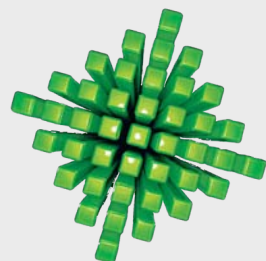


Sheet-Metal Forming Processes

Process	Characteristics
Roll forming	Long parts with constant complex cross-sections; good surface finish; high production rates; high tooling costs.
Stretch forming	Large parts with shallow contours; suitable for low-quantity production; high labor costs; tooling and equipment costs depend on part size.
Drawing	Shallow or deep parts with relatively simple shapes; high production rates; high tooling and equipment costs.
Stamping	Includes a variety of operations, such as punching, blanking, embossing, bending, flanging, and coining; simple or complex shapes formed at high production rates; tooling and equipment costs can be high, but labor costs are low.
Rubber-pad forming	Drawing and embossing of simple or complex shapes; sheet surface protected by rubber membranes; flexibility of operation; low tooling costs.
Spinning	Small or large axisymmetric parts; good surface finish; low tooling costs, but labor costs can be high unless operations are automated.
Superplastic forming	Complex shapes, fine detail, and close tolerances; forming times are long, and hence production rates are low; parts not suitable for high-temperature use.
Peen forming	Shallow contours on large sheets; flexibility of operation; equipment costs can be high; process is also used for straightening parts.
Explosive forming	Very large sheets with relatively complex shapes, although usually axisymmetric; low tooling costs, but high labor costs; suitable for low-quantity production; long cycle times.
Magnetic-pulse forming	Shallow forming, bulging, and embossing operations on relatively low-strength sheets; most suitable for tubular shapes; high production rates; requires special tooling.

TABLE 7.1 General characteristics of sheet-metal forming processes.



Localized Necking

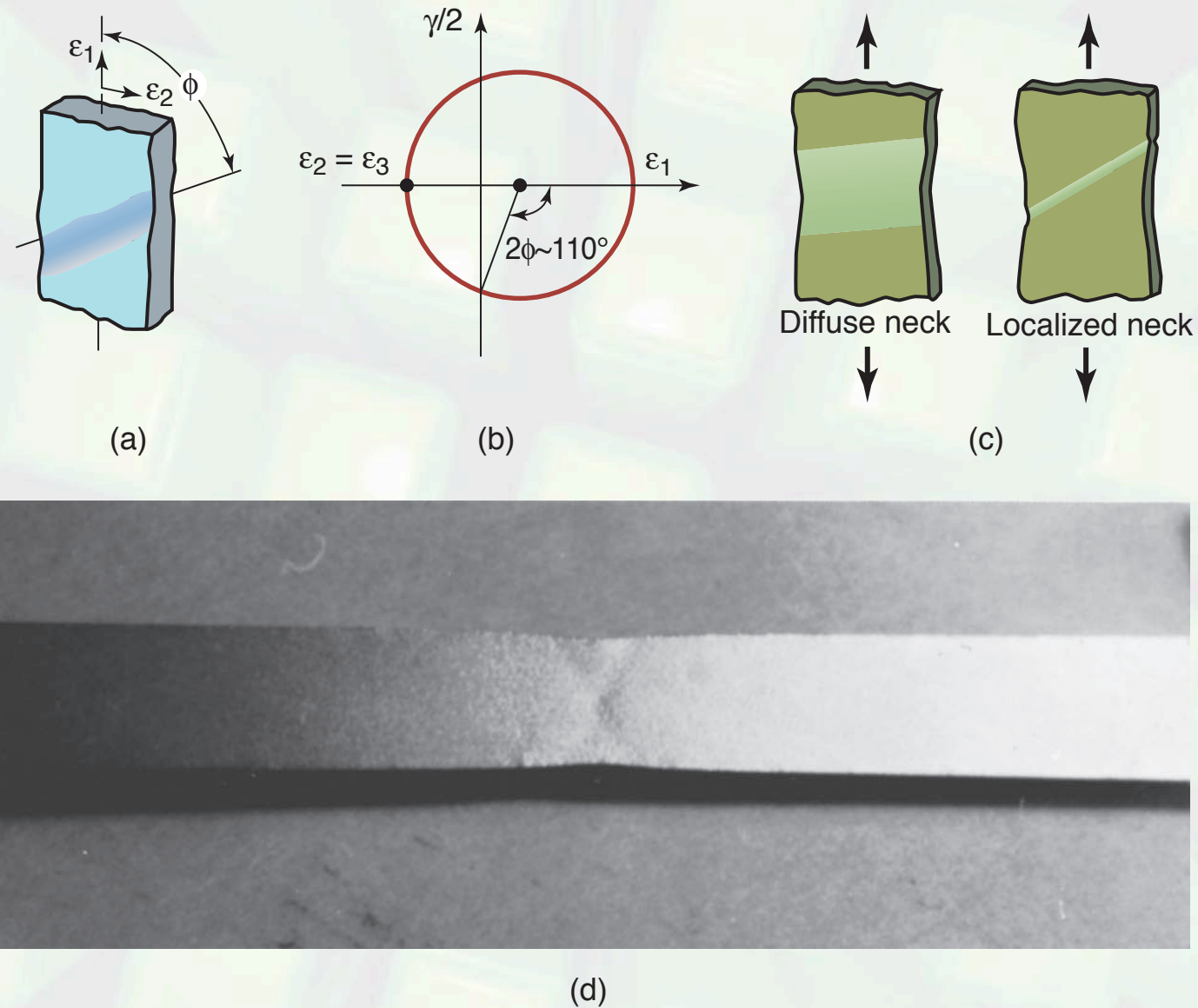
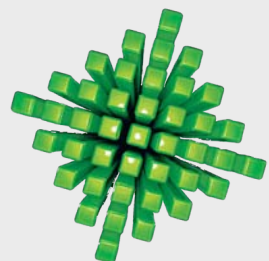


FIGURE 7.1 (a) Localized necking in a sheet-metal specimen under tension. (b) Determination of the angle of neck from the Mohr's circle for strain. (c) Schematic illustrations for diffuse and localized necking, respectively. (d) Localized necking in an aluminum strip in tension; note the double neck. Source: S. Kalpakjian.



Lueders Bands

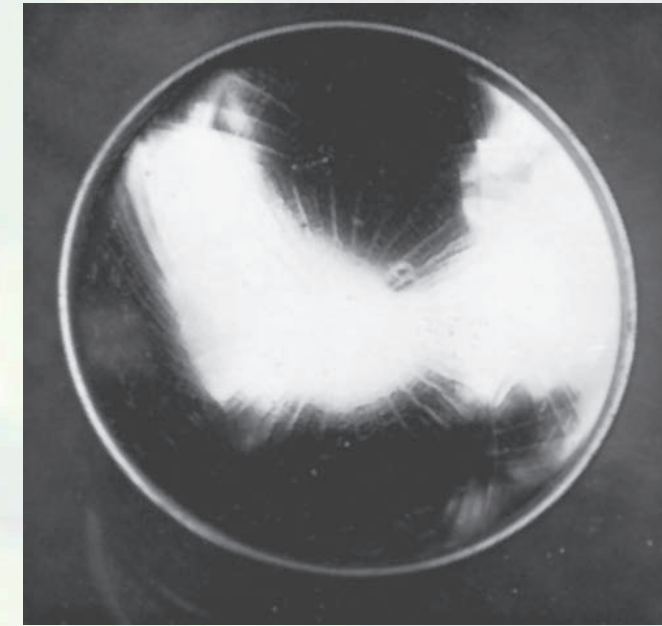
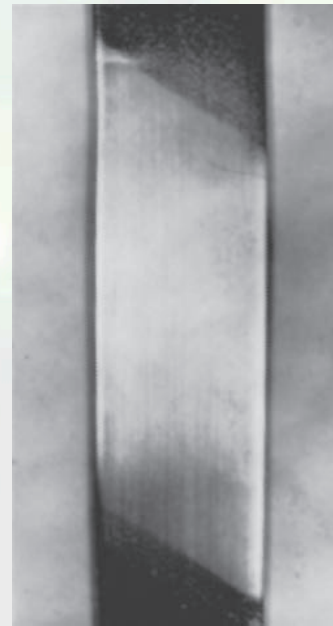
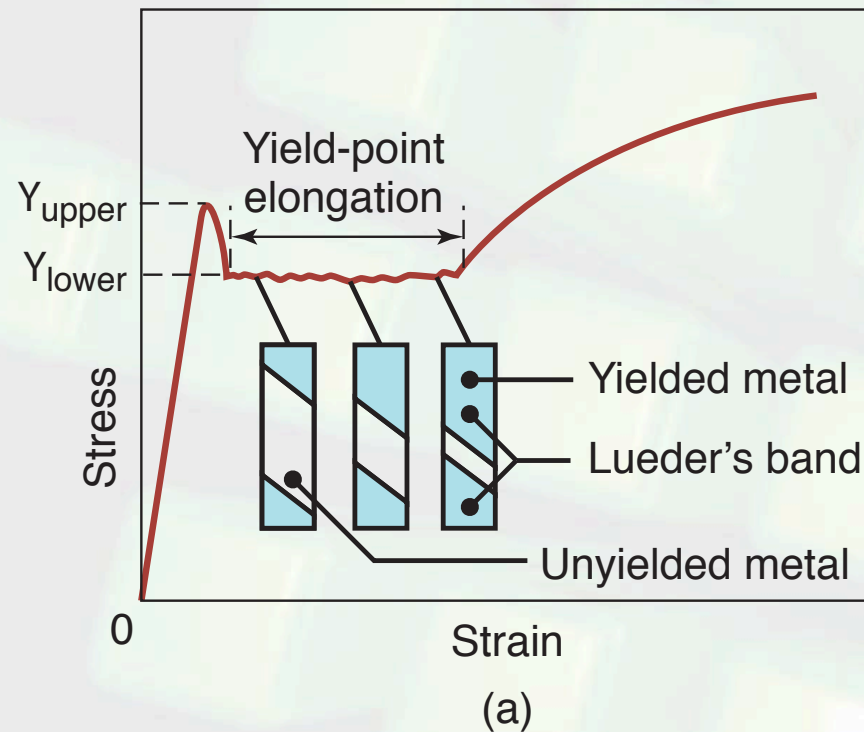
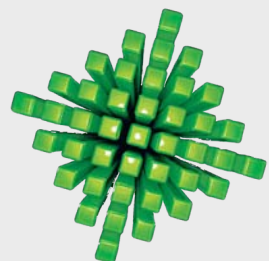


FIGURE 7.2 (a) Yield-point elongation and Lueders bands in tensile testing. (b) Lueder's bands in annealed low-carbon steel sheet. (c) Stretcher strains at the bottom of a steel can for common household products. Source: (b) Courtesy of Caterpillar Inc.



Stress-Corrosion Cracking

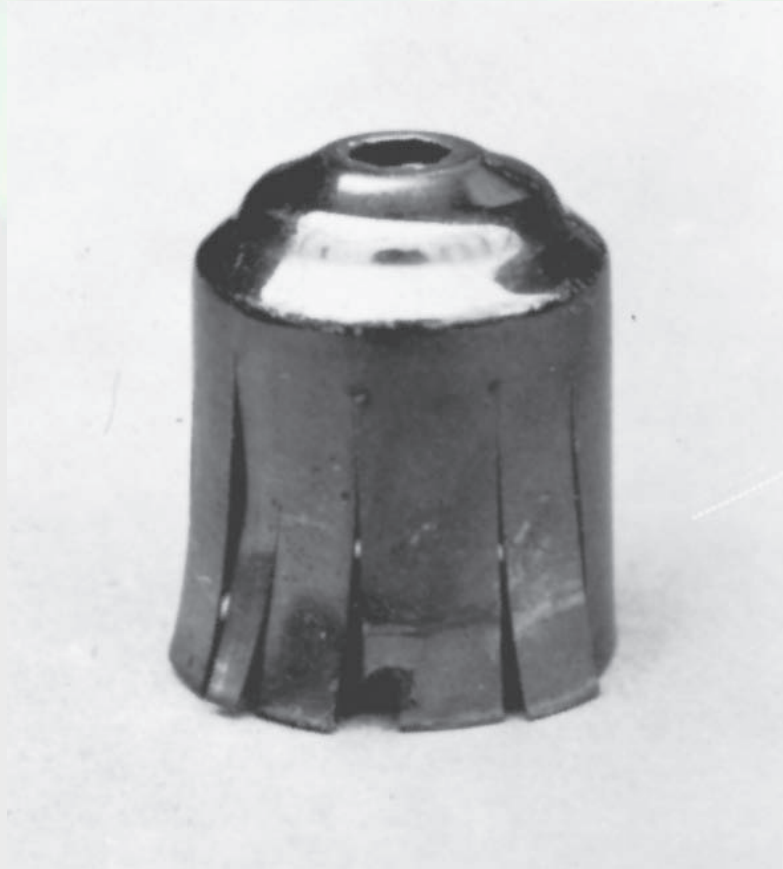
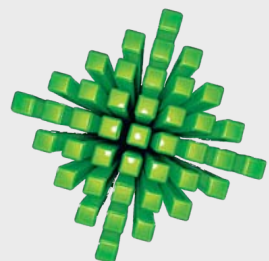


FIGURE 7.3 Stress-corrosion cracking in a deep-drawn brass part for a light fixture. The cracks have developed over a period of time. Brass and 300-series austenitic stainless steels are particularly susceptible to stress-corrosion cracking.



Shearing Process

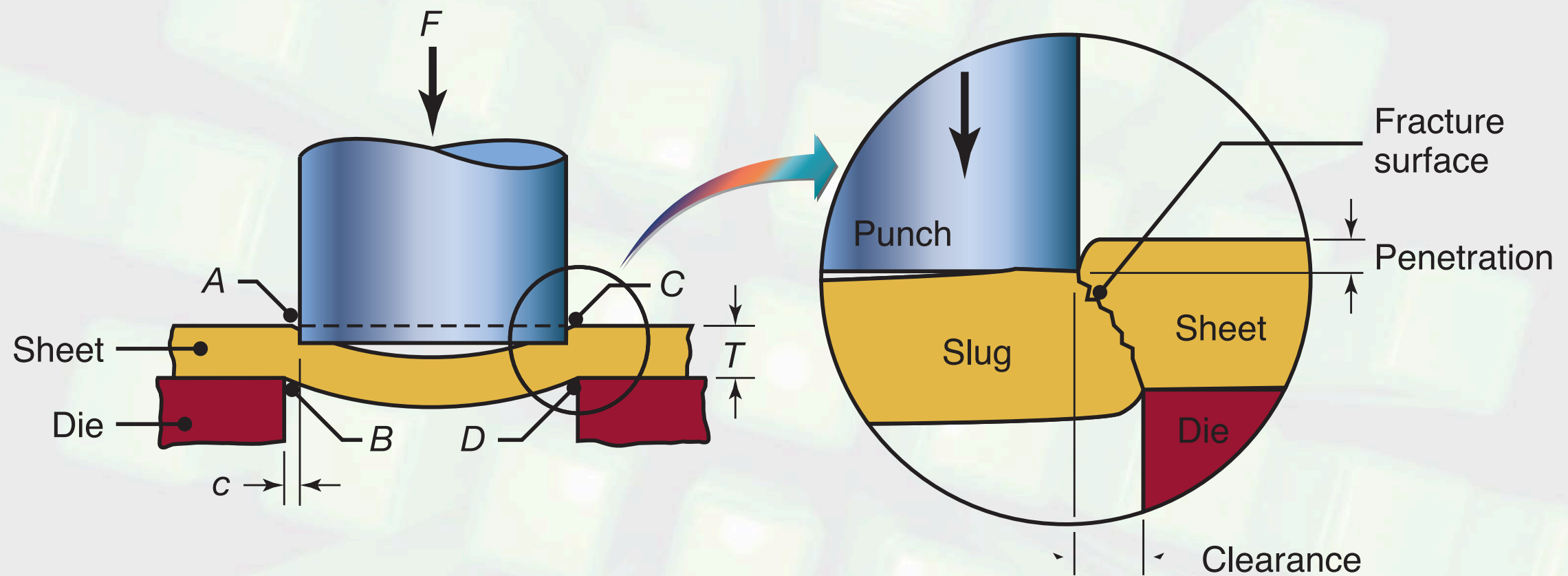
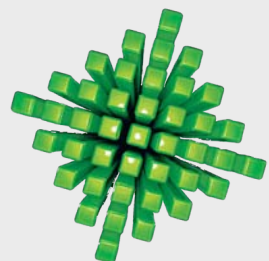


FIGURE 7.4 Schematic illustration of the shearing process with a punch and die, indicating important process variables.



Hole & Slug

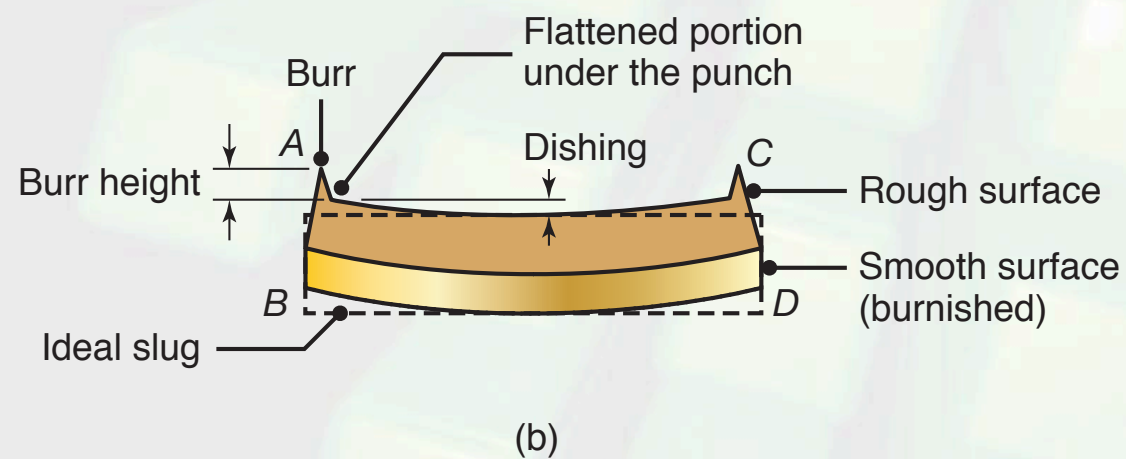
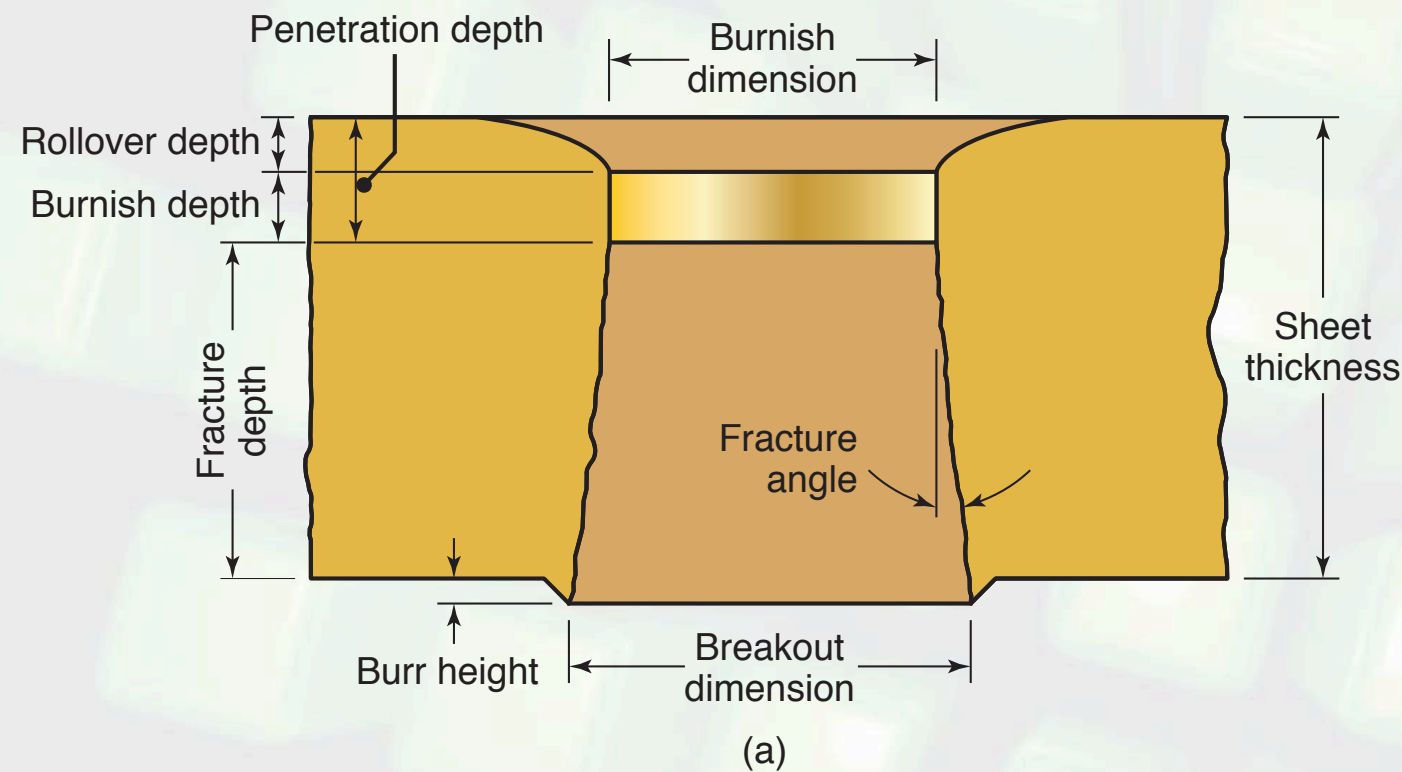
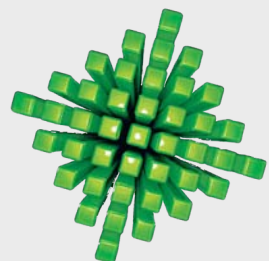


FIGURE 7.5 Characteristic features of (a) a punched hole and (b) the punched slug. Note that the slug has a different scale than the hole.



Shearing Mechanics

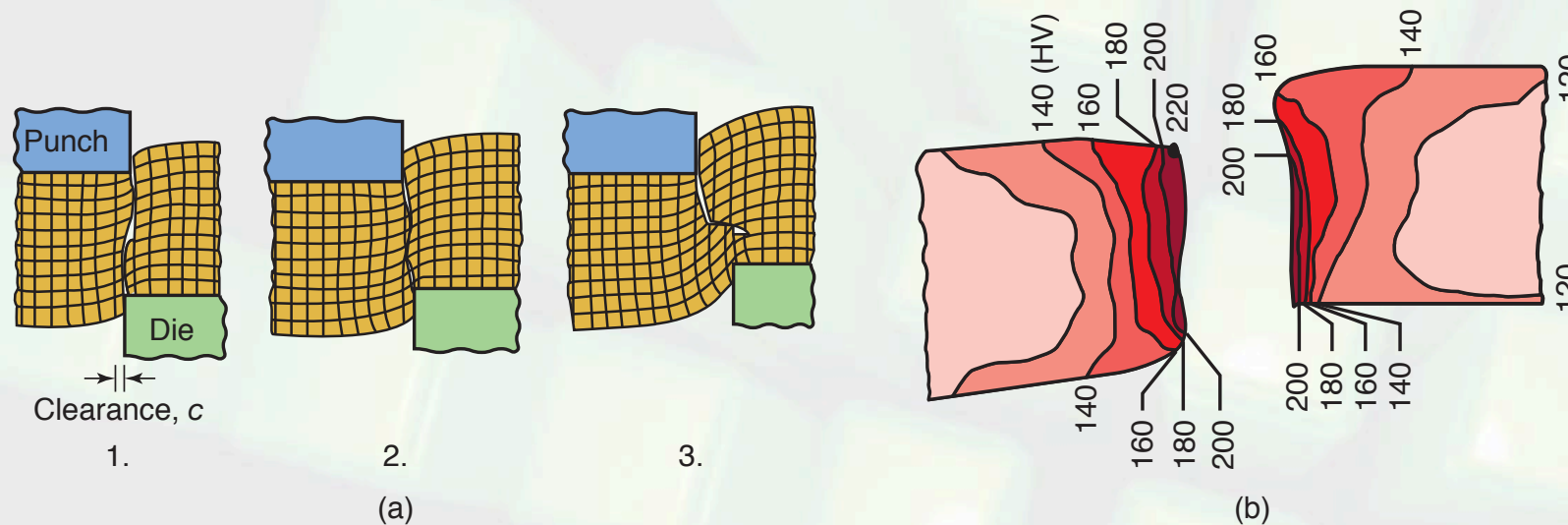


FIGURE 7.6 a) Effect of clearance, c , on the deformation zone in shearing. Note that, as clearance increases, the material tends to be pulled into the die, rather than being sheared. (b) Microhardness (HV) contours for a 6.4-mm (0.25-in.) thick AISI 1020 hot-rolled steel in the sheared region. *Source:* After H.P. Weaver and K.J. Weinmann.

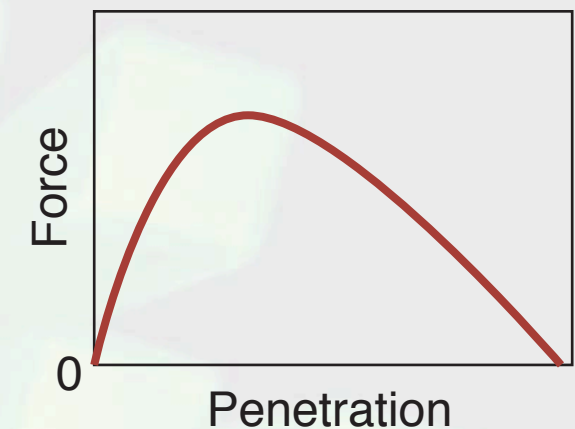
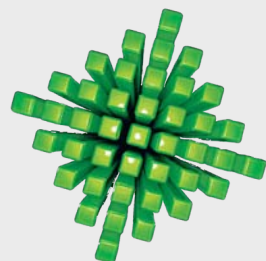


FIGURE 7.7 Typical punch force vs. penetration curve in shearing. The area under the curve is the work done in shearing. The shape of the curve depends on processing parameters and material properties.

Maximum punch force:

$$F_{max} = 0.7(UTS)tL$$



Shearing Operations

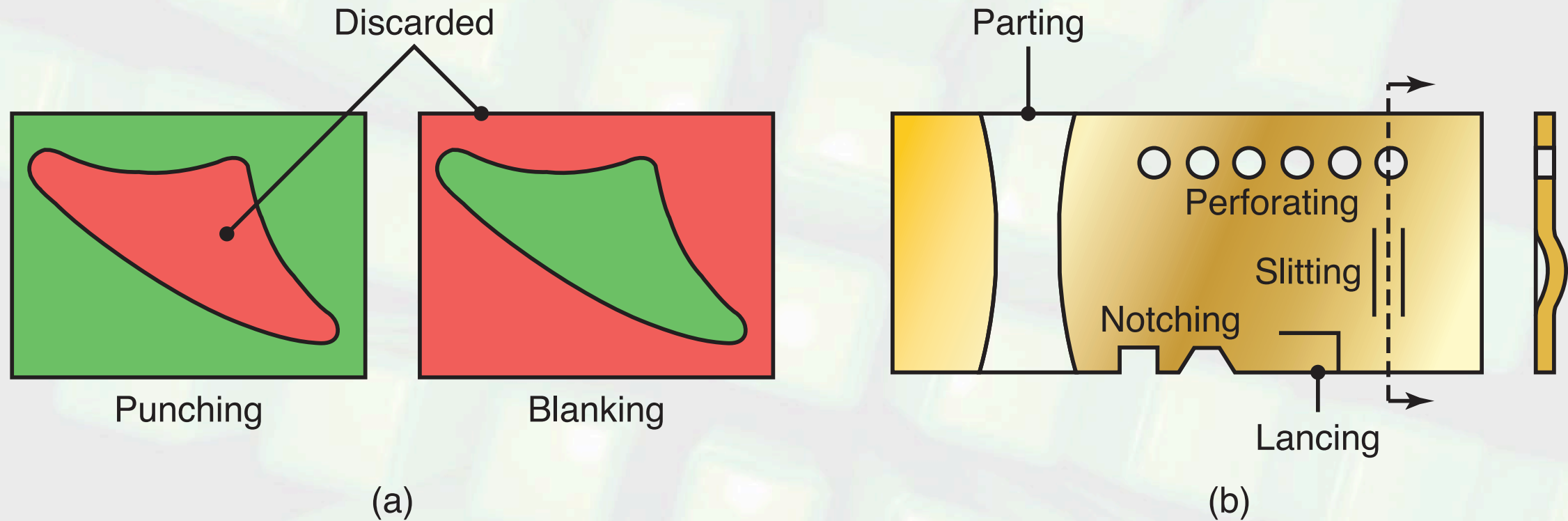
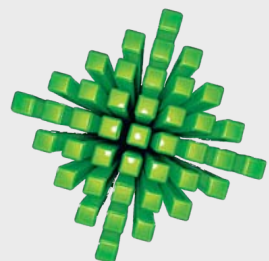


FIGURE 7.8 (a) Punching and blanking. (b) Examples of shearing operations on sheet metal.



Fine Blanking

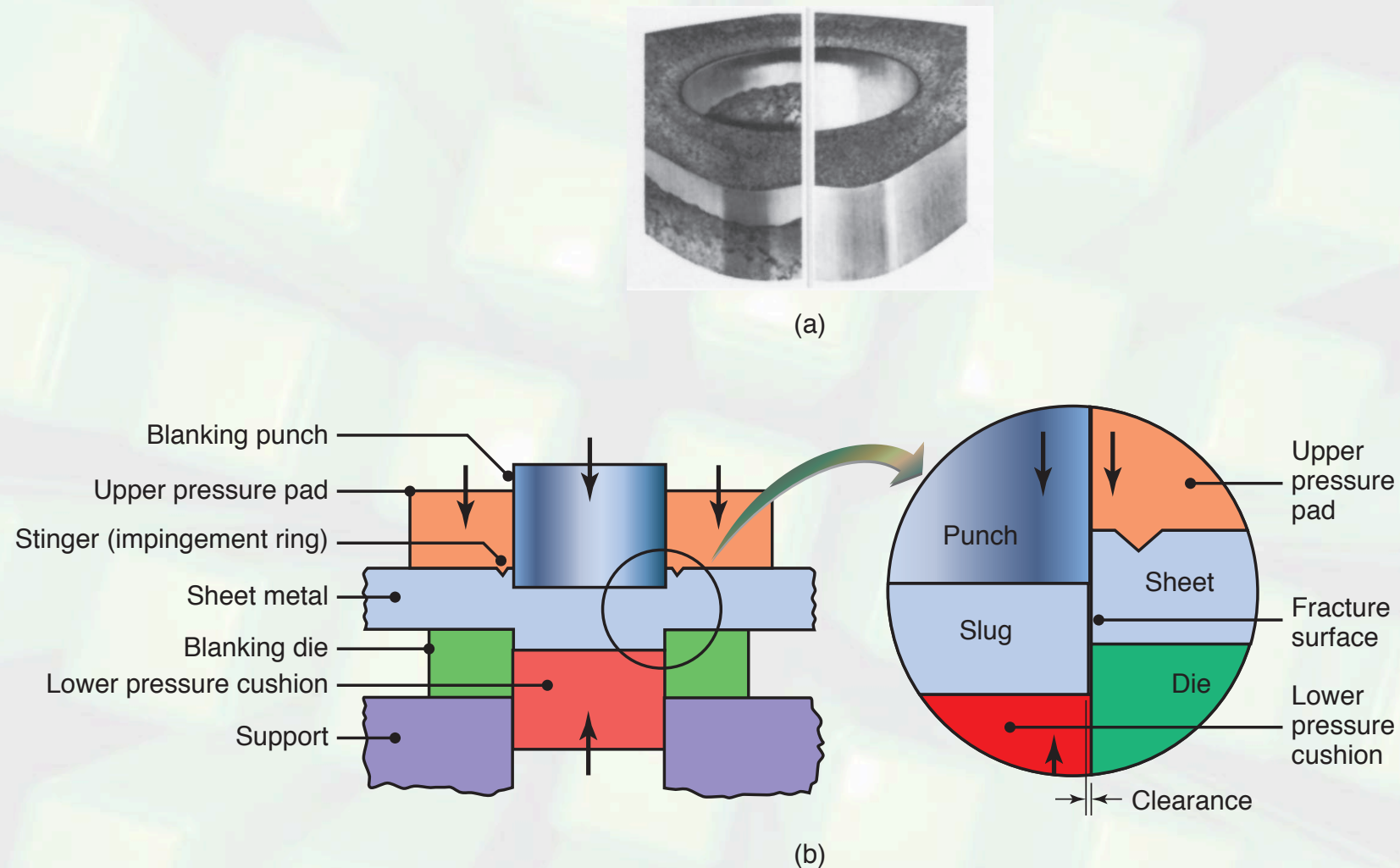
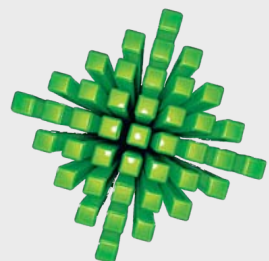


FIGURE 7.9 (a) Comparison of sheared edges by conventional (left) and fine-blanking (right) techniques. (b) Schematic illustration of a setup for fine blanking. *Source:* Feintool International Holding.



Rotary Shearing

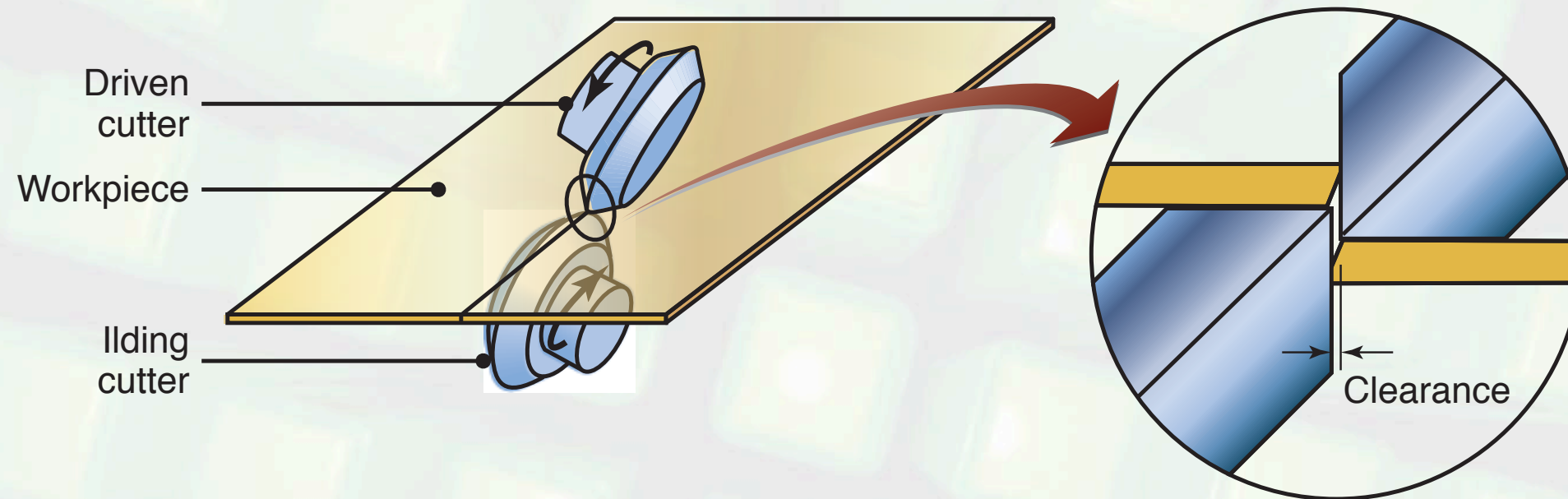
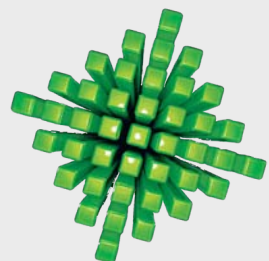


FIGURE 7.10 Slitting with rotary blades, a process similar to opening cans.



Shaving & Beveled Tooling

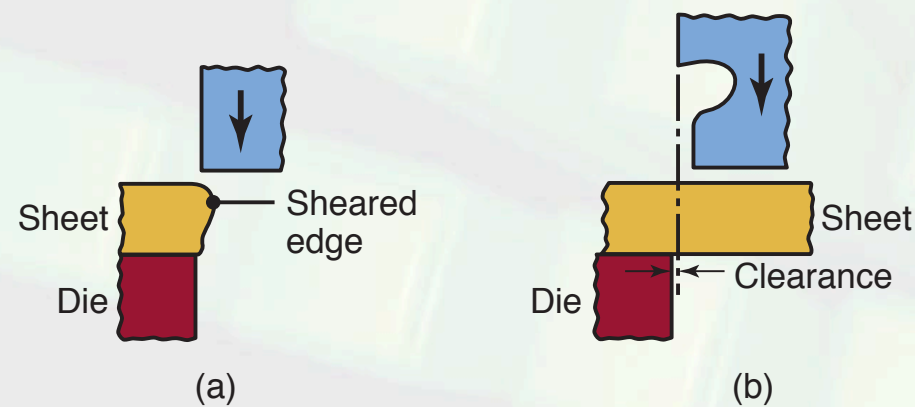


FIGURE 7.11 Schematic illustration of shaving on a sheared edge. (a) Shaving a sheared edge. (b) Shearing and shaving combined in one punch stroke.

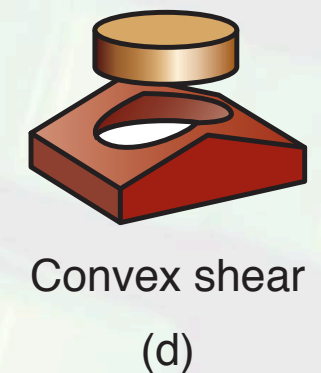
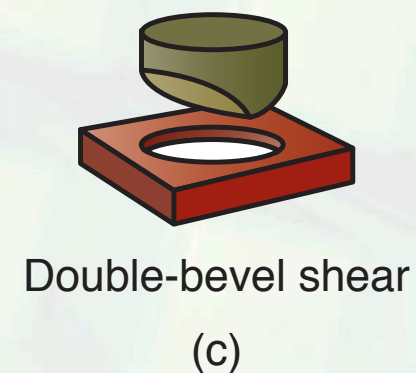
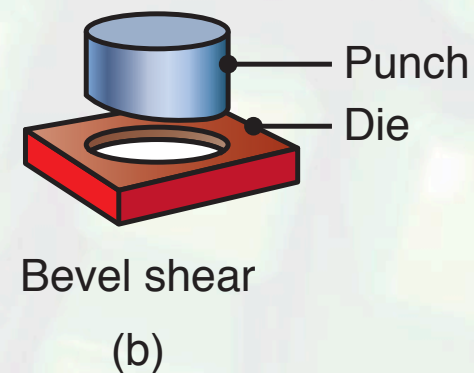
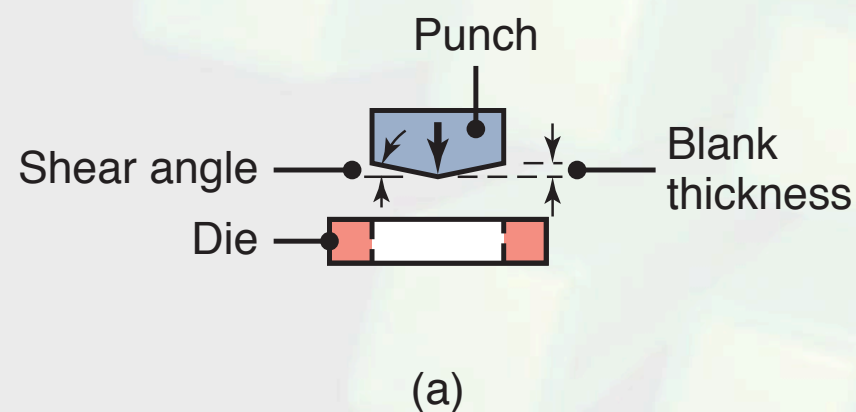
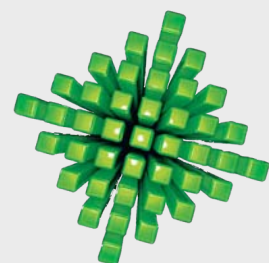


FIGURE 7.12 Examples of the use of shear angles on punches and dies. Compare these designs with that for a common paper punch.



Progressive Die

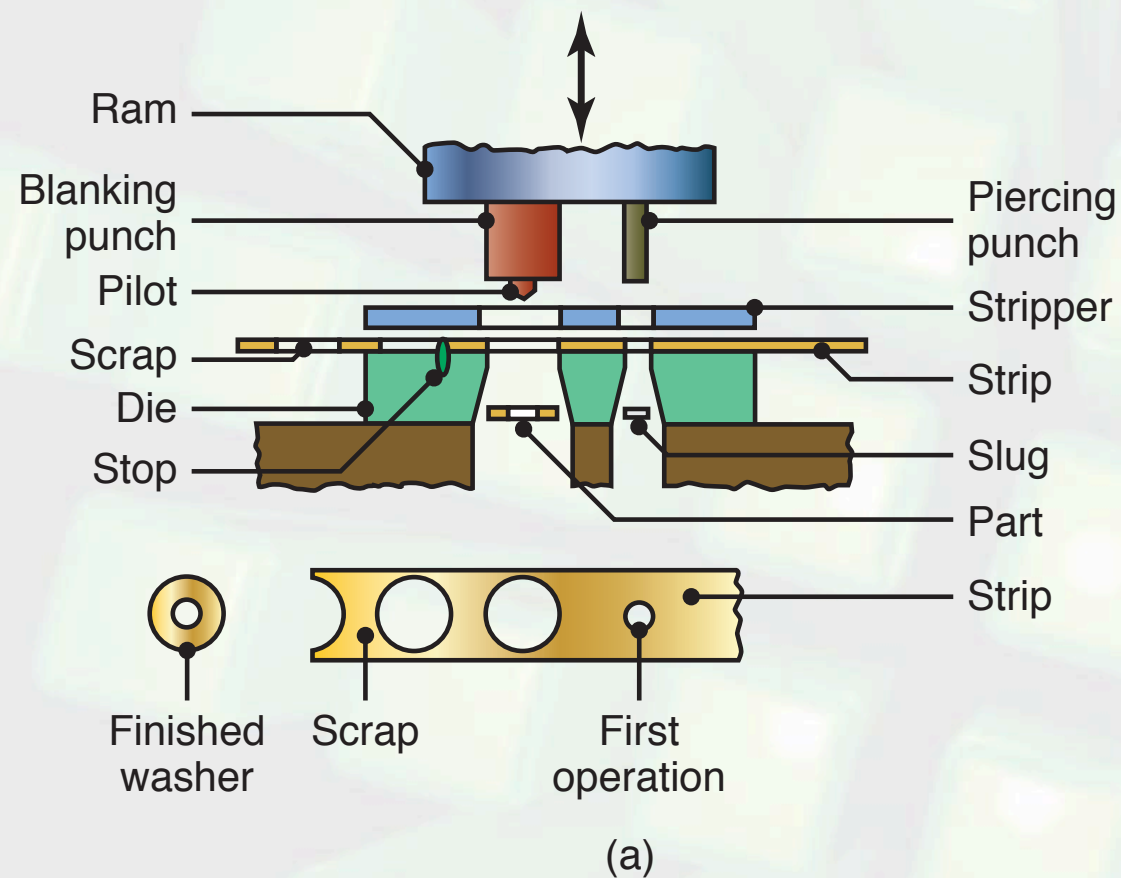
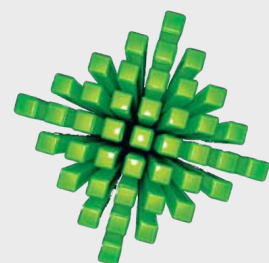
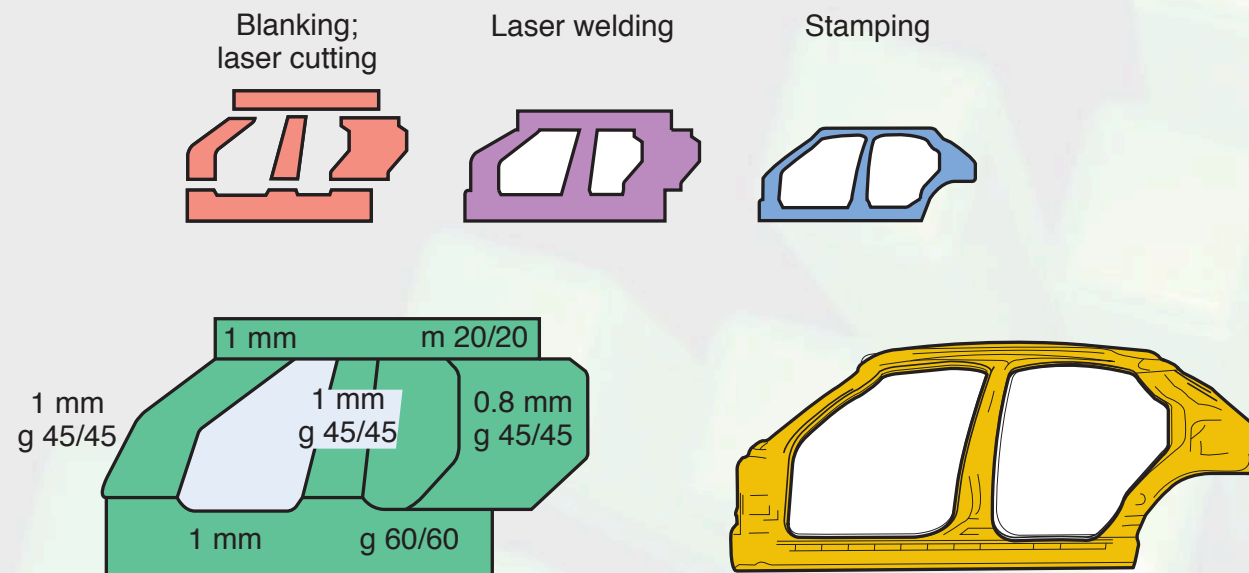


FIGURE 7.13 (a) Schematic illustration of producing a washer in a progressive die. (b) Forming of the top piece of a common aerosol spray can in a progressive die. Note that the part is attached to the strip until the last operation is completed.



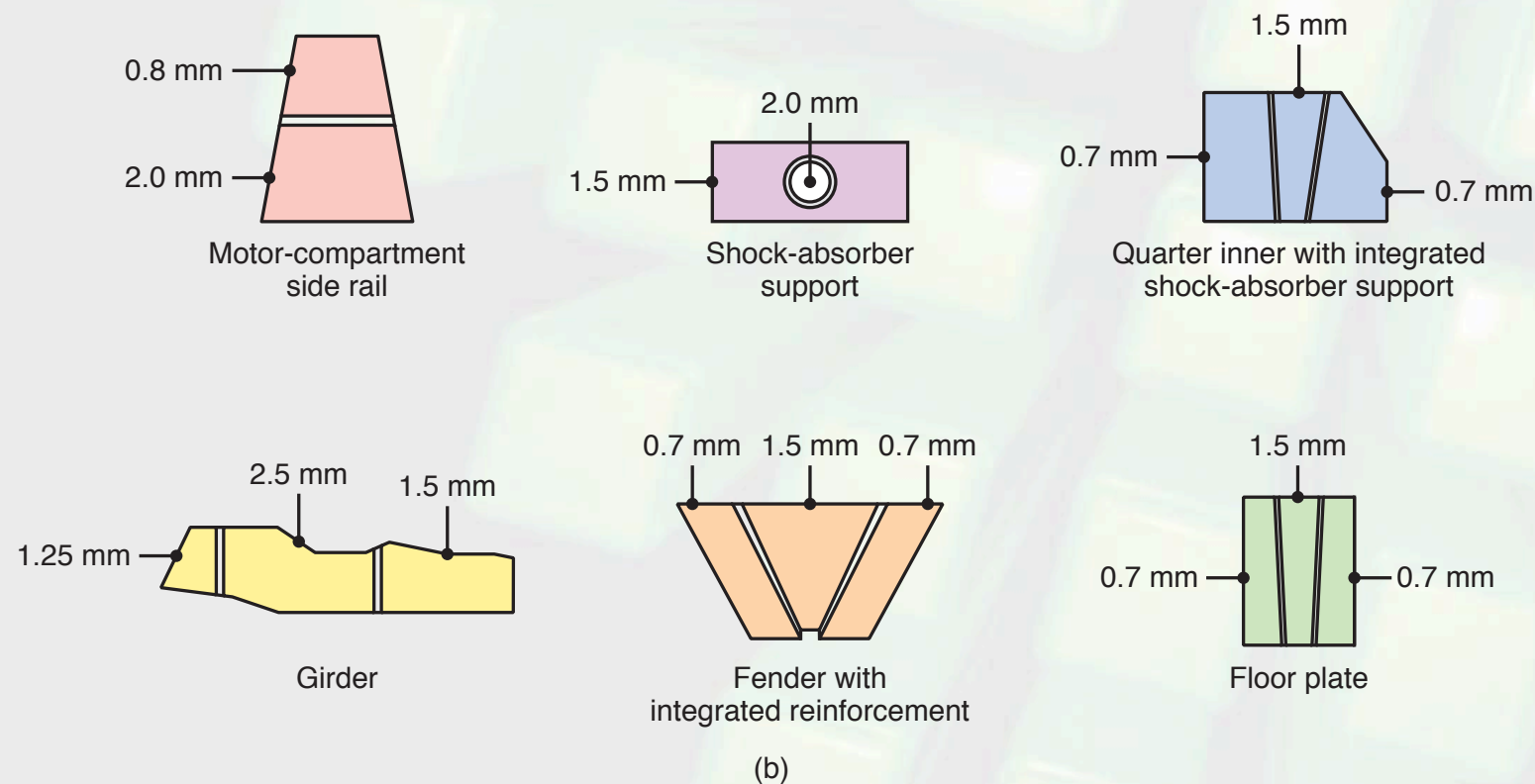
Tailor-Welded Blanks



Legend

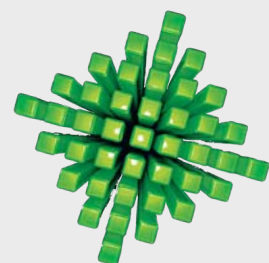
g 60/60 (45/45) Hot-galvanized alloy steel sheet. Zinc amount: 60/60 (45/45) g/m².
m 20/20 Double-layered iron-zinc alloy electroplated steel sheet. Zinc amount 20/20 g/m².

(a)

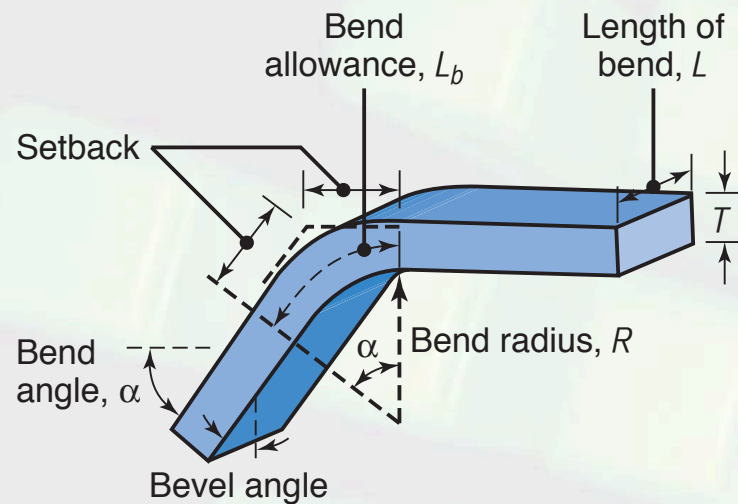


(b)

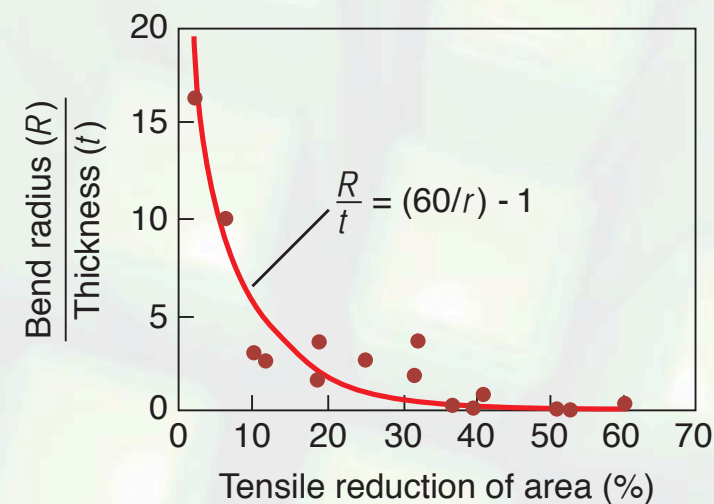
FIGURE 7.14 Examples of laser-welded and stamped automotive body components. Source: After M. Geiger and T. Nakagawa.



Bending & Minim Bend Radius



(a)

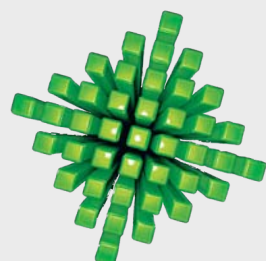


(b)

FIGURE 7.5 (a) Bending terminology. Note that the bend radius is measured to the inner surface of the bend, and that the length of the bend is the width of the sheet. (b) Relationship between the ratio of bend-radius to sheet-thickness and tensile reduction of area for a variety of materials. Note that sheet metal with a reduction of area of about 50% can be bent and flattened over itself without cracking, similar to folding paper. Source: After J. Datsko and C.T. Yang.

Material	Material Condition	
	Soft	Hard
Aluminum alloys	0	6t
Beryllium copper	0	4t
Brass, low leaded	0	2t
Magnesium	5t	13t
Steels		
austenitic stainless	0.5t	6t
low carbon, low alloy, and HSLA	0.5t	4t
Titanium	0.7t	3t
Titanium alloys	2.6t	4t

TABLE 7.2 Minimum bend radii for various materials at room temperature.



Bending Mechanics

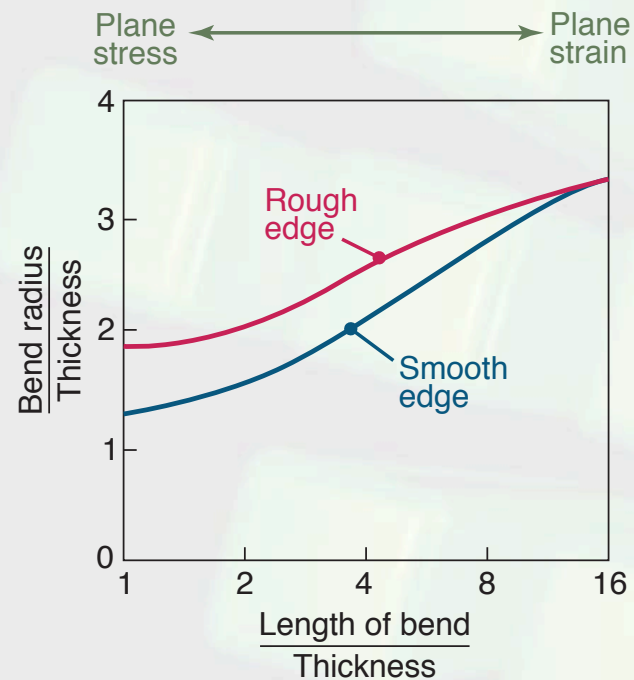


FIGURE 7.16 The effect of length of bend and edge condition on the ratio of bend radius to thickness for 7075-T aluminum sheet. *Source:* After G. Sachs and G. Espey.

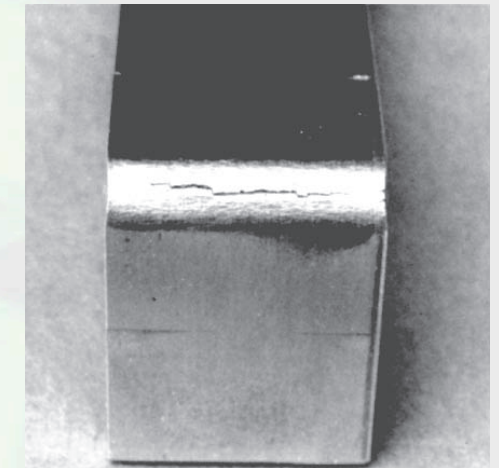
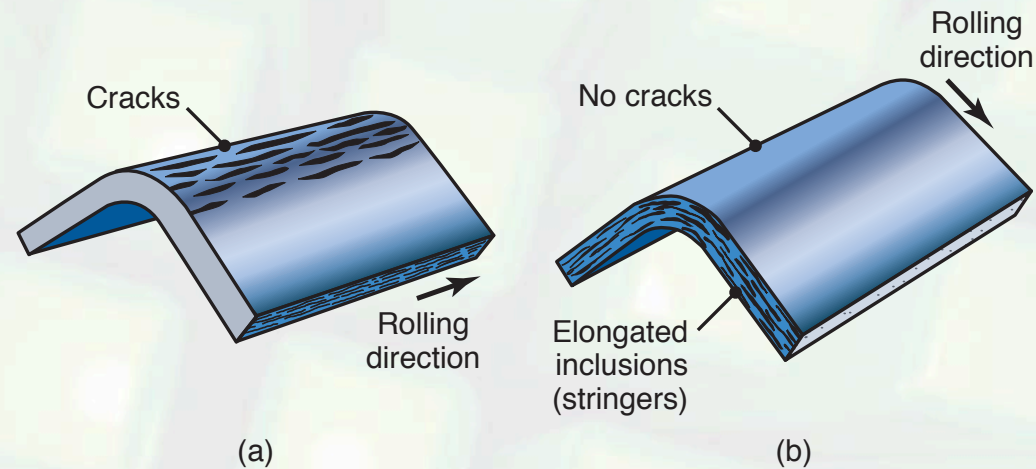
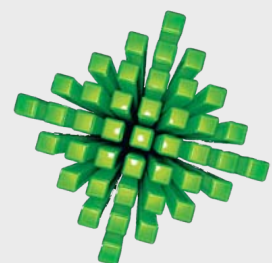


FIGURE 7.17 (a) and (b) The effect of elongated inclusions (stringers) on cracking in sheets as a function of the direction of bending with respect to the original rolling direction. This example shows the importance of orienting parts cut from sheet to maximize bendability. (c) Cracks on the outer radius of an aluminum strip bent to an angle of 90° ; compare this part with that shown in (a).



Springback

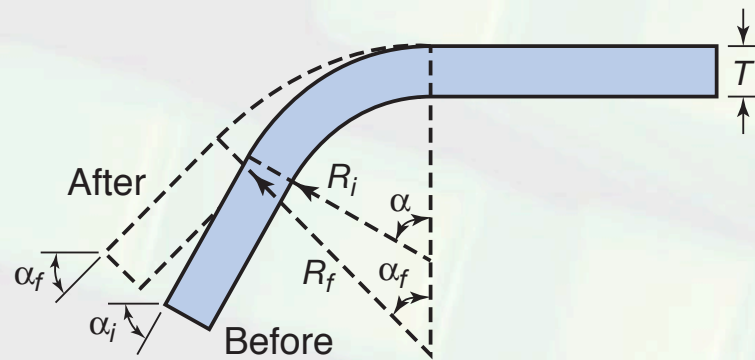


FIGURE 7.18 Terminology for springback in bending. Note that the bend angle has become smaller. There are situations whereby the angle becomes larger, called negative springback (see Fig. 7.20).

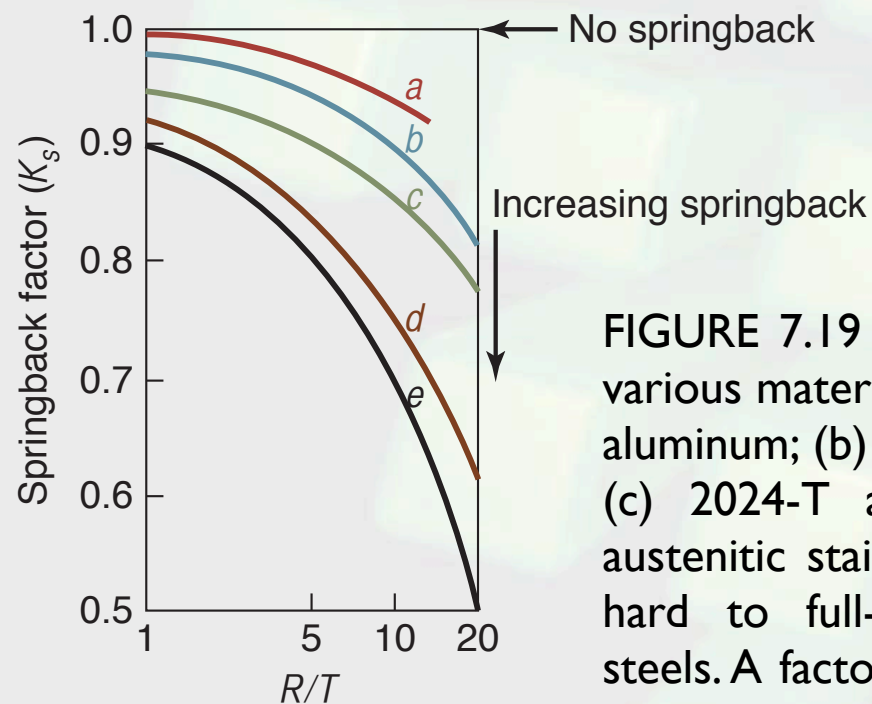


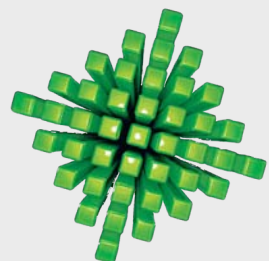
FIGURE 7.19 Springback factor, K_s , for various materials: (a) 2024-0 and 7075-0 aluminum; (b) austenitic stainless steels; (c) 2024-T aluminum; (d) 1/4-hard austenitic stainless steels; and (e) 1/2-hard to full-hard austenitic stainless steels. A factor of $K_s = 1$ indicates that there is no springback. Source: After G. Sachs.

Springback factor:

$$K_s = \frac{\alpha_f}{\alpha_i} = \frac{(2R_i/t) + 1}{(2R_f/t) + 1}$$

Springback estimation:

$$\frac{R_i}{R_f} = 4 \left(\frac{R_i Y}{Et} \right)^3 - 3 \left(\frac{R_i Y}{Et} \right) + 1$$



Negative Springback

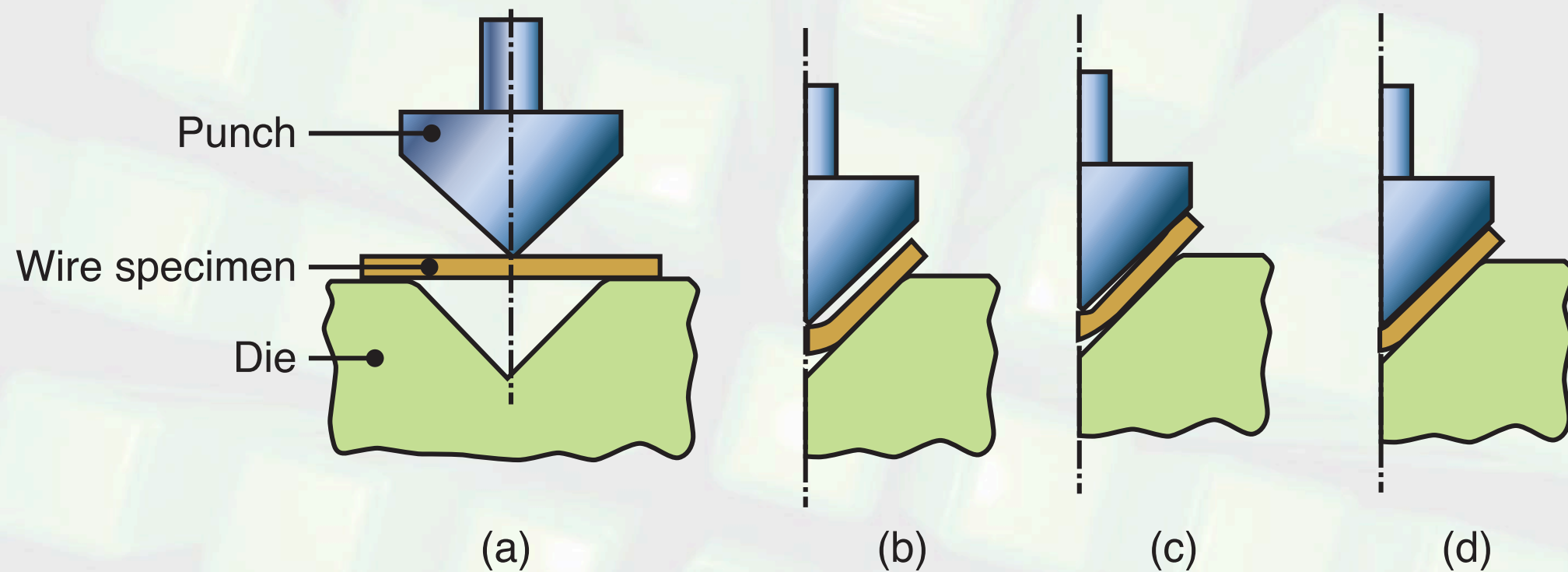
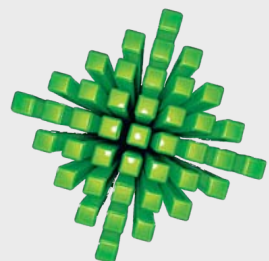


FIGURE 7.20 Schematic illustration of the stages in bending round wire in a V-die. This type of bending can lead to negative springback, which does not occur in air bending (shown in Fig. 7.24a). Source: After K.S. Turke and S. Kalpakjian.



Springback Compensation

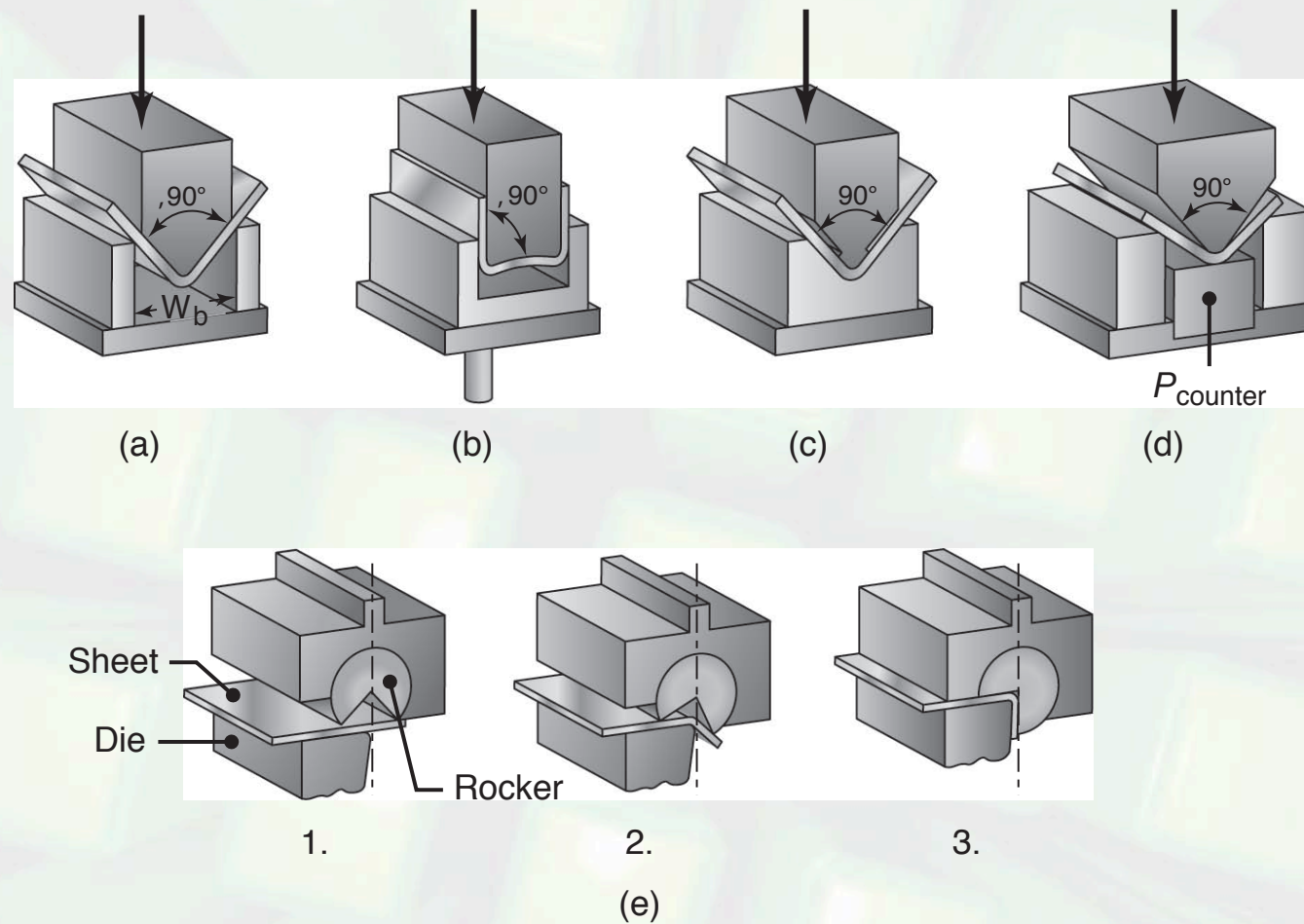
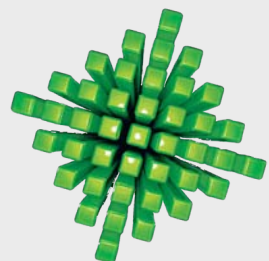


FIGURE 7.21 Methods of reducing or eliminating springback in bending operations.
Source: After V. Cupka, T. Nakagawa, and H. Tyamoto.



Die-Bending Operations

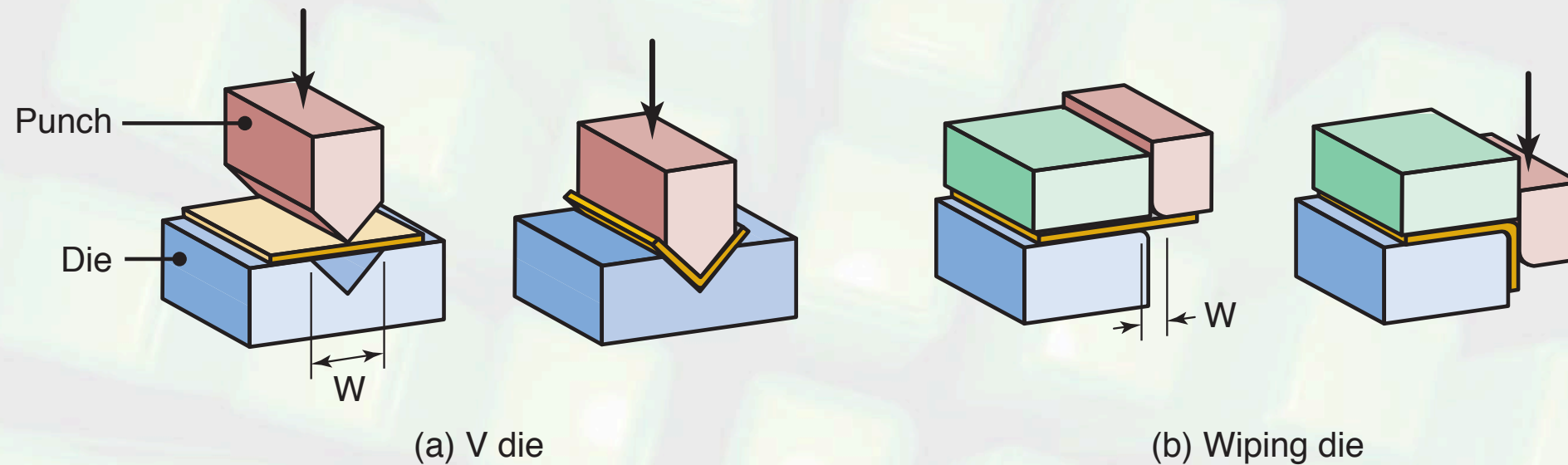
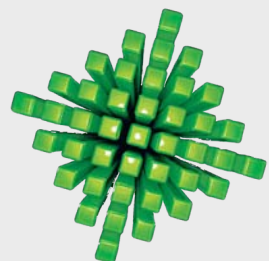


FIGURE 7.22 Common die-bending operations, showing the die-opening dimension W , used in calculating bending forces, as shown in Eq. (7.11).

Bending force:

$$F_{max} = k \frac{(UTS)Lt^2}{W}$$



Press Brake Operations

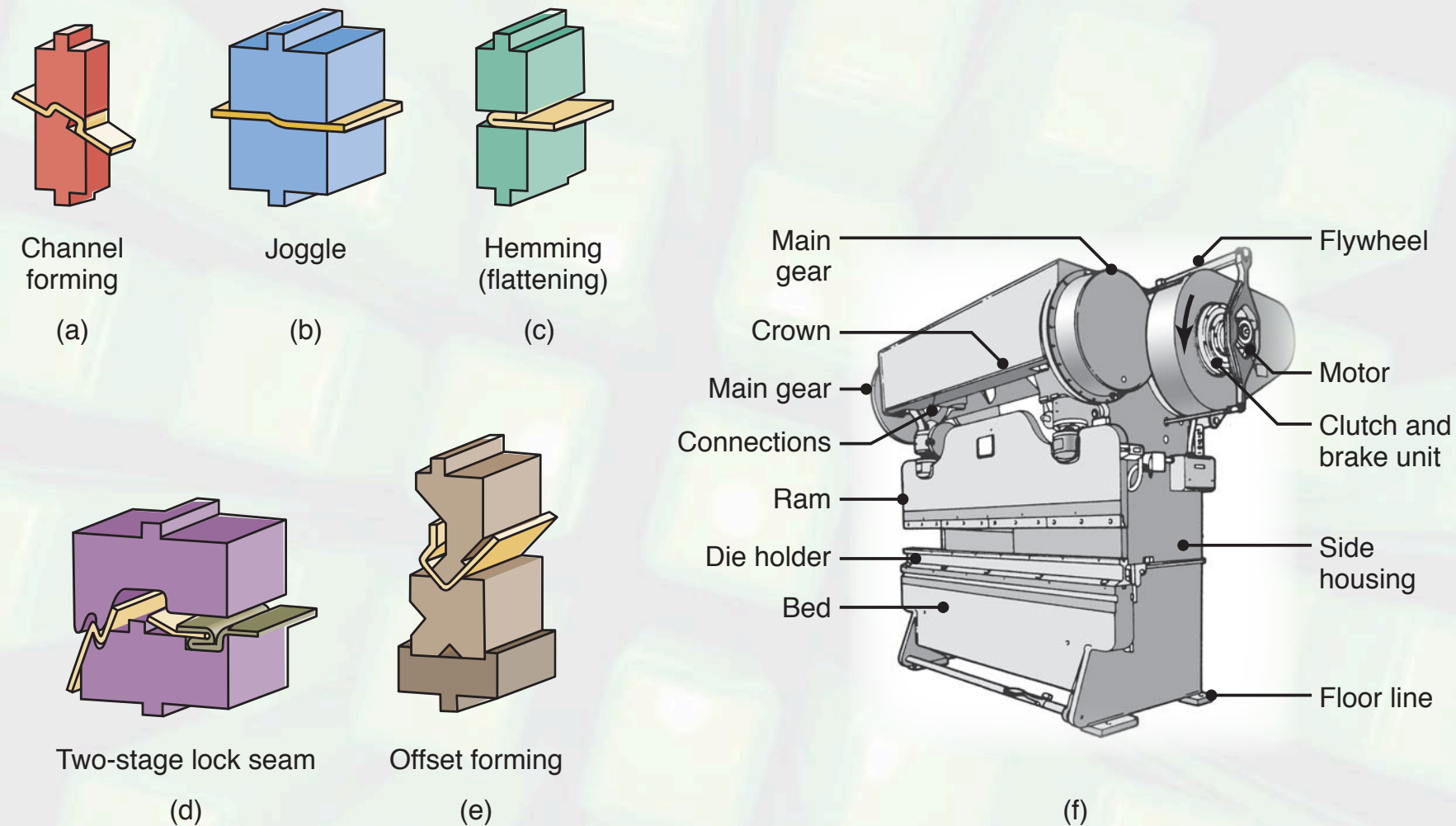
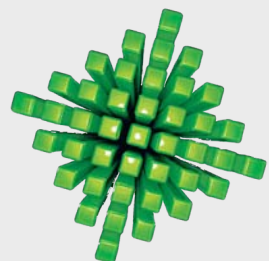


FIGURE 7.23 (a) through (e) Schematic illustrations of various bending operations in a press brake. (f) Schematic illustration of a press brake. *Source:* Courtesy of Verson Allsteel Company.



Bending Operations

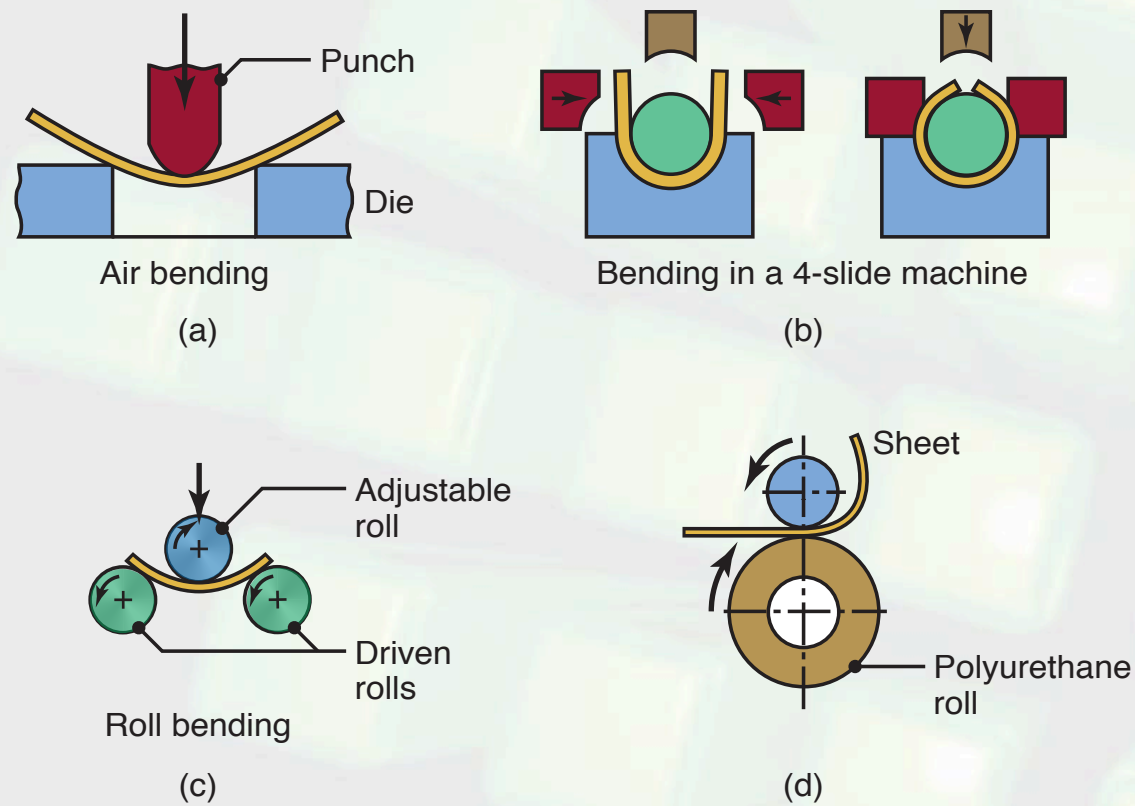


FIGURE 7.24 Examples of various bending operations.

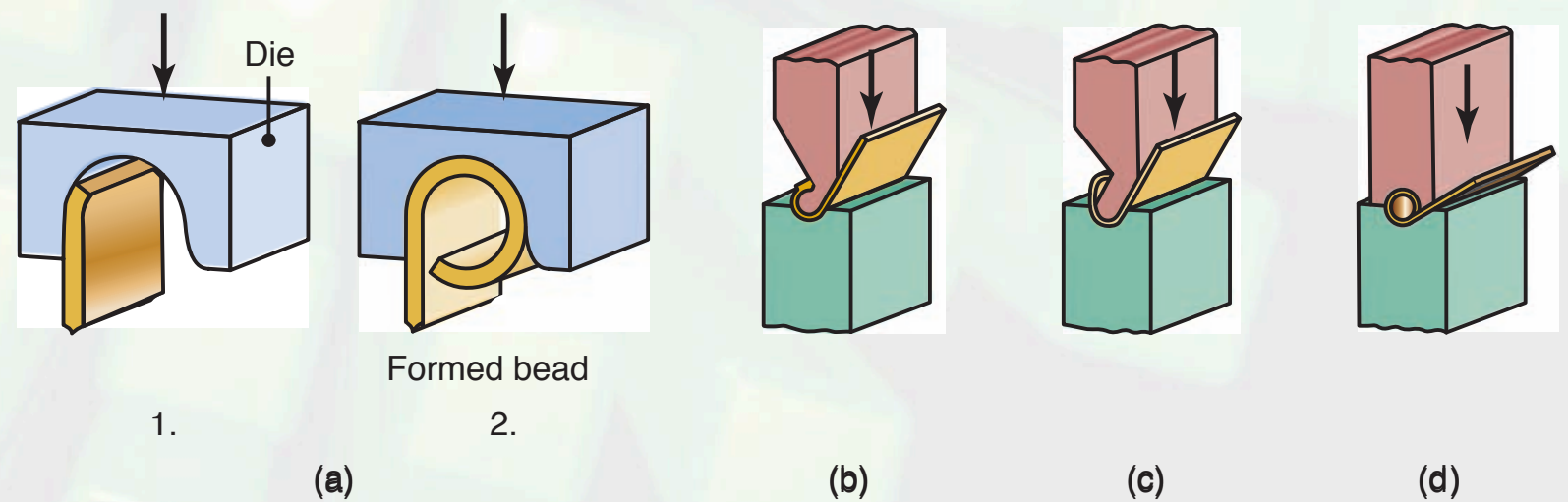
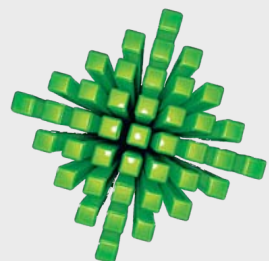


FIGURE 7.25 (a) Bead forming with a single die. (b)-(d) Bead forming with two dies in a press brake.



Flanging Operations

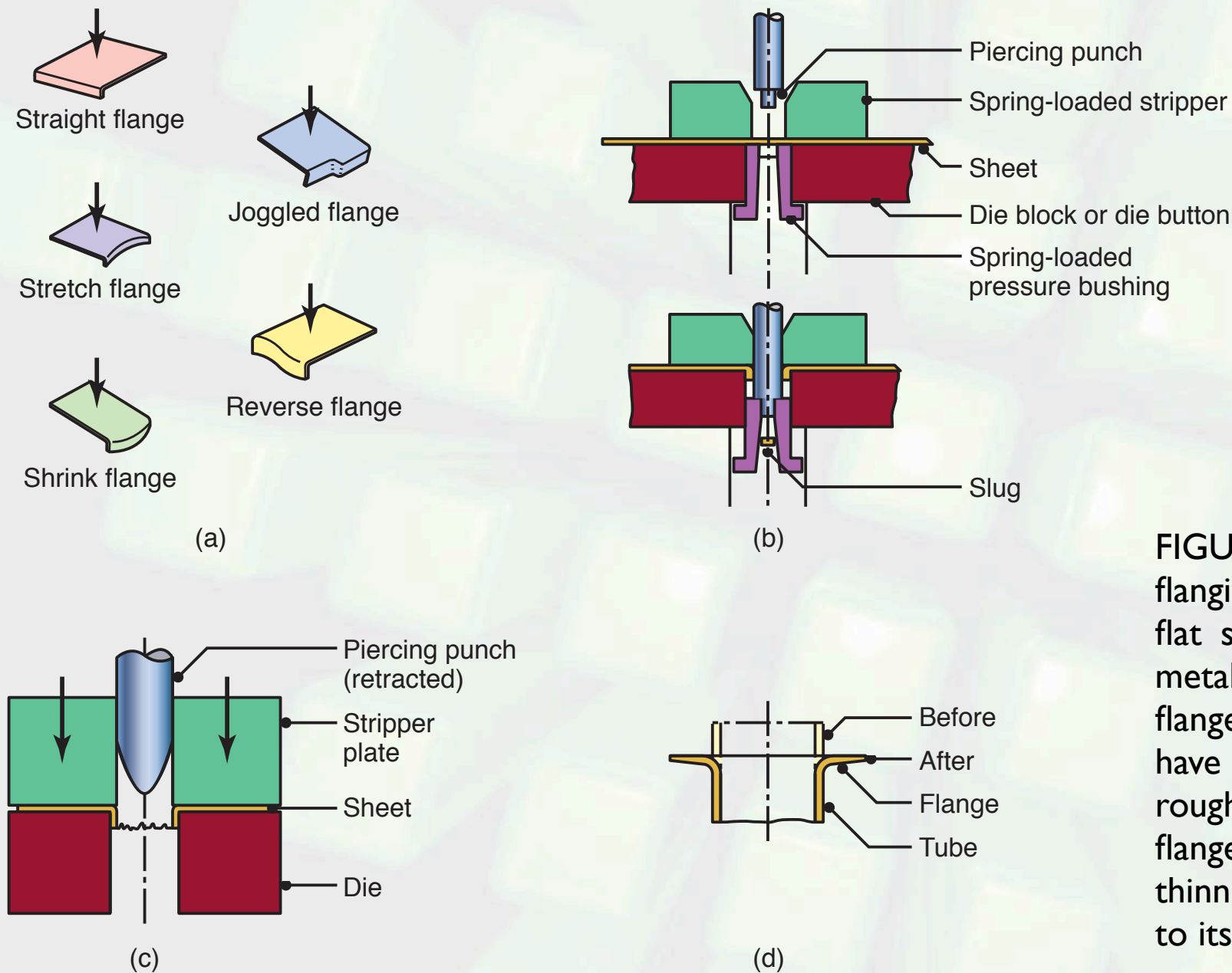
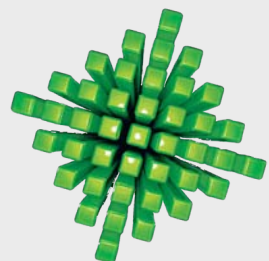


FIGURE 7.26 Illustrations of various flanging operations. (a) Flanges formed on flat sheet. (b) Dimpling. (c) Piercing sheet metal with a punch to form a circular flange. In this operation, a hole does not have to be prepunched; note, however, the rough edges along the circumference of the flange. (d) Flanging of a tube; note the thinning of the periphery of the flange, due to its diametral expansion.



Roll-Forming

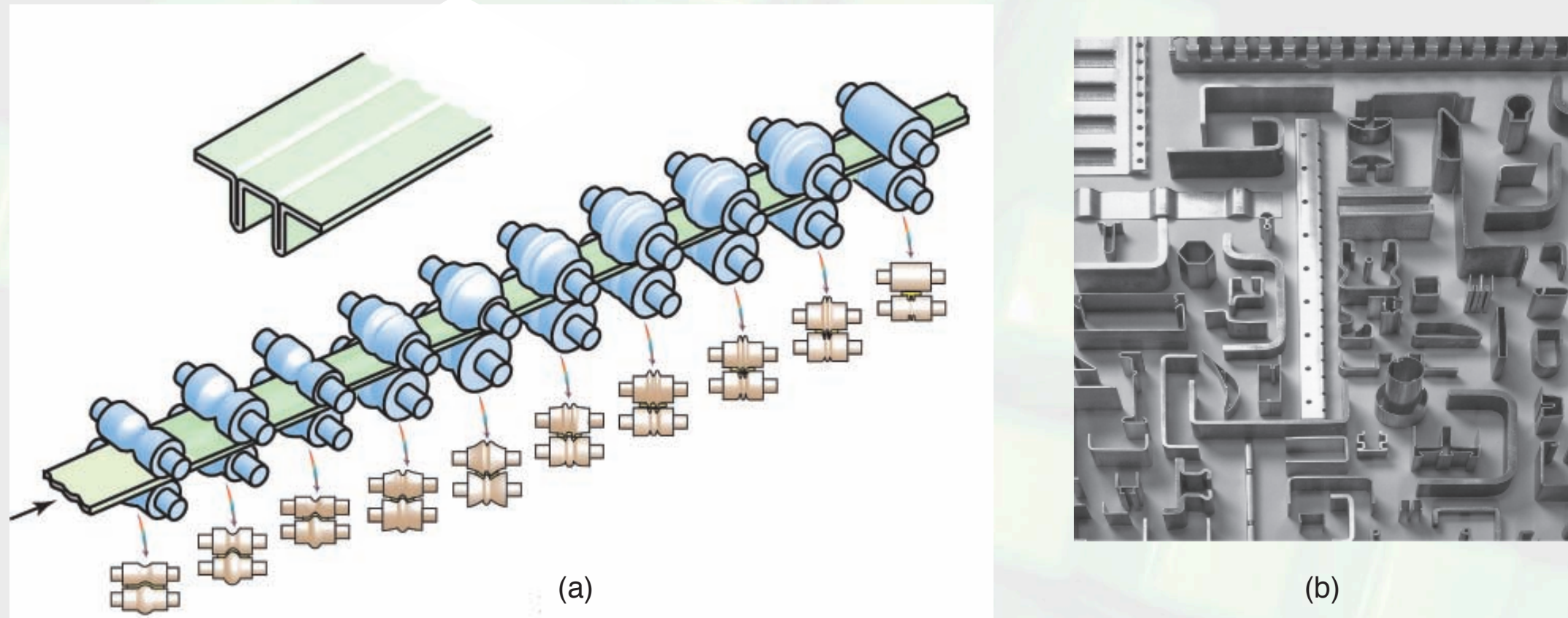
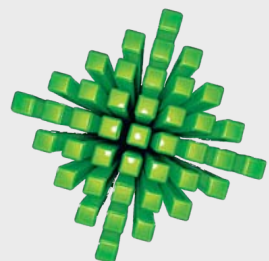


FIGURE 7.27 (a) The roll-forming operation, showing the stages in roll forming of a structural shape. (b) Examples of roll-formed cross-sections. *Source:* Courtesy of Sharon Custom Metal Forming, Inc.



Bending and Forming Tubes

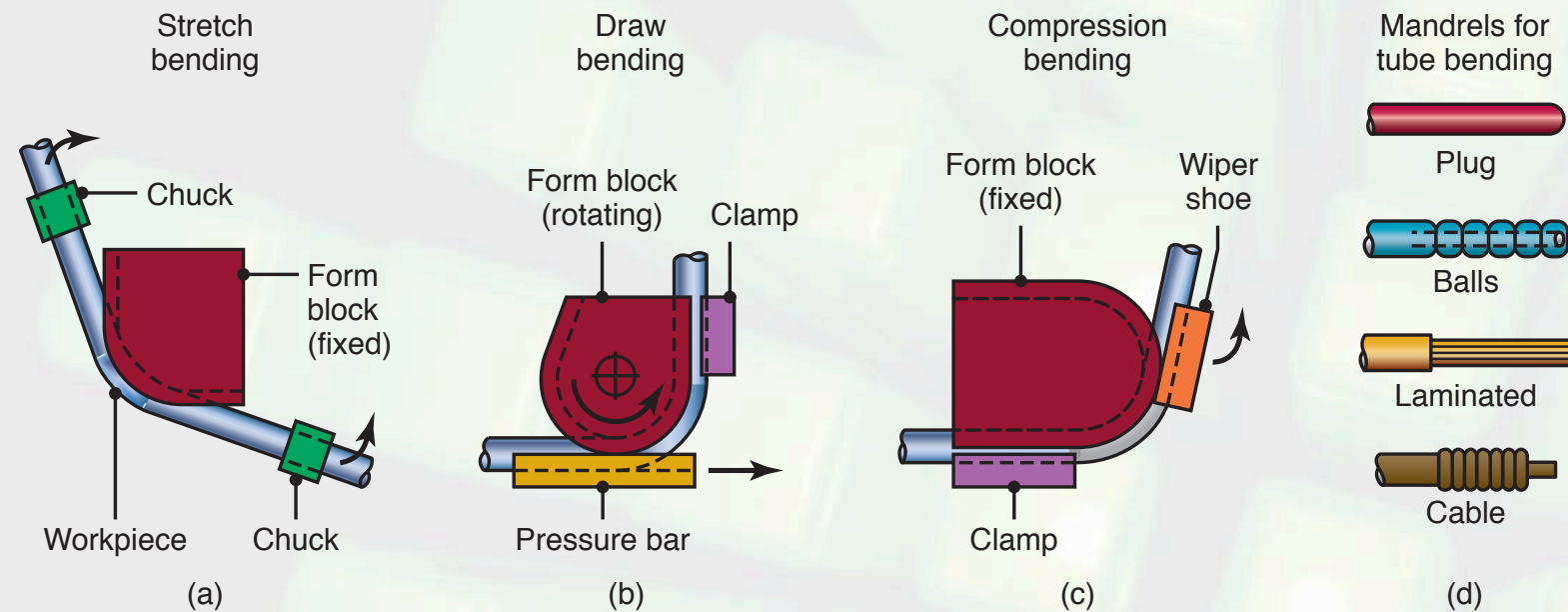


FIGURE 7.28 Methods of bending tubes. Using internal mandrels, or filling tubes with particulate materials such as sand, prevents the tubes from collapsing during bending. Solid rods and structural shapes are also bent by these techniques.

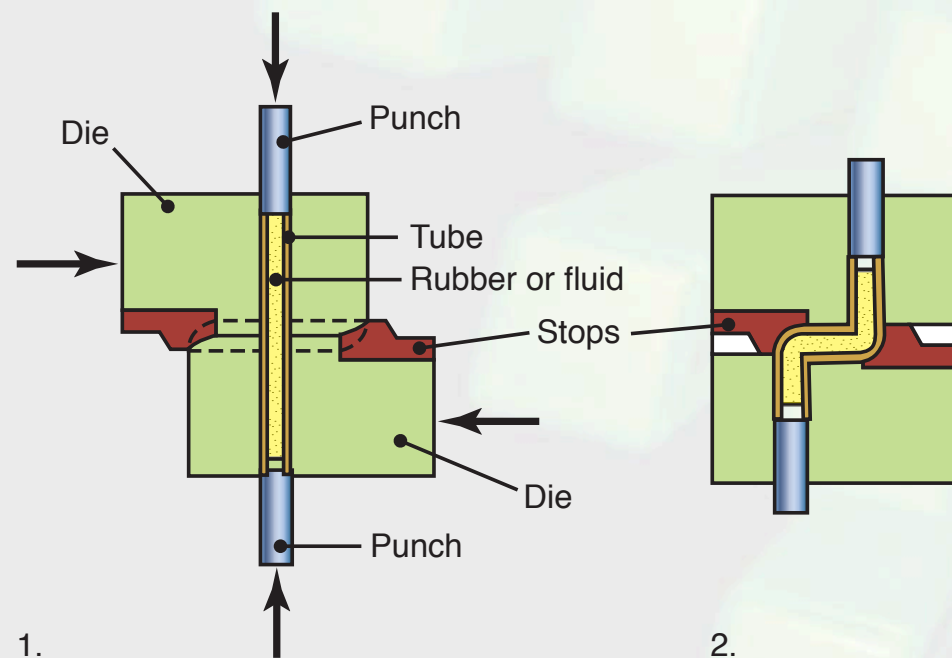
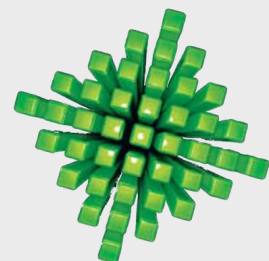


FIGURE 7.29 A method of forming a tube with sharp angles, using an axial compressive force. Compressive stresses are beneficial in forming operations because they delay fracture. Note that the tube is supported internally with rubber or fluid to avoid collapsing during forming. *Source: After J.L. Remmerswaal and A.Verkaik.*



Stretch-Forming

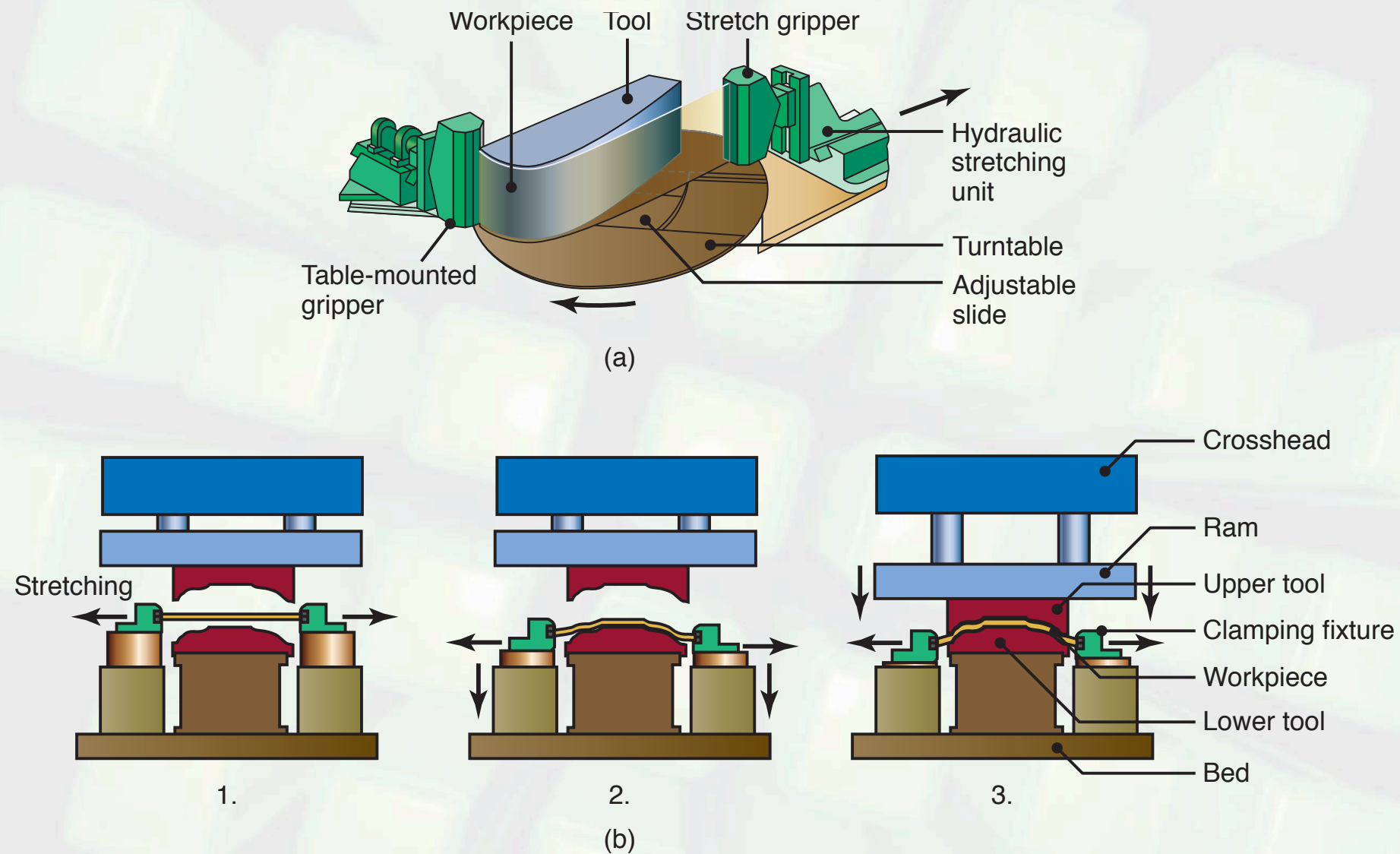
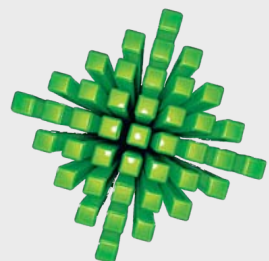


FIGURE 7.30 (a) Schematic illustration of a stretch-forming operation. Aluminum skins for aircraft can be made by this process. *Source:* Cyril Bath Co. (b) Stretch forming in a hydraulic press.



Bulging

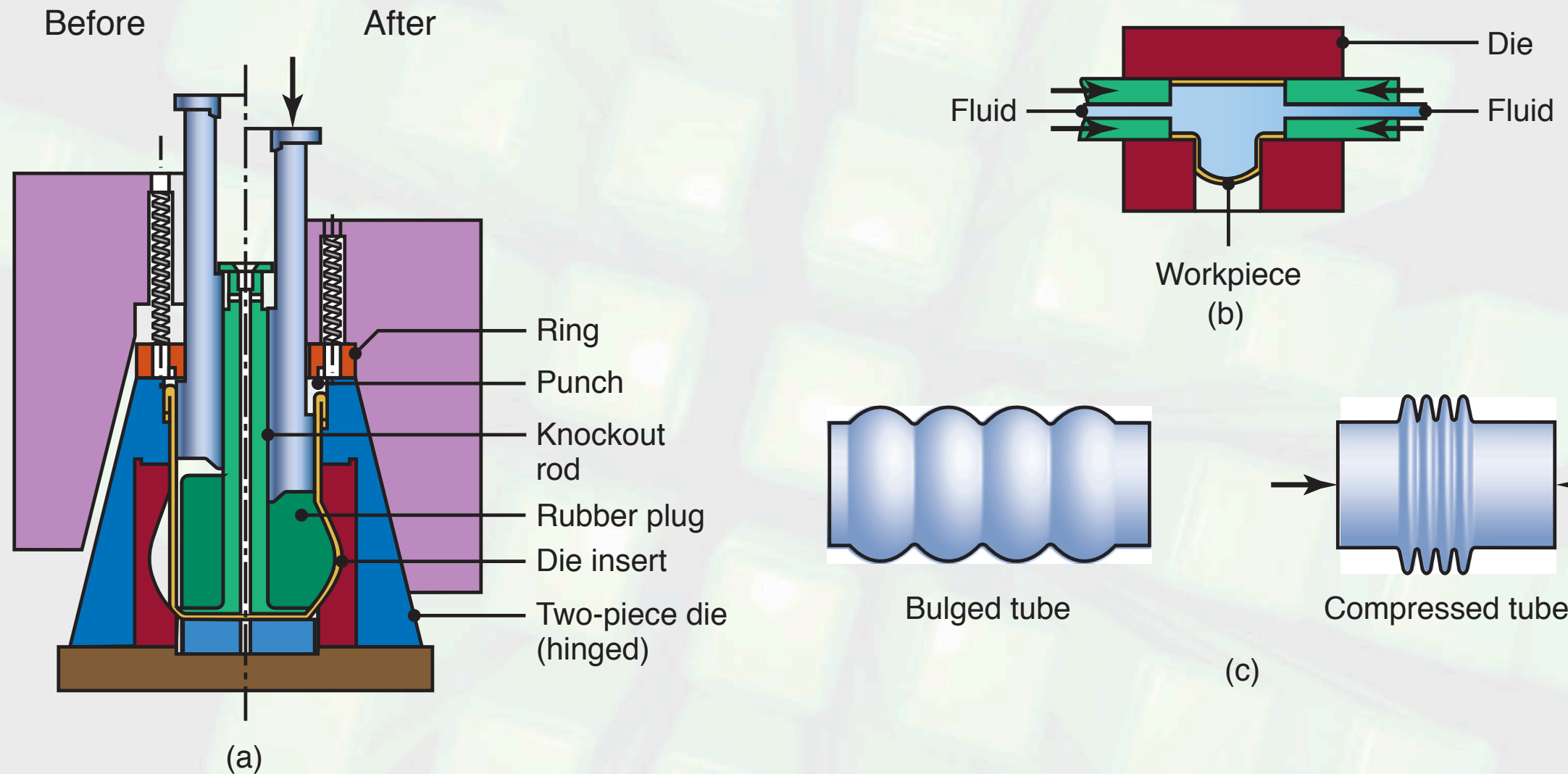
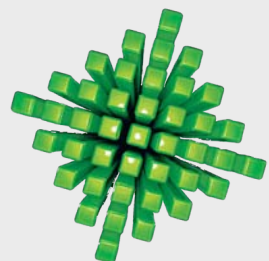


FIGURE 7.32 (a) Bulging of a tubular part with a flexible plug. Water pitchers can be made by this method. (b) Production of fittings for plumbing by expanding tubular blanks with internal pressure; the bottom of the piece is then punched out to produce a “T” section. *Source:* After J.A. Schey. (c) Sequence involved in manufacturing of a metal bellows.



Forming with a Rubber Pad

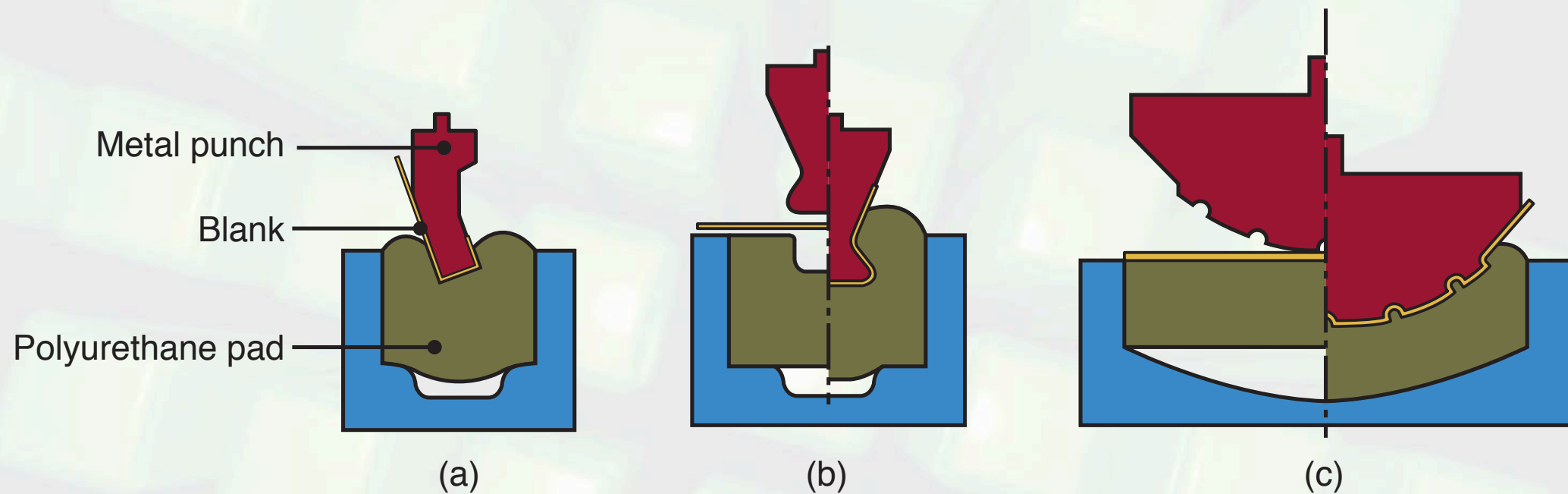
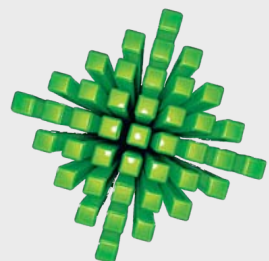


FIGURE 7.33 Examples of bending and embossing sheet metal with a metal punch and a flexible pad serving as the female die. *Source:* Polyurethane Products Corporation.



Sheet Hydroforming

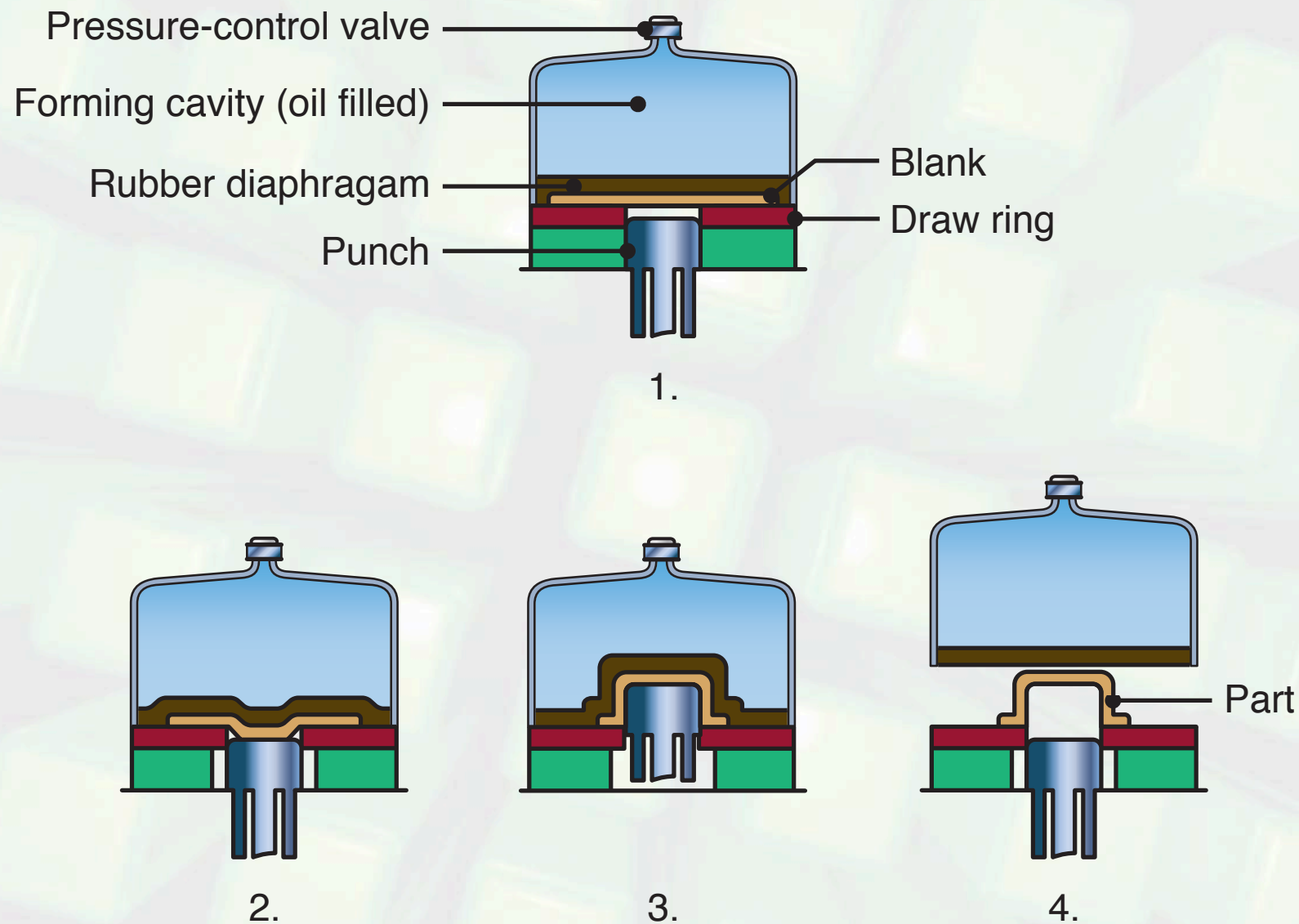
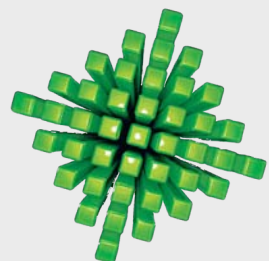


FIGURE 7.34 The principle of the hydroform process, also called fluid forming.



Tube Hydroforming

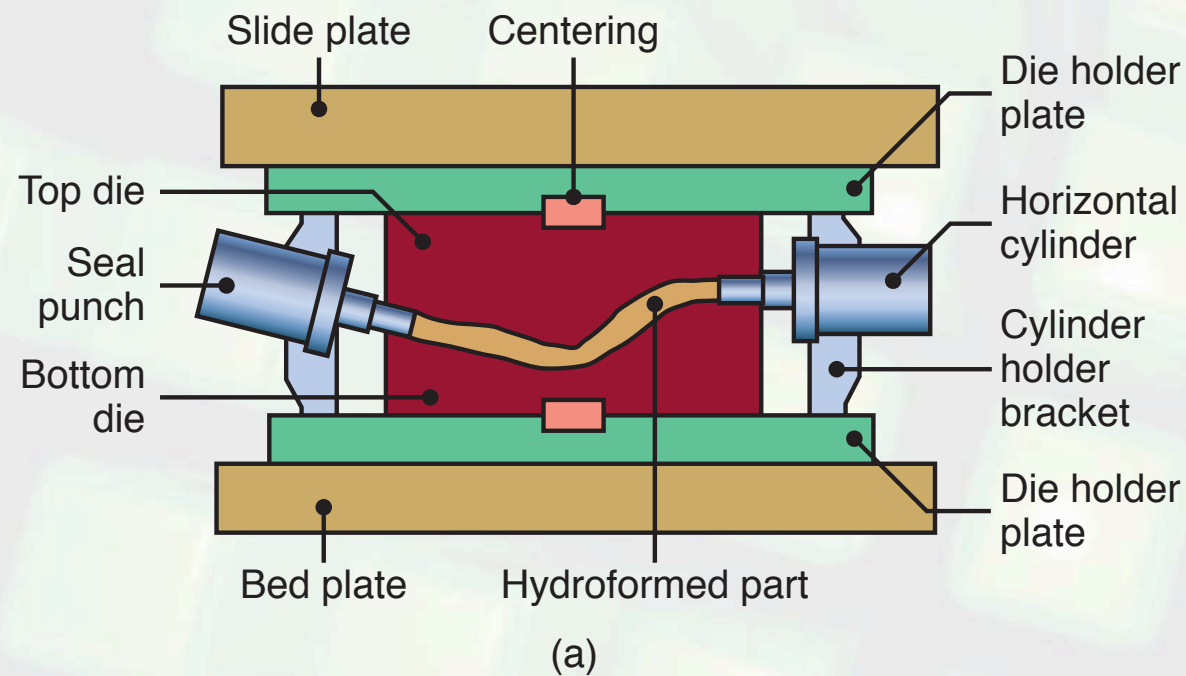
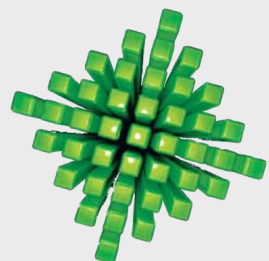


FIGURE 7.35 (a) Schematic illustration of the tube hydroforming process. (b) Example of tube hydroformed parts. Automotive exhaust and structural components, bicycle frames, and hydraulic and pneumatic fittings can be produced through tube hydroforming. Source: Schuler GmbH.



Spinning

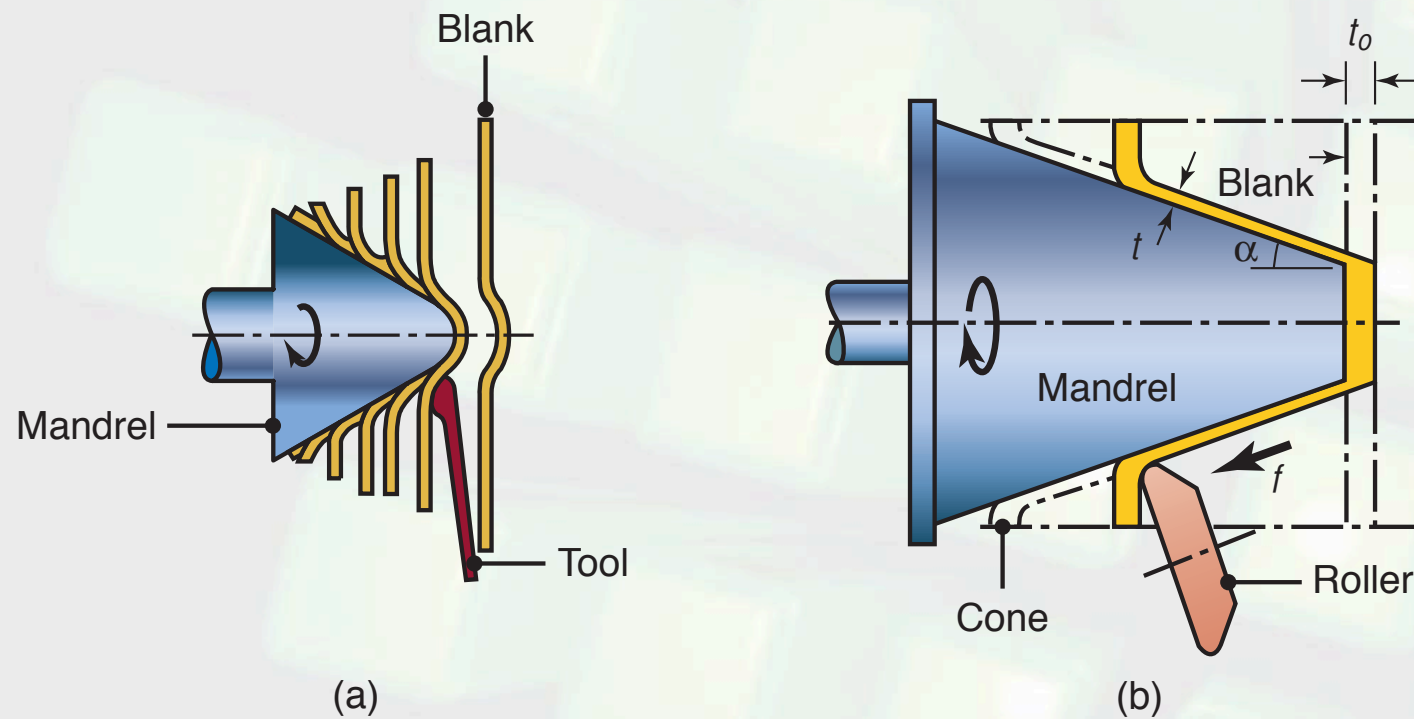
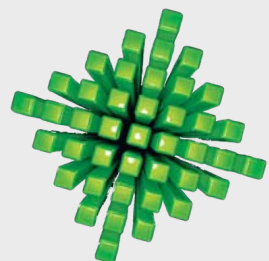


FIGURE 7.36 Schematic illustration of spinning processes: (a) conventional spinning, and (b) shear spinning. Note that in shear spinning, the diameter of the spun part, unlike in conventional spinning, is the same as that of the blank. The quantity f is the feed (in mm/rev or in./rev).



FIGURE 7.37 Typical shapes produced by the conventional spinning process. Circular marks on the external surfaces of components usually indicate that the parts have been made by spinning, such as aluminum kitchen utensils and light reflectors.



Shear Spinning

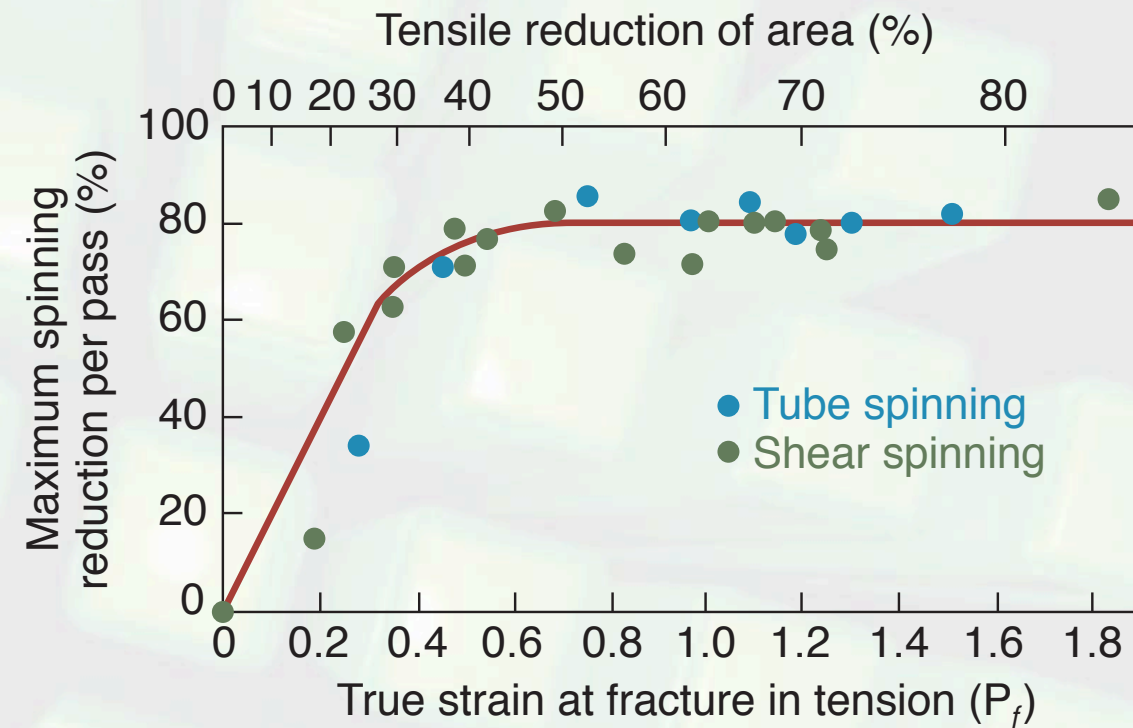
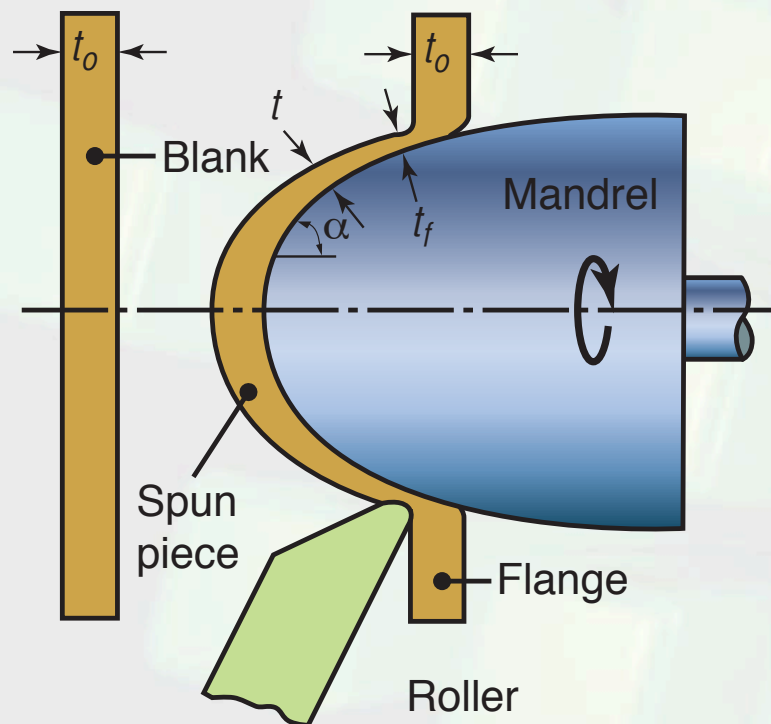
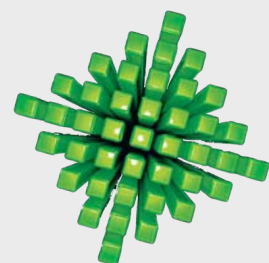


FIGURE 7.38 Schematic illustration of a shear spinnability test. Note that as the roller advances, the spun part thickness is reduced. The reduction in thickness at fracture is called the *maximum spinning reduction per pass*. Source: After R.L. Kegg.

FIGURE 7.39 Experimental data showing the relationship between maximum spinning reduction per pass and the tensile reduction of area of the original material. See also Fig. 7.15. Source: S. Kalpakjian.



Tube Spinning

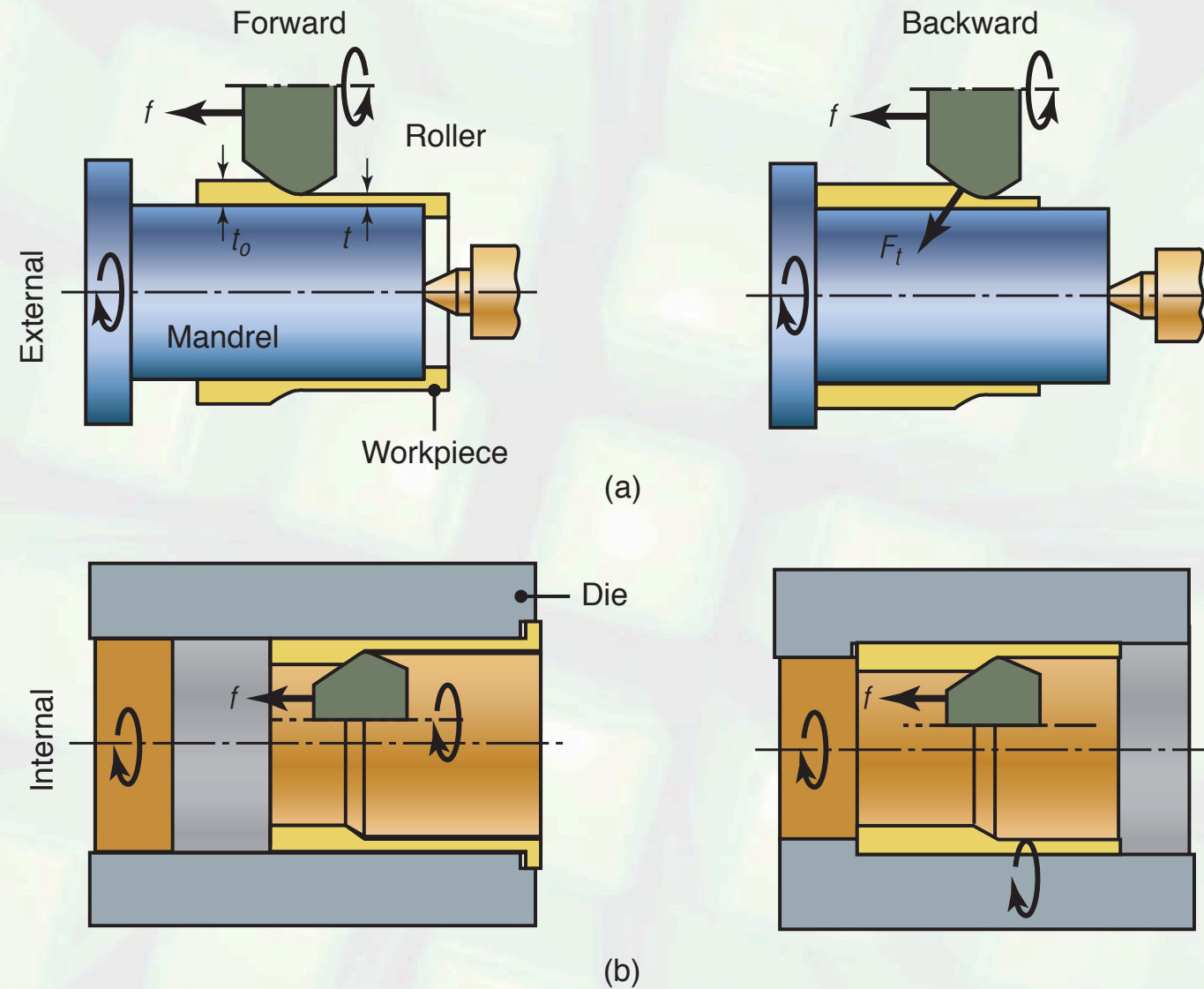
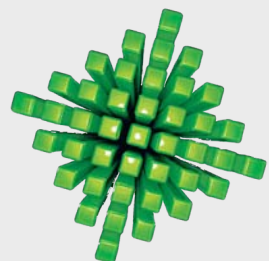


FIGURE 7.40 Examples of (a) external and (b) internal tube spinning, and the process variables involved.



Incremental Sheet-Metal Forming

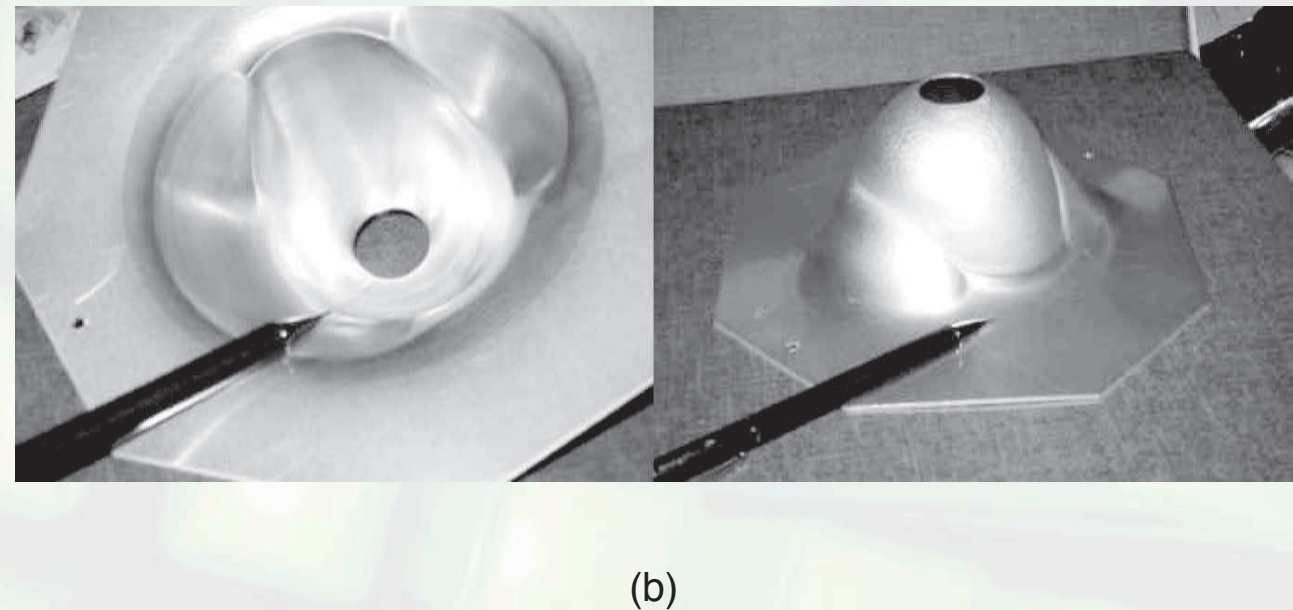
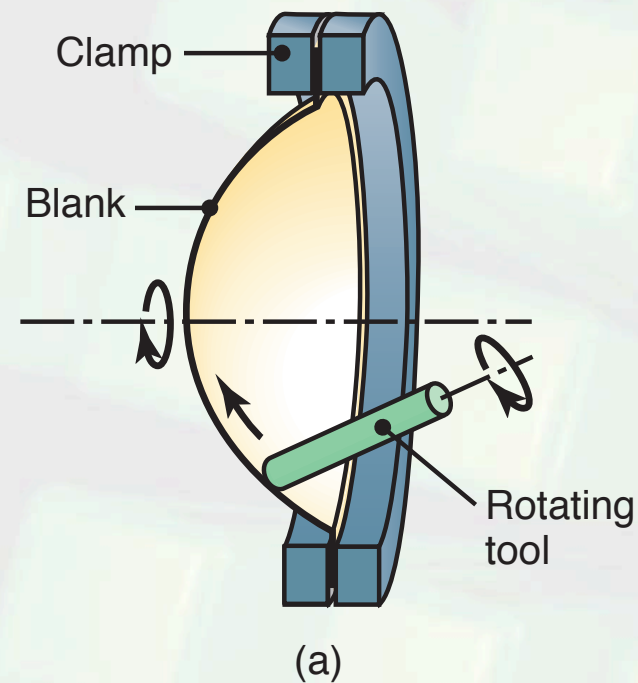
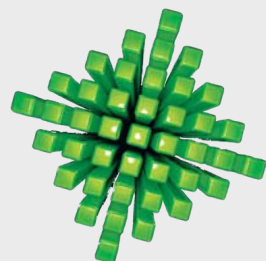


FIGURE 7.41 (a) Illustration of an incremental forming operation. Note that no mandrel is used, and that the final part shape depends on the path of the rotating tool. (b) An automotive headlight reflector produced through CNC incremental forming. Note that the part does not have to be axisymmetric. Source: After J. Jesweit.



Explosive Forming

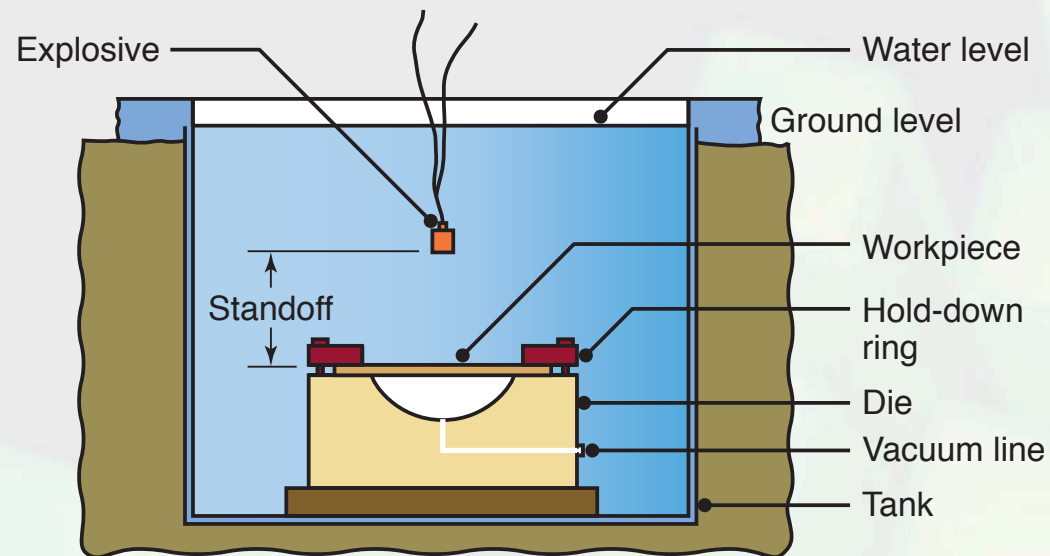


FIGURE 7.42 Schematic illustration of the explosive forming process. Although explosives are typically used for destructive purposes, their energy can be controlled and employed in forming large parts that would otherwise be difficult or expensive to produce by other methods.

Pressure generated:

$$p = K \left(\frac{\sqrt[3]{W}}{R} \right)^a$$

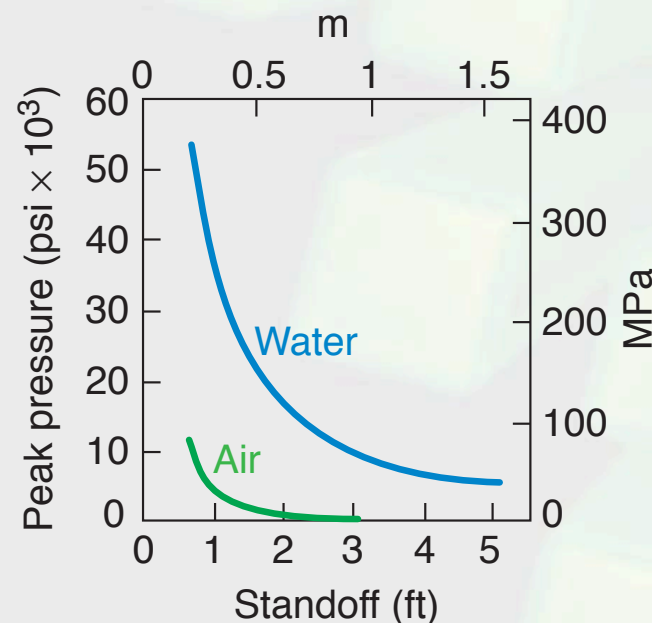
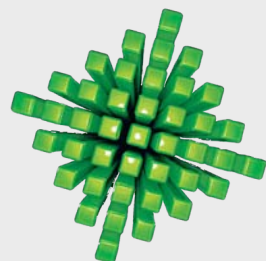


FIGURE 7.43 Effect of the standoff distance and type of energy-transmitting medium on the peak pressure obtained using 1.8 kg (4 lb) of TNT. The pressure-transmitting medium should have a high density and low compressibility. In practice, water is a commonly used medium.



Electrohydraulic and Magnetic-Pulse Forming

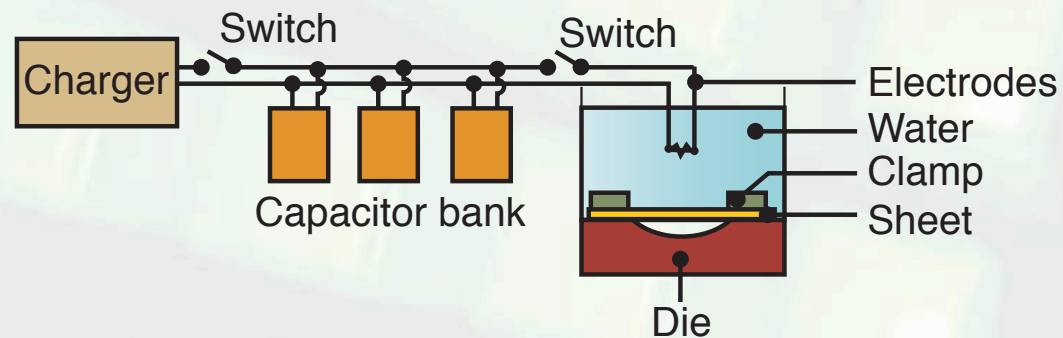
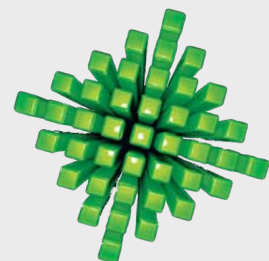
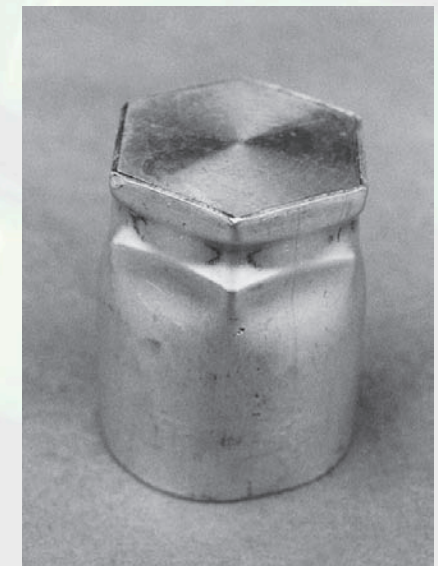
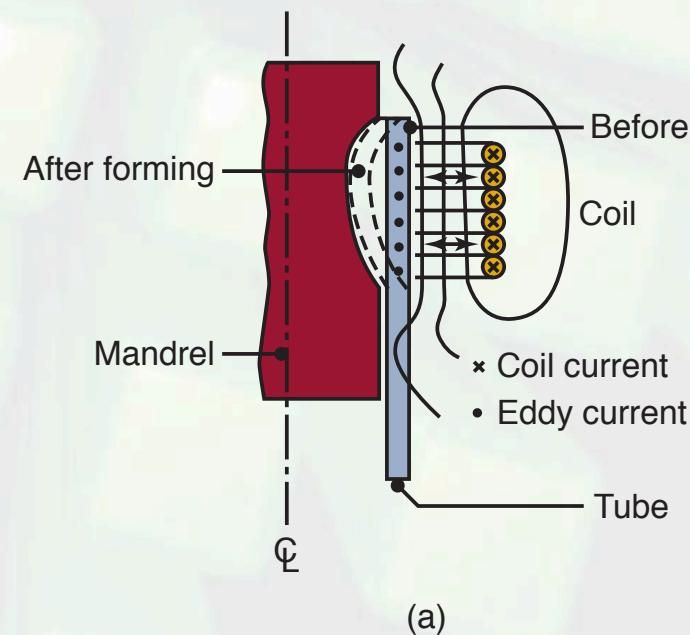


FIGURE 7.44 Schematic illustration of the electrohydraulic forming process.

FIGURE 7.45 (a) Schematic illustration of the magnetic-pulse forming process. The part is formed without physical contact with any object, and (b) aluminum tube collapsed over a hexagonal plug by the magnetic-pulse forming process.



Superplastic Forming

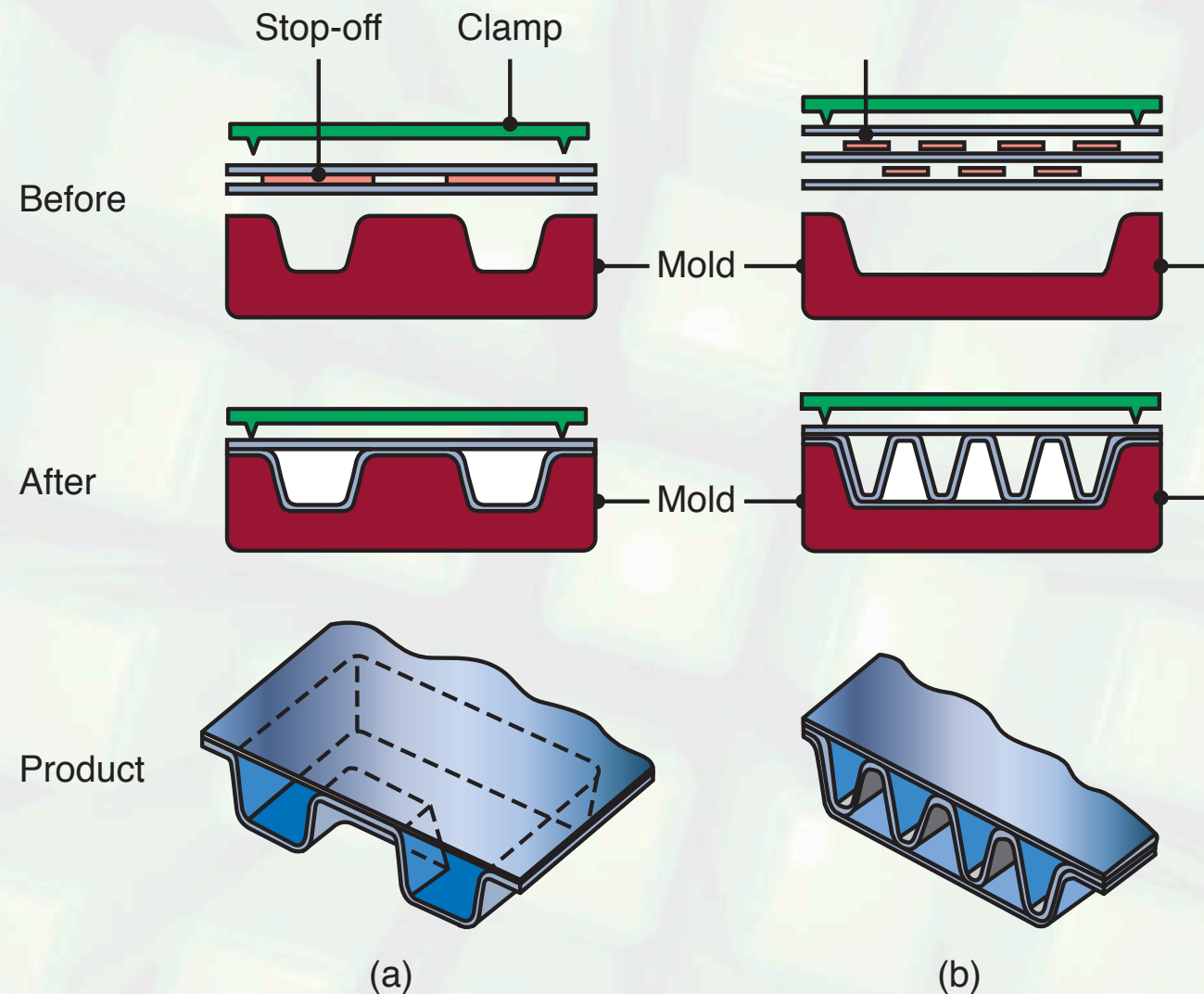
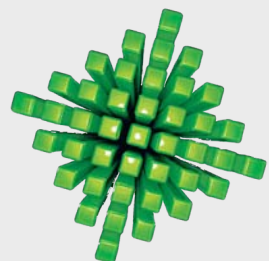


FIGURE 7.46 Two types of structures made by combining diffusion bonding and superplastic forming of sheet metal. Such structures have a high stiffness-to-weight ratio.
Source: Rockwell Automation, Inc.



Peen-Forming

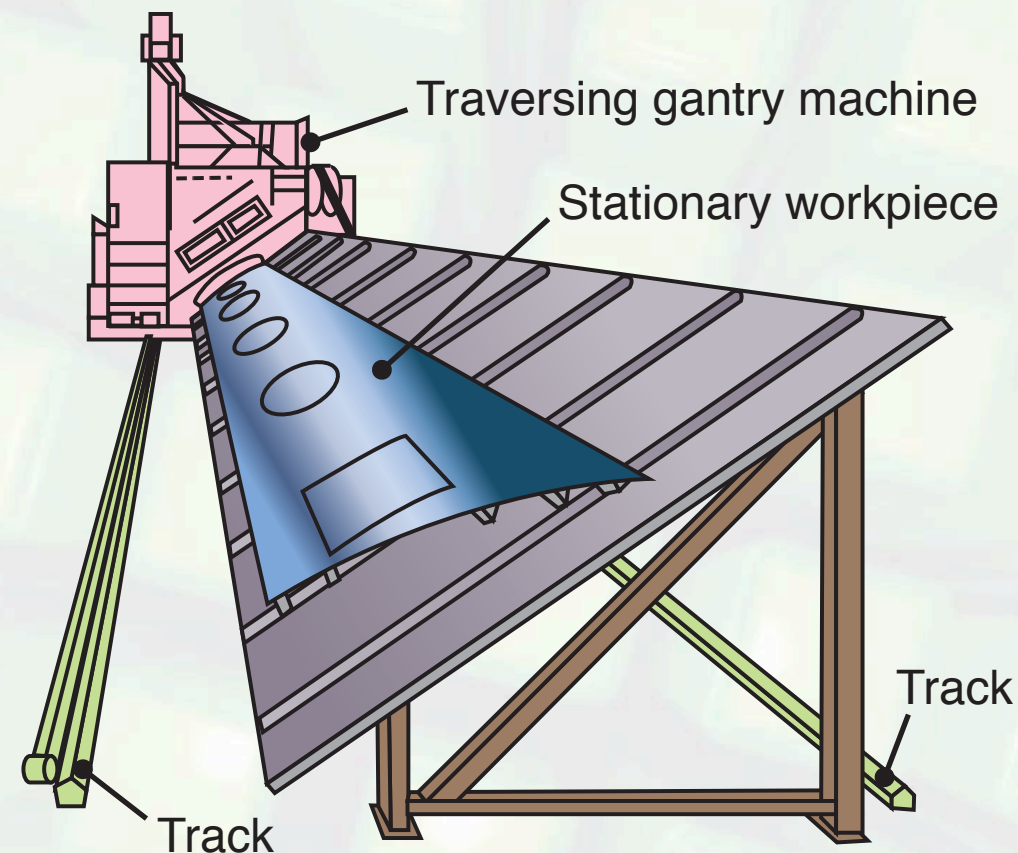
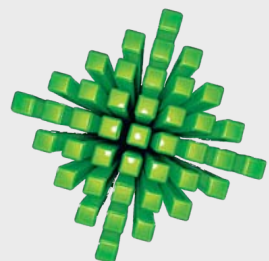


FIGURE 7.47 Schematic illustration of a peen forming machine to shape a large sheet-metal part, such as an aircraft-skin panel. Note that the sheet is stationary and the peening head travels along its length.
Source: Metal Improvement Company.



Honeycomb Structures

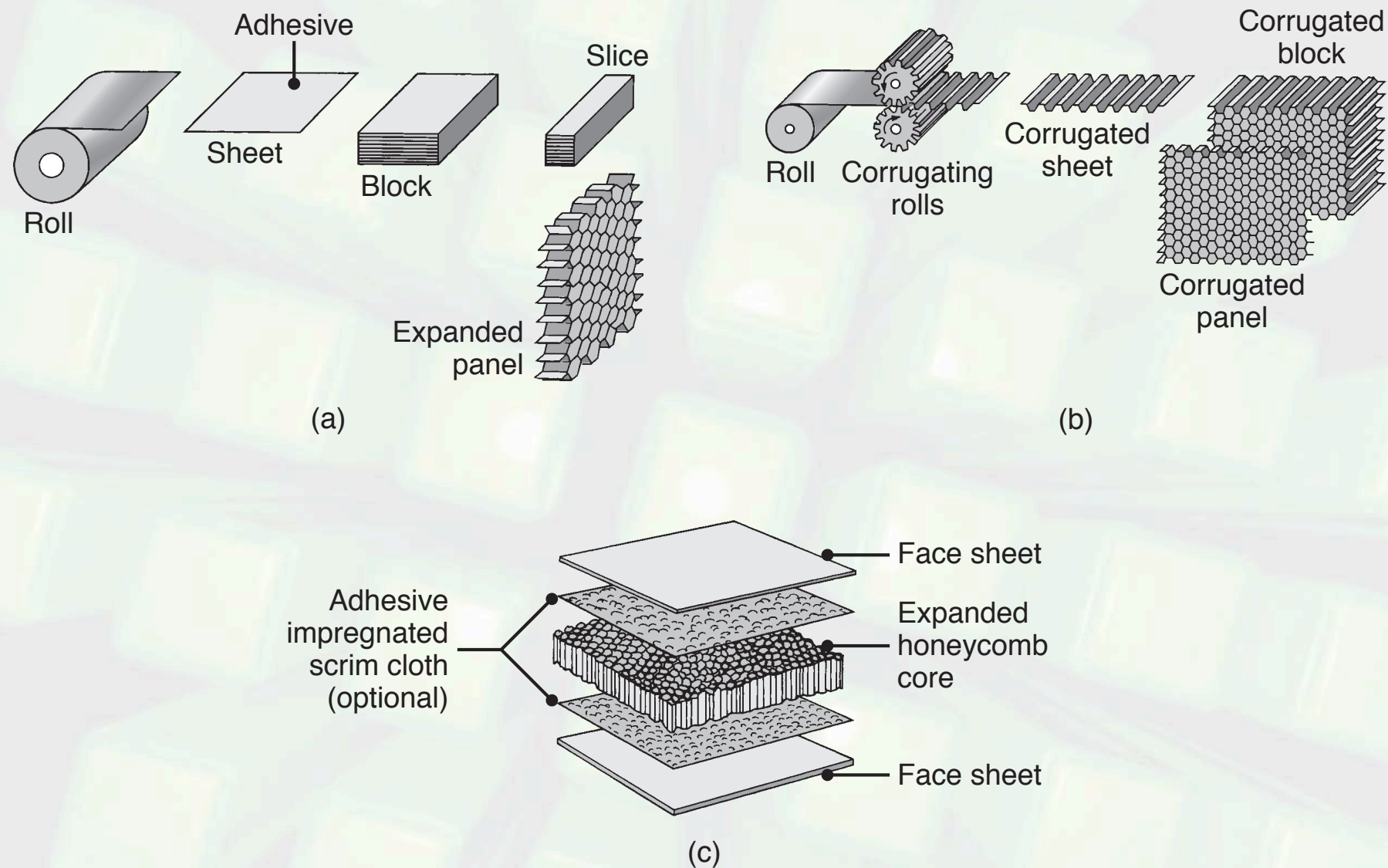
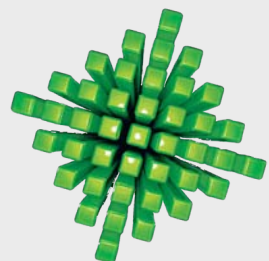


FIGURE 7.48 Methods of making honeycomb structures: (a) expansion process, and (b) corrugation process; (c) assembling a honeycomb structure into a laminate.



Deep-Drawing

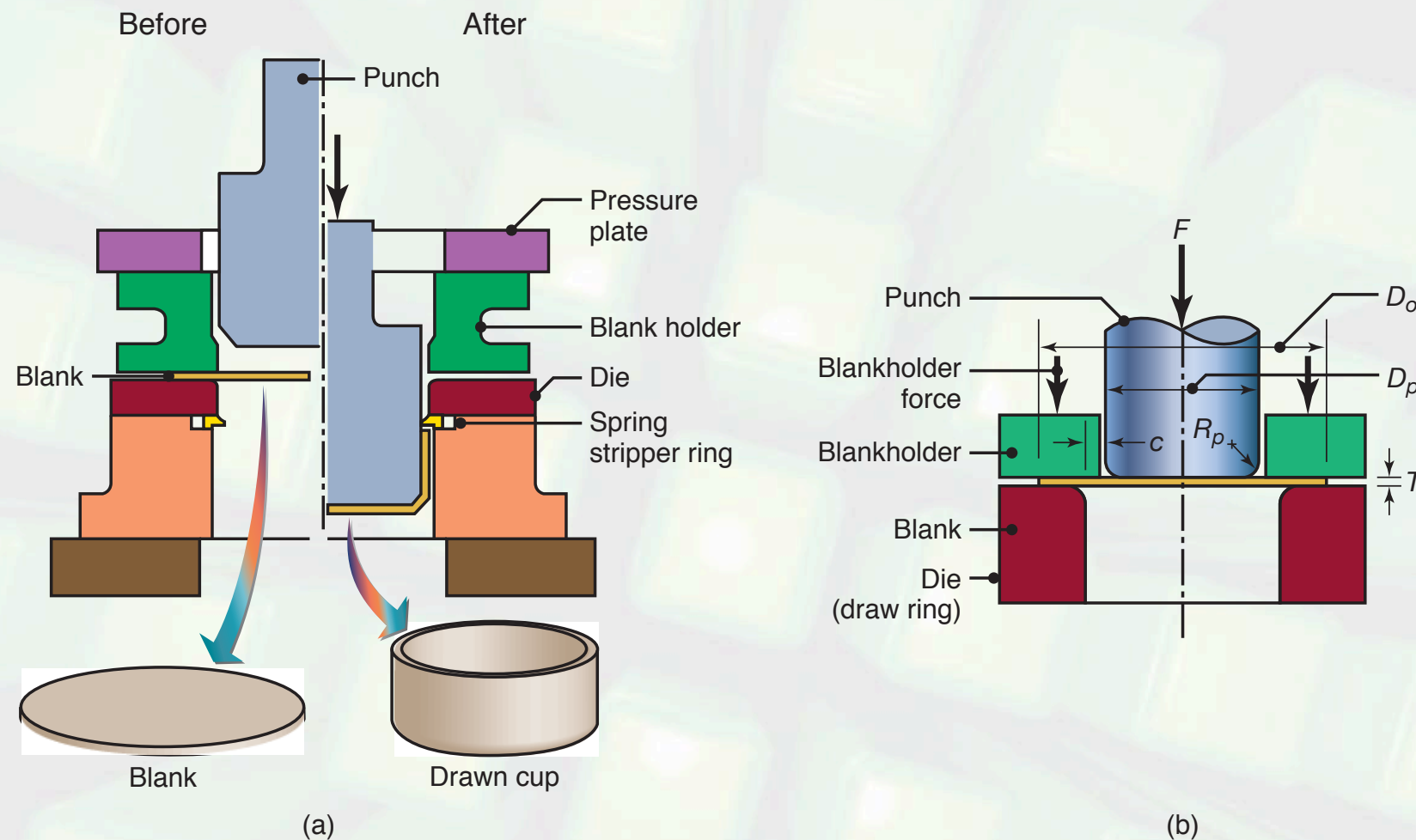
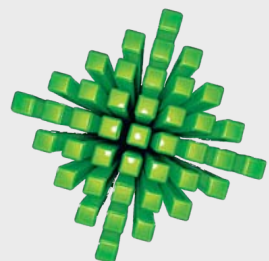


FIGURE 7.49 (a) Schematic illustration of the deep drawing process on a circular sheet-metal blank. The stripper ring facilitates the removal of the formed cup from the punch. (b) Variables in deep drawing of a cylindrical cup. Note that only the punch force in this illustration is a dependent variable; all others are independent variables, including the blankholder force.



Deformation in Flange and Wall

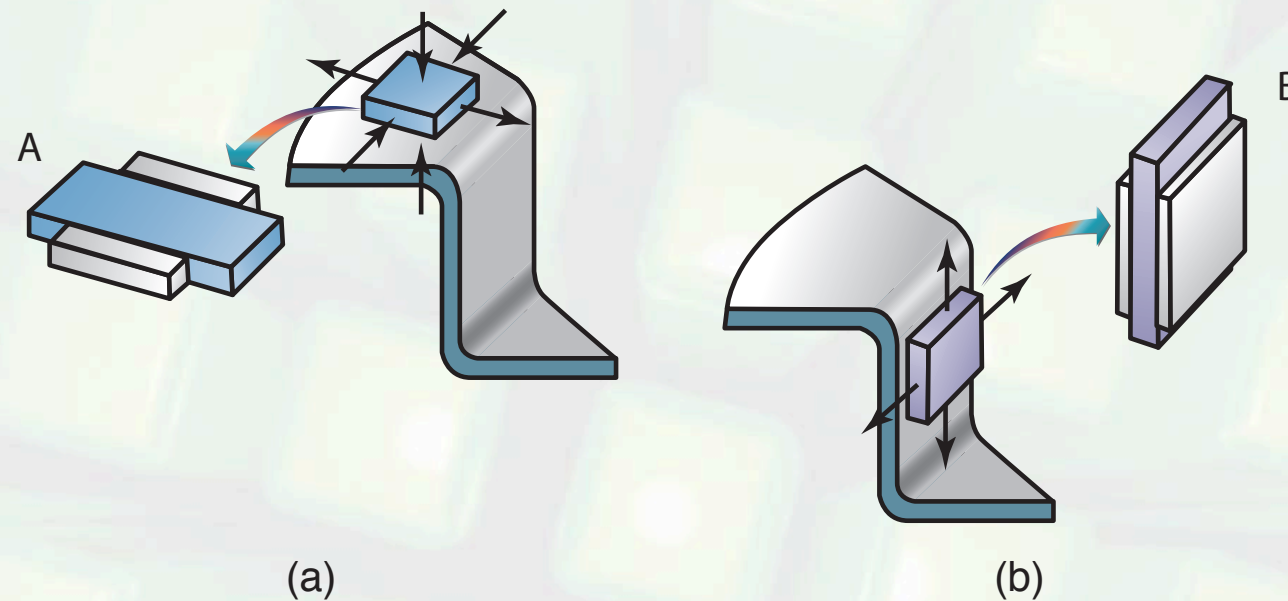
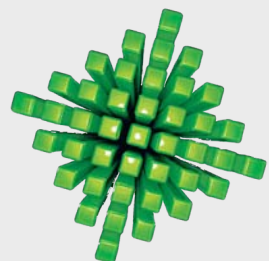


FIGURE 7.50 Deformation of elements in (a) the flange and (b) the cup wall in deep drawing of a cylindrical cup.



Pure Drawing vs. Pure Stretching

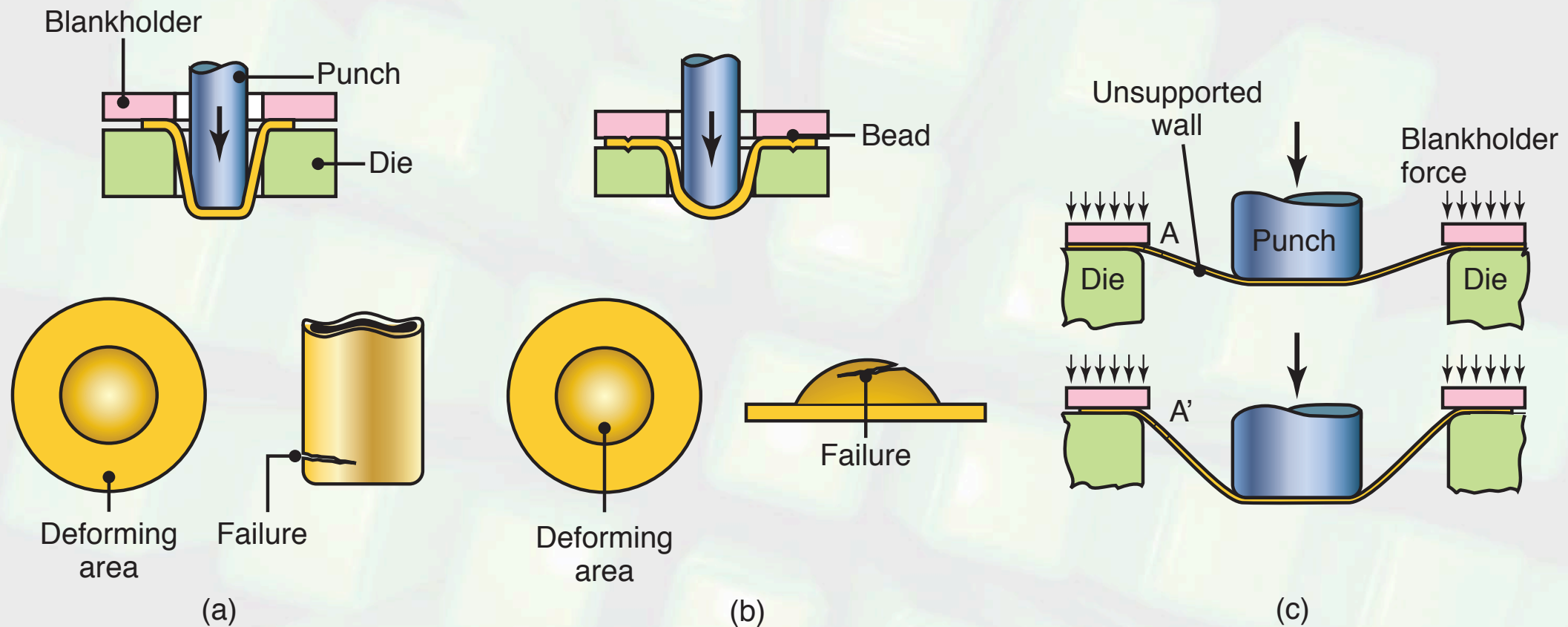
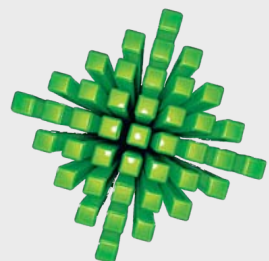


FIGURE 7.51 Examples of (a) pure drawing and (b) pure stretching; the bead prevents the sheet metal from flowing freely into the die cavity. (c) Unsupported wall and possibility of wrinkling of a sheet in drawing. Source: After W.F. Hosford and R.M. Caddell.



Draw Beads & Metal Flow

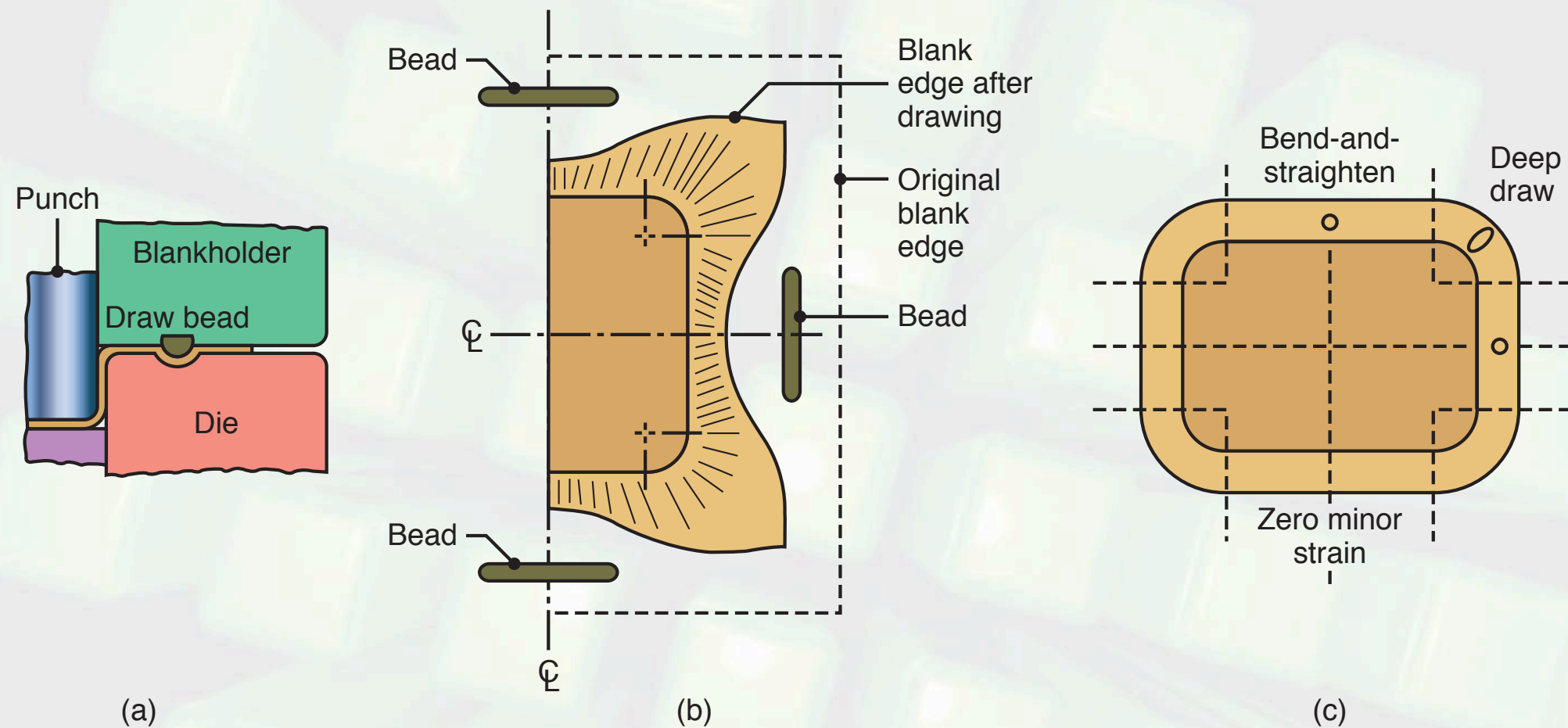
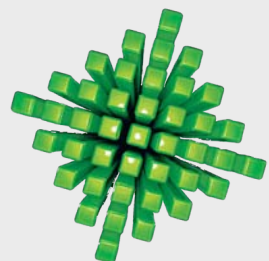


FIGURE 7.52 (a) Schematic illustration of a draw bead. (b) Metal flow during drawing of a box-shaped part, using beads to control the movement of the material. (c) Deformation of circular grids in drawing. (See Section 7.7.)



Ironing

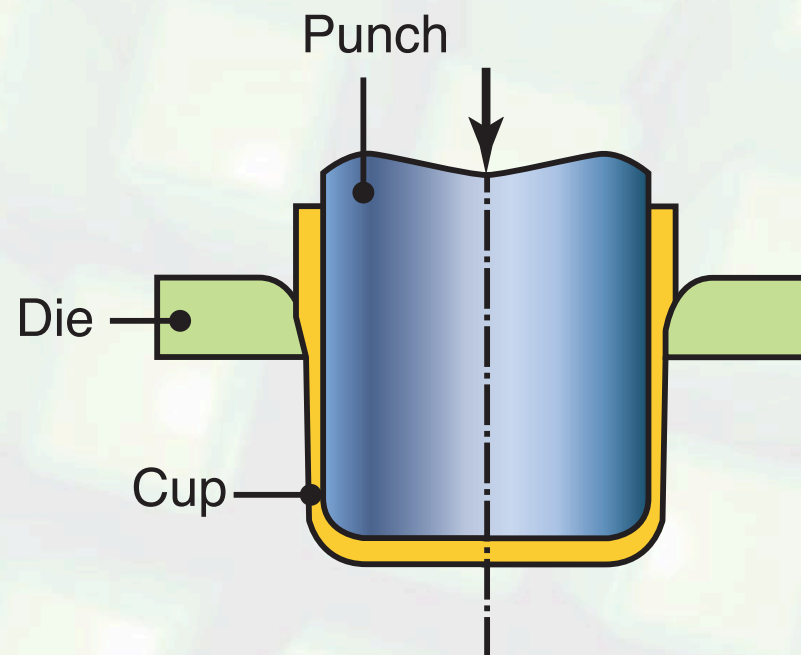
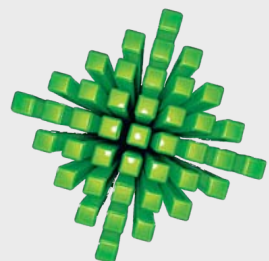


FIGURE 7.53 Schematic illustration of the ironing process. Note that the cup wall is thinner than its bottom. All beverage cans without seams (known as two-piece cans) are ironed, generally in three steps, after being deep drawn into a cup. Cans with separate tops and bottoms are known as three-piece cans.



Anisotropy

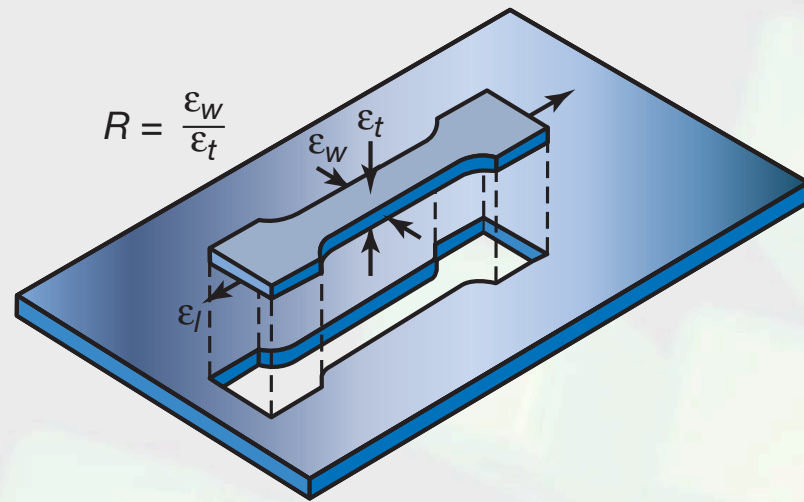


FIGURE 7.54 Definition of the normal anisotropy, R , in terms of width and thickness strains in a tensile-test specimen cut from a rolled sheet. Note that the specimen can be cut in different directions with respect to the length, or rolling direction, of the sheet.

Material	\bar{R}
Zinc alloys	0.4-0.6
Hot-rolled steel	0.8-1.0
Cold-rolled rimmed steel	1.0-1.4
Cold-rolled aluminum-killed steel	1.4-1.8
Aluminum alloys	0.6-0.8
Copper and brass	0.6-0.9
Titanium alloys (α)	3.0-5.0
Stainless steels	0.9-1.2
High-strength low-alloy steels	0.9-1.2

TABLE 7.3 Typical range of the average normal anisotropy ratio, \bar{R} , for various sheet metals.

Normal anisotropy:

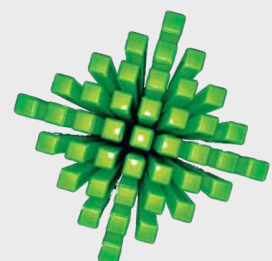
$$R = \frac{\epsilon_w}{\epsilon_t} = \frac{\ln \left(\frac{w_o}{w_f} \right)}{\ln \left(\frac{t_o}{t_f} \right)}$$

Average anisotropy:

$$\bar{R} = \frac{R_0 + 2R_{45} + R_{90}}{4}$$

Planar anisotropy:

$$\Delta R = \frac{R_0 - 2R_{45} + R_{90}}{2}$$



Anisotropy and Effects

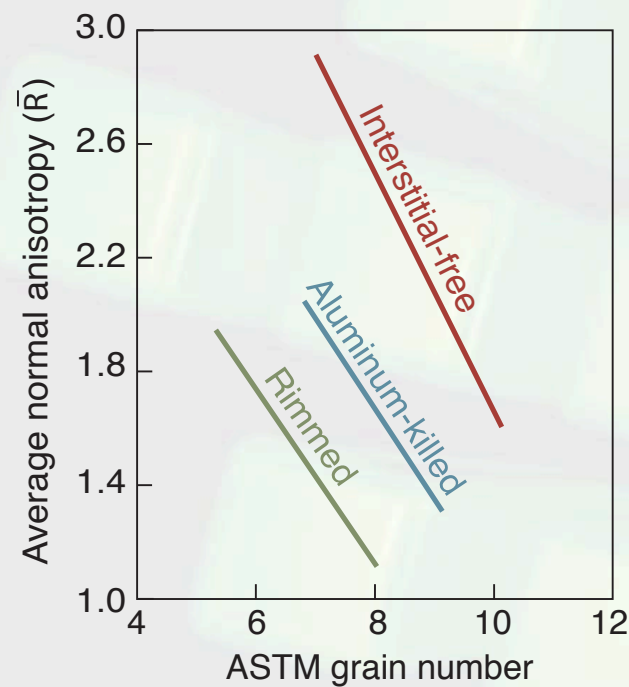


FIGURE 7.55 Effect of grain size on the average normal anisotropy for various low-carbon steels. Source: After D.J. Blickwede.

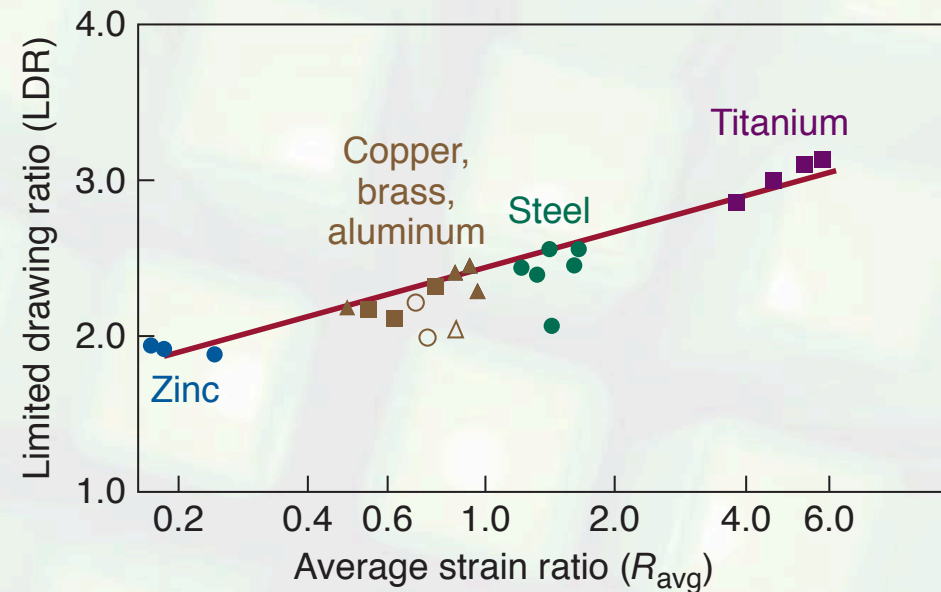


FIGURE 7.56 Effect of average normal anisotropy, \bar{R} on limiting drawing ratio (LDR) for a variety of sheet metals. Source: After M. Atkinson.

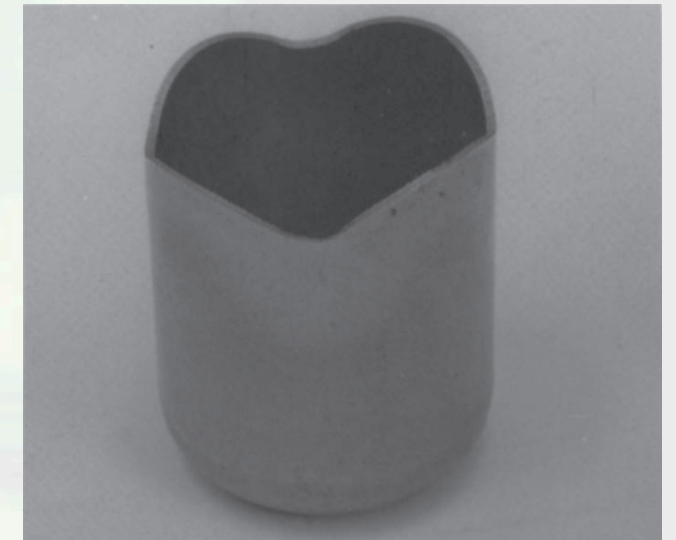
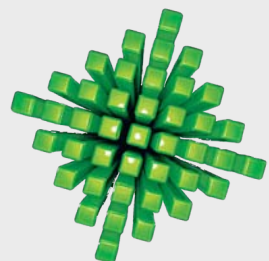


FIGURE 7.57 Typical earring in a drawn steel cup, caused by the planar anisotropy of the sheet metal.



Punch Force

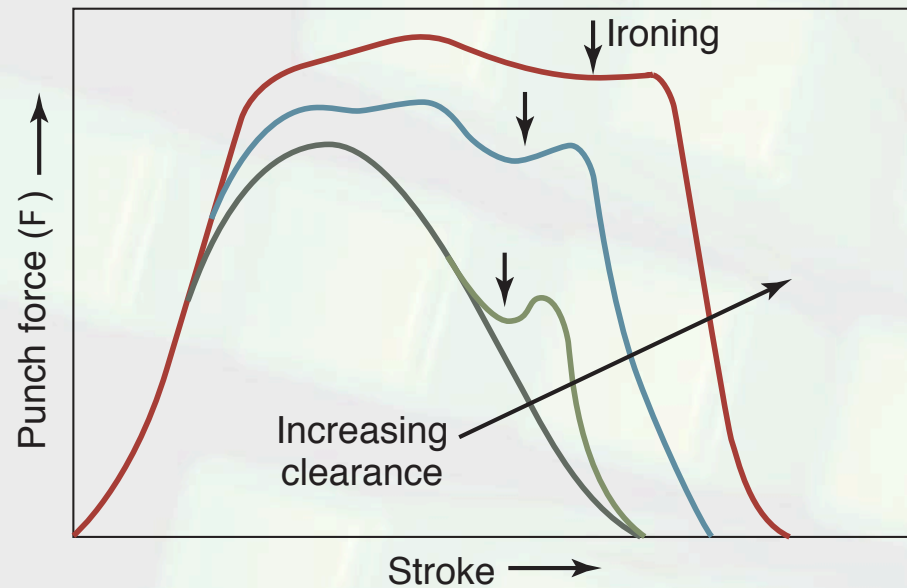


FIGURE 7.58 Schematic illustration of the variation of punch force with stroke in deep drawing. Arrows indicate the initiation of ironing. Note that ironing does not begin until after the punch has traveled a certain distance and the cup is partially formed.

Maximum punch force:

$$F_{max} = \pi D_p t_o (UTS) \left(\frac{D_o}{D_p} - 0.7 \right)$$

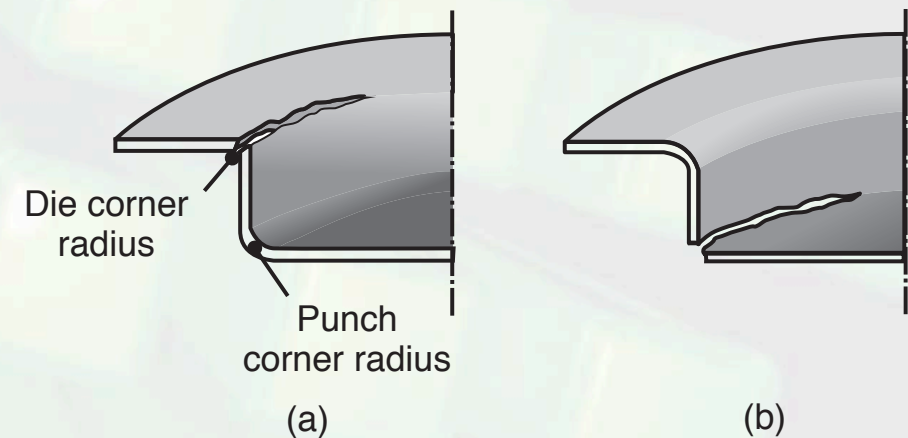
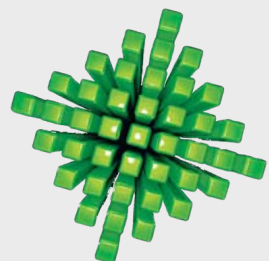


FIGURE 7.59 Effect of die and punch corner radii on fracture in deep drawing of a cylindrical cup. (a) Die corner radius too small; typically, it should be 5 to 10 times the sheet thickness. (b) Punch corner radius too small. Because friction between the cup and the punch aids in the drawing operation, excessive lubrication of the punch is detrimental to drawability.



Redrawing & Tractrix Die

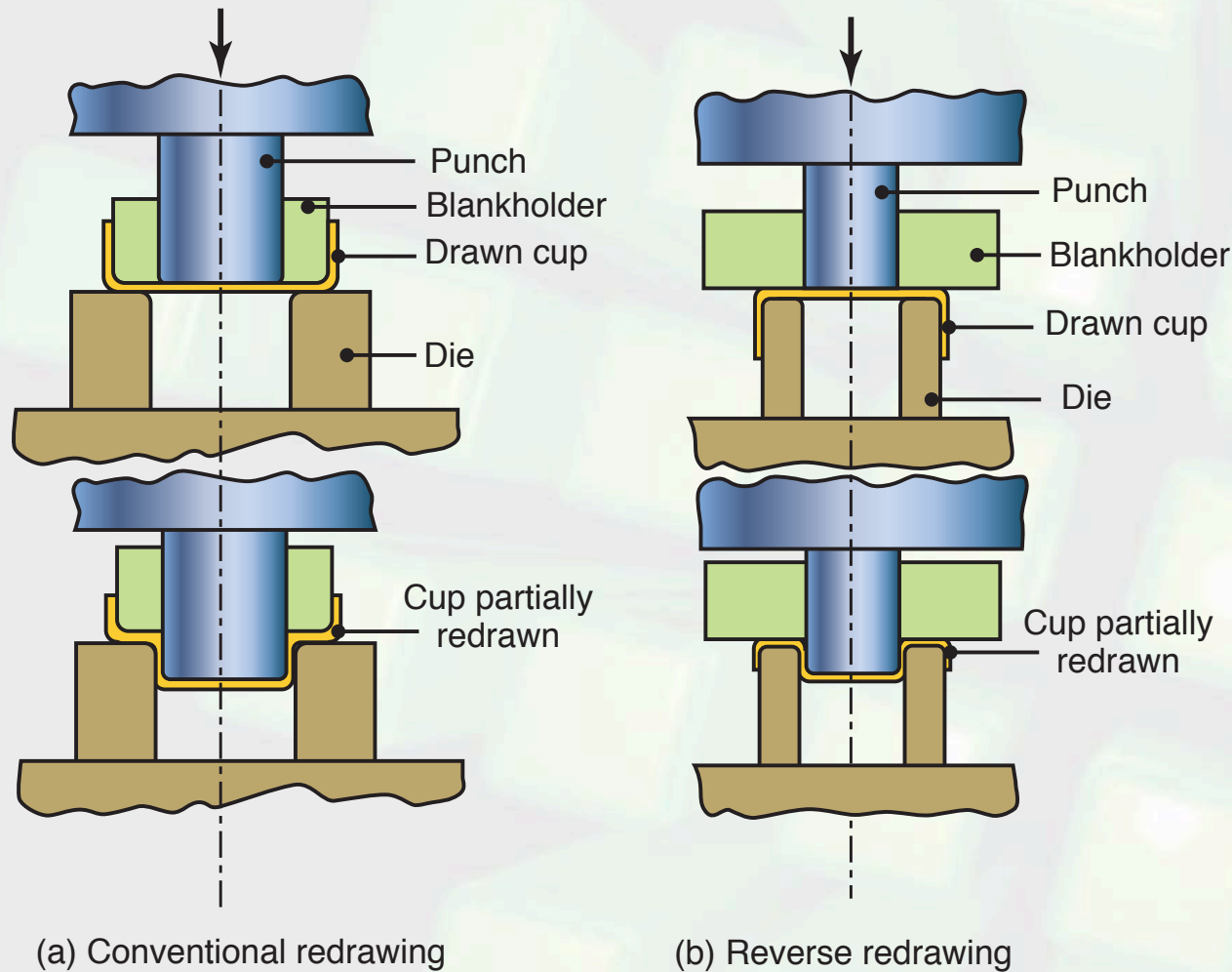


FIGURE 7.60 Reducing the diameter of drawn cups by redrawing operations: (a) conventional redrawing, and (b) reverse redrawing. Small-diameter deep containers may undergo several redrawing operations.

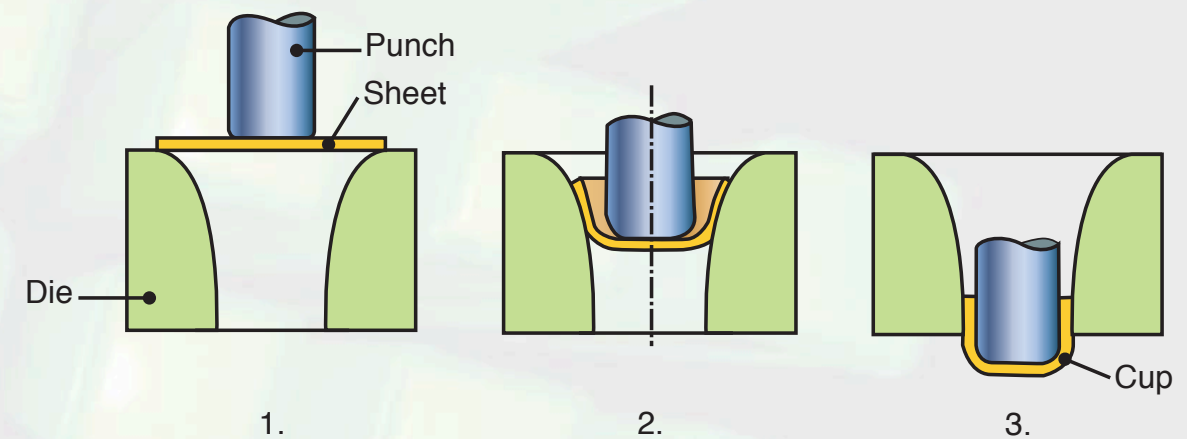
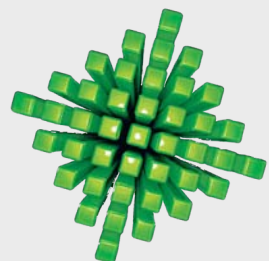


FIGURE 7.61 Stages in deep drawing without a blankholder, using a *tractrix* die profile. The tractrix is a special curve, the construction for which can be found in texts on analytical geometry or in handbooks.



Punch-Stretch Test

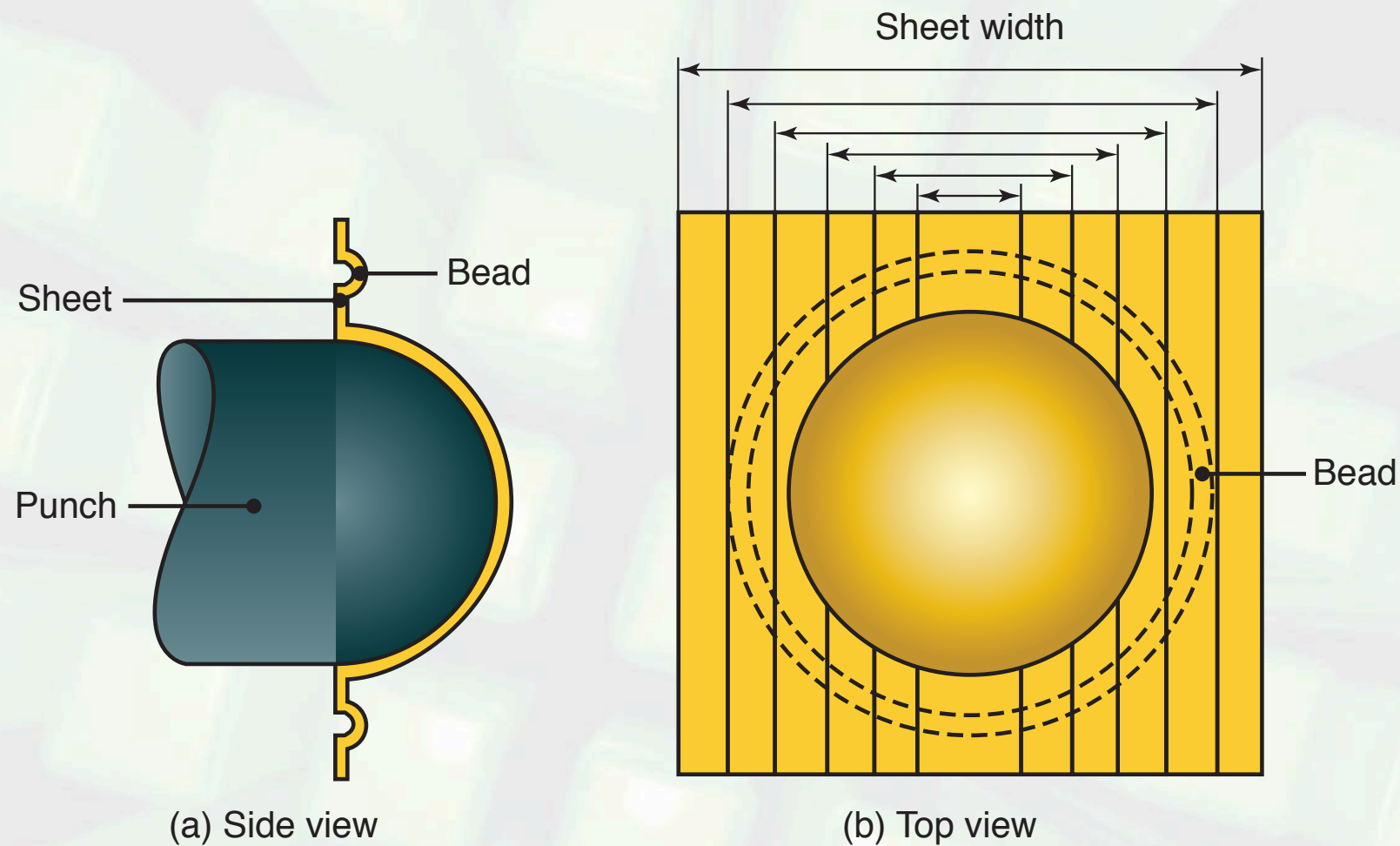
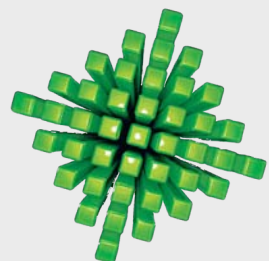


FIGURE 7.62 Schematic illustration of the punch-stretch test on sheet specimens with different widths, clamped along the narrower edges. Note that the narrower the specimen, the more uniaxial is the stretching. (See also Fig. 7.65.)



Forming Limit Diagram

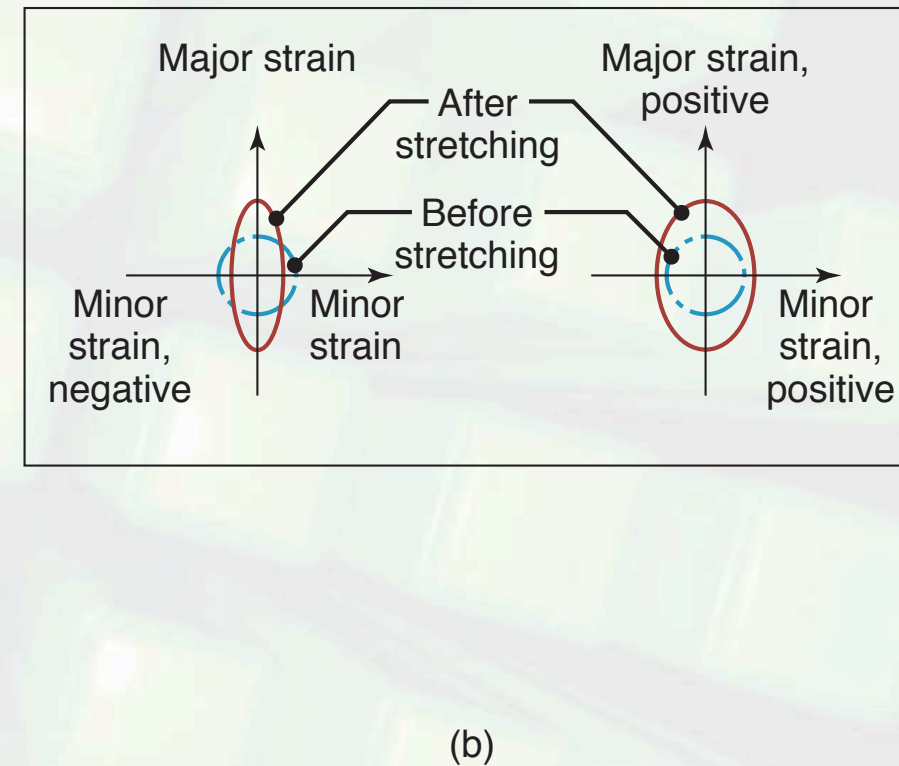
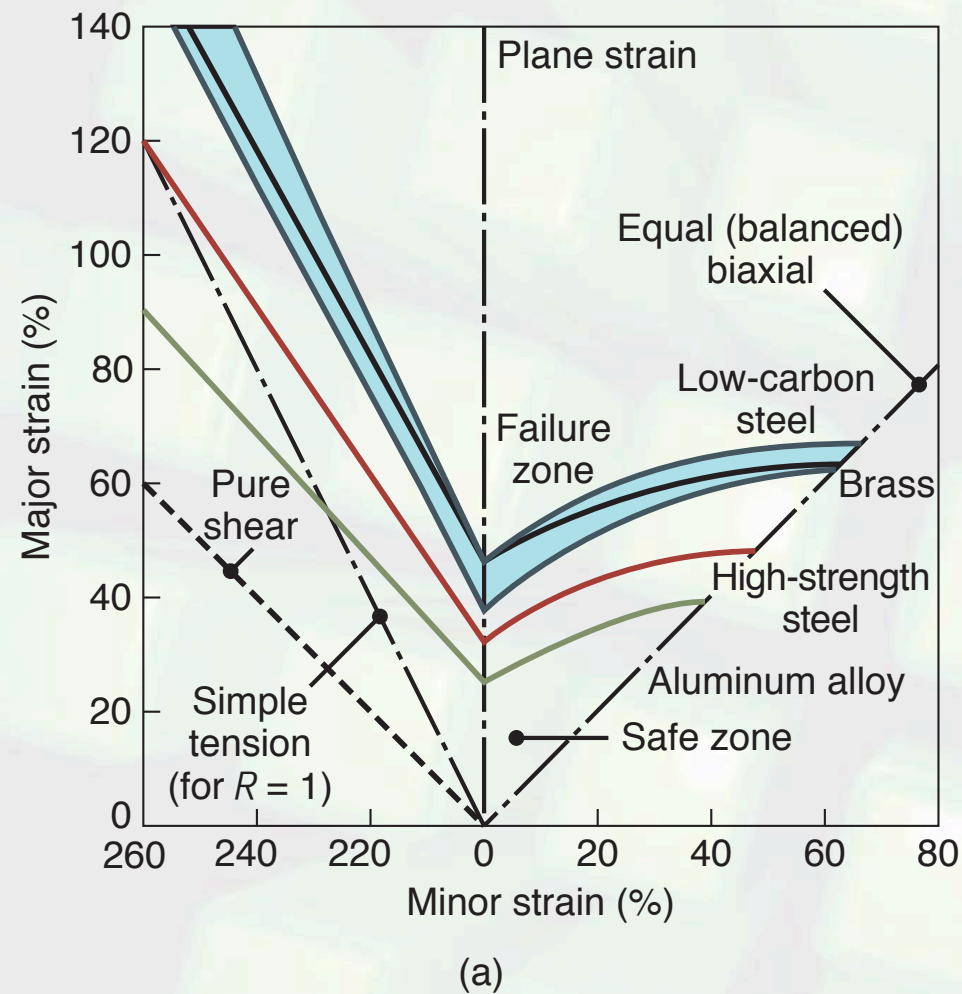
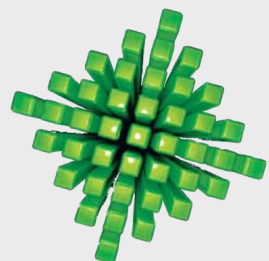


FIGURE 7.63 (a) Forming-limit diagram (FLD) for various sheet metals. Note that the major strain is always positive. The region above the curves is the failure zone; hence, the state of strain in forming must be such that it falls below the curve for a particular material; R is the normal anisotropy. (b) Illustrations of the definition of positive and negative minor strains. If the area of the deformed circle is larger than the area of the original circle, the sheet is thinner than the original thickness because the volume remains constant during plastic deformation. *Source:* After S.S. Hecker and A.K. Ghosh.



Formability Testing

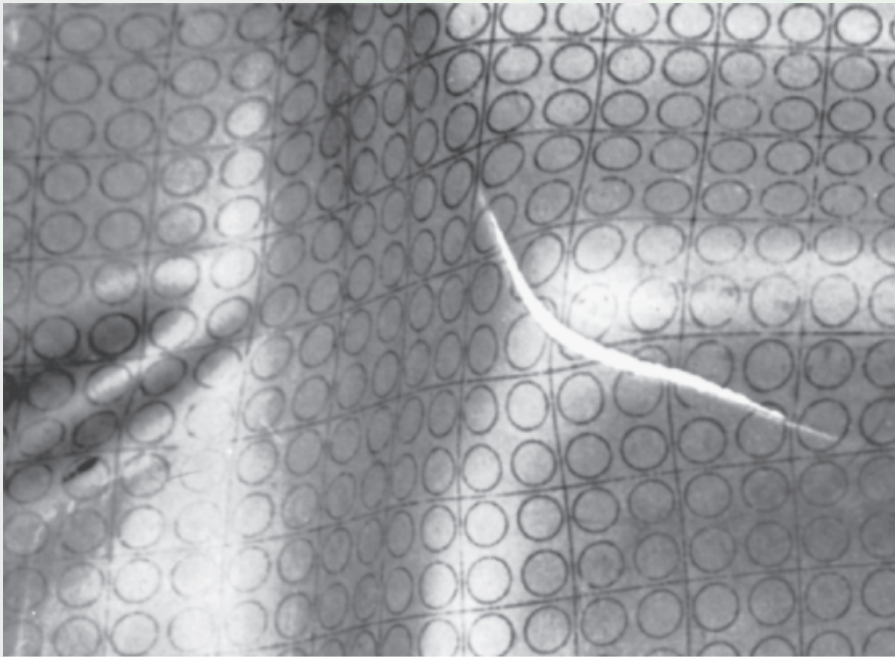


FIGURE 7.64 An example of the use of grid marks (circular and square) to determine the magnitude and direction of surface strains in sheet-metal forming. Note that the crack (tear) is generally perpendicular to the major (positive) strain. *Source:* After S.P. Keeler.

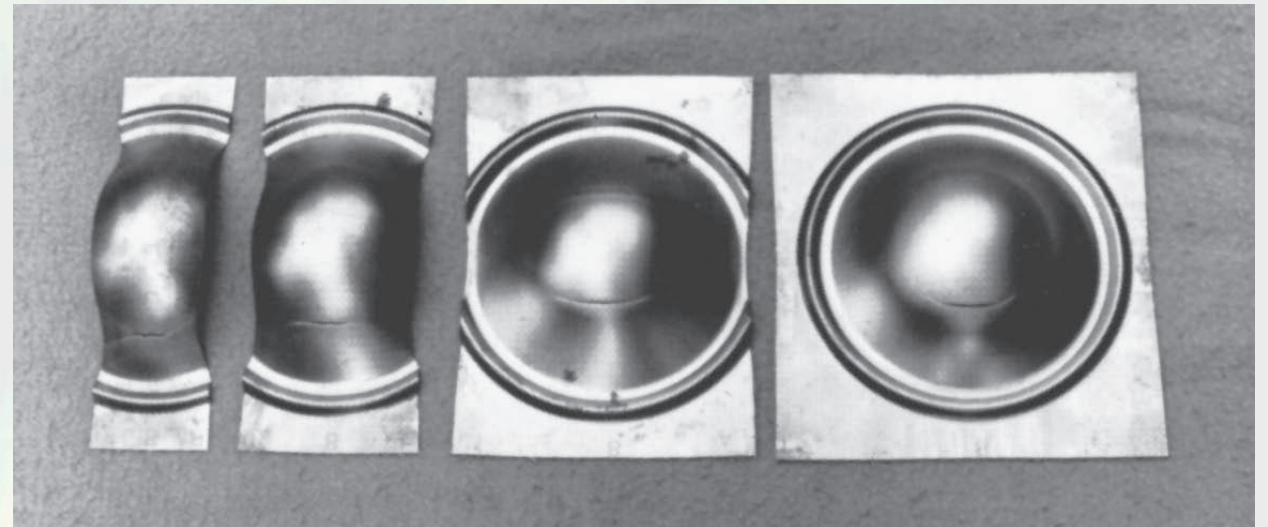
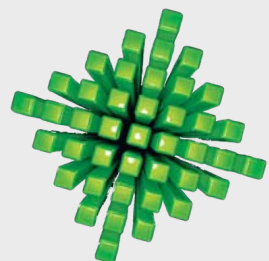


FIGURE 7.65 Bulge test results on steel sheets of various widths. The first specimen (farthest left) stretched farther before cracking than the last specimen. From left to right, the state of stress changes from almost uniaxial to biaxial stretching. *Source:* Courtesy of Ispat Inland, Inc.



Strains in an Automobile

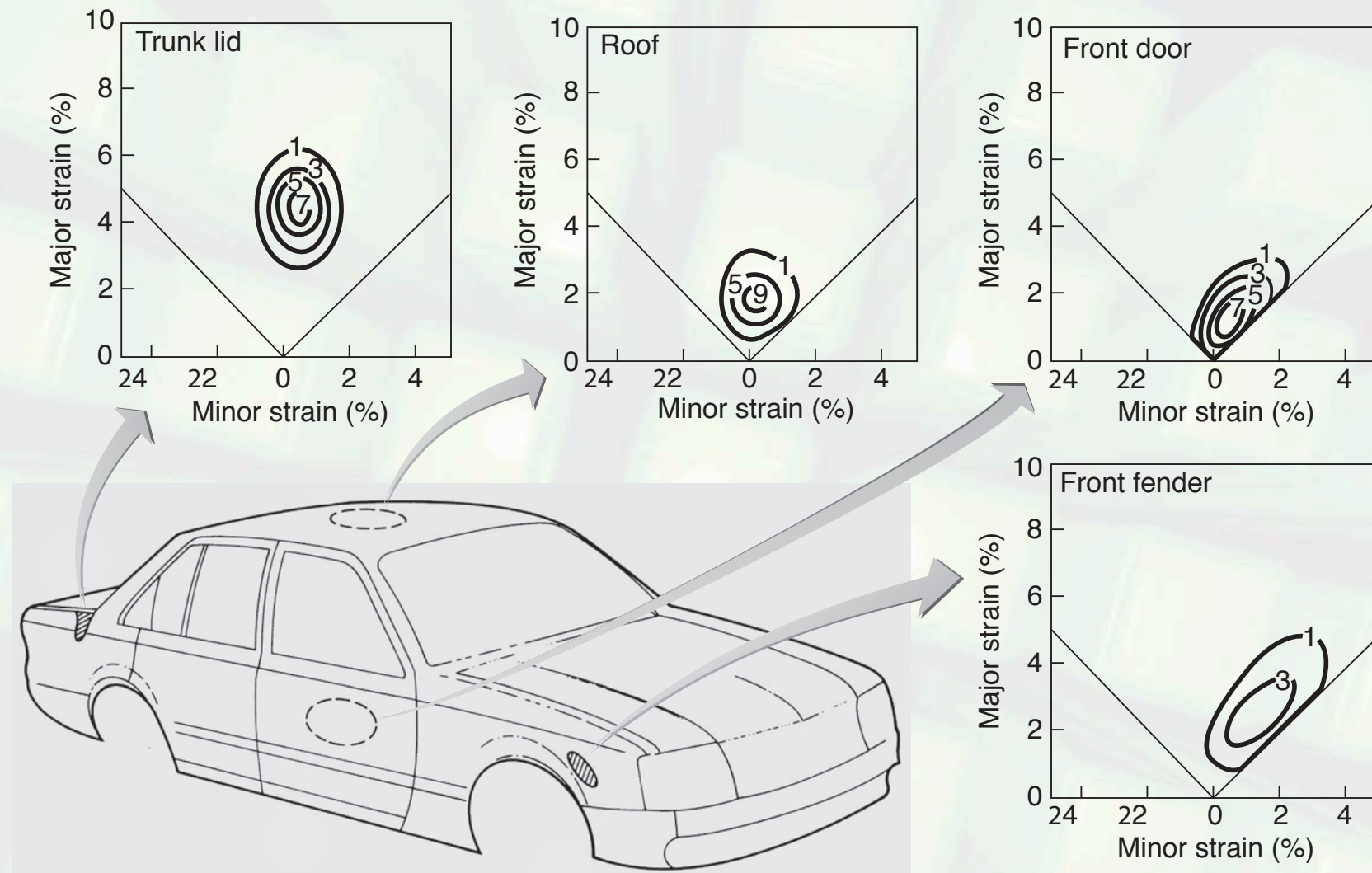
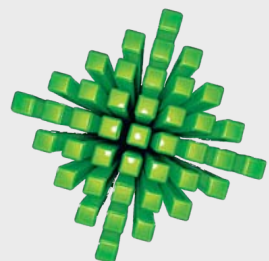


FIGURE 7.66 Major and minor strains in various regions of an automobile body.



Design Considerations

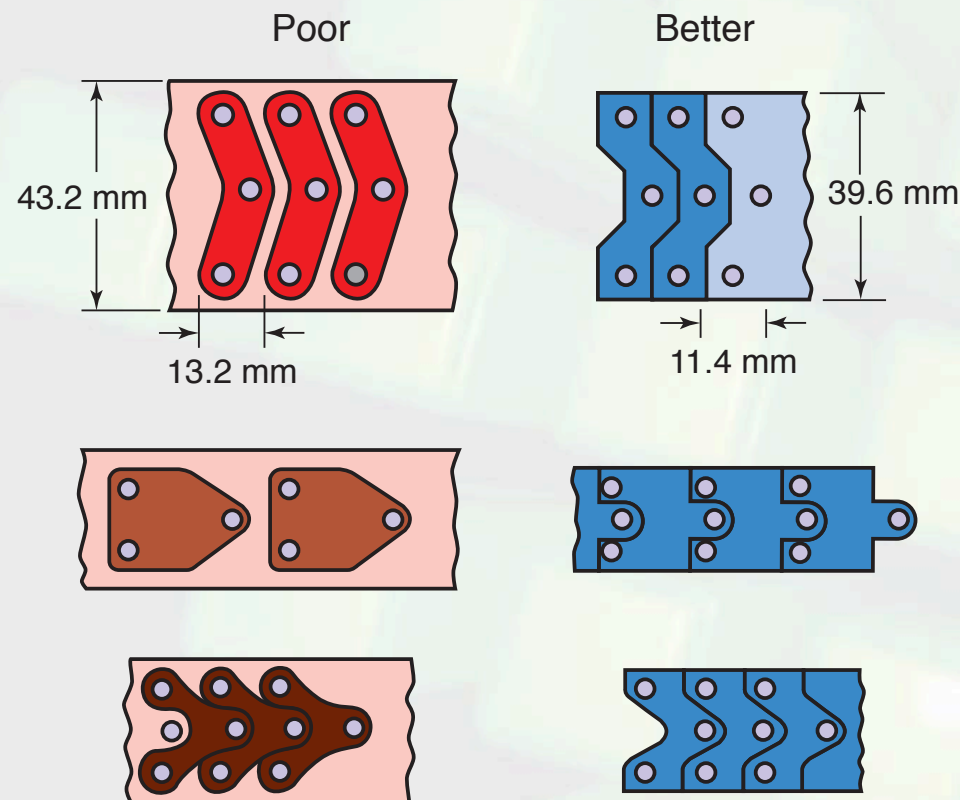


FIGURE 7.67 Efficient nesting of parts for optimum material utilization in blanking. Source: Society of Manufacturing Engineers.

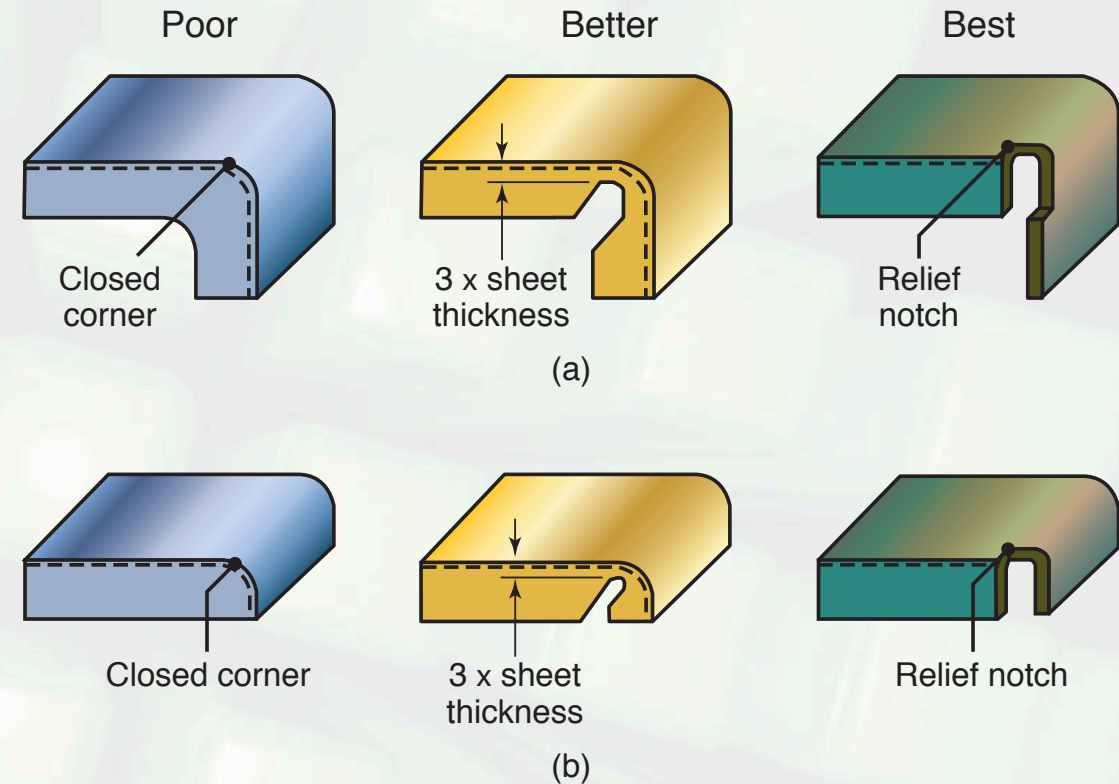
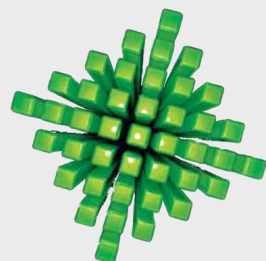


FIGURE 7.68 Control of tearing and buckling of a flange in a right-angle bend. Source: Society of Manufacturing Engineers.



Design Considerations (cont.)

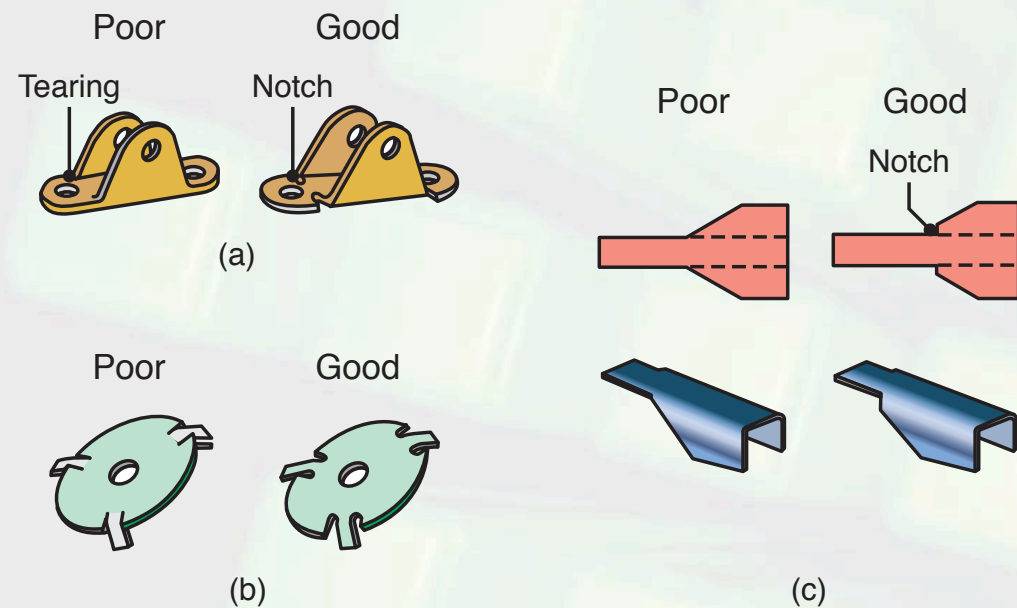


FIGURE 7.69 Application of notches to avoid tearing and wrinkling in right-angle bending operations. Source: Society of Manufacturing Engineers.

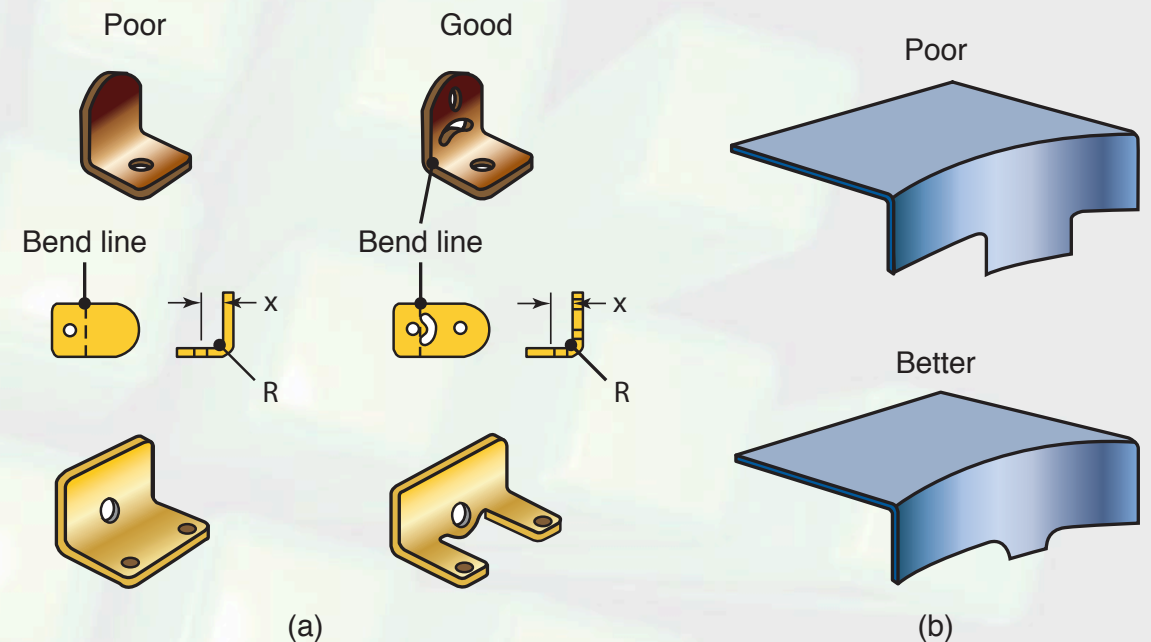


FIGURE 7.70 Stress concentrations near bends. (a) Use of a crescent or ear for a hole near a bend. (b) Reduction of the severity of a tab in a flange. Source: Society of Manufacturing Engineers.

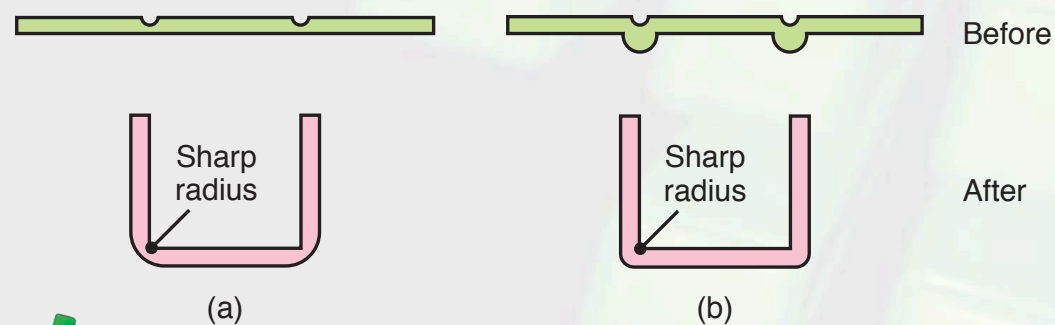
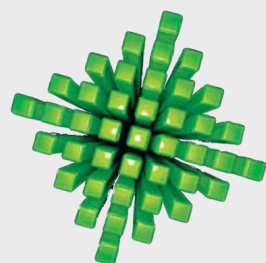


FIGURE 7.71 Application of (a) scoring, or (b) embossing to obtain a sharp inner radius in bending. However, unless properly designed, these features can lead to fracture. Source: Society of Manufacturing Engineers.



Economics of Sheet-Metal Forming

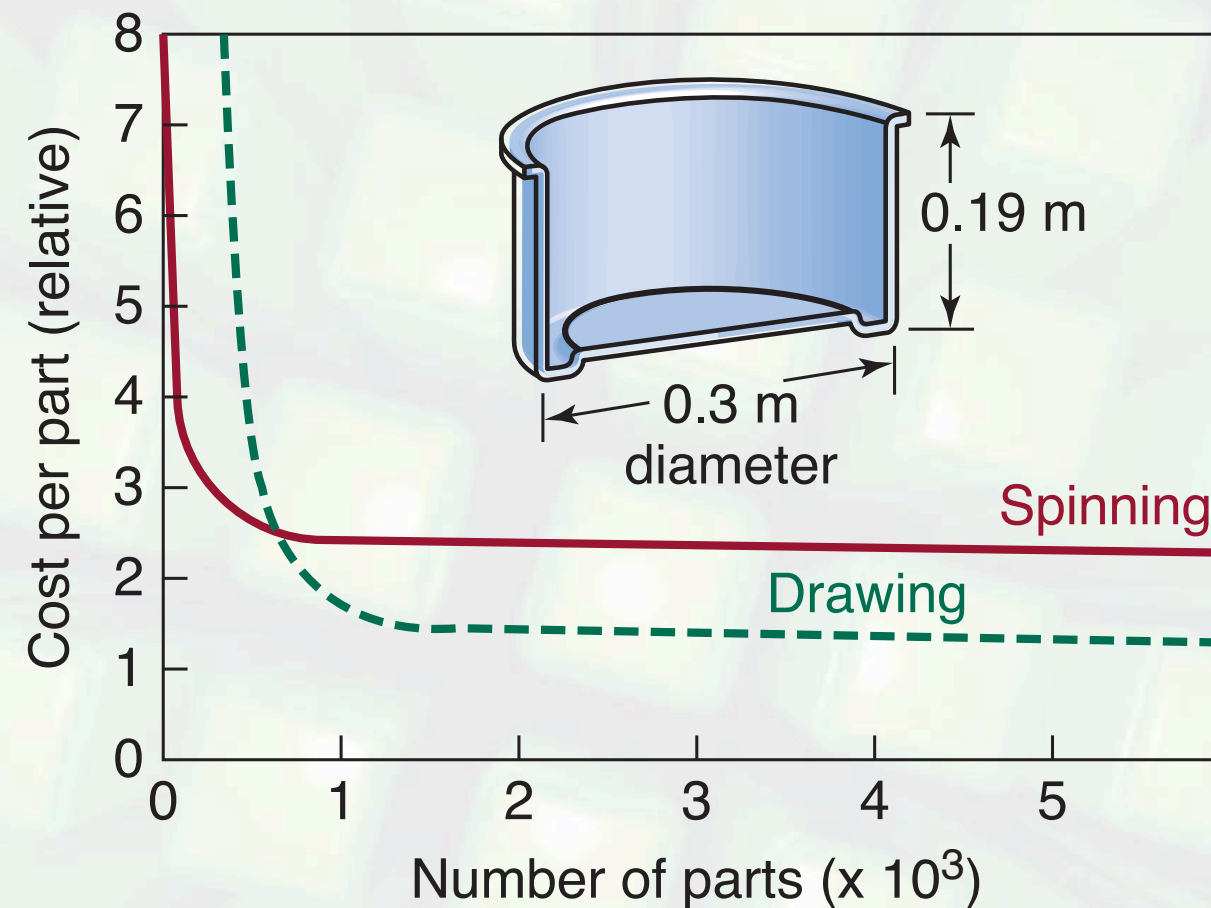
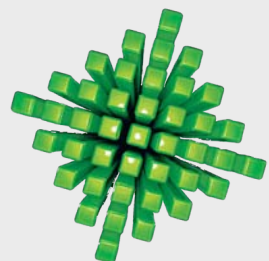


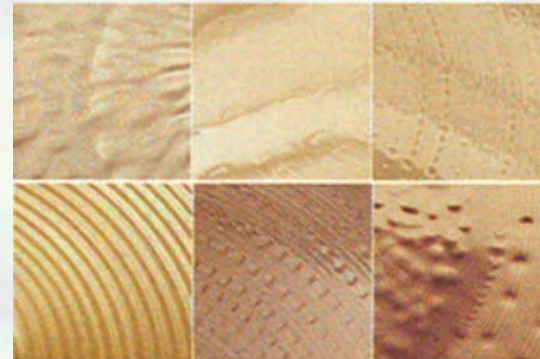
FIGURE 7.72 Cost comparison for manufacturing a cylindrical sheet-metal container by conventional spinning and deep drawing. Note that for small quantities, spinning is more economical.



Cast Study: Drum Cymbals



(a)



(b)

FIGURE 7.73 (a) A selection of common cymbals; (b) detailed view of different surface texture and finish of cymbals. Source: Courtesy W. Blanchard, Sabian Ltd.

FIGURE 7.74 (a) Manufacturing sequence for production of cymbals. Source: Courtesy W. Blanchard, Sabian Ltd.

1. As-cast



2. After rolling; multiple rolling/annealing cycles necessary



3. Stretch formed and trimmed



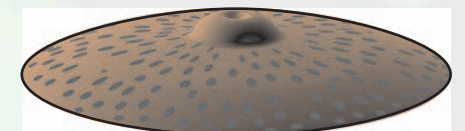
4. Hang hole punched



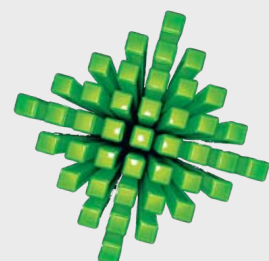
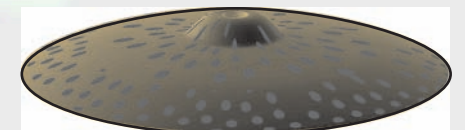
5. Stretch formed



6. Hammered



7. Lathe-turned and polished



Cymbal Hammering



(a)



(b)

FIGURE 7.75 Hammering of cymbals. (a) Automated hammering on a peening machine; (b) hand hammering of cymbals. Source: Courtesy W. Blanchard, Sabian Ltd.

