is raised to melt the filler (용가재) metal, but not the workpiece.
- Filler metals generally melt above 450°C.
- Fluxes(용재) : in order to prevent oxidation and to remove oxide films from workpiece surface.

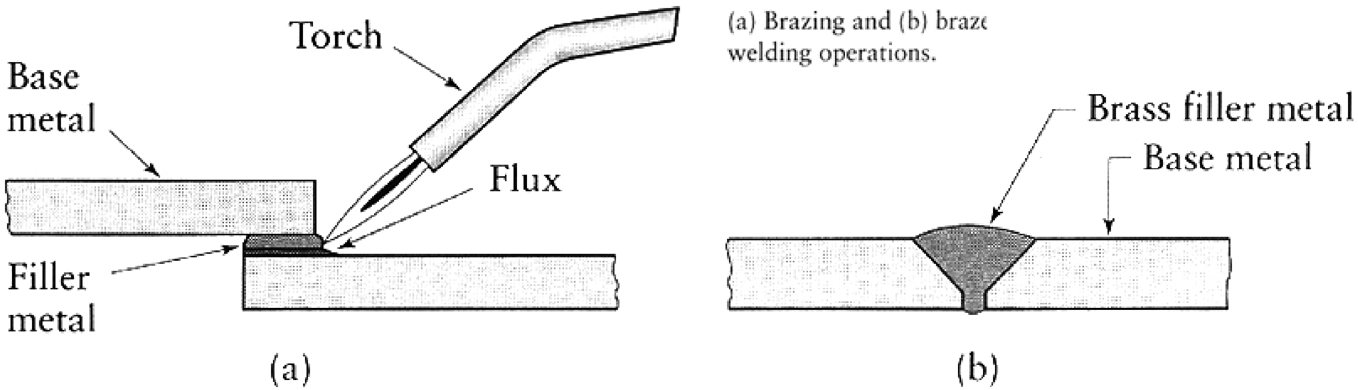


FIGURE 12.40 (a) Brazing and (b) braze welding operations.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Brazed joints

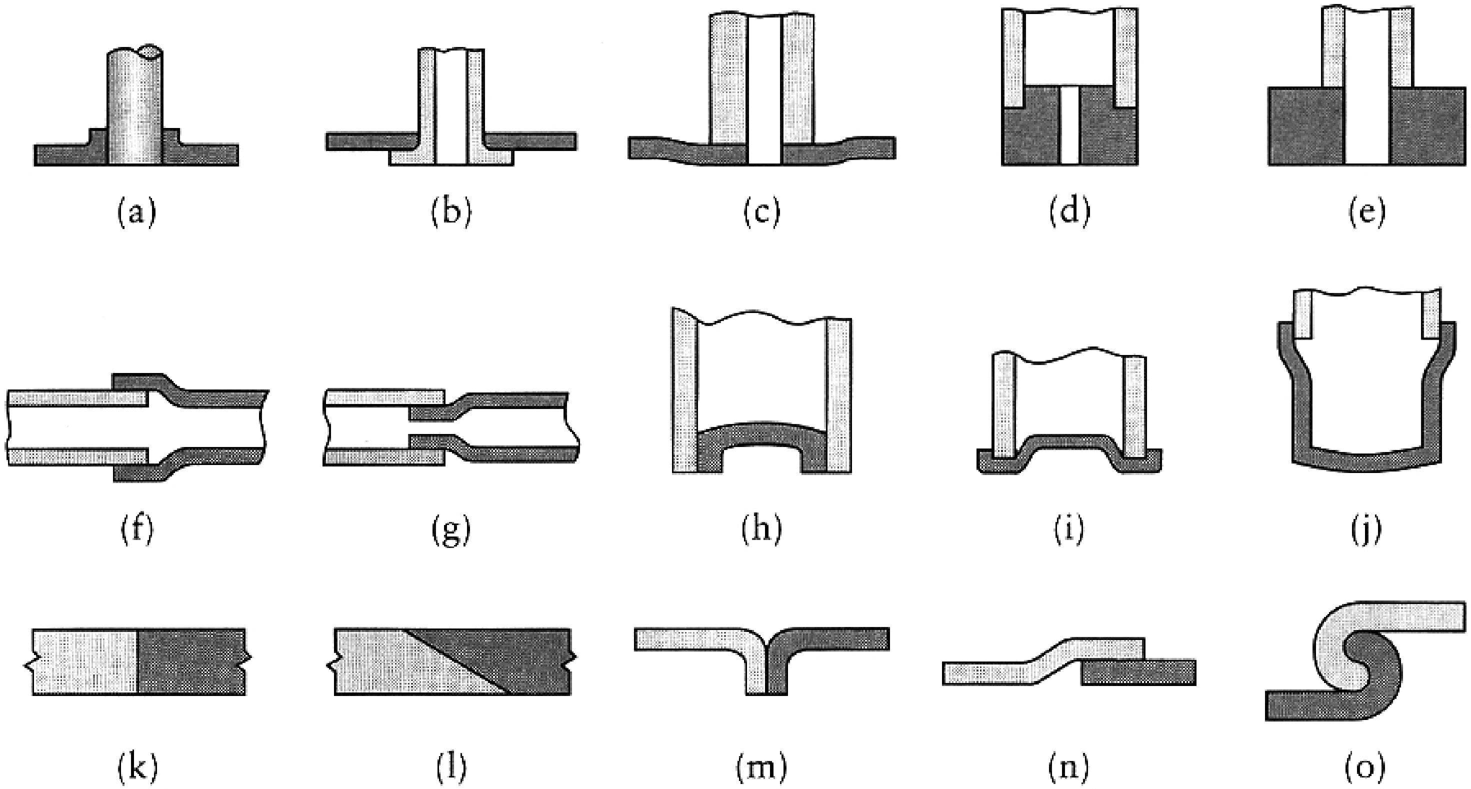


FIGURE 12.42 Joint designs commonly used in brazing operations.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Soldering (연납접)

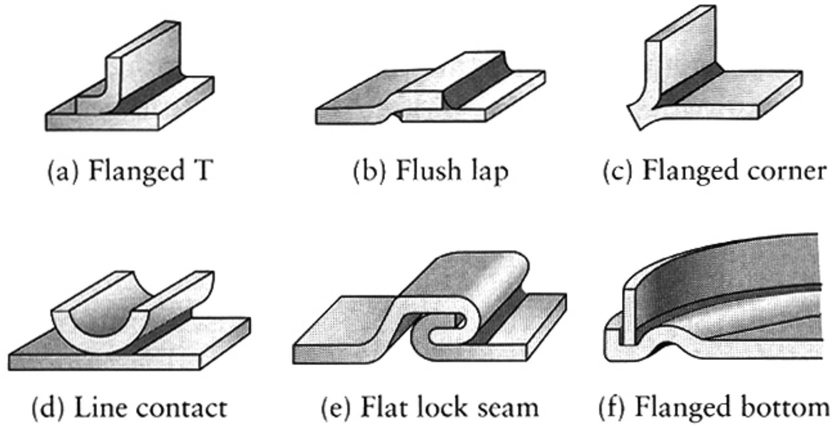


FIGURE 12.43 Joint designs commonly used for soldering.

- **Filler metals melt below 450°C.**
- **Fluxes are used.**

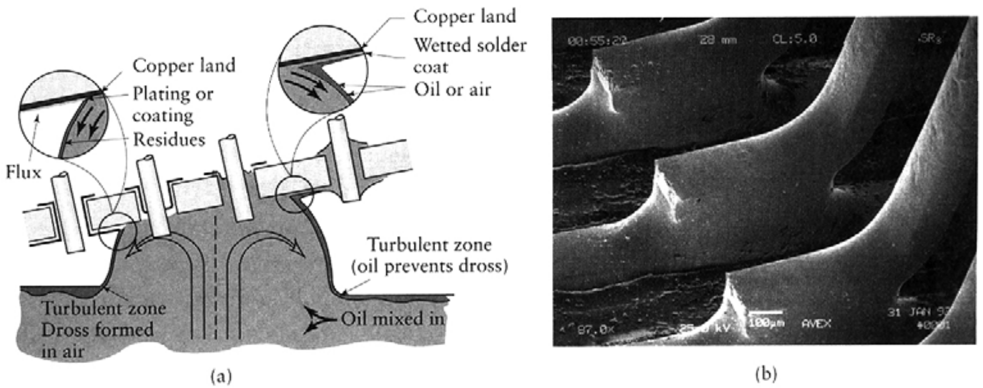


FIGURE 12.45 (a) Schematic illustration of the wave-soldering process. (b) SEM image of a wave-soldered joint on a surface-mount device.

TABLE 12.4

Types of Solders and their Applications

Tin–lead	General purpose
Tin–zinc	Aluminum
Lead–silver	Strength at higher than room temperature
Cadmium–silver	Strength at high temperatures
Zinc–aluminum	Aluminum; corrosion resistance
Tin–silver	Electronics
Tin–bismuth	Electronics

From 2006, lead cannot be used

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Adhesive bonding (접착)

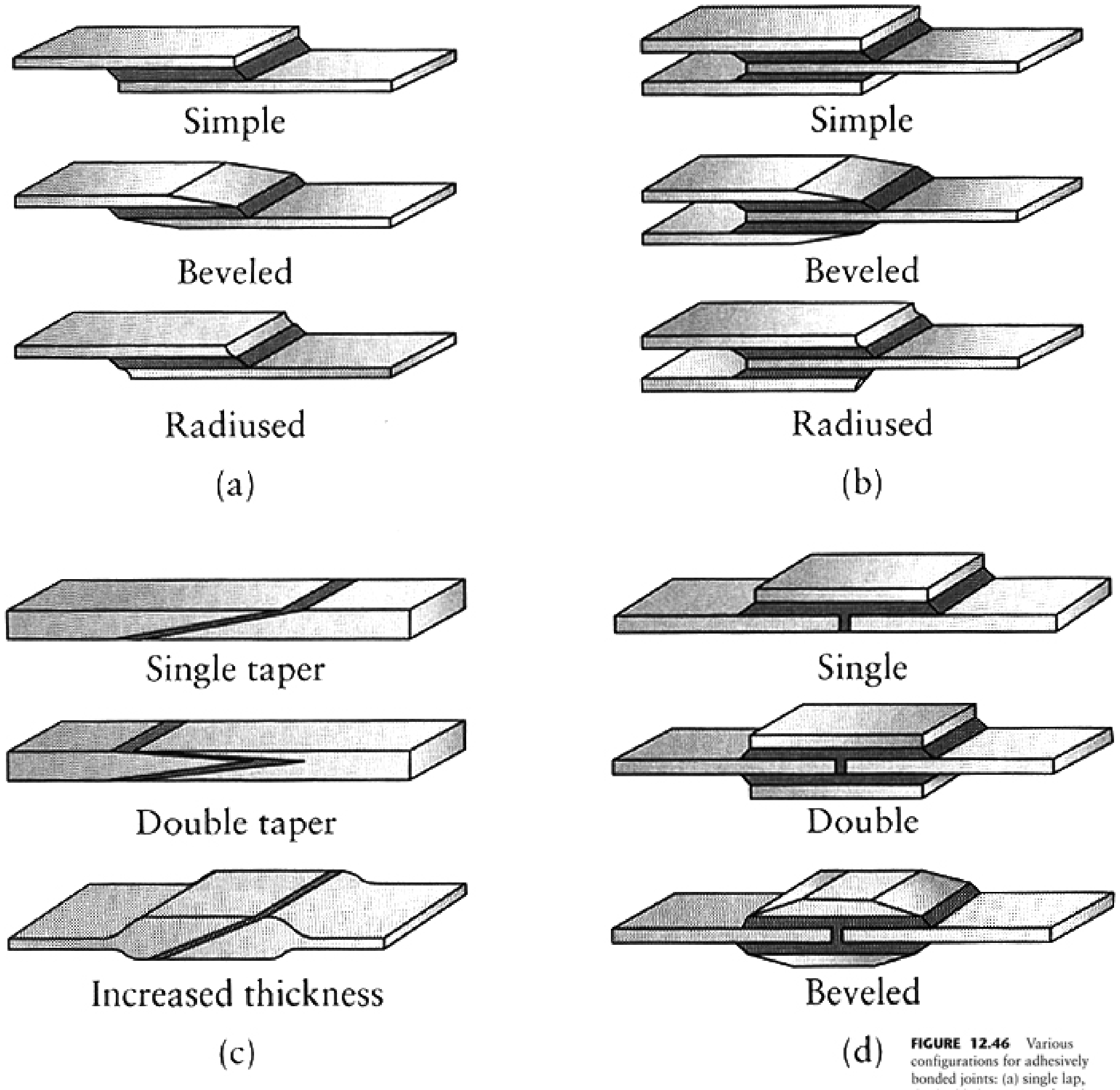


FIGURE 12.46 Various configurations for adhesively bonded joints: (a) single lap, (b) double lap, (c) scarf, and (d) strap.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Mechanical fastening (기계적 이음)

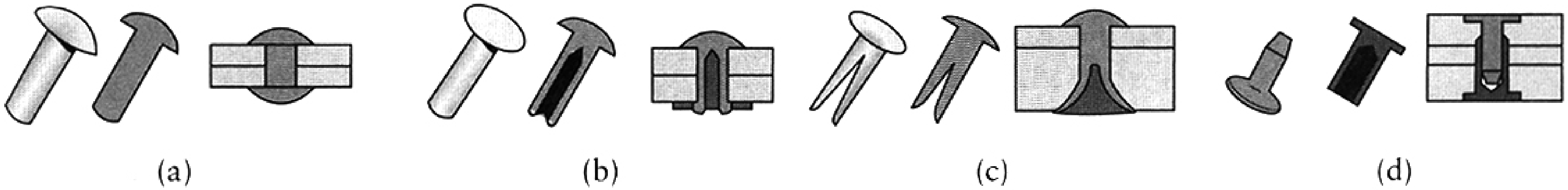


FIGURE 12.48 Examples of rivets: (a) solid, (b) tubular, (c) split, or bifurcated and (d) compression.

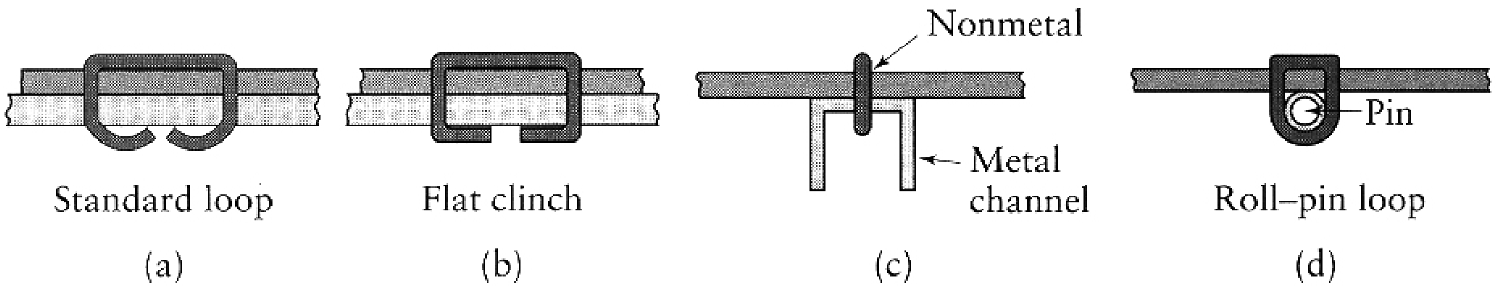


FIGURE 12.49 Examples of metal stitching.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Failure modes of riveted joint

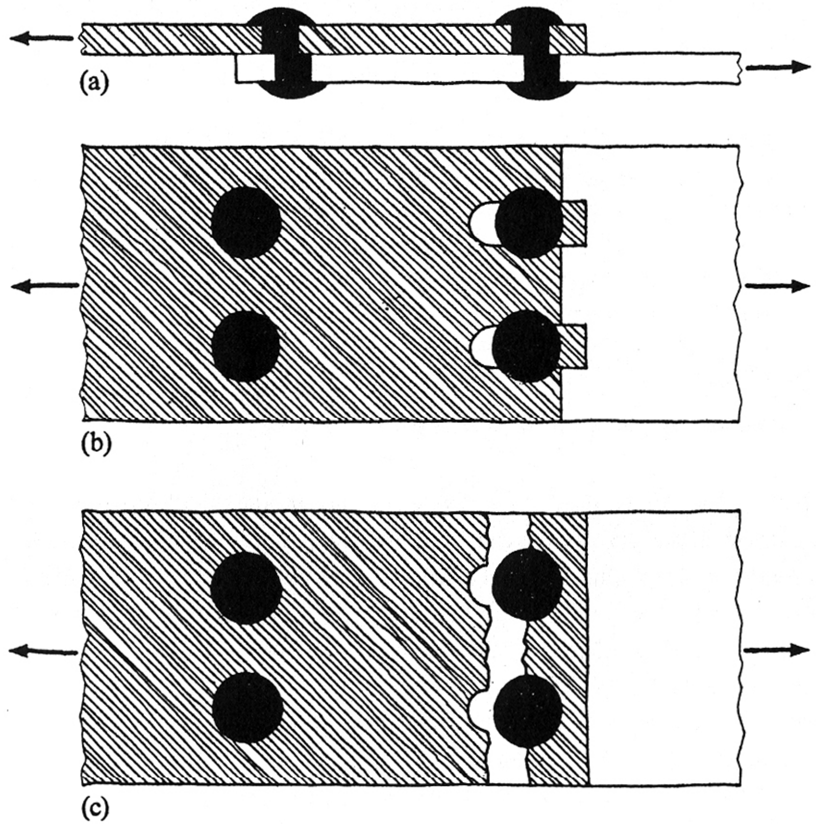


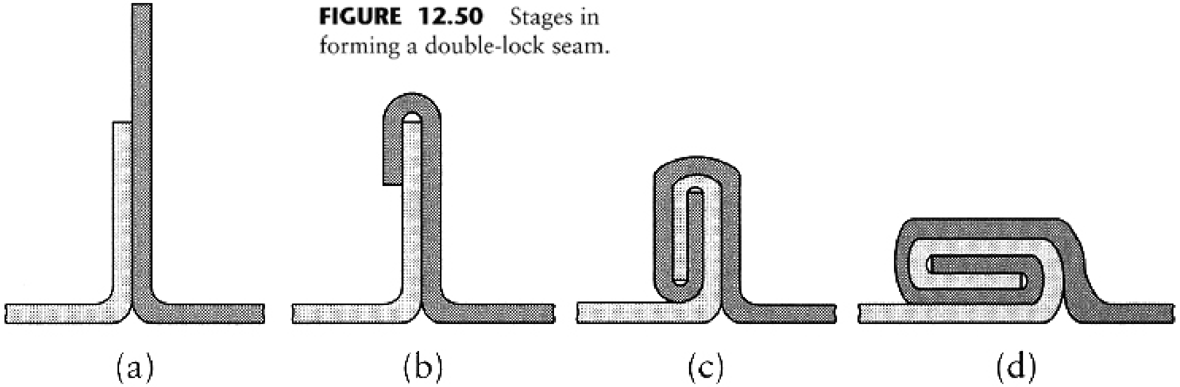
Figure 10. Three of the ways in which a riveted joint may fail.
(a) Failure by shearing the rivets.
(b) Failure by tearing the rivets out of the plate (i.e. by 'bearing' or elongation of the holes).
(c) Failure by tearing the plates.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Other methods of fastening

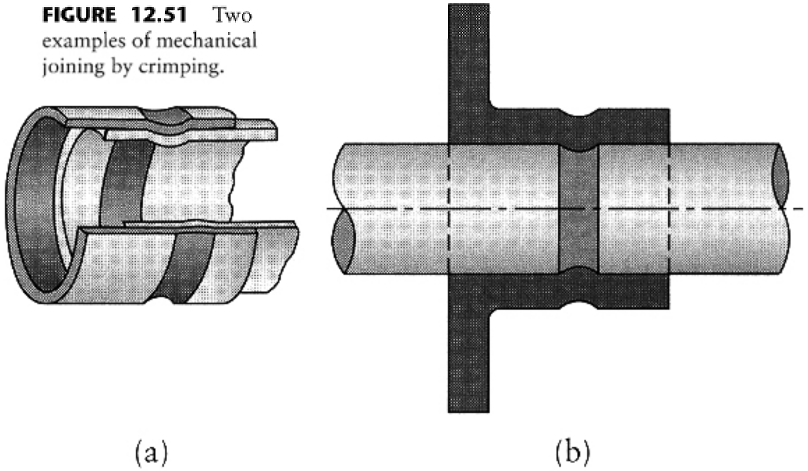
- **Seaming**

FIGURE 12.50 Stages in forming a double-lock seam.



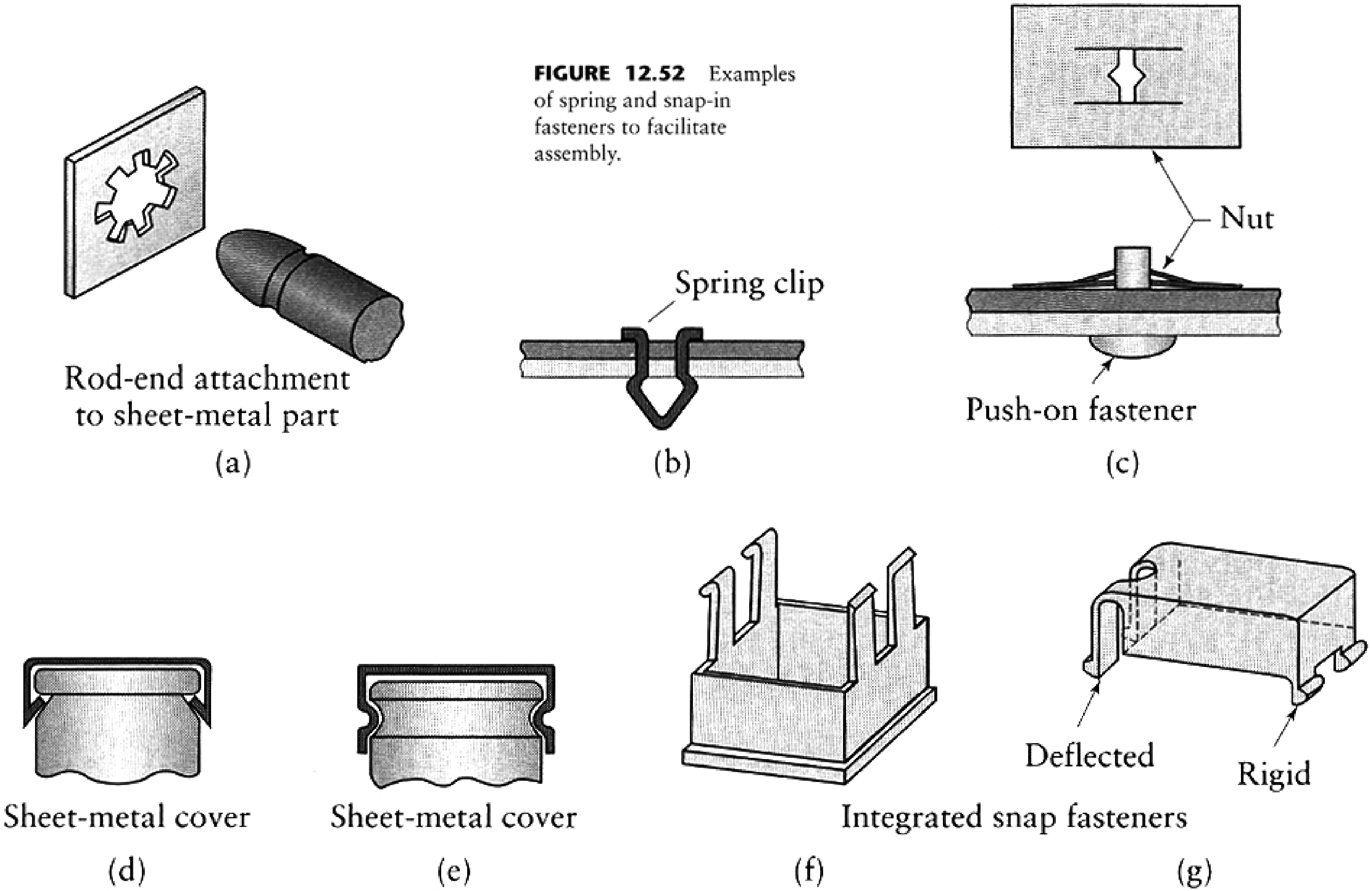
- **Crimping**

FIGURE 12.51 Two examples of mechanical joining by crimping.



Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

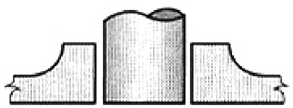
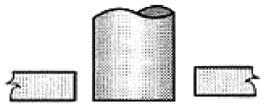
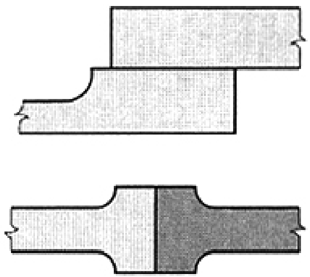
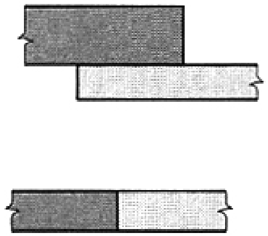
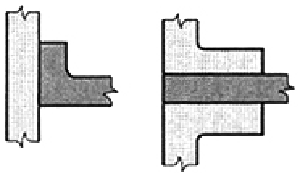
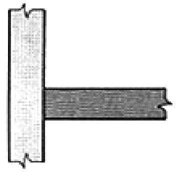
Snap-in fasteners



Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Design considerations (1)

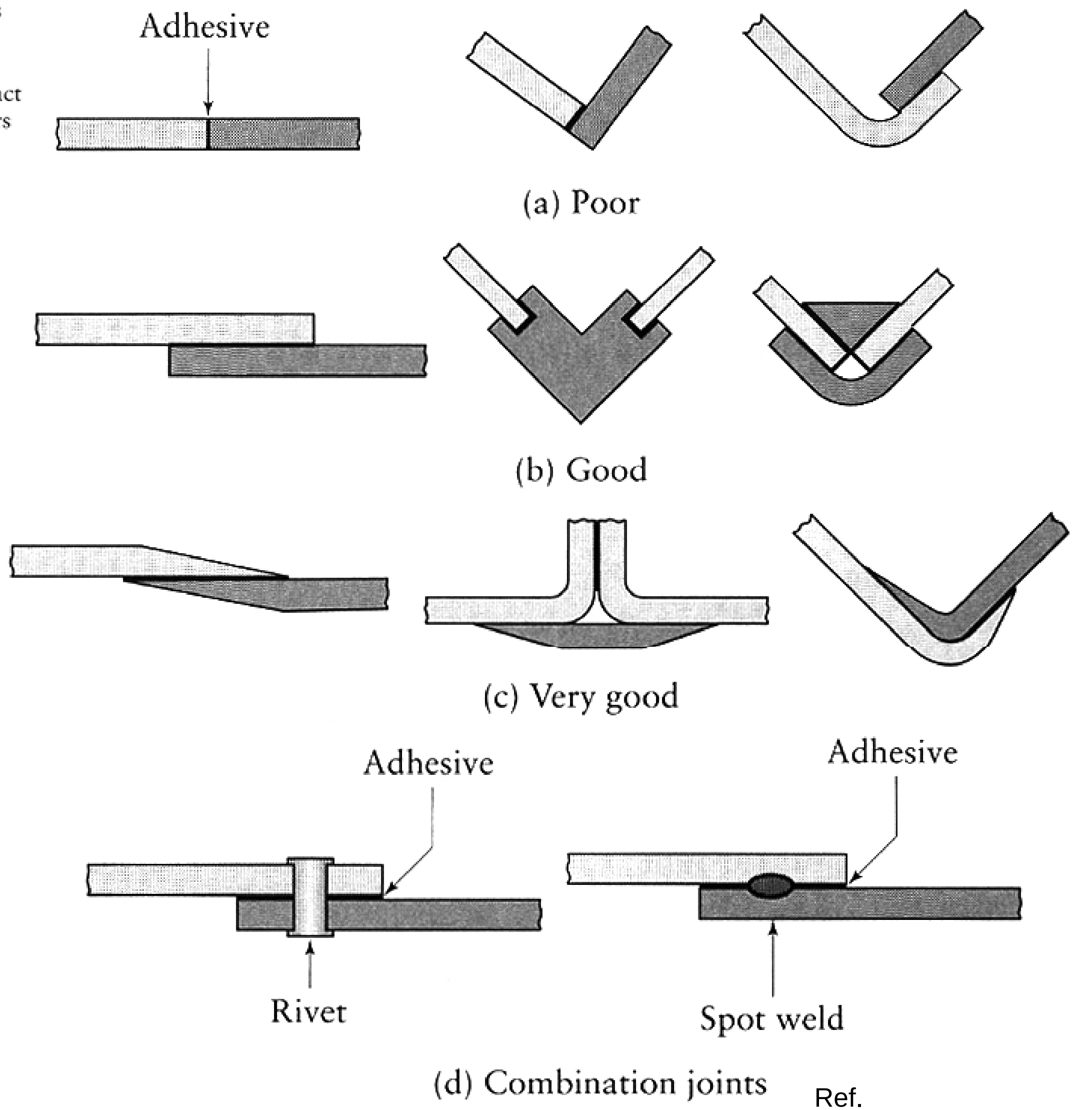
FIGURE 12.56 Examples of good and poor designs for brazing.

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

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Design considerations (2)

FIGURE 12.57 Various joint designs in adhesive bonding. Note that good design requires large contact areas between the members to be joined.



Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley

Design considerations (3)

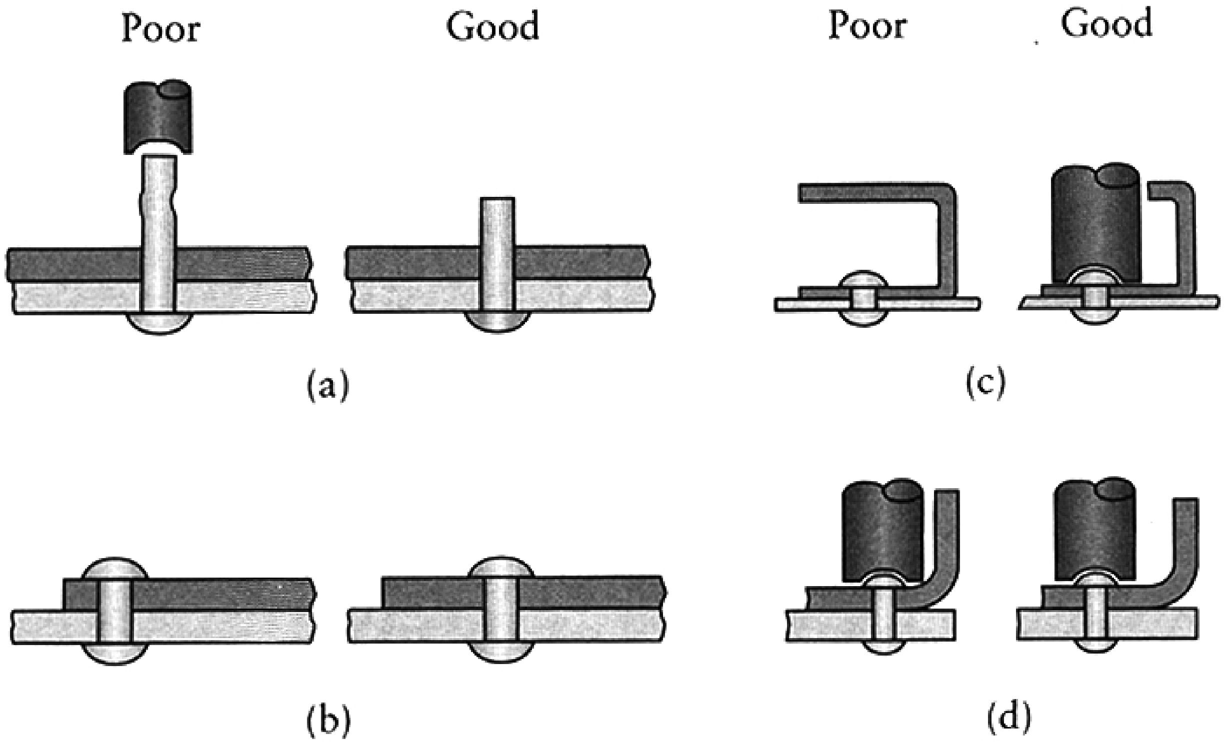


FIGURE 12.58 Design guidelines for riveting. *Source*: Bralla, J. G. (ed.) *Handbook of Product Design for Manufacturing*, 2d ed. New York, McGraw-Hill, 1999.

Ref.
S. Kalpakjian, "Manufacturing Processes for Engineering Materials", 3rd/4th ed. Addison Wesley