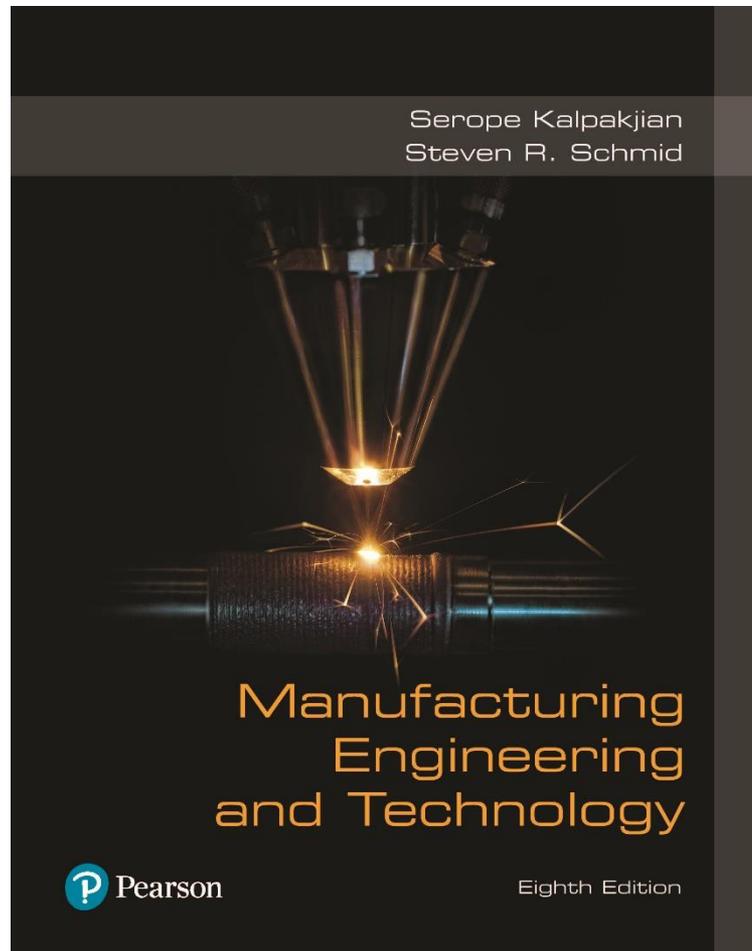


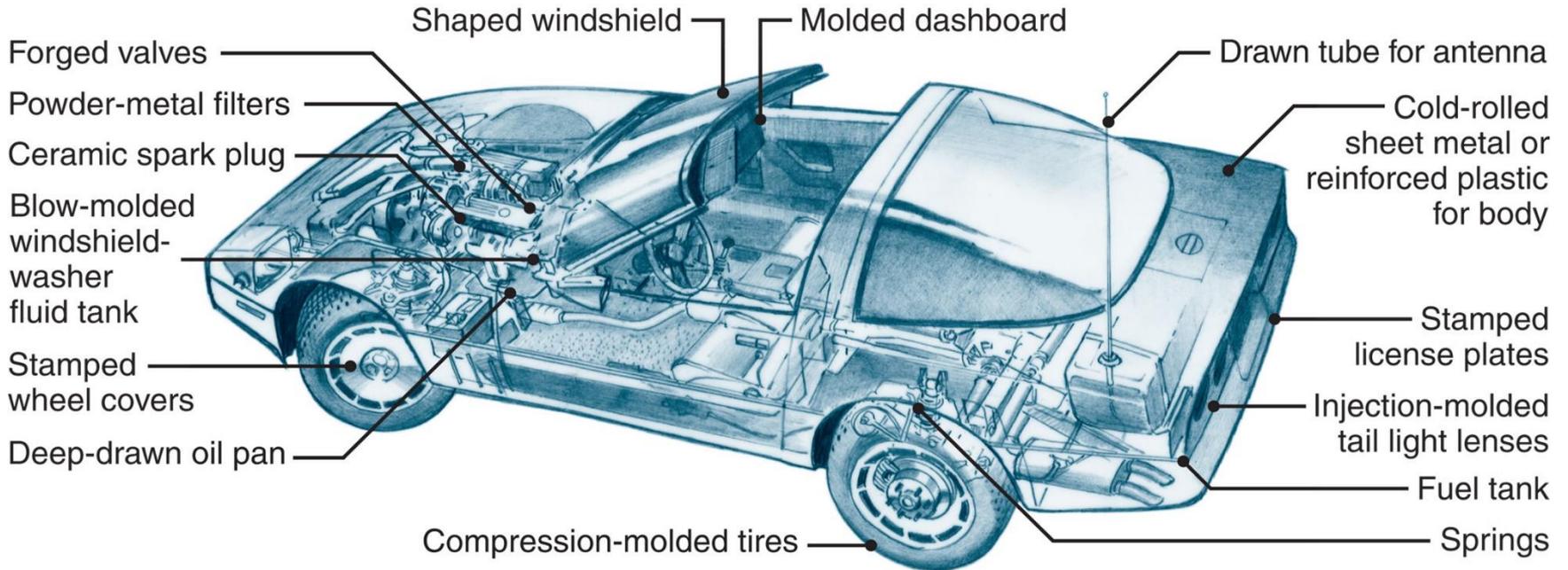
Manufacturing Engineering and Technology

Eighth Edition



Chapter 13-15

FIGURE III.1 Formed and shaped parts in a typical automobile.



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TABLE III.1 General Characteristics of Forming and Shaping Processes

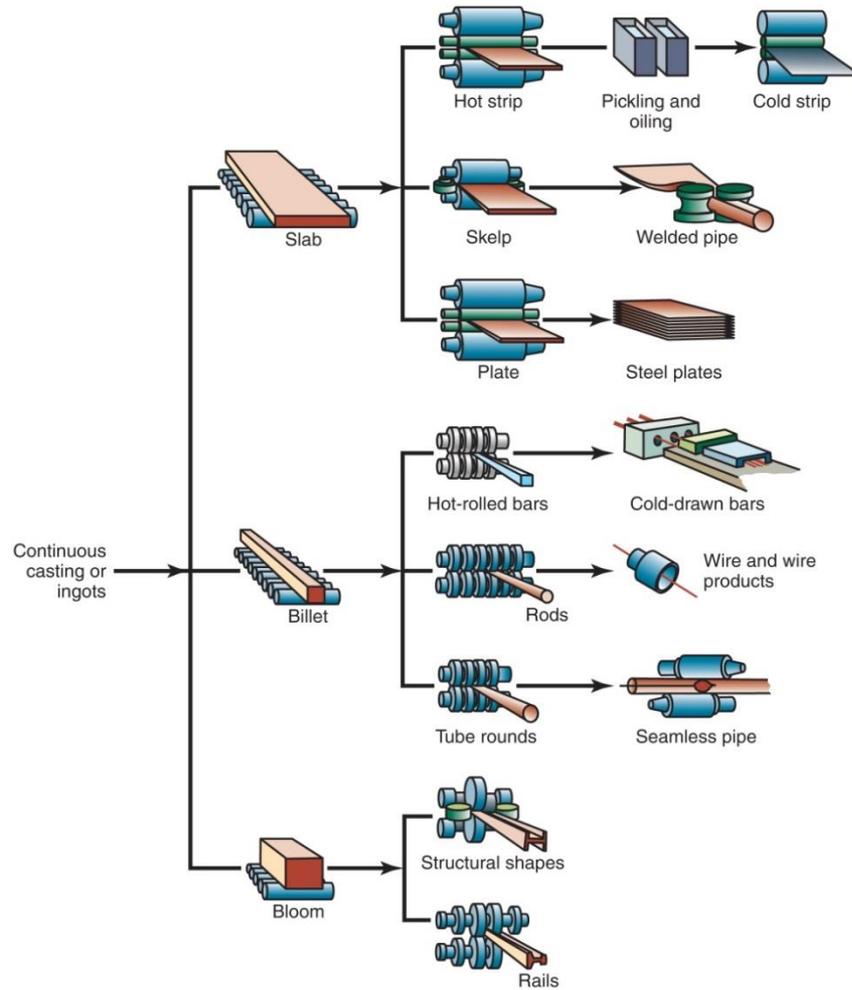
TABLE III.1

General Characteristics of Forming and Shaping Processes	
Process	Characteristics
Rolling Flat	Production of flat plate, sheet, and foil at high speeds; good surface finish, especially in cold rolling; very high capital investment; low-to-moderate labor cost
Shape	Production of various structural shapes (such as I-beams and rails) at high speeds; includes thread rolling; requires shaped rolls and expensive equipment; low-to-moderate labor cost; requires moderate operator skill
Forging	Production of discrete parts with a set of dies; some finishing operations usually required; usually performed at elevated temperatures, but also cold for smaller parts; die and equipment costs are high; moderate-to-high labor cost; requires moderate-to-high operator skill
Extrusion	Production of long lengths of solid or hollow shapes with constant cross-section; product is then cut into desired lengths; usually performed at elevated temperatures; cold extrusion has similarities to forging and is used to make discrete products; moderate-to-high die and equipment cost; low-to-moderate labor cost; requires low-to-moderate operator skill
Drawing	Production of long rod and wire with various cross-sections; good surface finish; low-to-moderate die, equipment, and labor costs; requires low-to-moderate operator skill
Sheet-metal forming	Production of a wide variety of shapes with thin walls and simple or complex geometries; generally low-to-moderate die, equipment, and labor costs; requires low-to-moderate operator skill
Powder metallurgy	Production of simple or complex shapes by compacting and sintering metal powders; moderate die and equipment cost; low labor cost and skill
Processing of plastics and composite materials	Production of a wide variety of continuous or discrete products by extrusion, molding, casting, and fabricating processes; moderate die and equipment costs; requires high operator skill in processing of composite materials
Forming and shaping of ceramics	Production of discrete products by various shaping, drying, and firing processes; low-to-moderate die and equipment cost; requires moderate-to-high operator skill

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Figure 13.1

Schematic outline of various flat-rolling and shape-rolling processes.



Source: After American Iron and Steel Institute.

Rolling

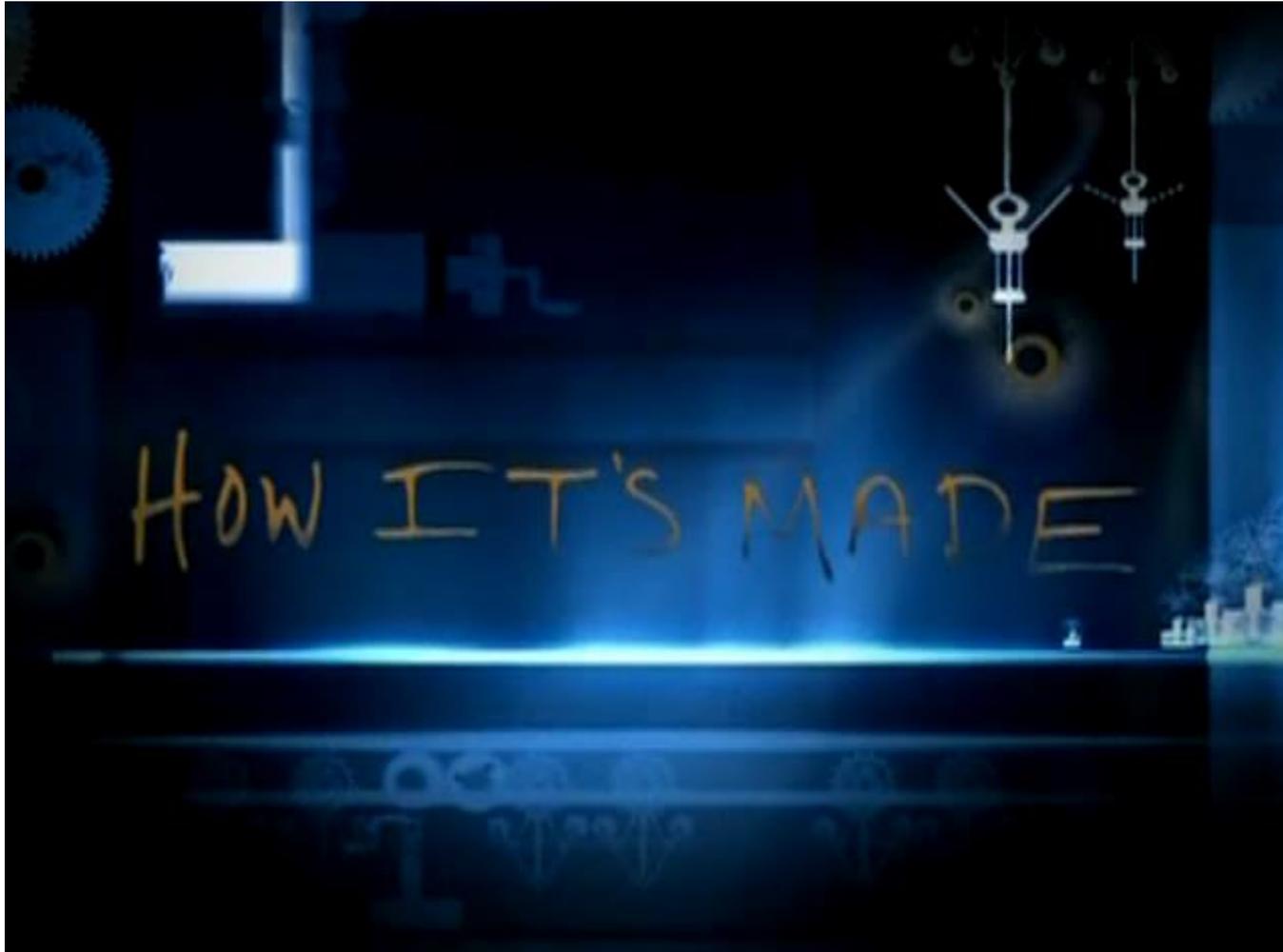
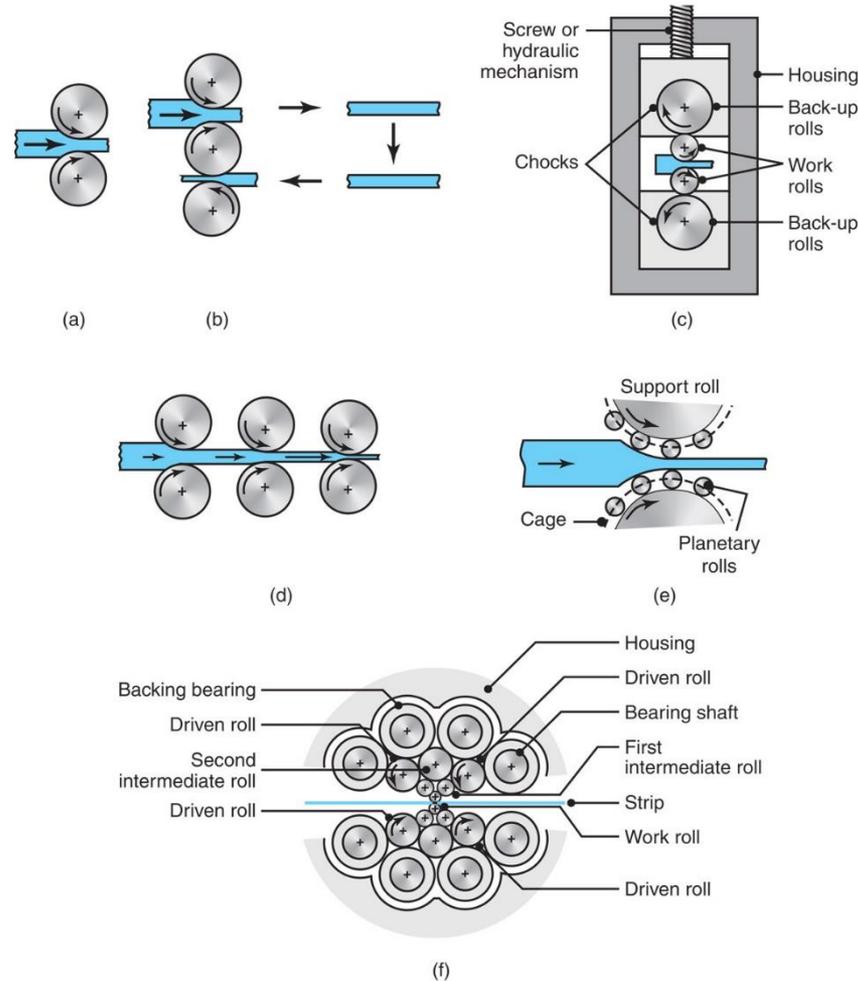


FIGURE 13.3 Schematic illustration of various roll arrangements: (a) Two-high mill; if a two-high mill is used for thick but short workpieces, it will commonly roll a billet back and forth in multiple passes, known as a *reversing mill*. (b) Three-high mill with elevator for multiple passes. (c) Four-high rolling mill showing various features; the stiffness of the housing, the rolls, and the roll bearings are all important in controlling and maintaining the thickness of the rolled strip. (d) Tandem rolling, with three stands. (e) Planetary mill, and (f) Cluster mill, also known as a *Sendzimir* or Z-mill.



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Figure 13.4

(a) Bending of straight cylindrical rolls caused by roll forces.

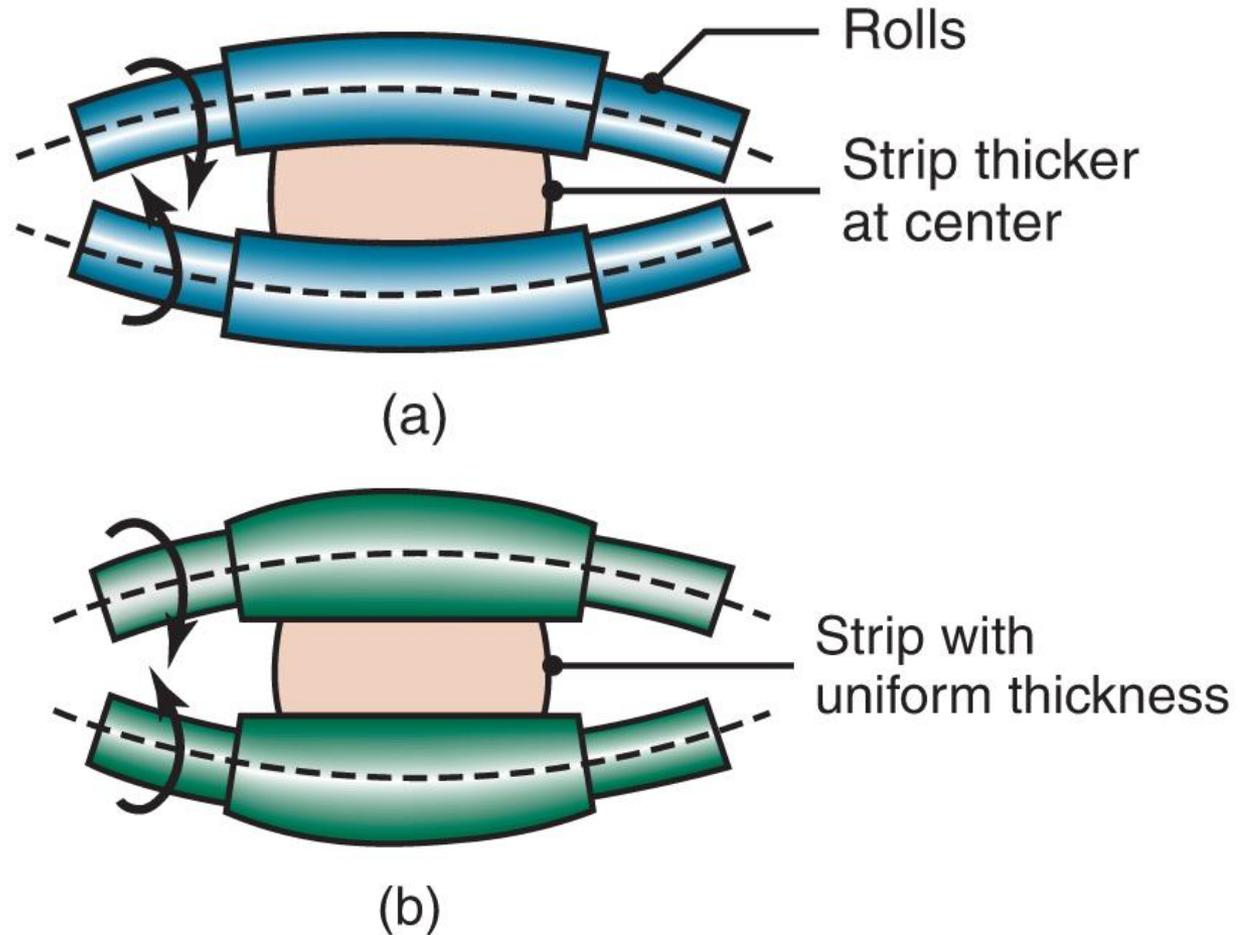


Figure 13.5

Spreading in flat rolling; note that similar spreading can be observed when dough is rolled with a rolling pin.

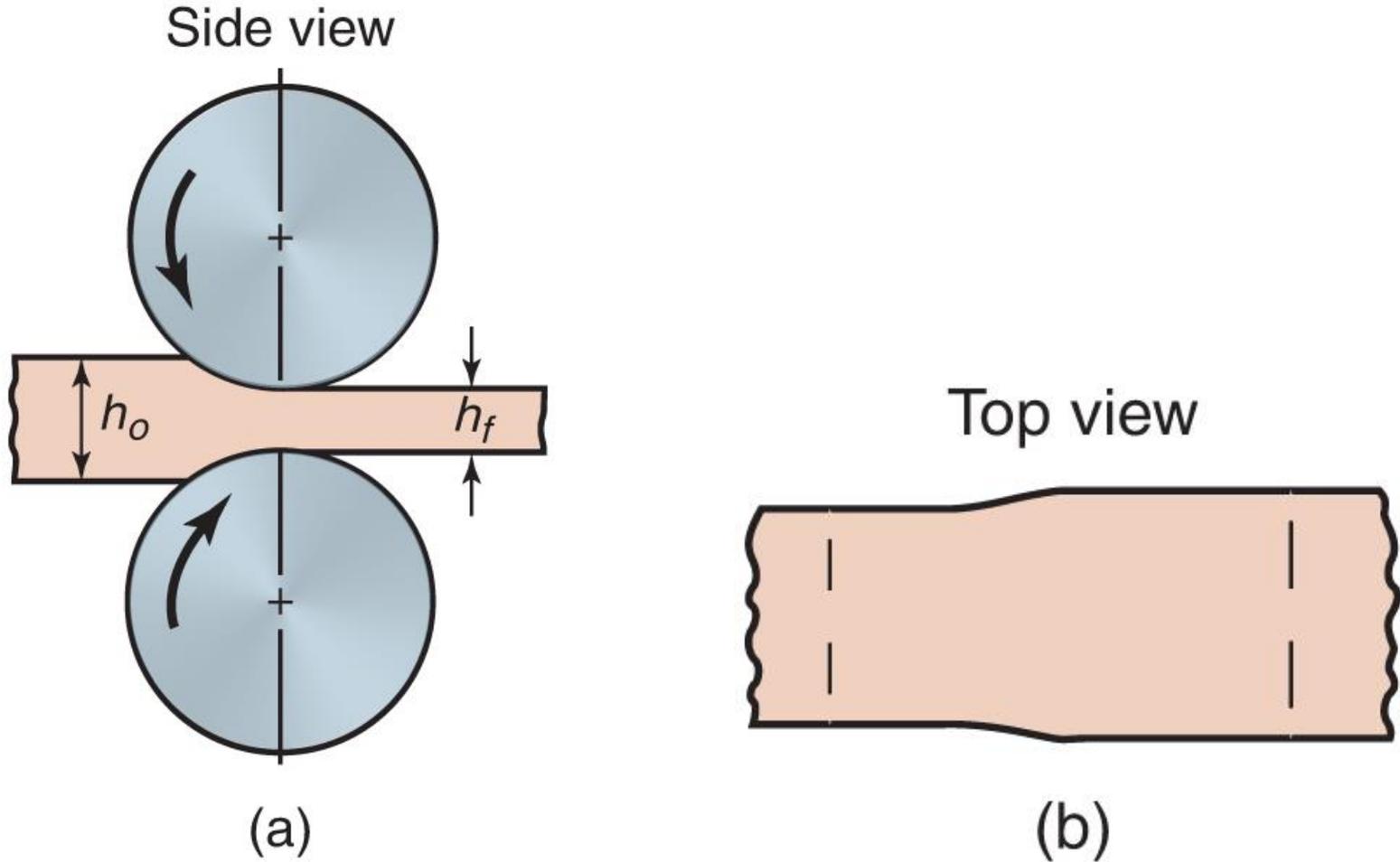
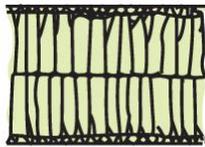


Figure 13.6

Changes in the grain structure of cast or of large-grain wrought metals during hot rolling. Hot rolling is an effective way of reducing grain size in metals for improved strength and ductility. The cast structures of ingots or of continuous castings are converted to a wrought structure by hot working.



Ingot with nonuniform grains

(a)

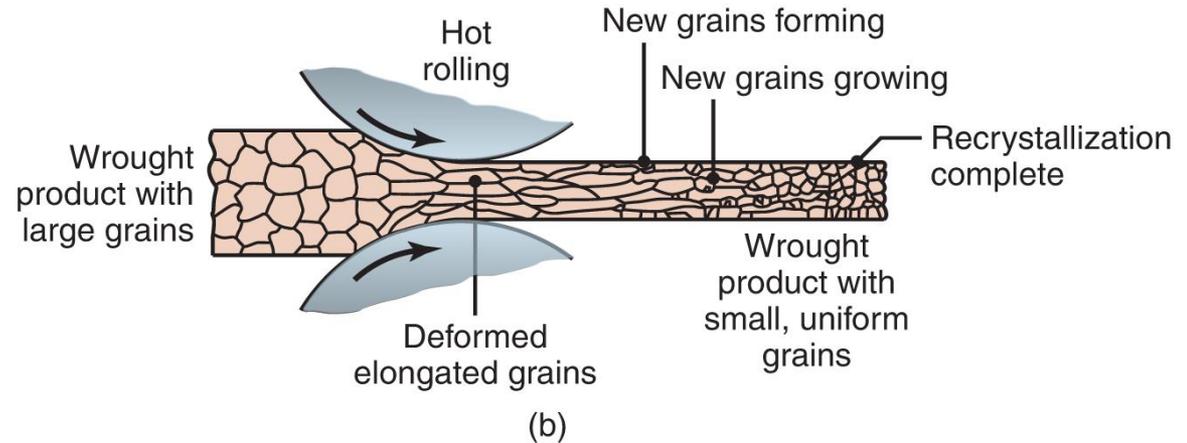


Figure 13.9

Schematic illustration of typical defects in flat rolling: (a) wavy edges; (b) zipper cracks in the center of the strip.

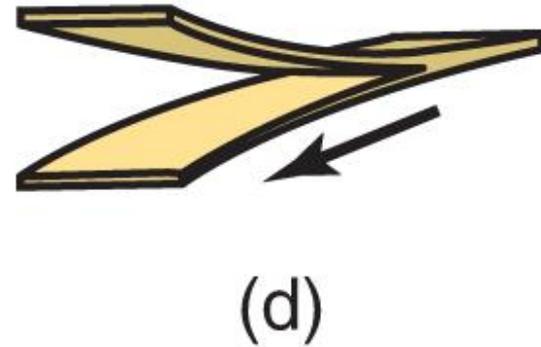
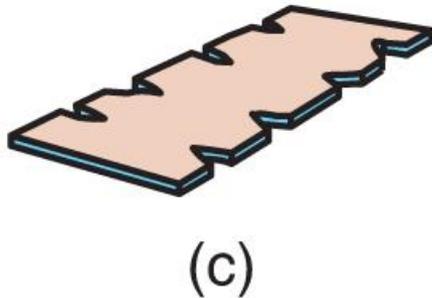
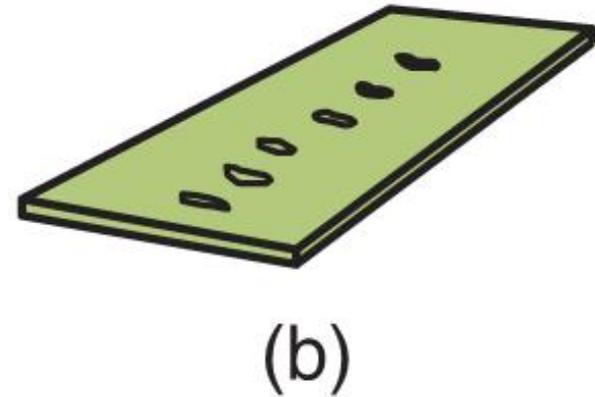
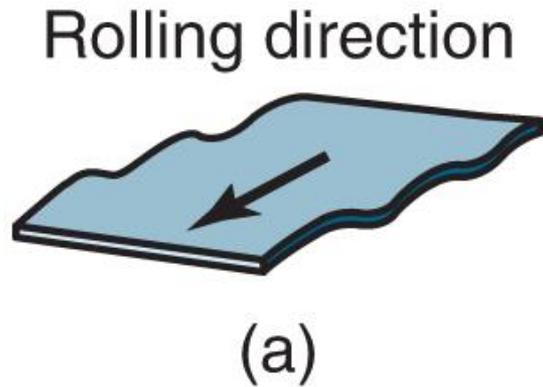


Figure 13.10

(a) Residual stresses developed in rolling with small-diameter rolls or at small reductions in thickness per pass. (b) Residual stresses developed in rolling with large-diameter rolls or at high reductions per pass. Note the reversal of the residual stress patterns.

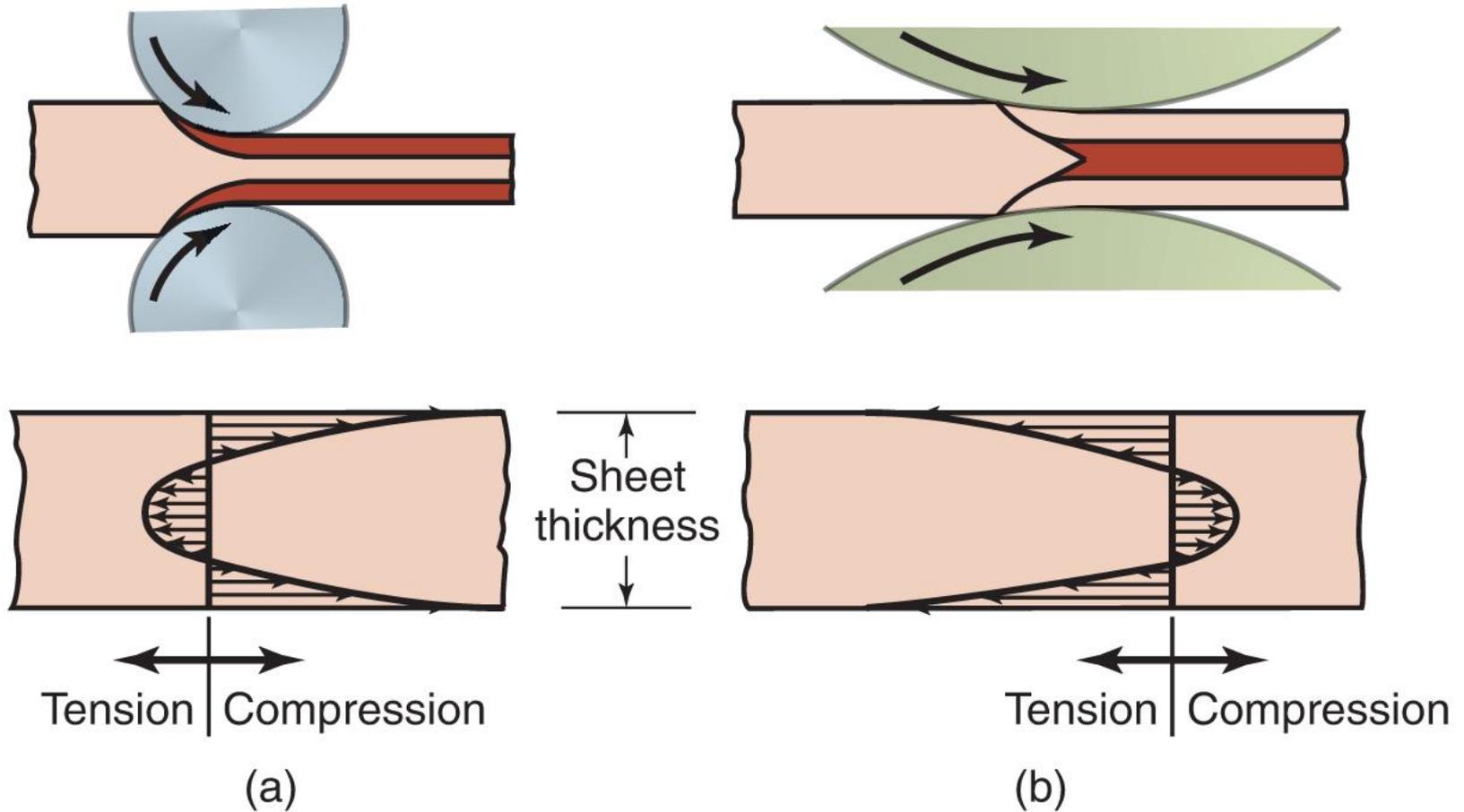
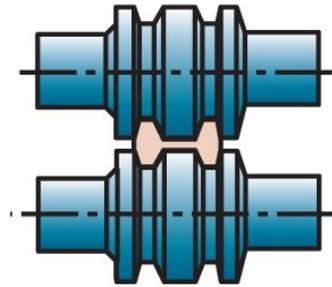
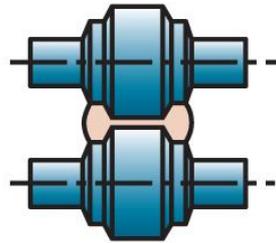


Figure 13.13

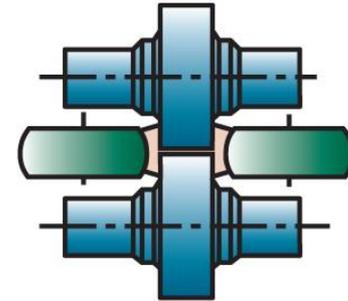
Steps in the shape rolling of an I-beam. Various other structural sections, such as channels and rails, also are rolled by this kind of process.



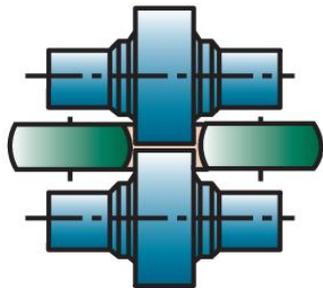
Stage 1: Blooming rolls



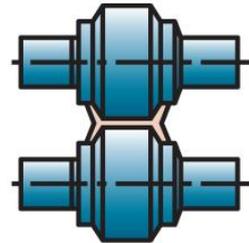
Stage 2: Edging rolls



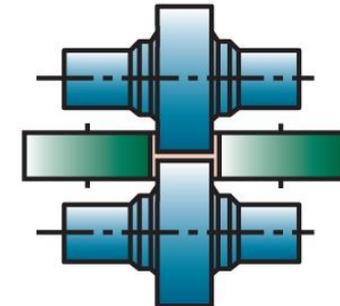
Stage 3: Roughing horizontal and vertical rolls



Stage 4: Intermediate horizontal and vertical rolls



Stage 5: Edging rolls



Stage 6: Finishing horizontal and vertical rolls

Figure 13.14 (1 of 2)

Two examples of the roll-forging operation, also known as *cross rolling*. Tapered leaf springs and knives can be made by this process.

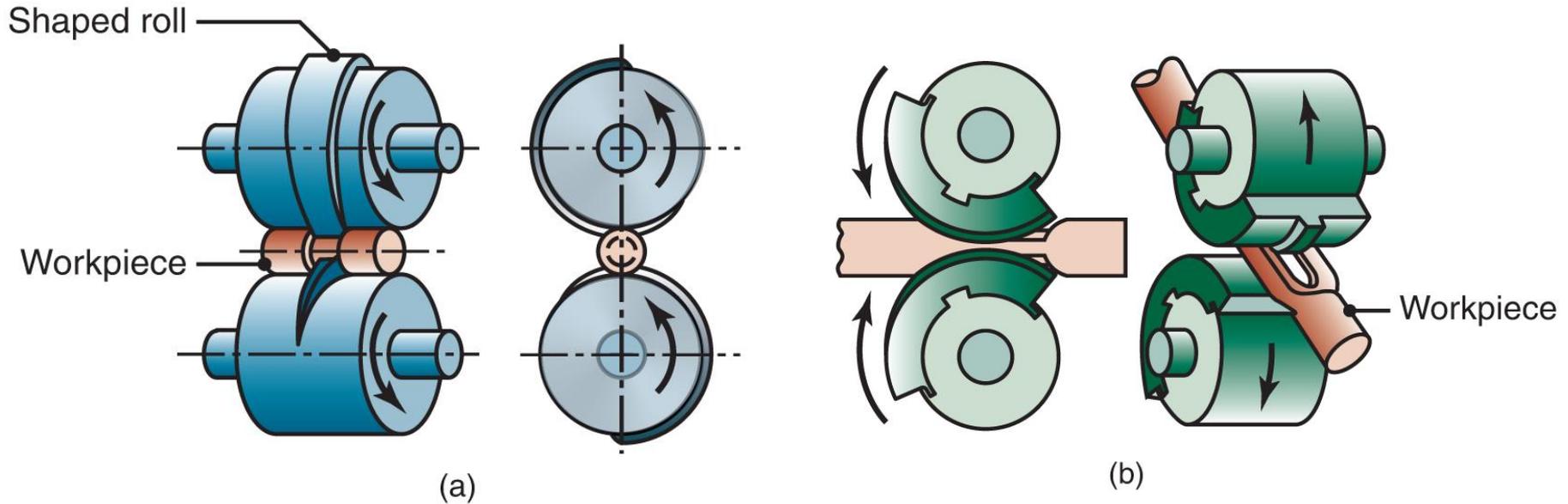


Figure 13.15

(a) Producing steel balls by the skew-rolling process. (b) Producing steel balls by upsetting a cylindrical blank. Note the formation of flash. The balls made by these processes are subsequently ground and polished for use in ball bearings.

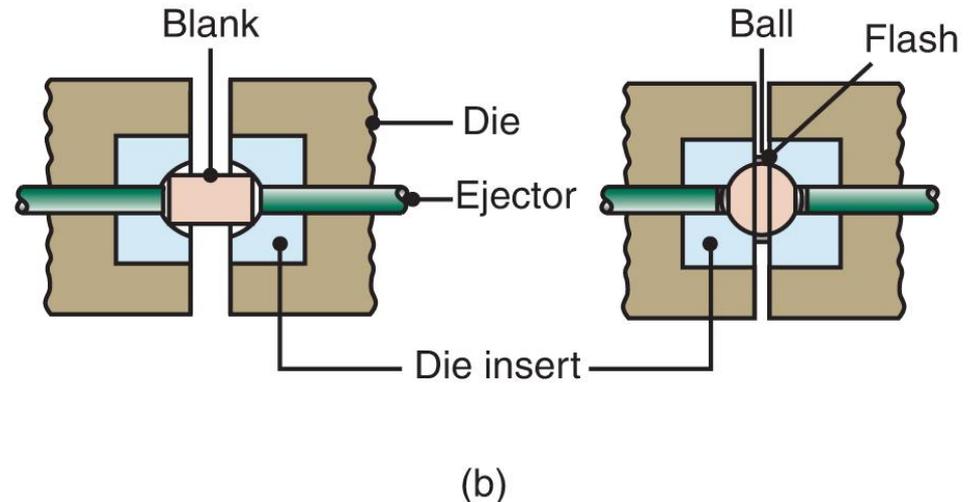
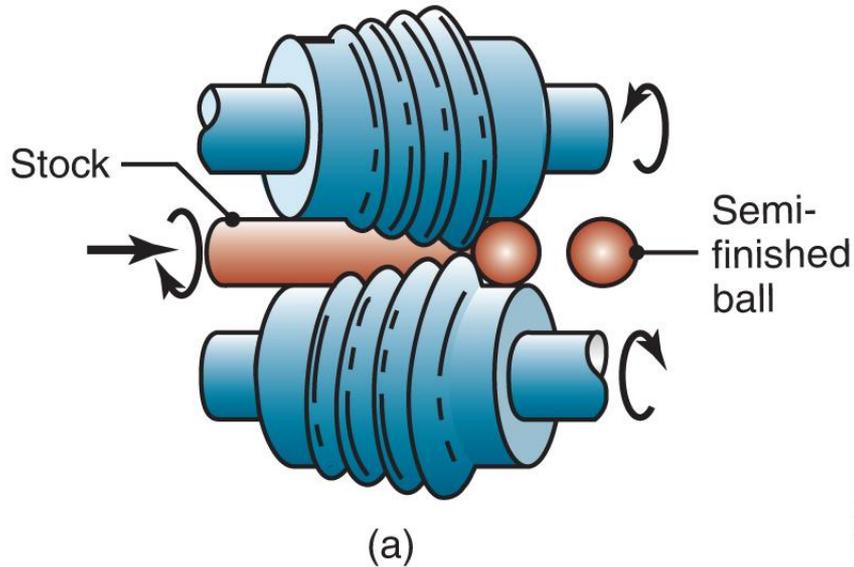


Figure 13.16

(a) Schematic illustration of a ring-rolling operation. Thickness reduction results in an increase in the part diameter. (b) through (d) Examples of cross sections that can be formed by ring rolling.

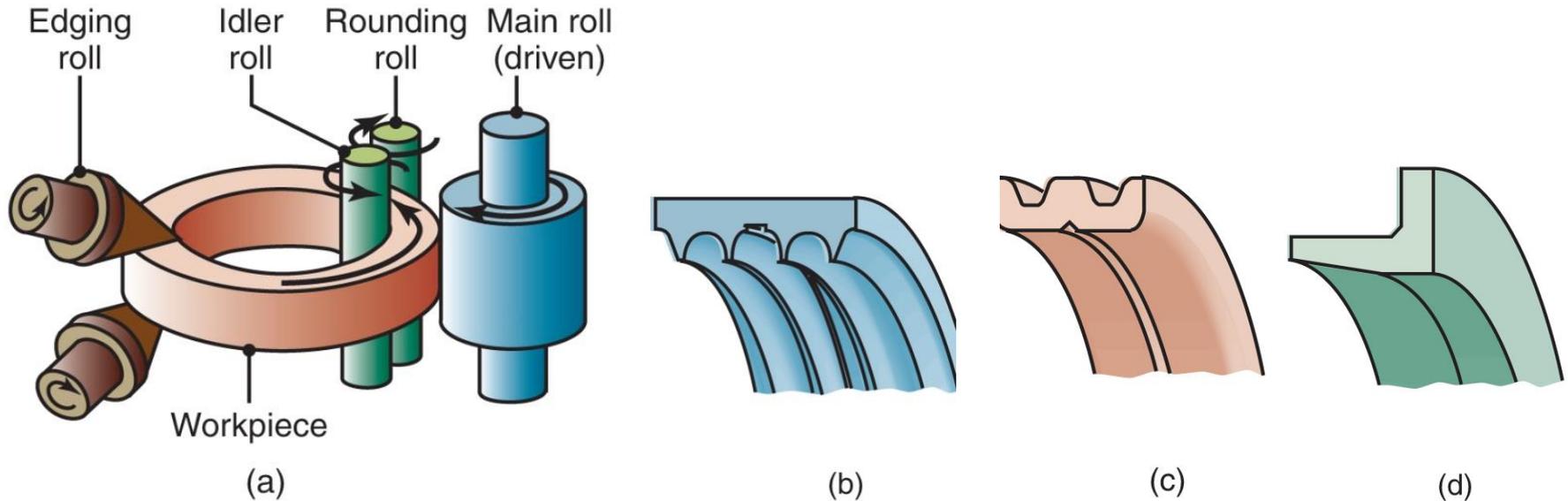
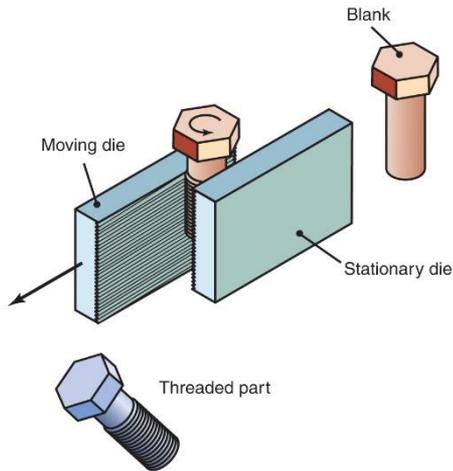
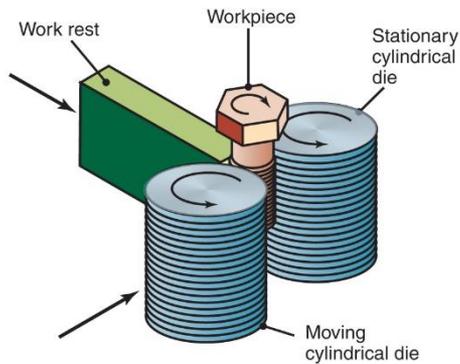


Figure 13.17

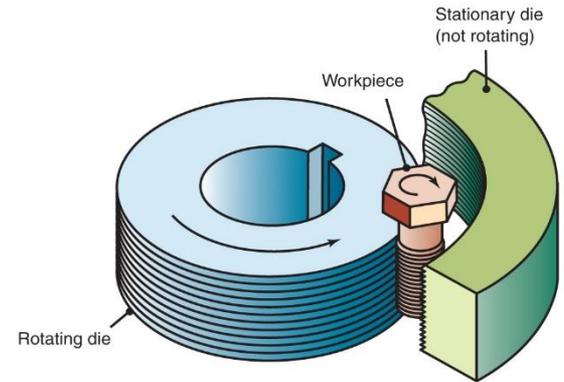
Thread-rolling processes: (a) reciprocating flat dies used to produce a threaded fastener, (b) two-roll dies, (c) rotary or planetary die set, (d) A collection of thread-rolled parts made economically at high production rates.



(a)



(b)



(c)



(d)

Figure 13.18

(a) Features of a machined or rolled thread. Grain flow in (b) machined and (c) rolled threads. Unlike machining, which cuts through the grains of the metal, the rolling of threads imparts improved strength because of cold working and favorable grain flow.

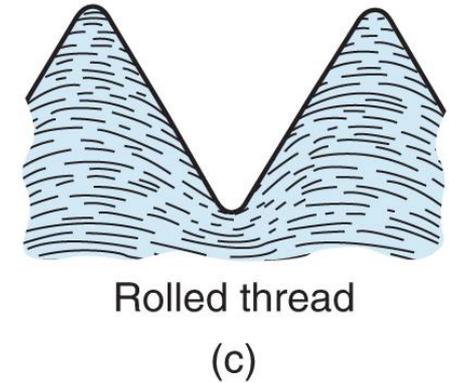
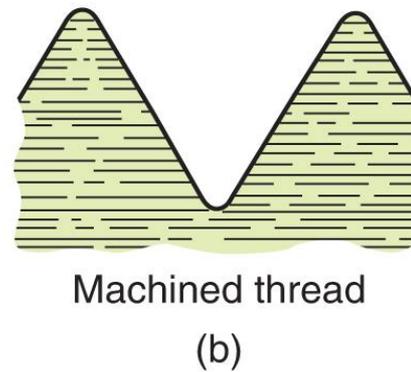
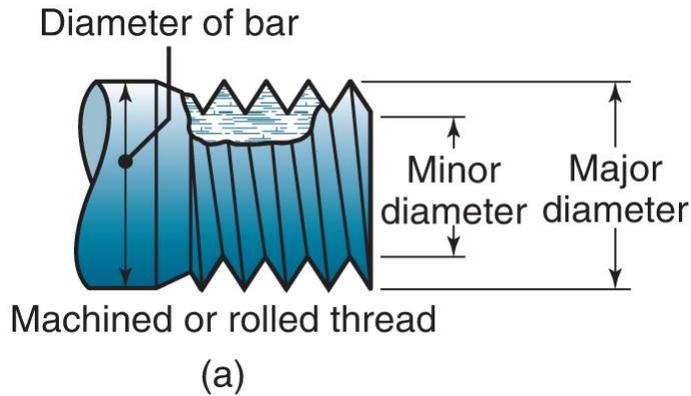
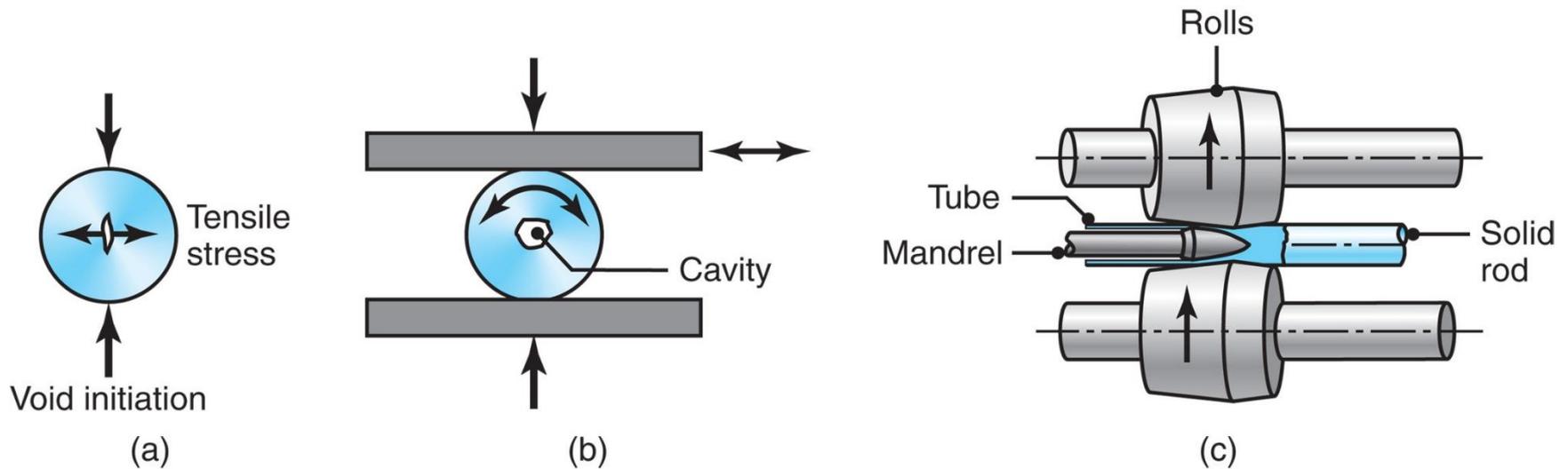


FIGURE 13.19 Cavity formation in a solid, round bar and its utilization in the rotary tube piercing process for making seamless pipe and tubing. (See also Fig. 2.9.)



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Figure 14.1

(a) Illustration of the steps involved in forging a knife, (b) Open die forging of a steel billet.



(a)

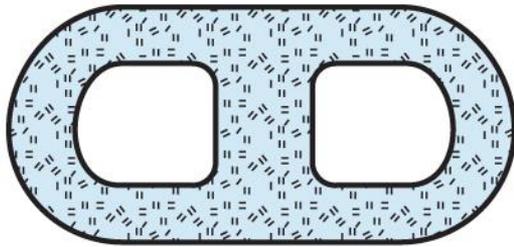


(b)

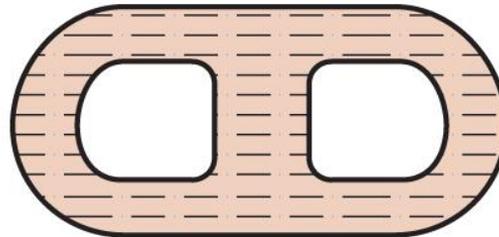
Source: (a) Courtesy of Mundial, Inc. (b) Shutterstock/Milos Zvicer.

Figure 14.2

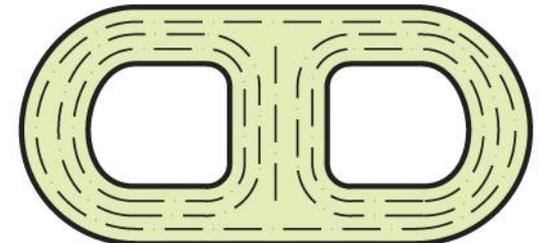
Schematic illustration of a part (dragline chain link, approximately 2-m long) made by three different processes and showing grain flow. (a) Casting by the processes described in Chapter 11. (b) Machining from a blank, described in Part IV of this book, and (c) forging. Each process has its own advantages and limitations regarding external and internal characteristics, material properties, dimensional accuracy, surface finish, and the economics of production.



(a)



(b)



(c)

Table 14.1

General Characteristics of Forging Processes.

Process	Advantages	Limitations
Open die	Simple and inexpensive dies; wide range of part sizes; good strength characteristics; generally for small quantities	Limited to simple shapes; difficult to hold close tolerances; machining to final shape necessary; low production rate; relatively poor utilization of material; high degree of skill required
Closed die	Relatively good utilization of material; generally better properties than open-die forgings; good dimensional accuracy; high production rates; good reproducibility	High die cost, not economical for small quantities; machining often necessary
Blocker	Low die costs; high production rates	Machining to final shape necessary; parts with thick webs and large fillets
Conventional	Requires much less machining than blocker type; high production rates; good utilization of material	Higher die cost than blocker type
Precision	Close dimensional tolerances; very thin webs and flanges possible; machining generally not necessary; very good material utilization	High forging forces, intricate dies, and provision for removing forging from dies

Figure 14.3 (1 of 3)

(a) Solid cylindrical billet upset between two flat dies, (b) Uniform deformation of the billet without friction, (c) Deformation with friction. Note barreling of the billet caused by friction forces at the billet–die interfaces.

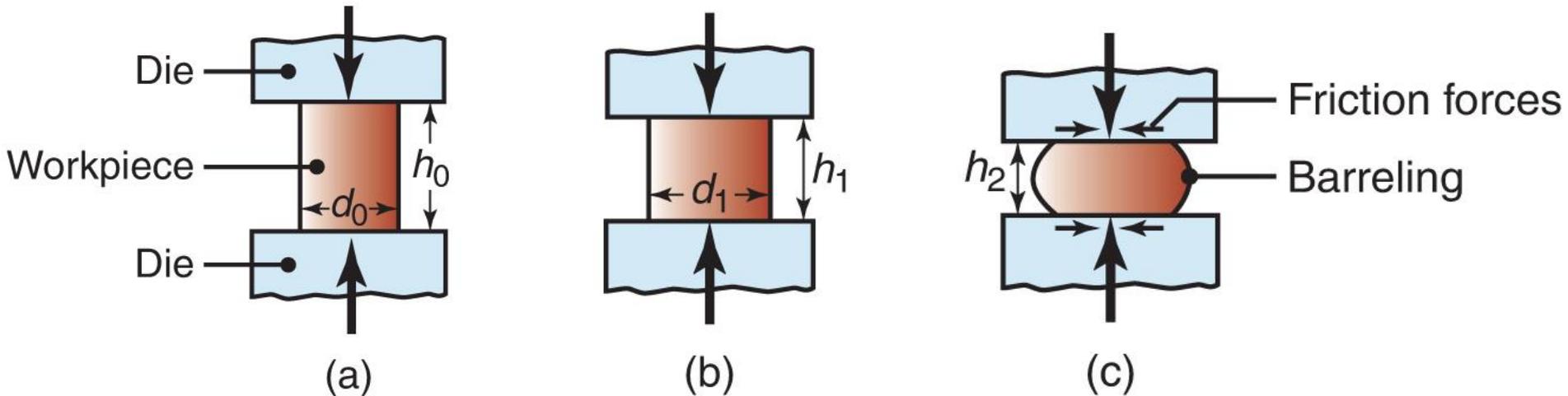
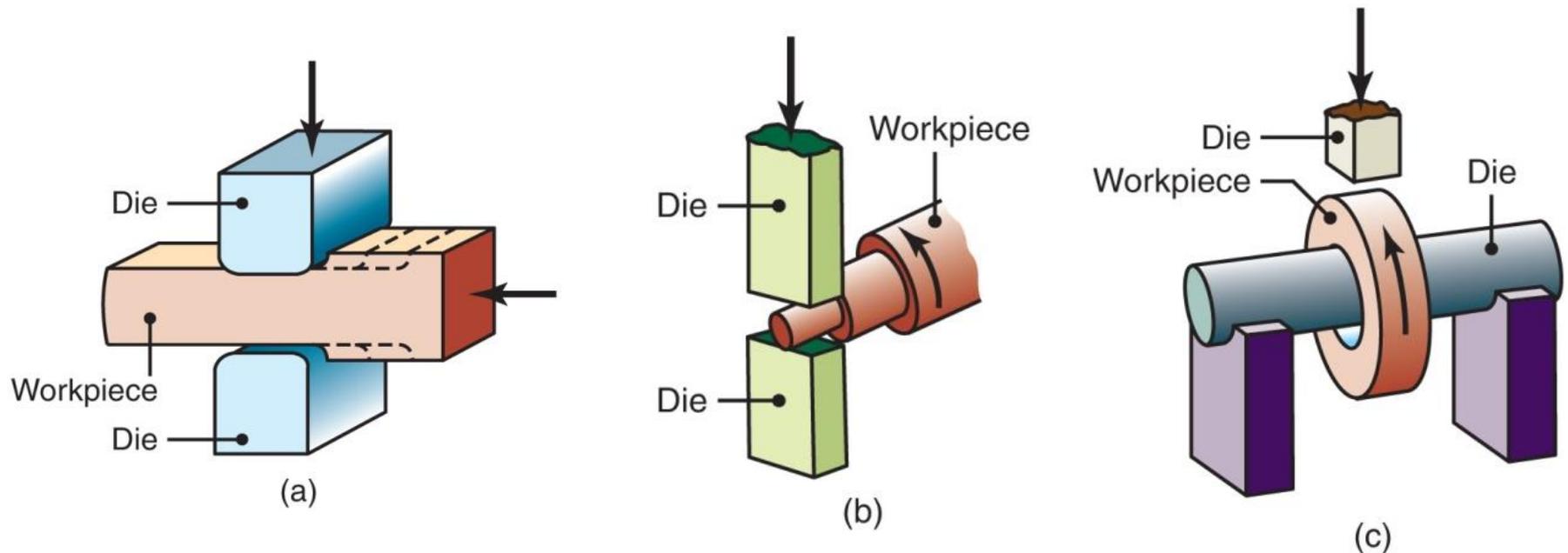


Figure 14.4 (1 of 3)

(a) Schematic illustration of a cogging operation on a rectangular bar. Blacksmiths use this process to reduce the thickness of bars by hammering the part on an anvil. Reduction in thickness is accompanied by barreling, as in Fig. 14.3c, (b) Reducing the diameter of a bar by open-die forging; note the movements of the dies and the workpiece, (c) The thickness of a ring being reduced by open-die forging.



Forging



Figure 14.5

Distribution of die pressure in upsetting with sliding friction. Note that the pressure at the outer radius is equal to the flow stress, σ_f , of the material. Sliding friction means that the frictional stress is directly proportional to the normal stress.

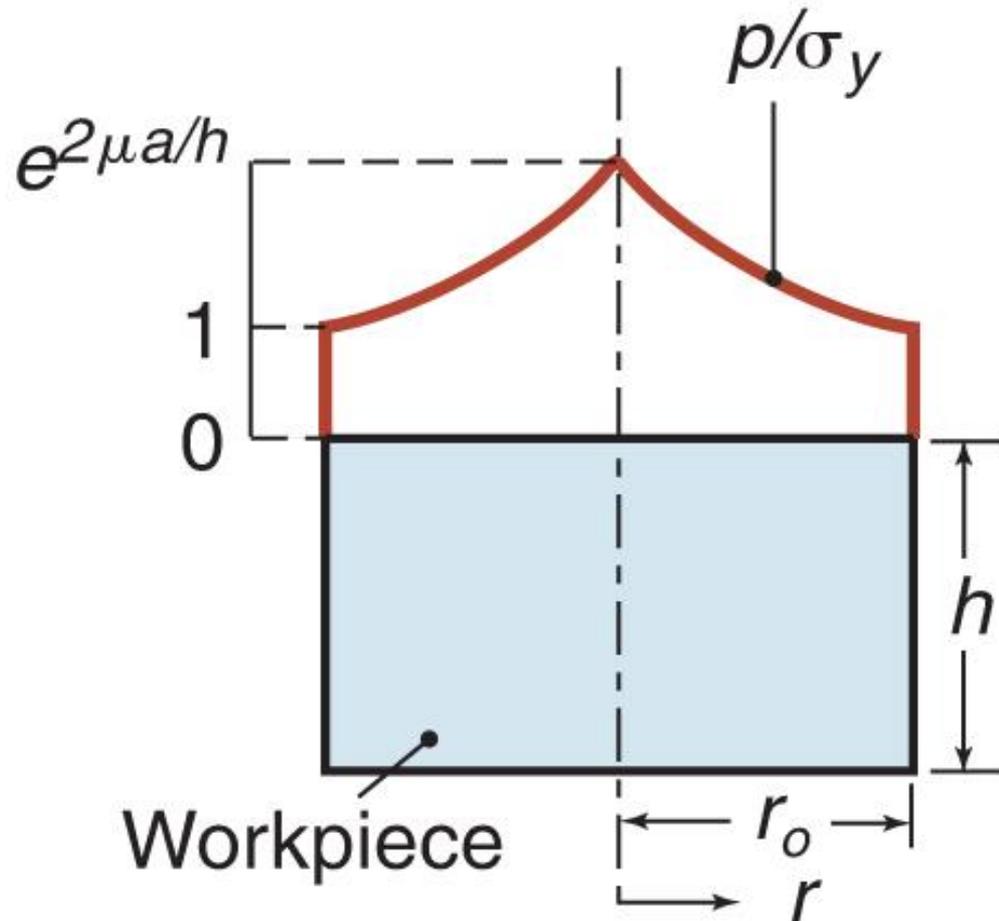


Figure 14.6

(a) through (d) Stages in impression-die forging of a solid round billet, with contours showing effective strain. Note the formation of flash, which is excess metal that is subsequently trimmed off. (e) Standard terminology for various features of a forging die.

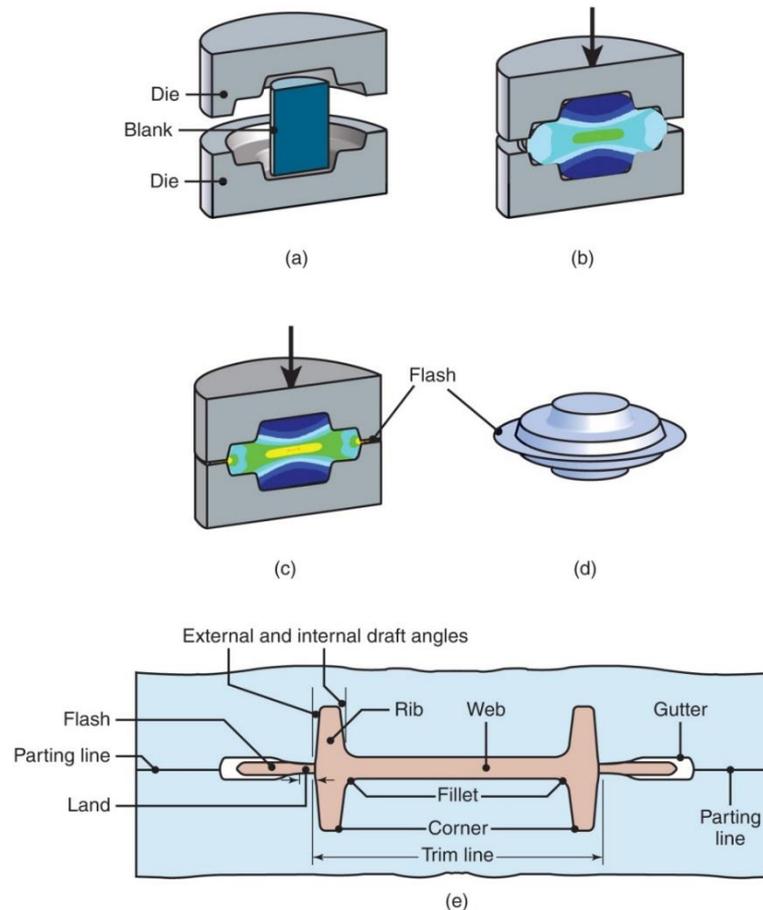


Figure 14.8

(a) Stages in forging a connecting rod for an internal combustion engine. Note the amount of flash required to ensure proper filling of the die cavities. (b) Fullering and (c) edging operations to distribute the material properly when preshaping the blank for forging.

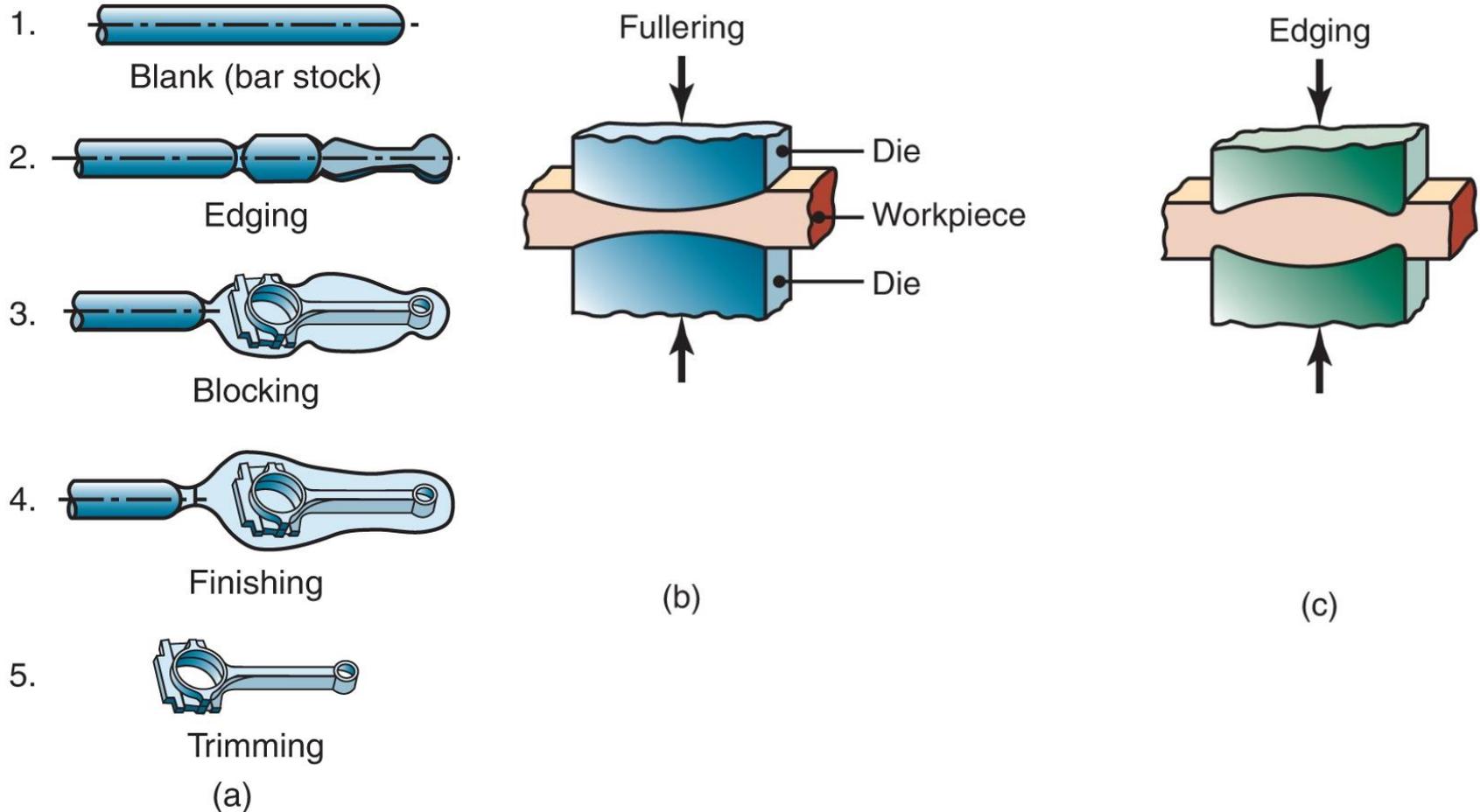


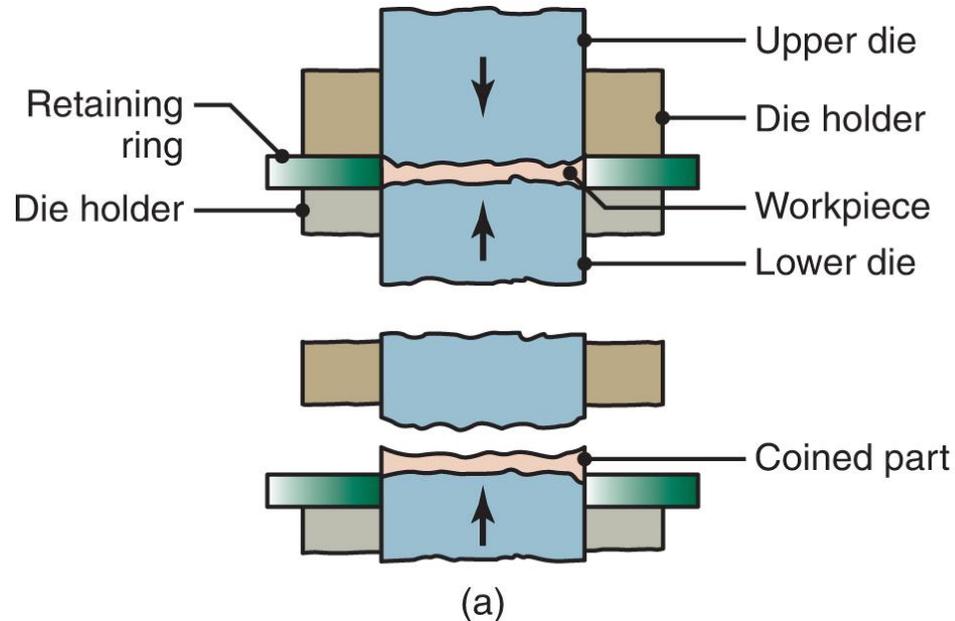
Table 14.2

Range of k Values for Eq. (14.3).

Shape	k
Simple shapes, without flash	3–5
Simple shapes, with flash	5–8
Complex shapes, with flash	8–12

Figure 14.11

(a) Schematic illustration of the coining process, (b) An example of a modern coining operation, showing the coins and tooling. Note the detail and superior surface finish that can be achieved in this process.



Source: Courtesy of C & W Steel Stamp Co., Inc.

Figure 14.12

(a) Heading operation to form heads on fasteners, such as nails and rivets, (b) Sequence of operations used to produce a typical bolt head by heading.

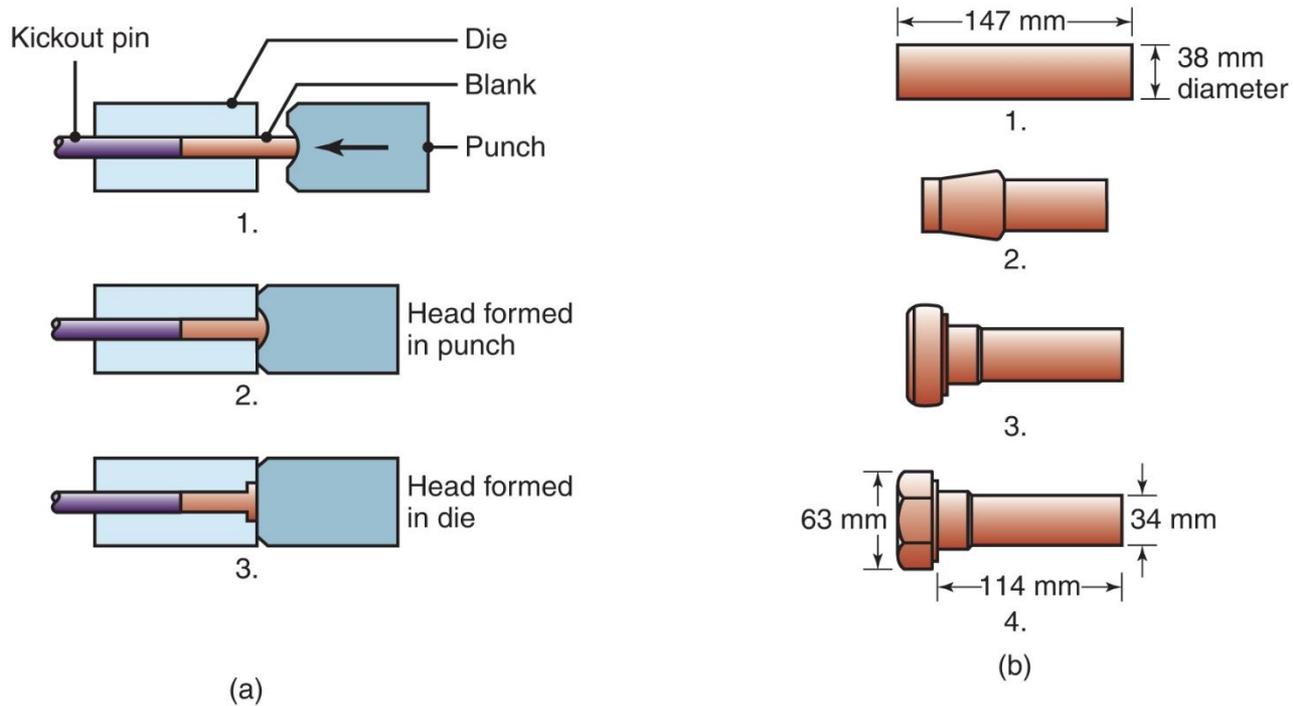
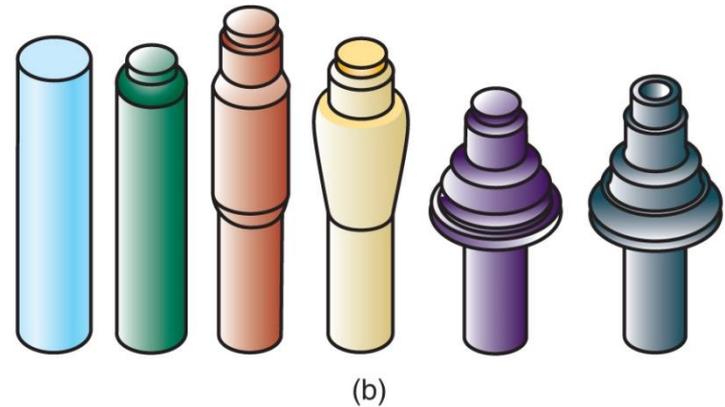
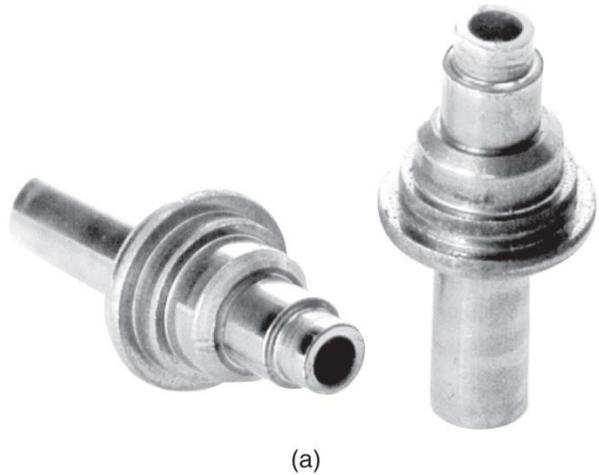


Figure 14.14 (1 of 2)

(a) The stepped pin used in Case Study 14.1, (b) Illustration of the steps used to produce the stepped pin.



Source: Courtesy of National Machinery, LLC.

Table 14.3

Forgeability of Metals, in Decreasing Order. See also Table 15.1.

Metal or alloy	Approximate range of hot-forging temperatures (°C)
Aluminum alloys	400–550
Magnesium alloys	250–350
Copper alloys	600–900
Carbon- and low-alloy steels	850–1150
Martensitic stainless steels	1100–1250
Austenitic stainless steels	1100–1250
Titanium alloys	700–950
Iron-based superalloys	1050–1180
Cobalt-based superalloys	1180–1250
Tantalum alloys	1050–1350
Molybdenum alloys	1150–1350
Nickel-based superalloys	1050–1200
Tungsten alloys	1200–1300

Figure 14.17

Examples of defects in forged parts. (a) Laps formed by web buckling during forging; web thickness should be increased to avoid this problem, (b) Internal defects caused by an oversized billet. Die cavities are filled prematurely, and the material at the center flows past the filled regions as the dies close.

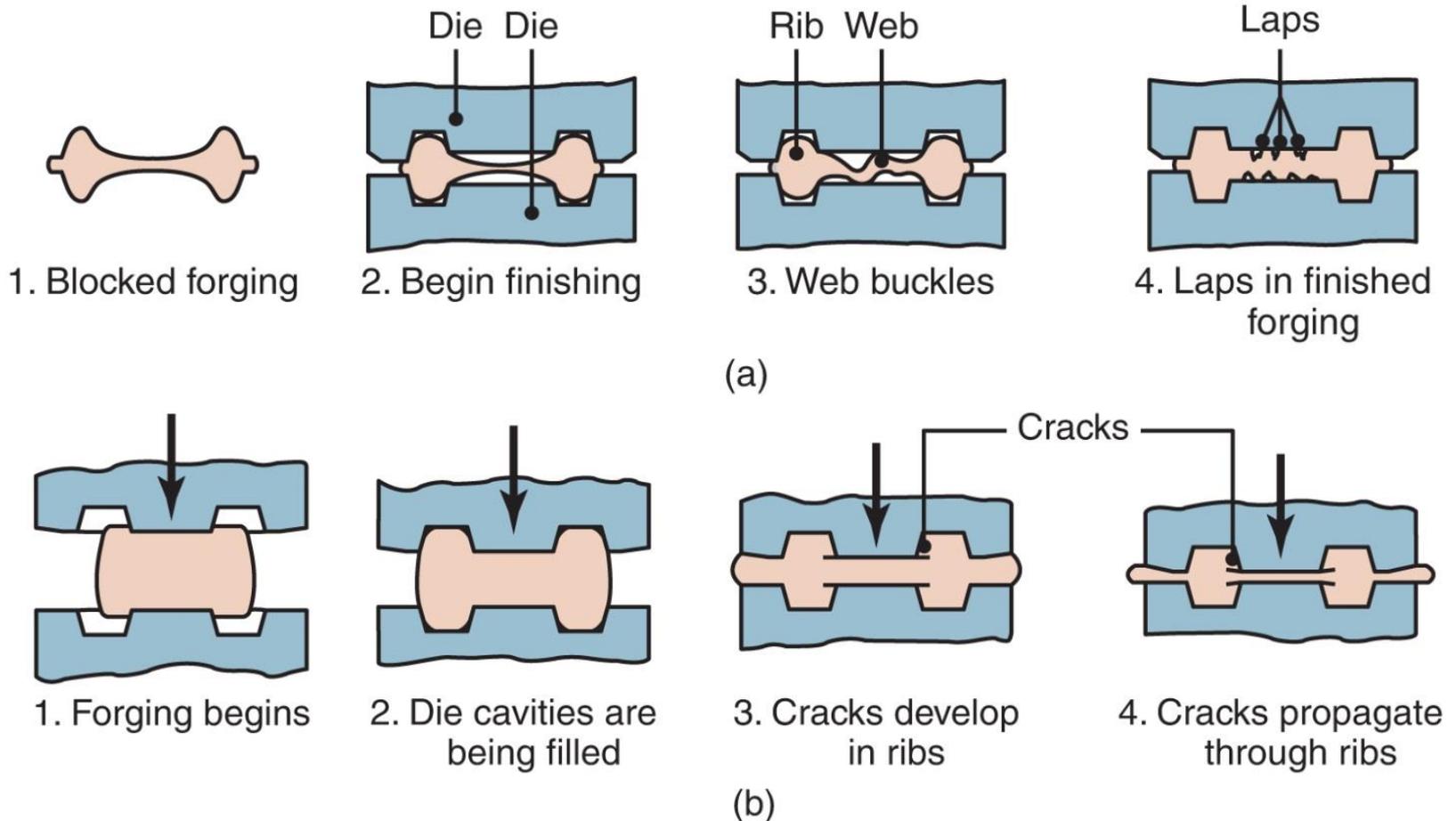


Figure 14.21

Typical cost per piece in forging; note how the setup and the tooling costs per piece decrease as the number of pieces forged increases if all pieces use the same die.

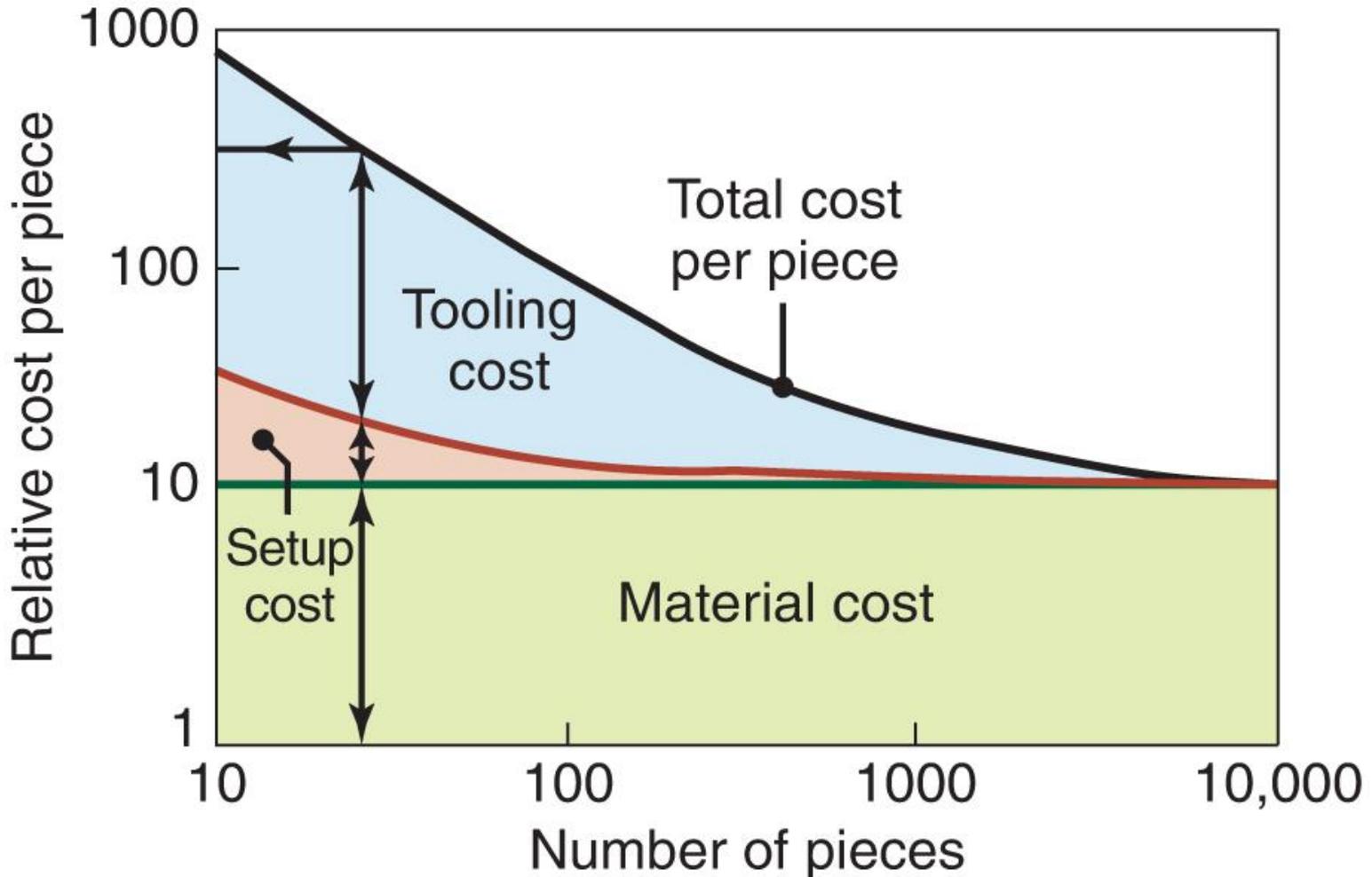


Figure 14.22

Relative unit costs of a small connecting rod made by various forging and casting processes. Note that, for large quantities, forging is more economical, and sand casting is the most economical process for fewer than about 20,000 pieces.

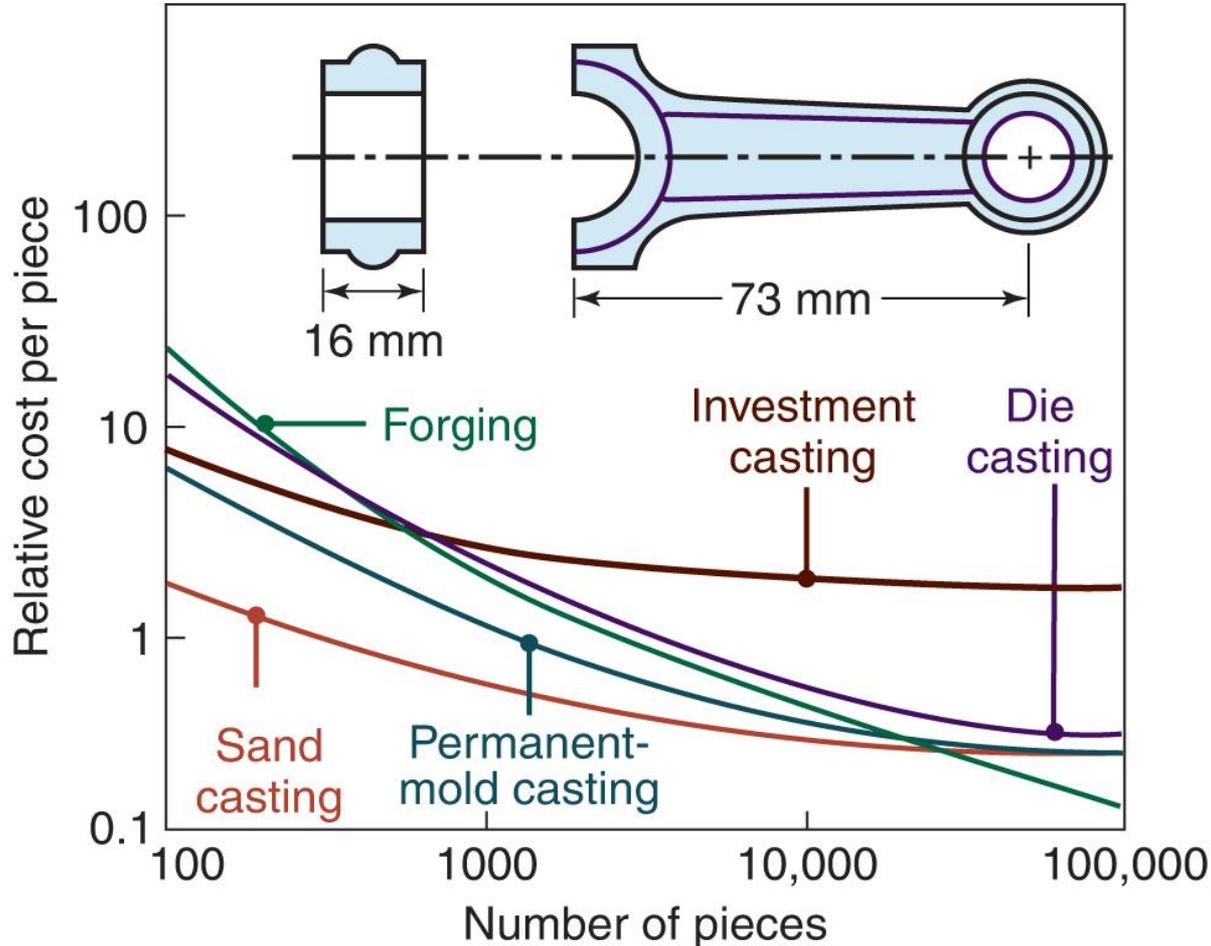
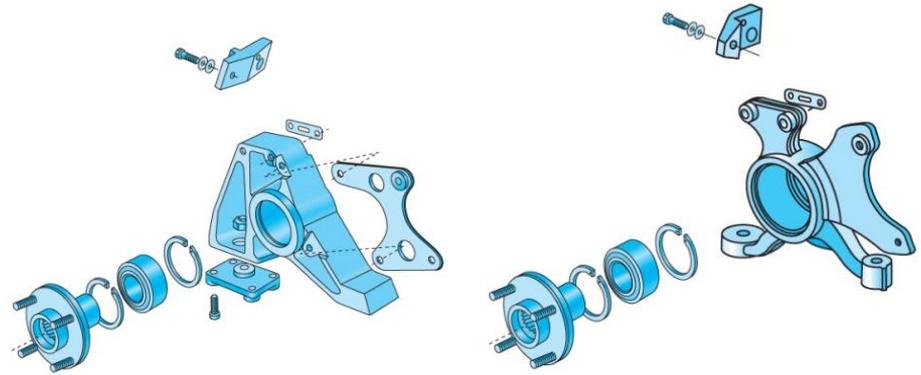


Figure 14.23 (1 of 4)

(a) The Lotus Elise Series 2 automobile, (b) illustration of the original design for the vertical suspension uprights, using an aluminum extrusion, (c) retrofit design, using a steel forging, (d) optimized steel forging design for new car models.

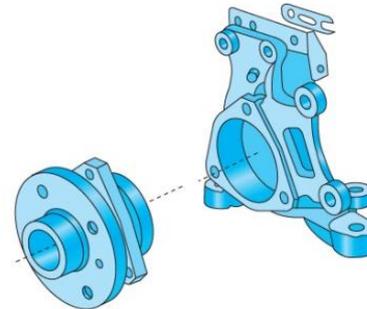


(a)



(b)

(c)



(d)

Source: (a) Shutterstock/VanderWolf Images.

Table 14.5

Comparison of Suspension Upright Designs for the Lotus Elise Automobile.

Fig. 14.23 sketch	Material	Application	Mass (kg)	Cost
(b)	Aluminum extrusion, steel bracket, steel bushing, housing	Original design	2.105	85
(c)	Forged steel	Phase I	2.685 (+28%)	27.7 (−67%)
(d)	Forged steel	Phase II	2.493 (+18%)	30.8 (−64%)

Figure 15.1

Schematic illustration of the direct extrusion process.

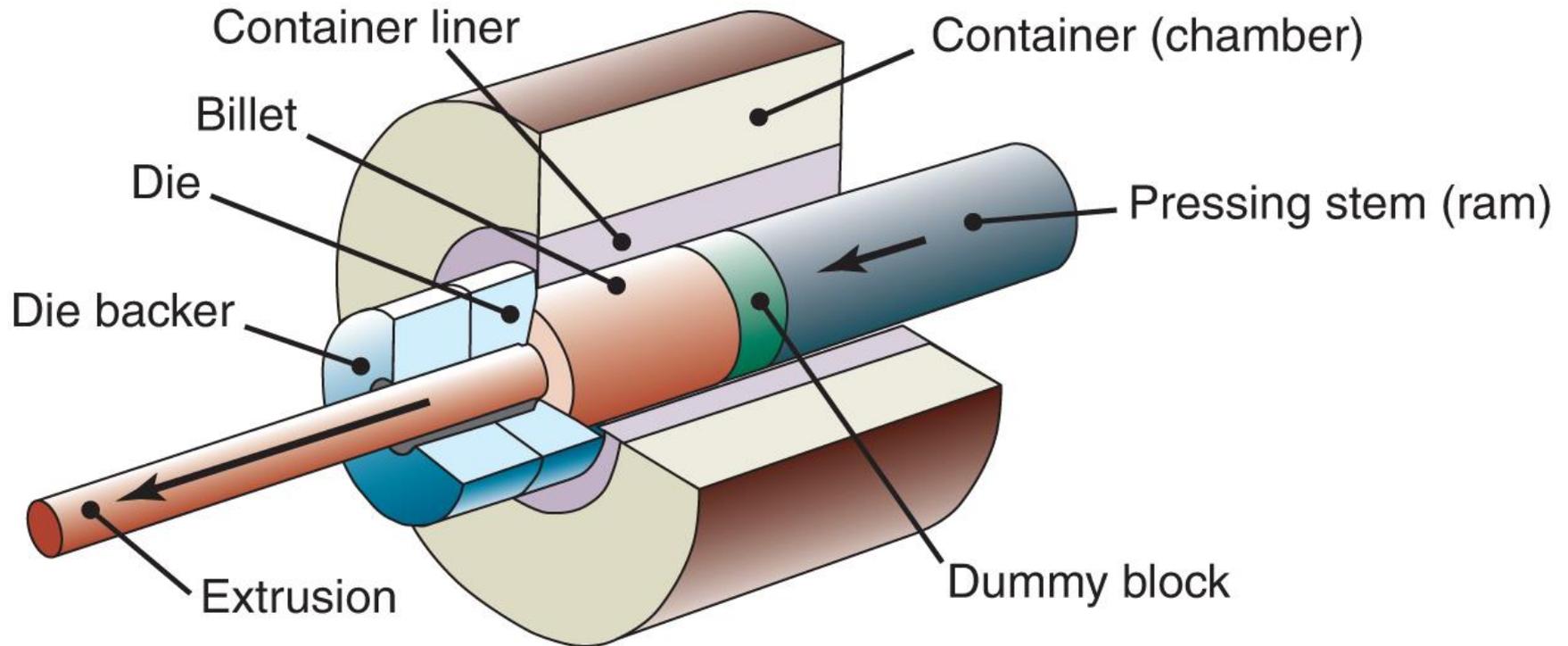


Figure 15.2

Extrusions and examples of products made by sectioning off extrusions.

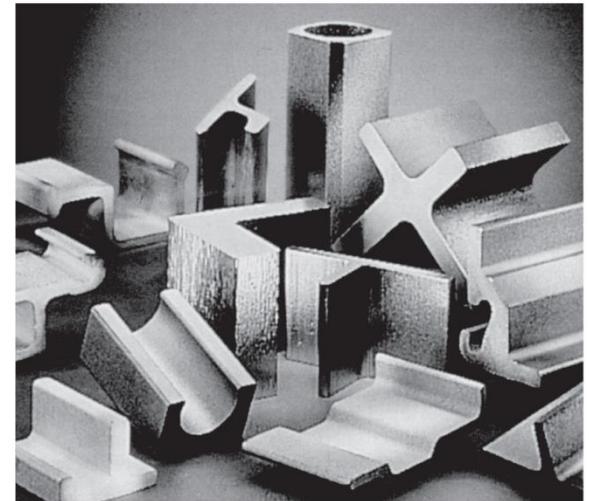
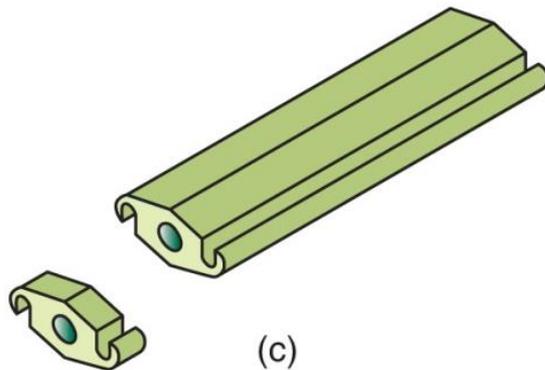
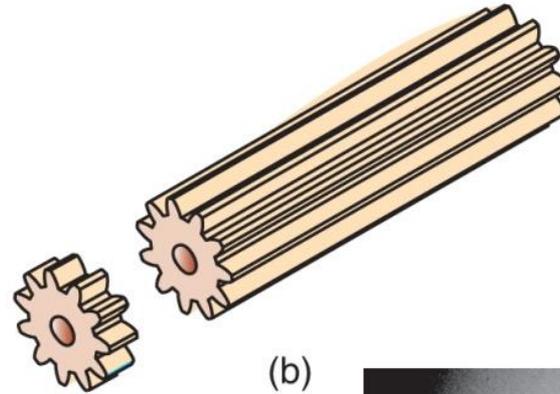
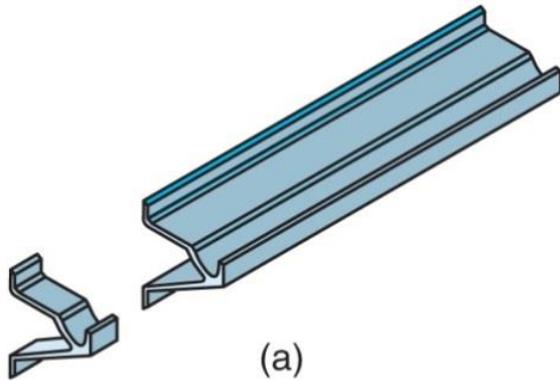
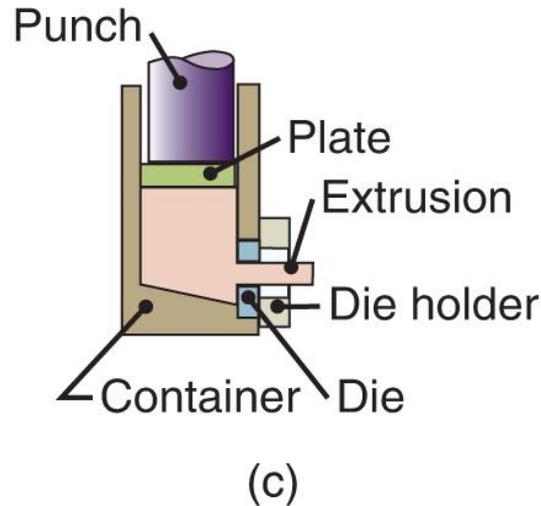
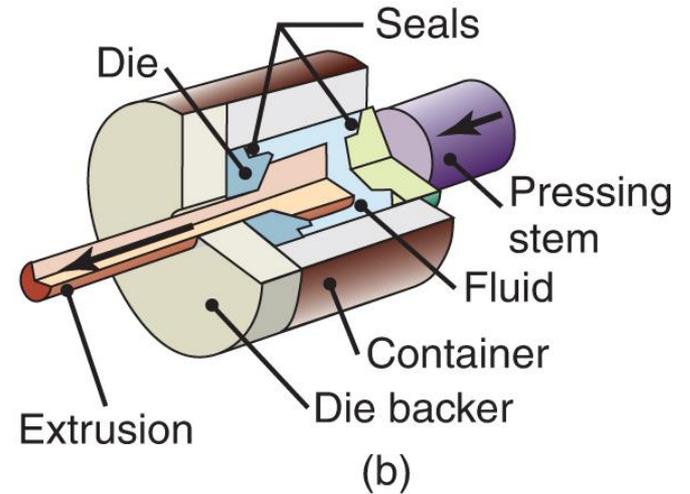
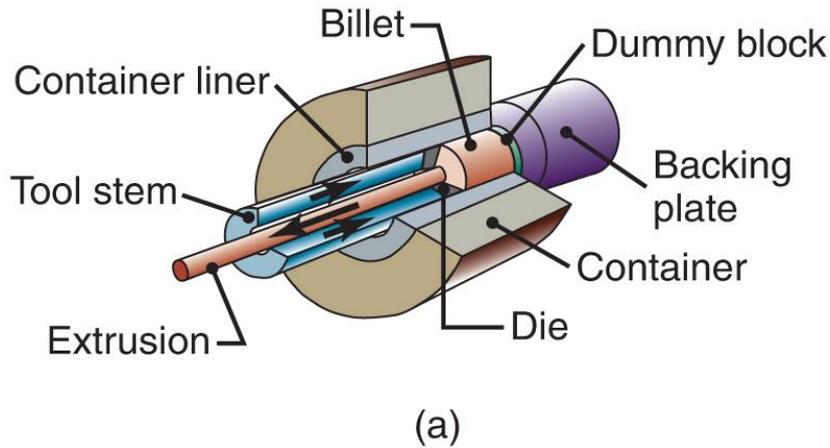
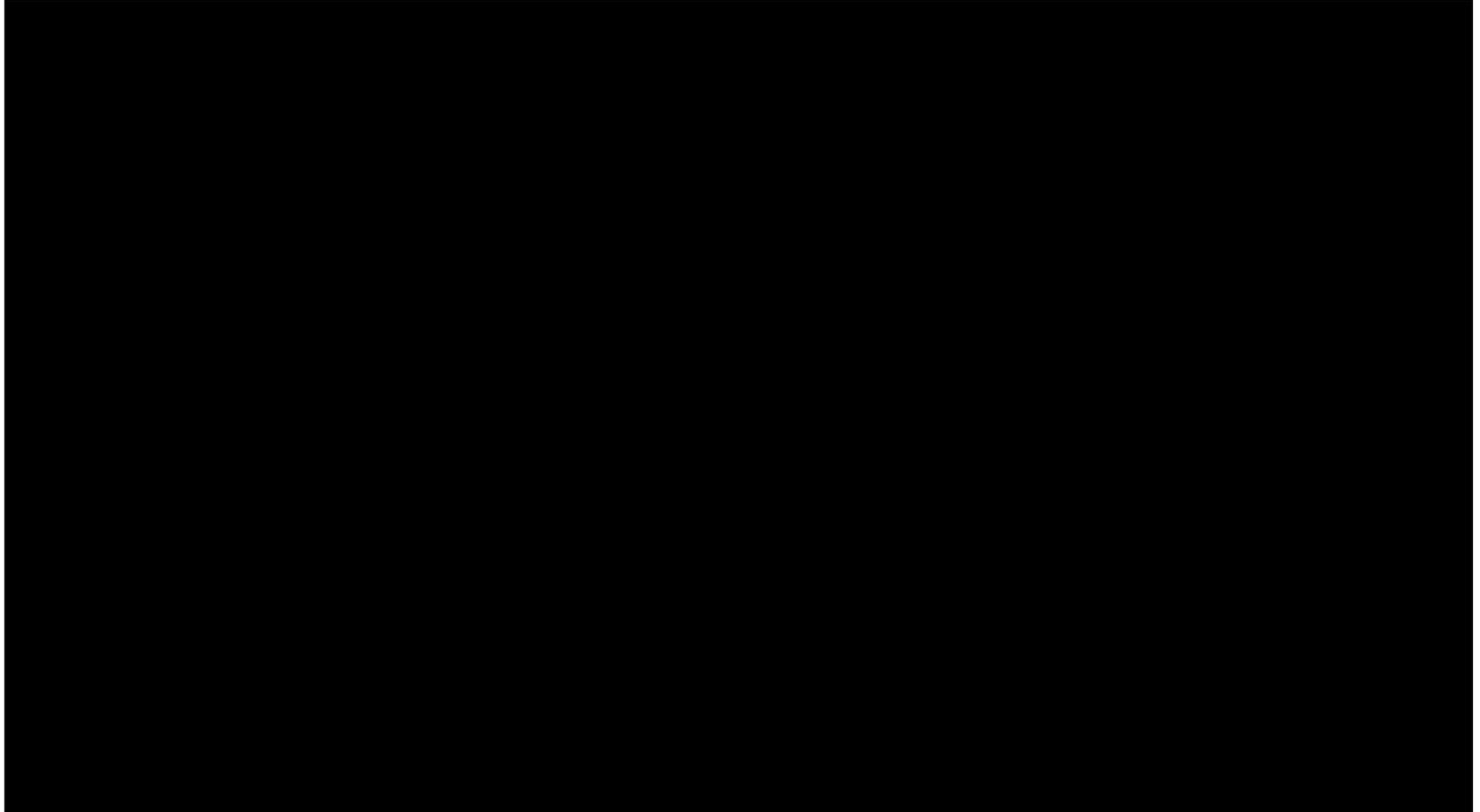


Figure 15.3

Types of extrusion: (a) indirect; (b) hydrostatic; (c) lateral.



Extrusion



<https://youtu.be/Y75IQksBb0M>

Figure 15.4

Process variables in direct extrusion. The die angle, reduction in cross section, extrusion speed, billet temperature, and lubrication all affect the extrusion pressure. The contour plot shows effective strain as obtained from a finite element simulation for the geometry shown.

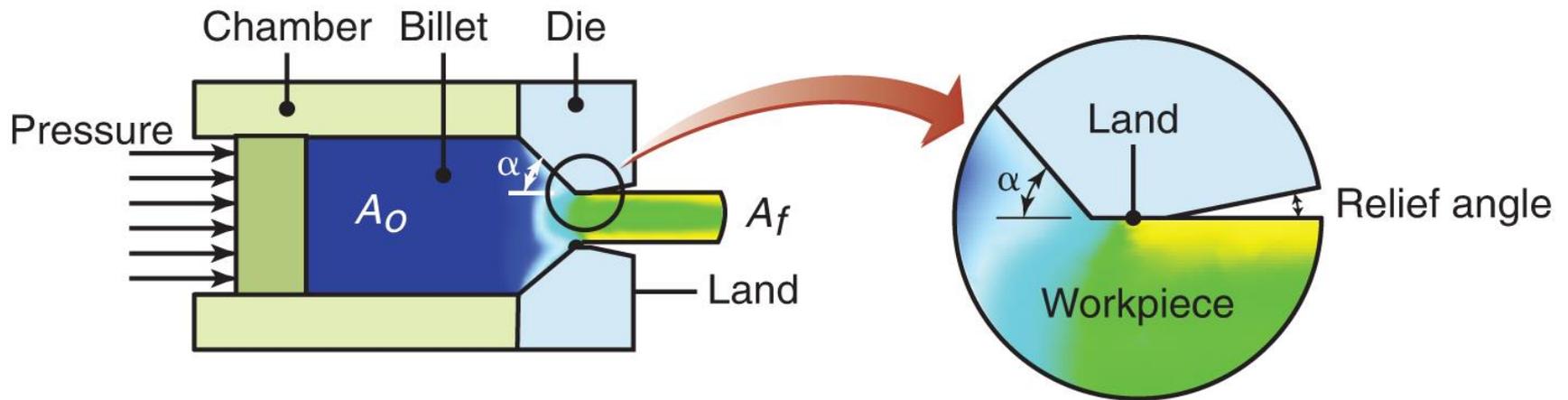
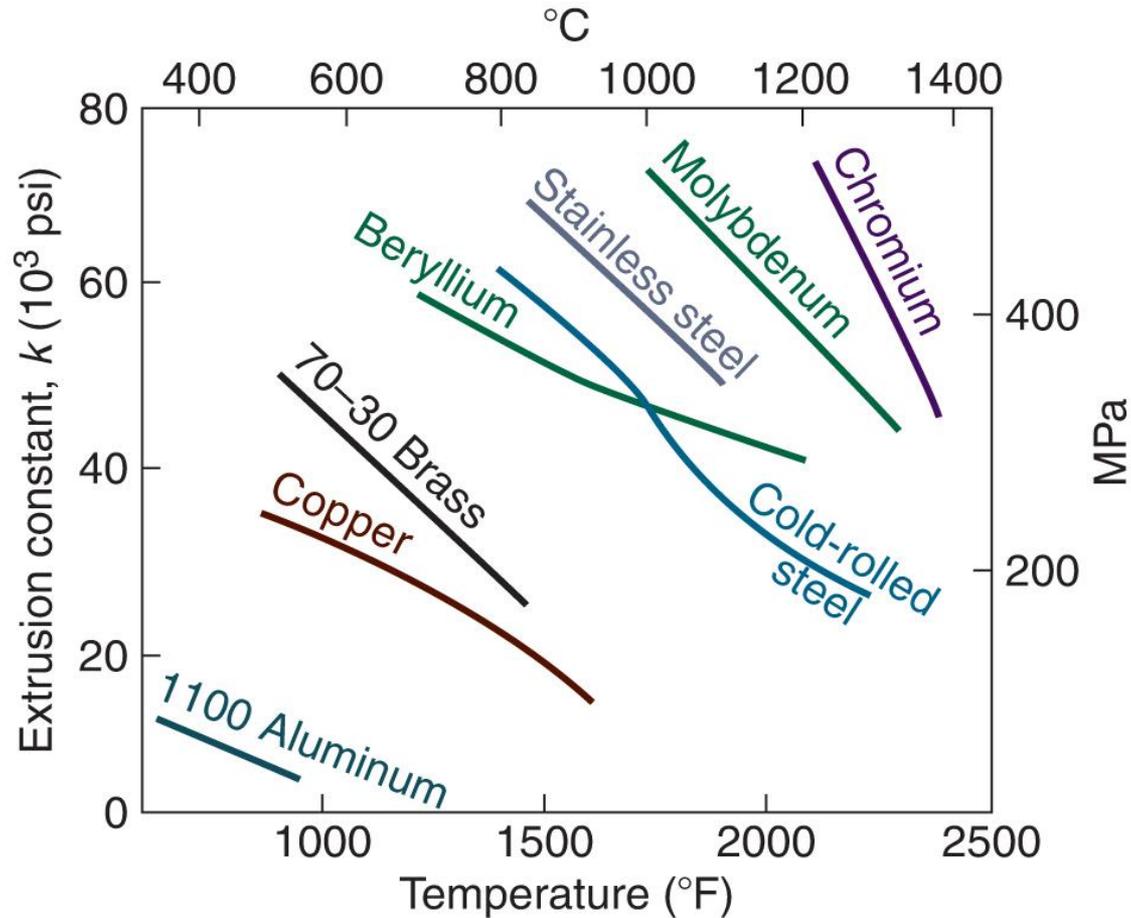


Figure 15.5

Extrusion constant k for various metals at different temperatures, as determined experimentally.



Source: After P. Loewenstein.

Figure 15.6

Types of metal flow in extruding with square dies. (a) Flow pattern obtained at low friction or in indirect extrusion. (b) Pattern obtained with high friction at the billet chamber interfaces. (c) Pattern obtained at high friction or with cooling of the outer regions of the billet in the chamber. This type of pattern, observed in metals whereby their strength increases rapidly with decreasing temperature, leads to a defect known as *pipe*, or *extrusion defect*.

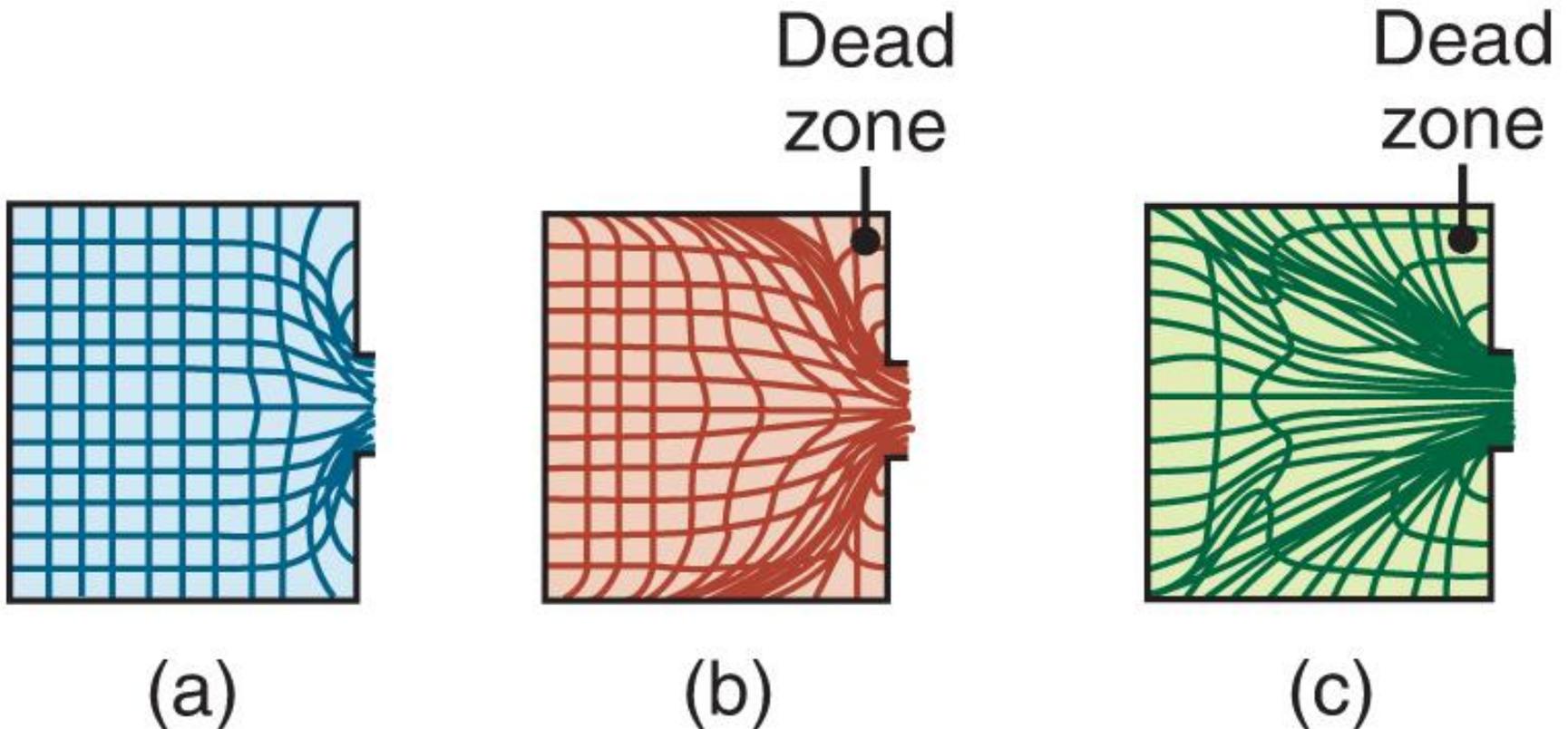


Figure 15.8

Extrusion of a seamless tube (a) using an internal mandrel that moves independently of the ram; an alternative arrangement has the mandrel integral with the ram, (b) using a spider die (see Fig. 15.9) to produce seamless tubing.

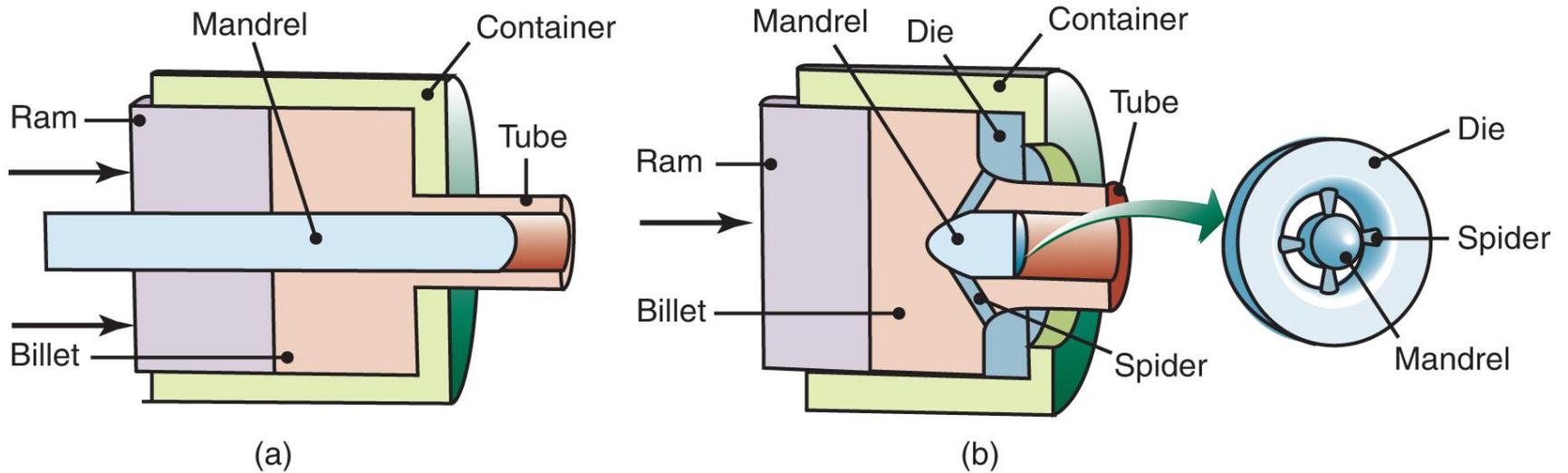
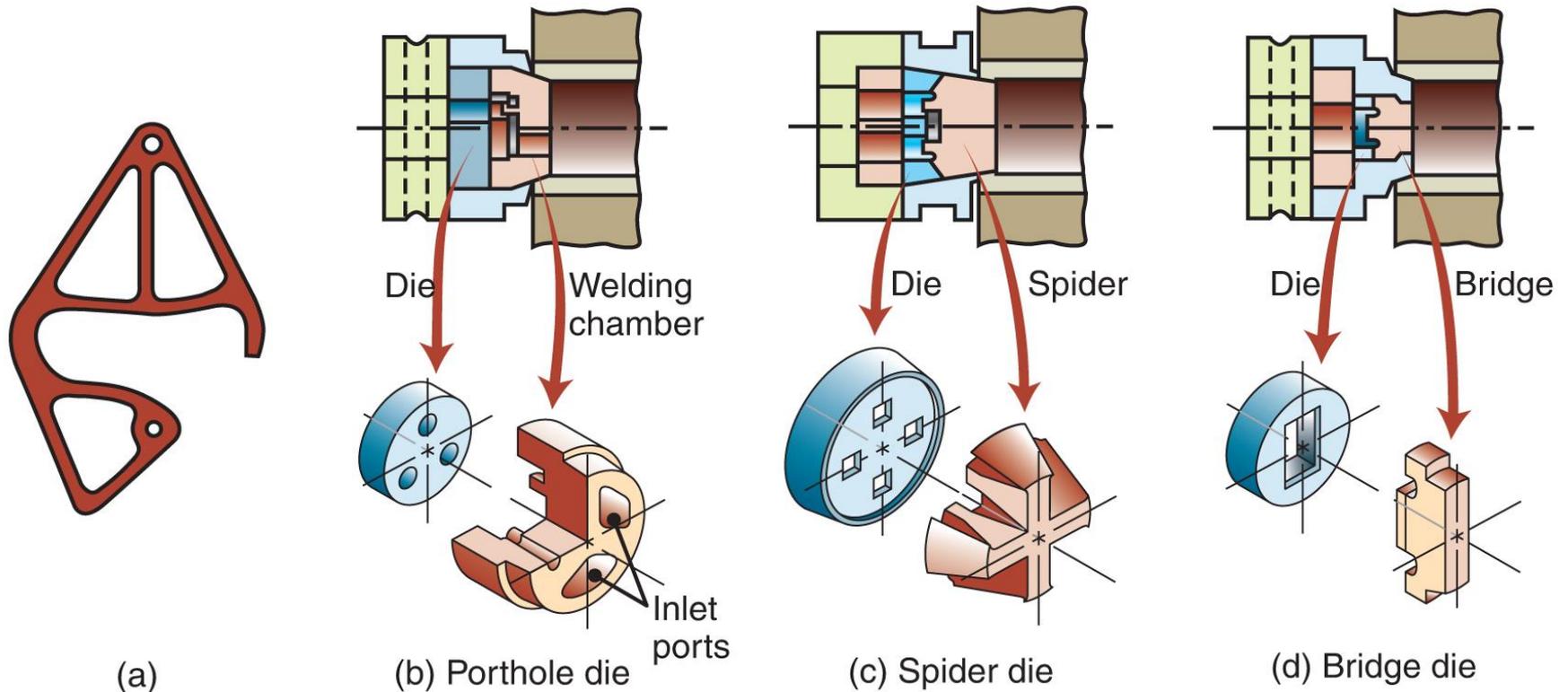


Figure 15.9

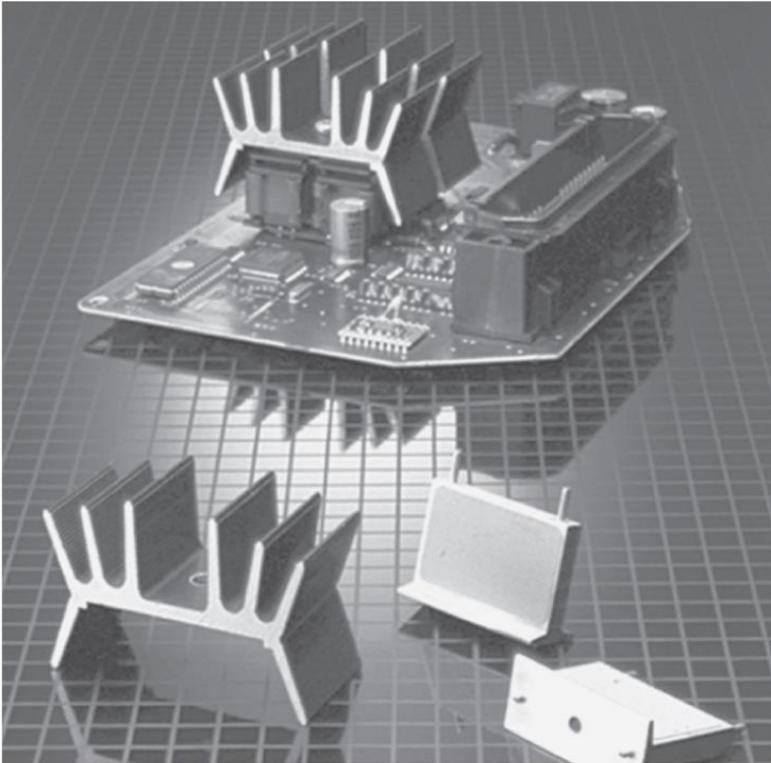
(a) An extruded 6063-T6 aluminum-ladder lock for aluminum extension ladders. This part is 8 mm (5/16 in.) thick and is sawed from the extrusion (see Fig. 15.2). (b) through (d) Components of various dies for extruding intricate hollow shapes.



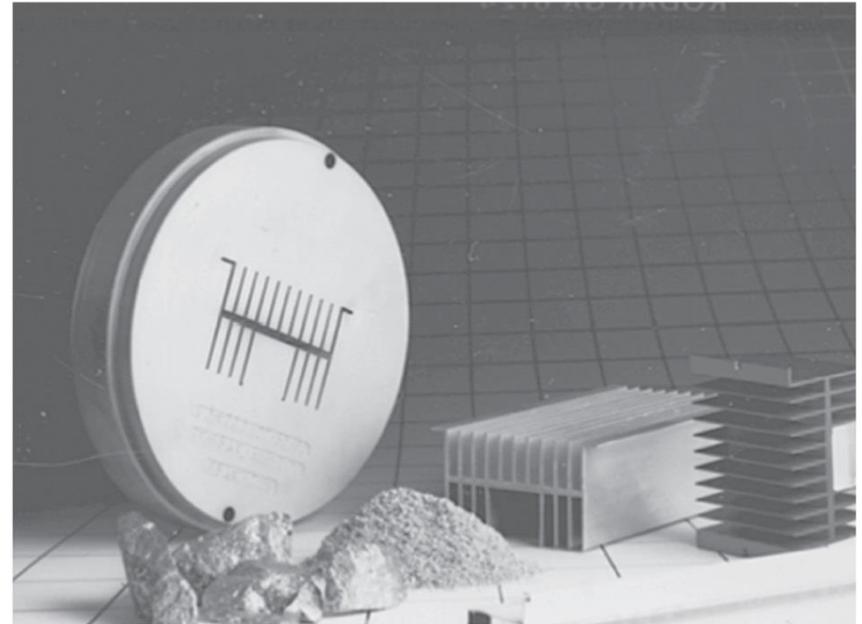
Source: (b) through (d) after K. Laue and H. Stenger.

Figure 15.10

(a) Aluminum extrusion used as a heat sink for a printed circuit board, (b) extrusion die and extruded heat sinks.



(a)



(b)

Source: Courtesy of Aluminum Extruders Council.

Figure 15.11

Two examples of cold extrusion; arrows indicate the direction of metal flow during extrusion.

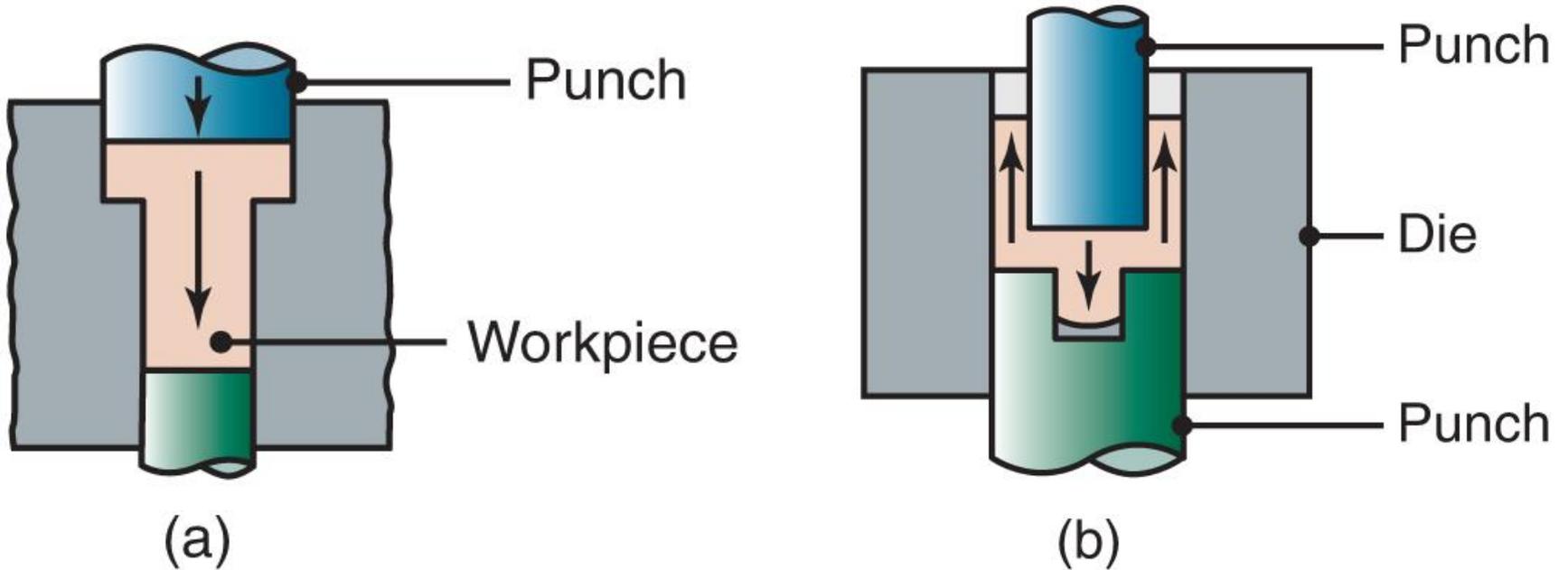
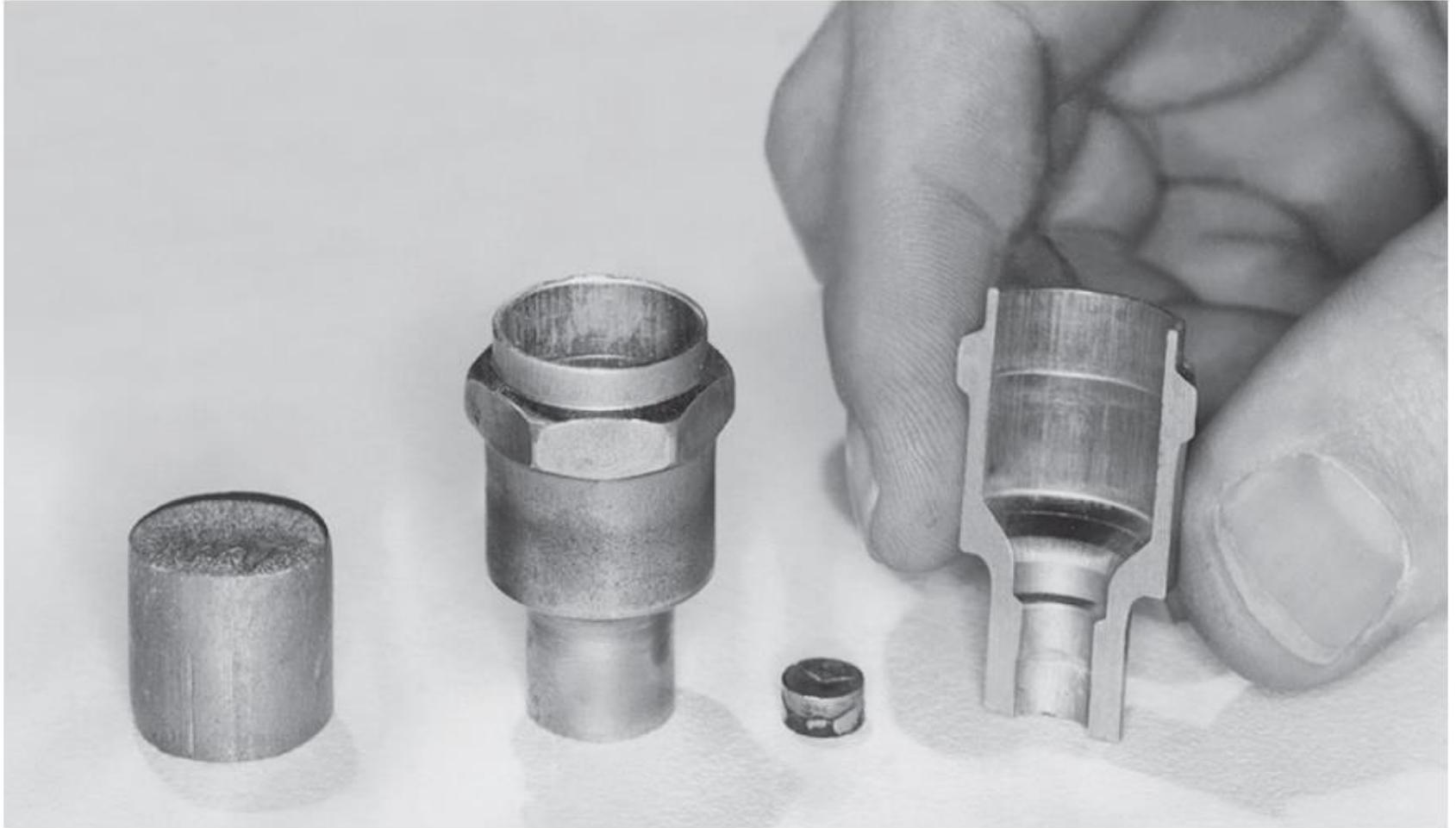


Figure 15.12

Production steps for the metal portion of a cold-extruded spark plug.



Source: Courtesy of National Machinery Company, LLC.

Figure 15.13

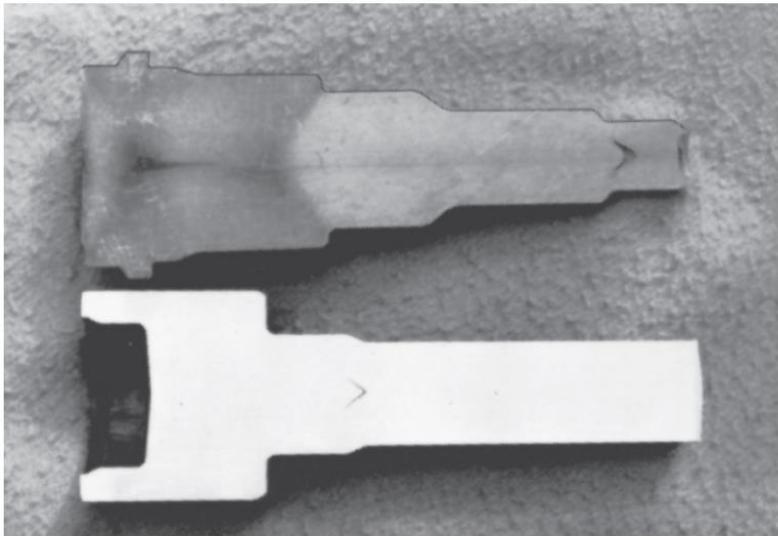
A cross section of the metal part in Fig. 15.12, showing the grain-flow pattern.



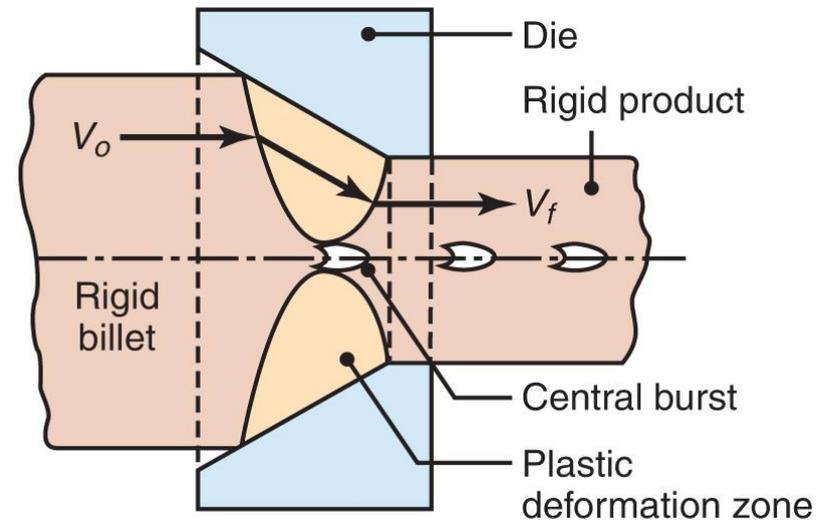
Source: Courtesy of National Machinery Company, LLC.

Figure 15.16

(a) Chevron cracking (central burst) in extruded round steel bars. Unless the products are inspected, such internal defects may remain undetected and later cause total failure of the part in service. This defect can also develop in the drawing of rod, wire, and tubes. (b) Schematic illustration of rigid and plastic zones in extrusion. The tendency toward chevron cracking increases if the two plastic zones do not meet. Note that the plastic zone can be made larger either by decreasing the die angle, increasing the reduction in cross section, or both.



(a)



(b)

Source: After B. Avitzur.

Figure 15.17

Examples of poor and good design practices for extrusion. Note the importance of eliminating sharp corners and of keeping section thicknesses uniform.

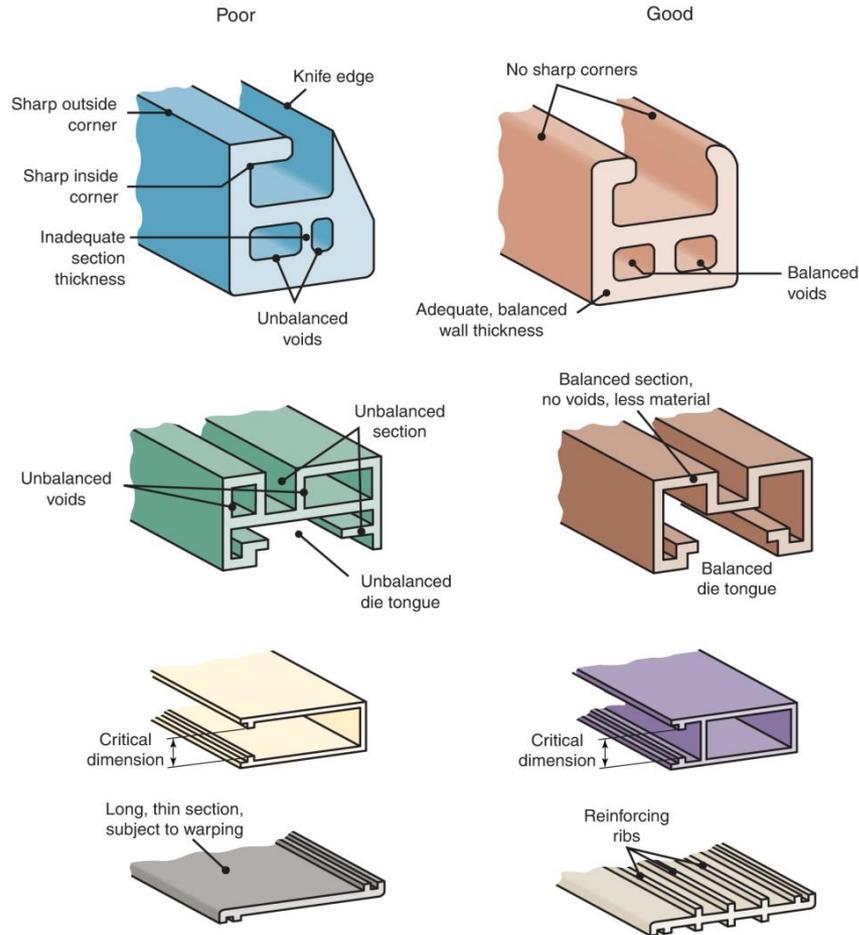


Figure 15.19

A 27 MN (3,000 ton) Sutton aluminum extrusion press. This is the first of the Sutton MK-V extrusion press series built in the United States to SMS group Engineering specifications. Photo courtesy of SMS Group, Inc., Pittsburgh, PA.



Figure 15.20

Process variables in wire drawing. The major processing variables in drawing are similar to those in extrusion, that is, reduction in cross-sectional area, die angle, frictional conditions along the die–workpiece interfaces, and drawing speed.

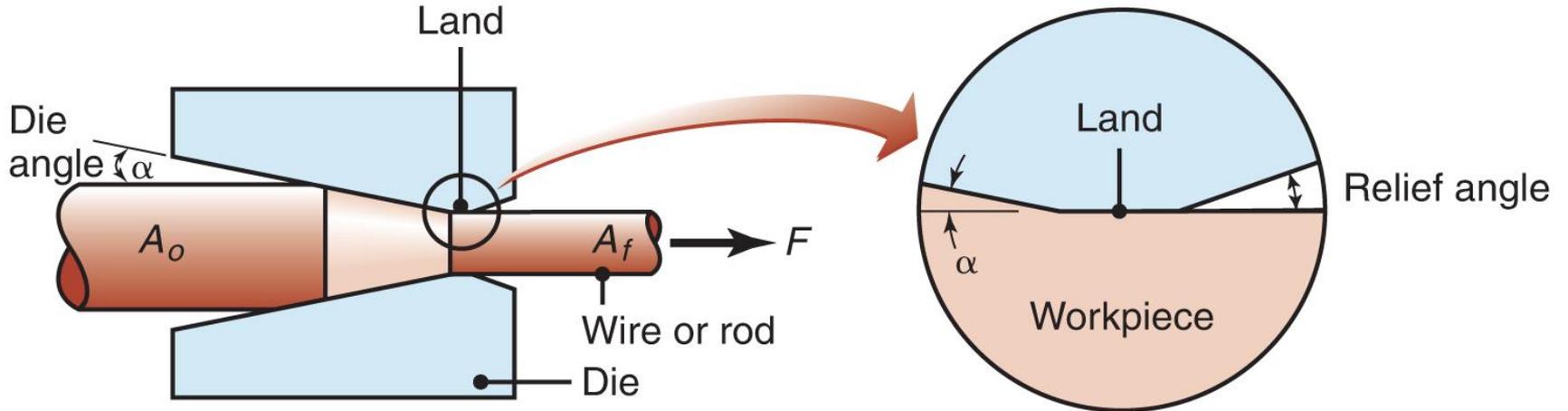
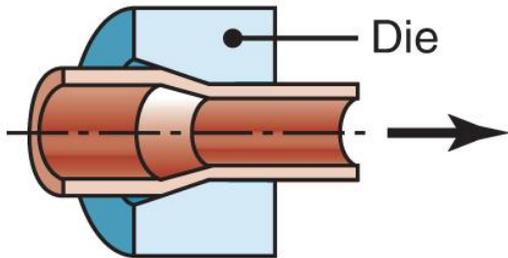
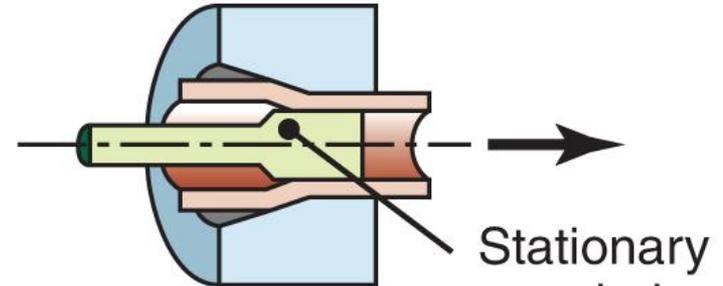


Figure 15.21

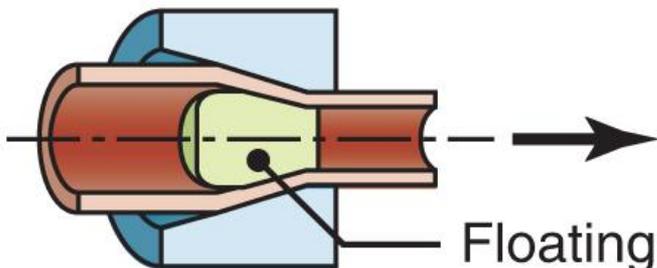
Examples of tube-drawing operations, with and without an internal mandrel. Note that a range of diameters and wall thicknesses can be produced from the same initial tube stock which has been made by other processes.



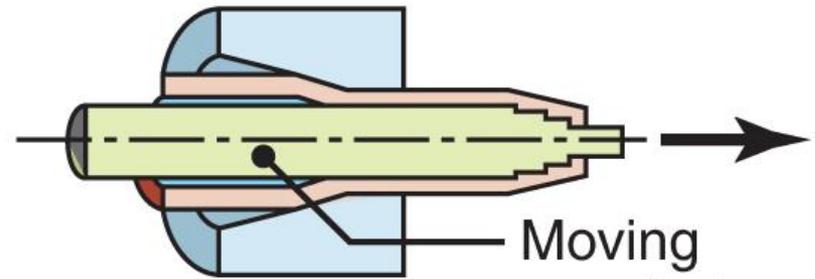
(a)



(b)



(c)



(d)

Figure 15.24

Cold drawing of an extruded channel on a draw bench to reduce its cross section. Individual lengths of straight rods or of cross sections are drawn by this method.

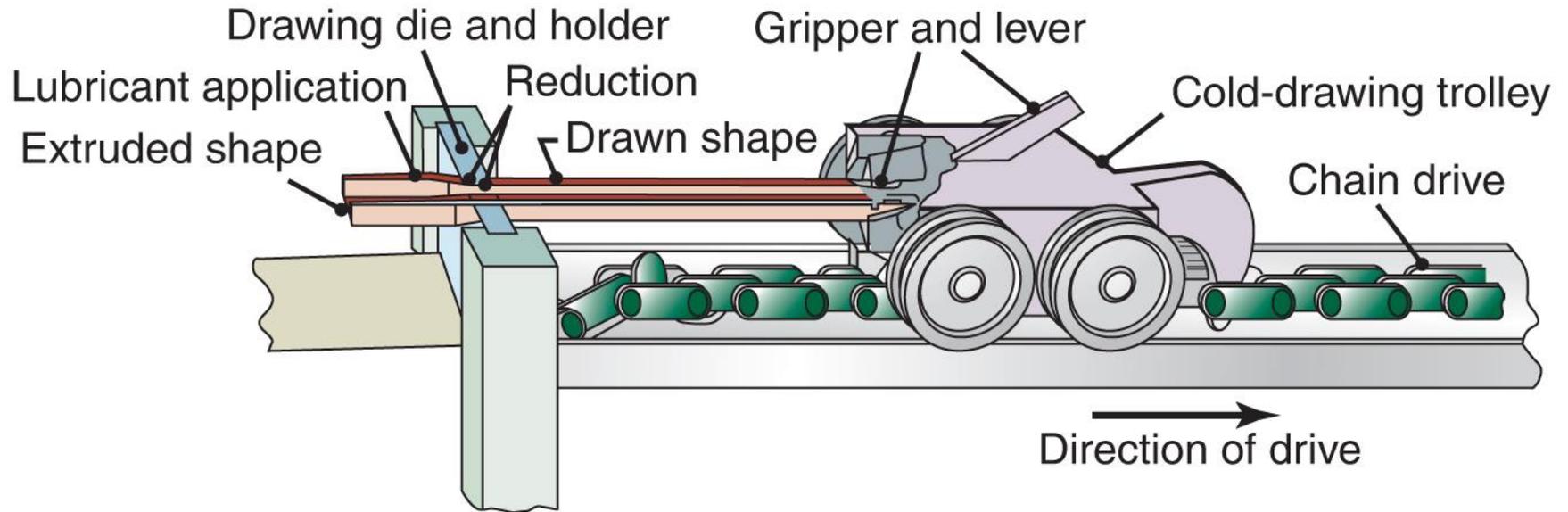
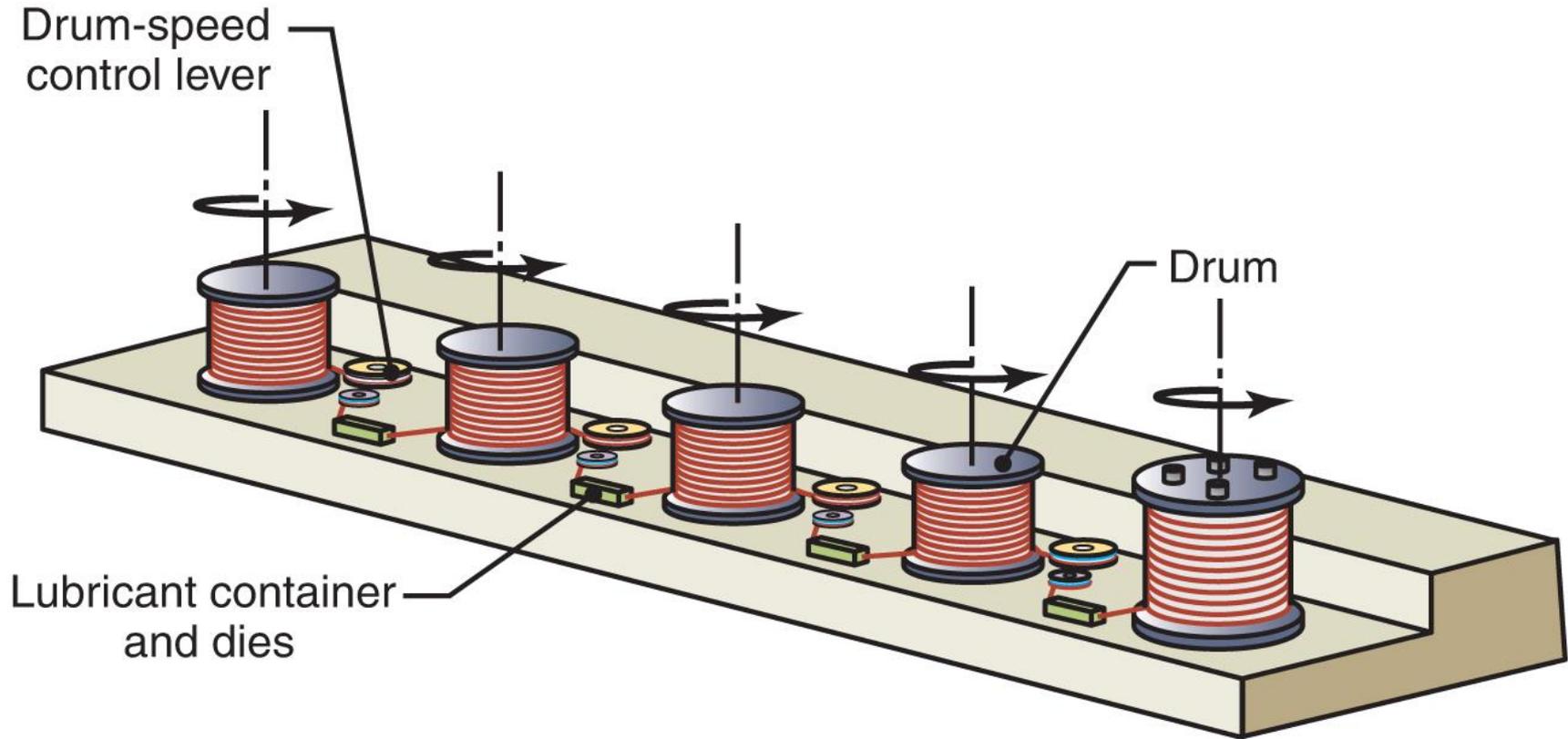


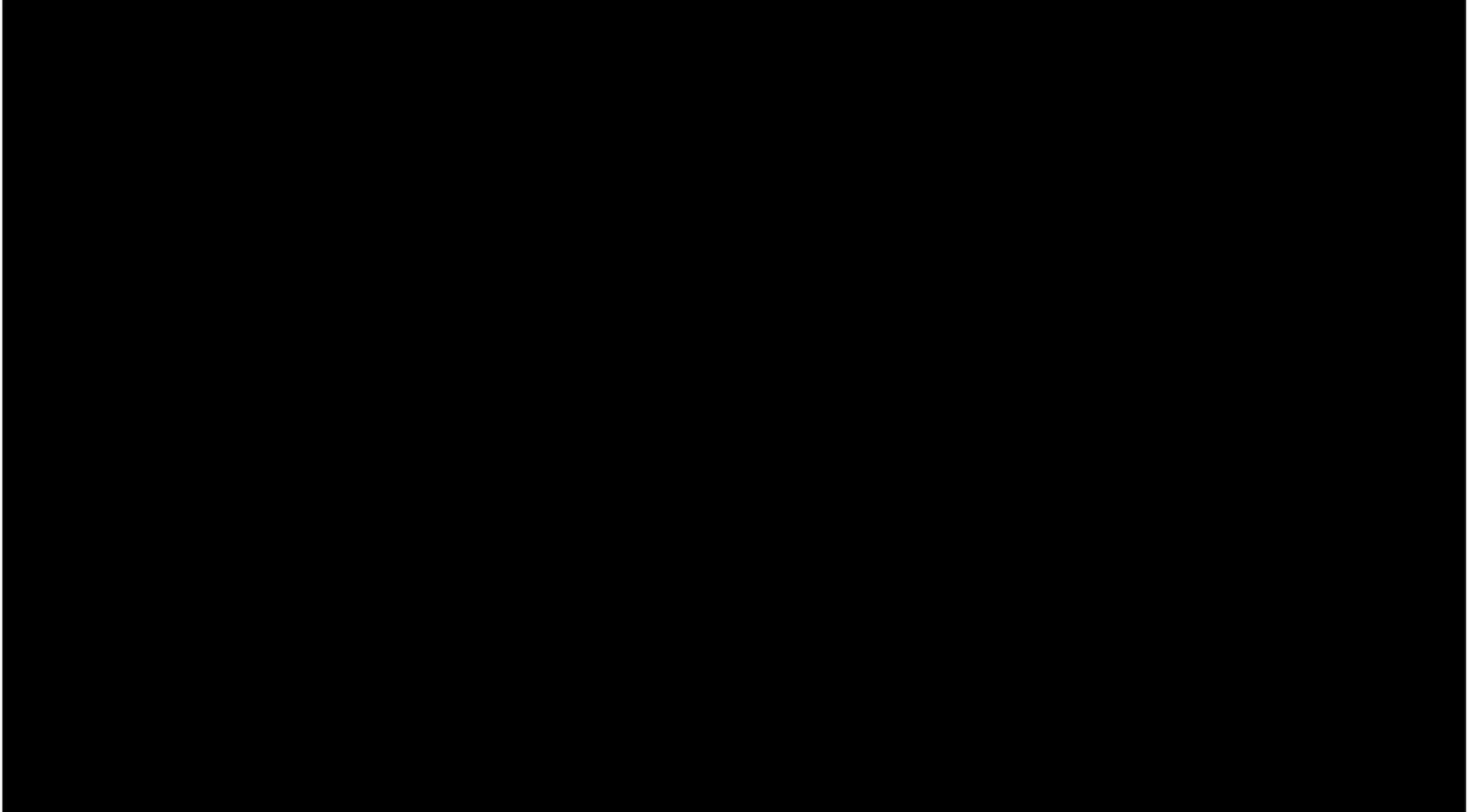
Figure 15.25

An illustration of multistage wire drawing typically used to produce copper wire for electrical wiring. Shown is a five bull block configuration; wire drawing machines can incorporate 15 or more drums, depending on the material and wire size.



Source: After H. Auerswald.

High Speed Wire Drawing



<https://youtu.be/jkZuetCFnls>