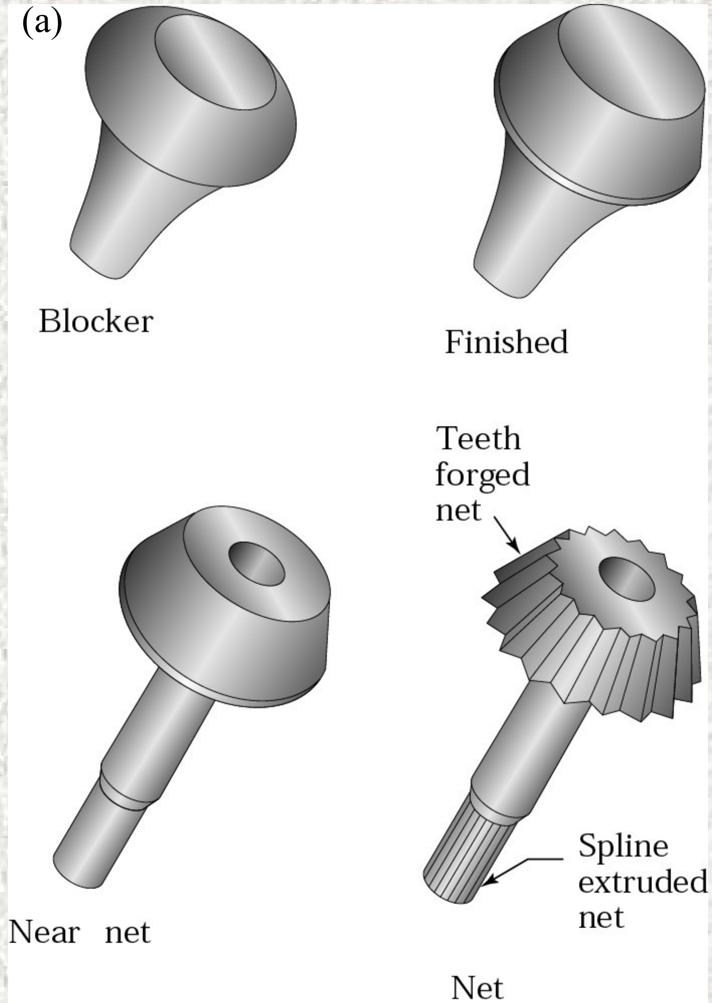
FORGING OF METALS

Ch-4

Forging



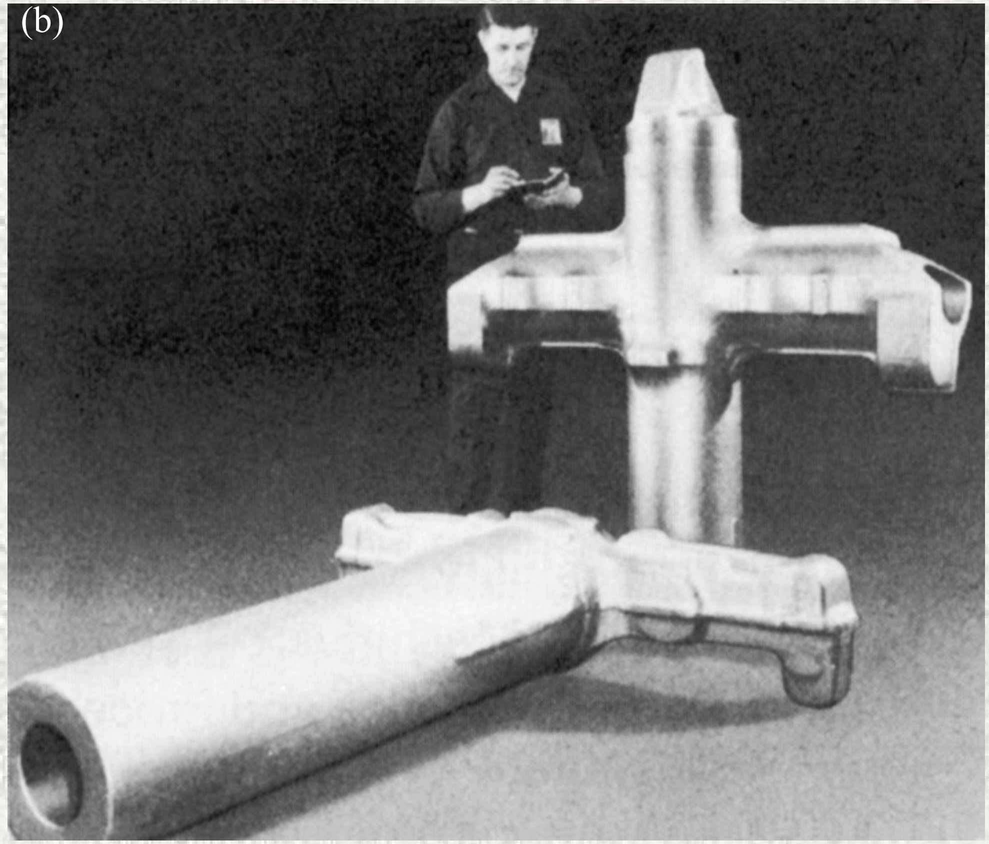


Figure 14.1 (a) Schematic illustration of the steps involved in forging a bevel gear with a shaft. *Source*: Forging Industry Association. (b) Landing-gear components for the C5A and C5B transport aircraft, made by forging. *Source*: Wyman-Gordon Company.

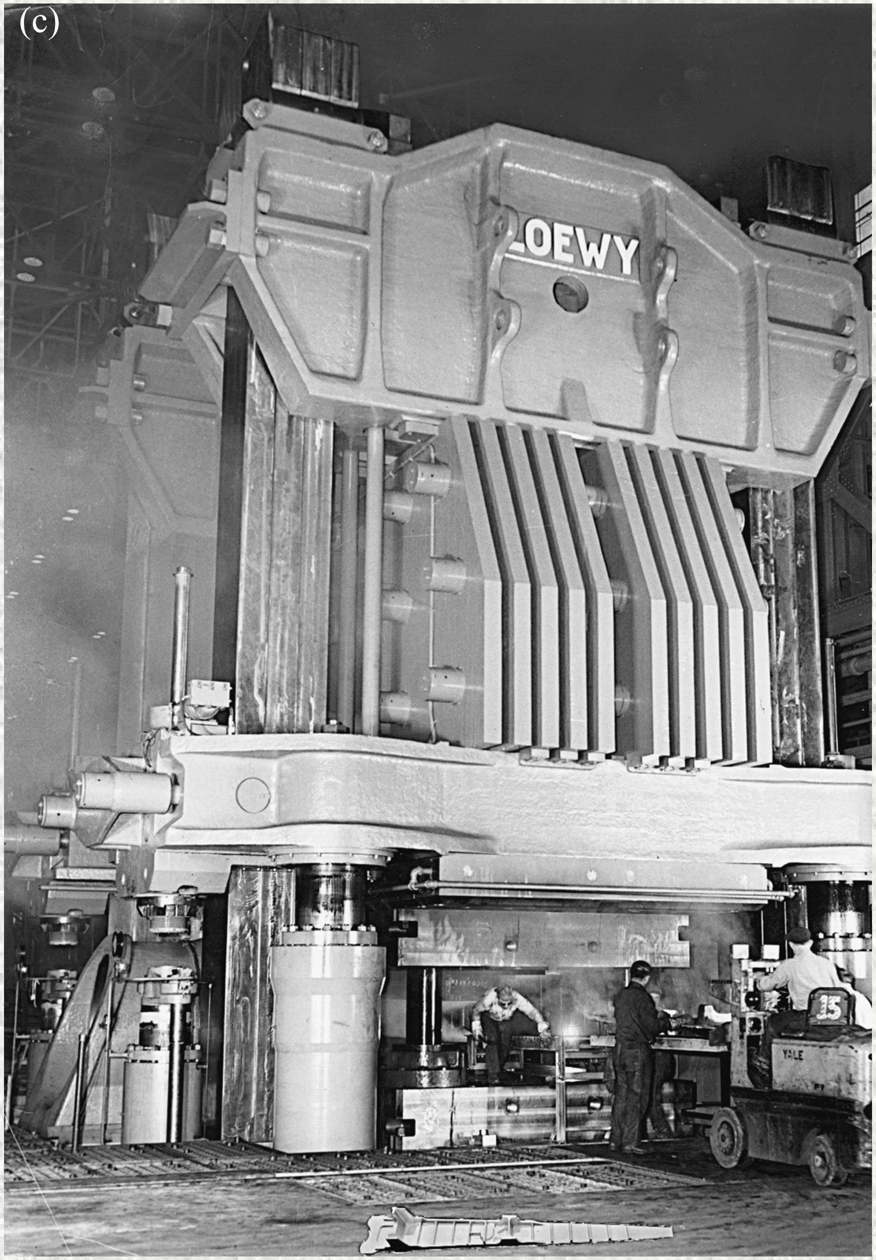
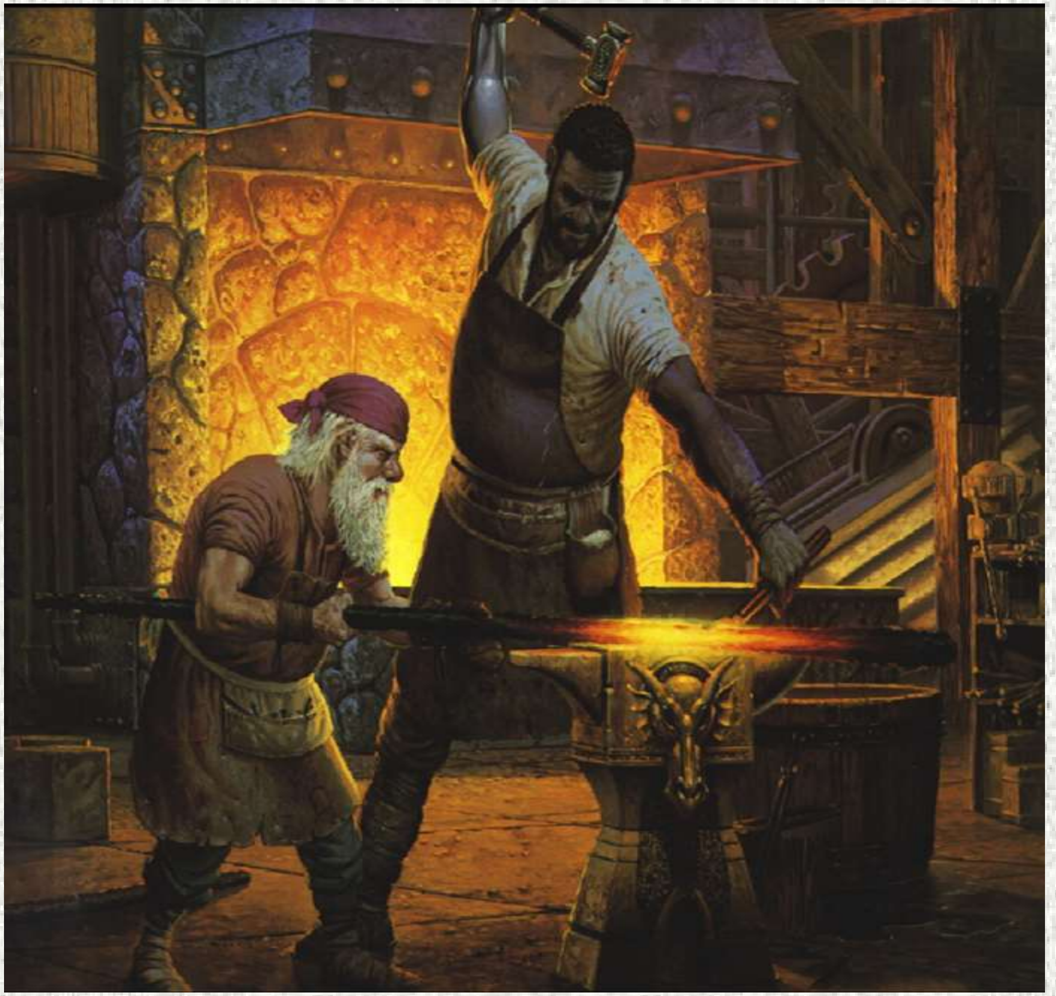
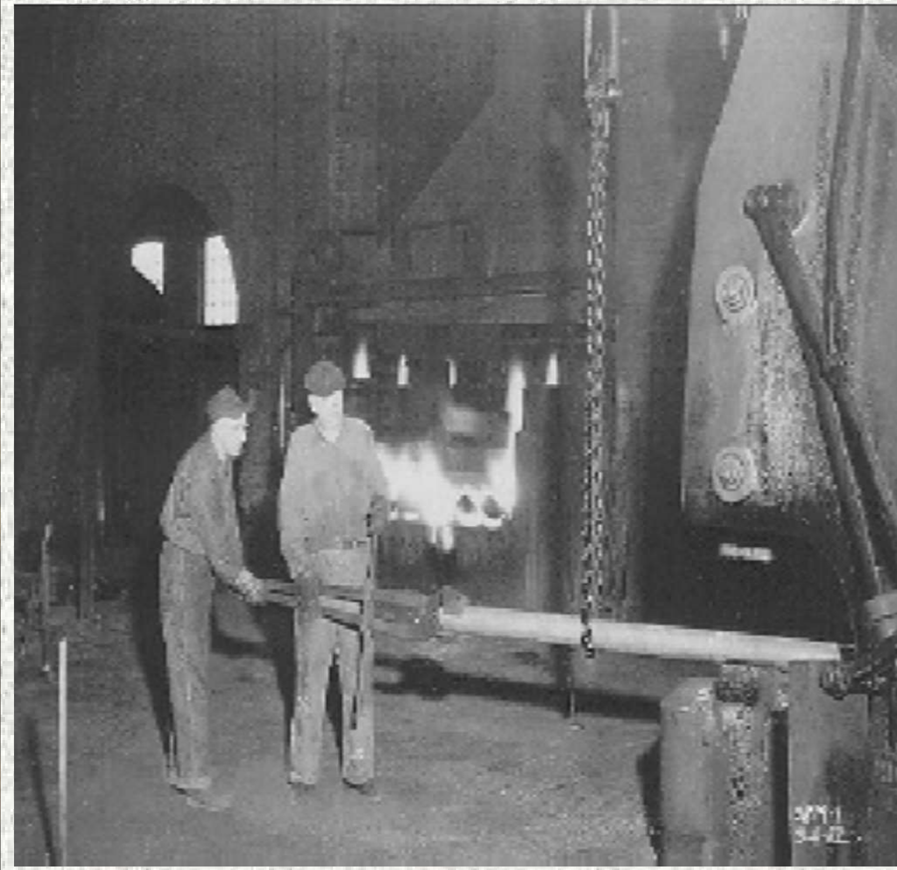
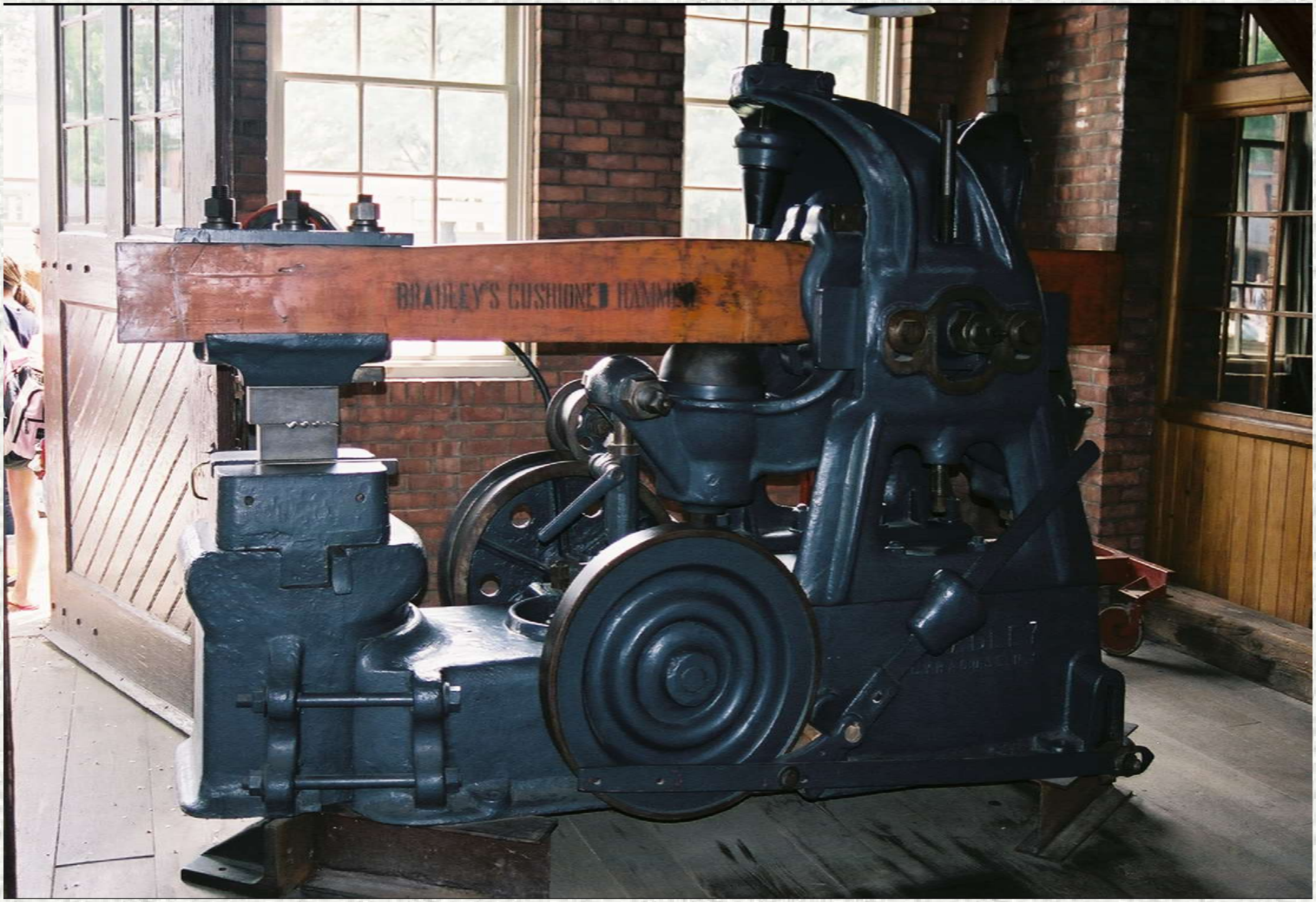


Figure 14.1 (c) general view of a 445 MN (50,000 ton) hydraulic press. *Source*: Wyman-Gordon Company.



Old Hammer Forge



Outline of Forging and Related Operations

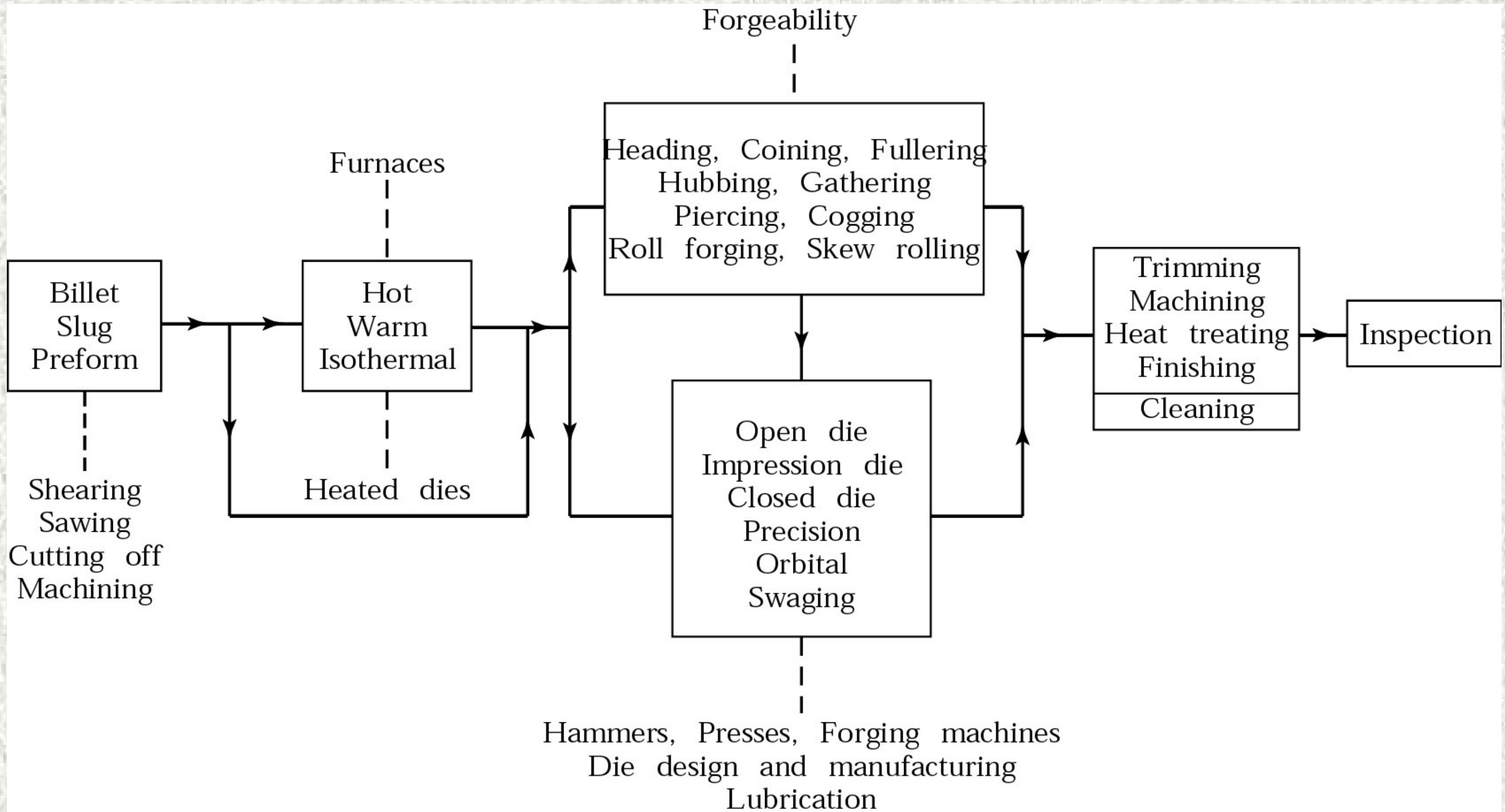


Figure 14.2

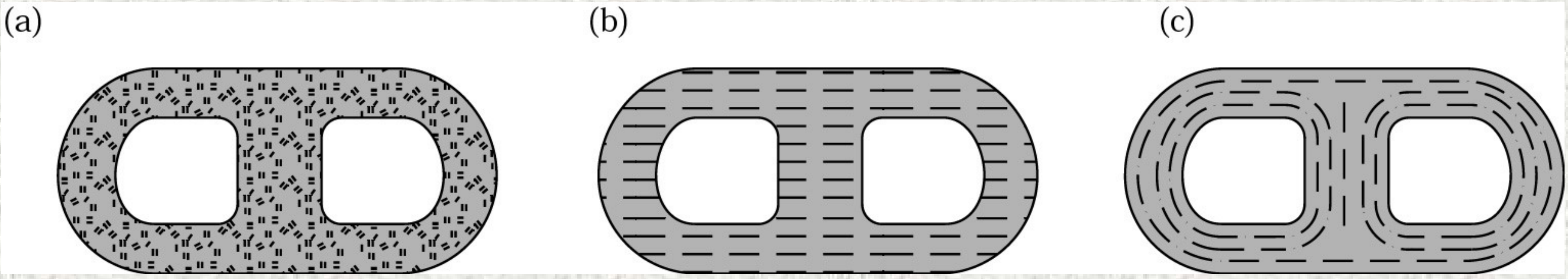
Forging steps

- Prepare slug
  - **saw**
  - **flame cut**
  - **shear**
- Clean slug surfaces
  - **shot blast**
  - **flame**
- For hot forging
  - **heat up and descale forging**
  - **make sure press is hot**
- Lubricate
  - **oil**
  - **soap**
  - **MoS_2**
  - **glass**
  - **graphite**
- Lubrication purposes
  - Reduce friction
  - Reduce die wear
  - Thermally insulate part – to keep it warm

- Forge
- Remove flash
  - **trim**
  - **machine**
- Check dimensions
- Post processing, if necessary
  - **heat treat**
  - **machine**

Grain Flow Comparison

Figure 14.3 A part made by three different processes, showing grain flow. (a) casting, (b) machining, (c) forging. *Source*: Forging Industry Association.

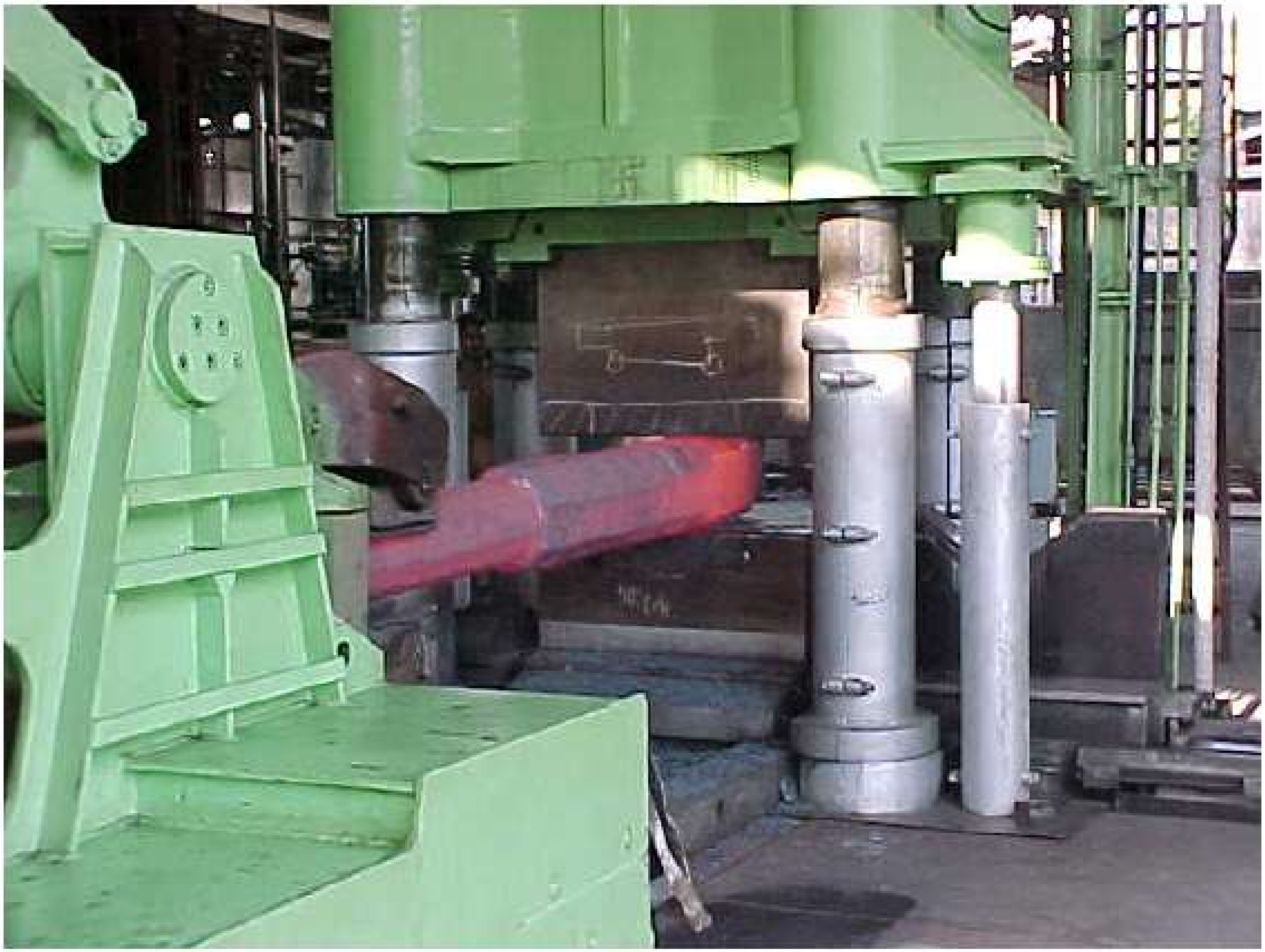


Characteristics of Forging Processes

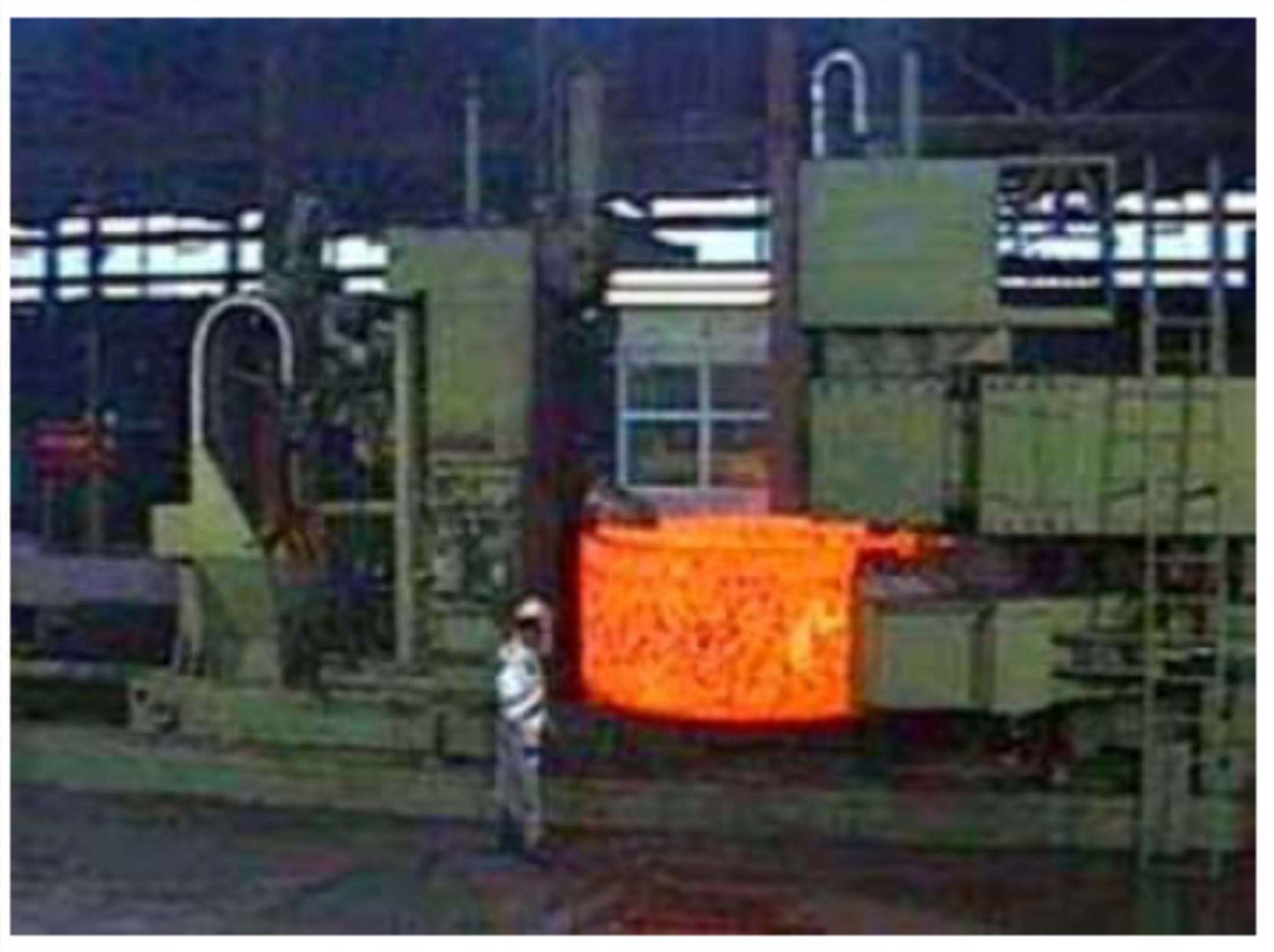
TABLE 14.1

Process	Advantages	Limitations
Open die	Simple, inexpensive dies; useful for small quantities; wide range of sizes available; good strength characteristics	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 for small quantities; machining often necessary
Blocker type	Low die costs; high production rates	Machining to final shape necessary; thick webs and large fillets necessary
Conventional type	Requires much less machining than blocker type; high production rates; good utilization of material	Somewhat higher die cost than blocker type
Precision type	Close tolerances; machining often unnecessary; very good material utilization; very thin webs and flanges possible	Requires high forces, intricate dies, and provision for removing forging from dies

Open Die Forging



Ring Forging



Upsetting

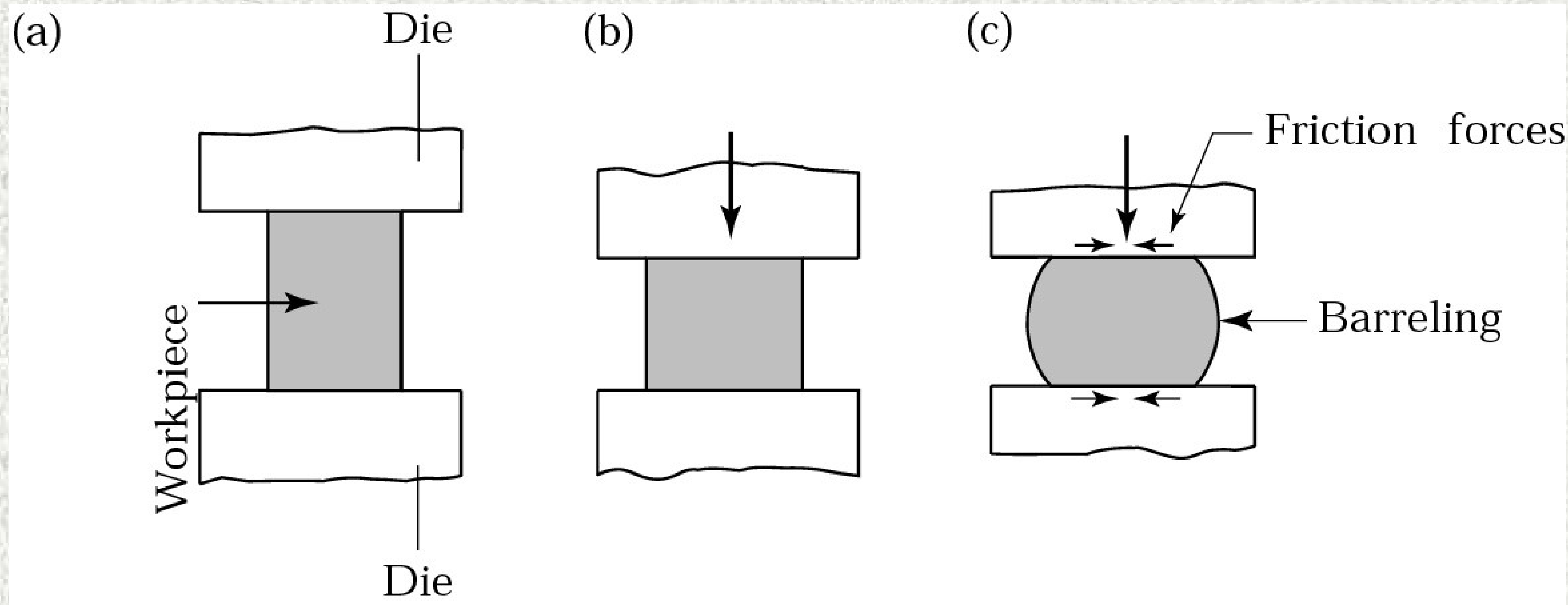


Figure 14.4 (a) Solid cylindrical billet upset between two flat dies. (b) Uniform deformation of the billet without friction. (c) Deformation with friction. Note barreling of the billet caused by friction forces at the billet-die interfaces.

Hot upsetting machine parameters

Rate size (mm) (upset diameter)	Forging force (MN)	Strokes/min	Power (kW)
25	0.5	90	5
38	1	65	10
50	2	60	15
75	4	45	25
100	6	35	40
125	8	30	50
150	10	27	60
175	13	25	90
200	16	23	110
225	20	20	150

Cogging

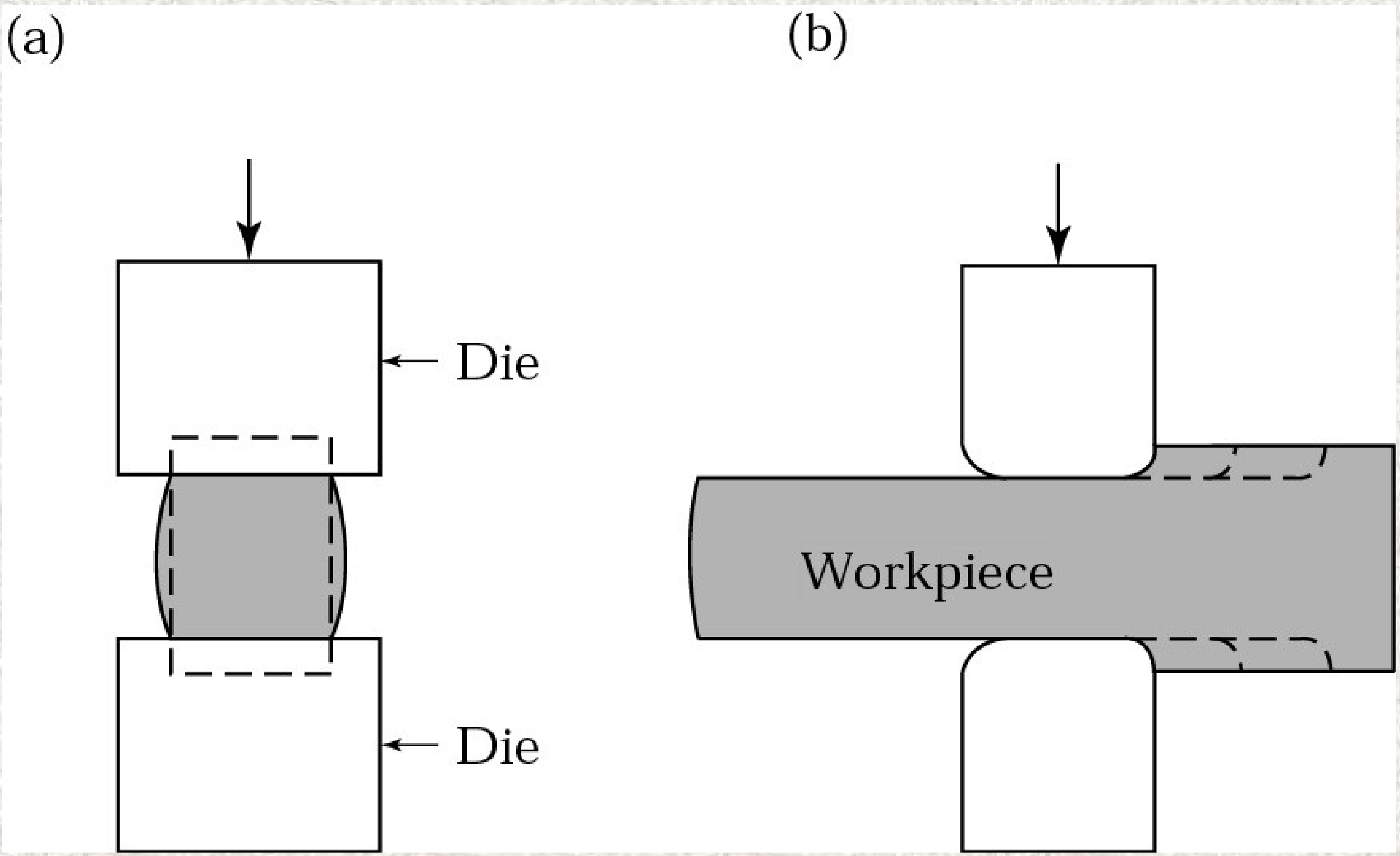


Figure 14.5 Two views of a cogging operation on a rectangular bar. Blacksmiths use this process to reduce the thickness of bars by hammering the part on an anvil. Note the barreling of the workpiece.

Impression-Die Forging

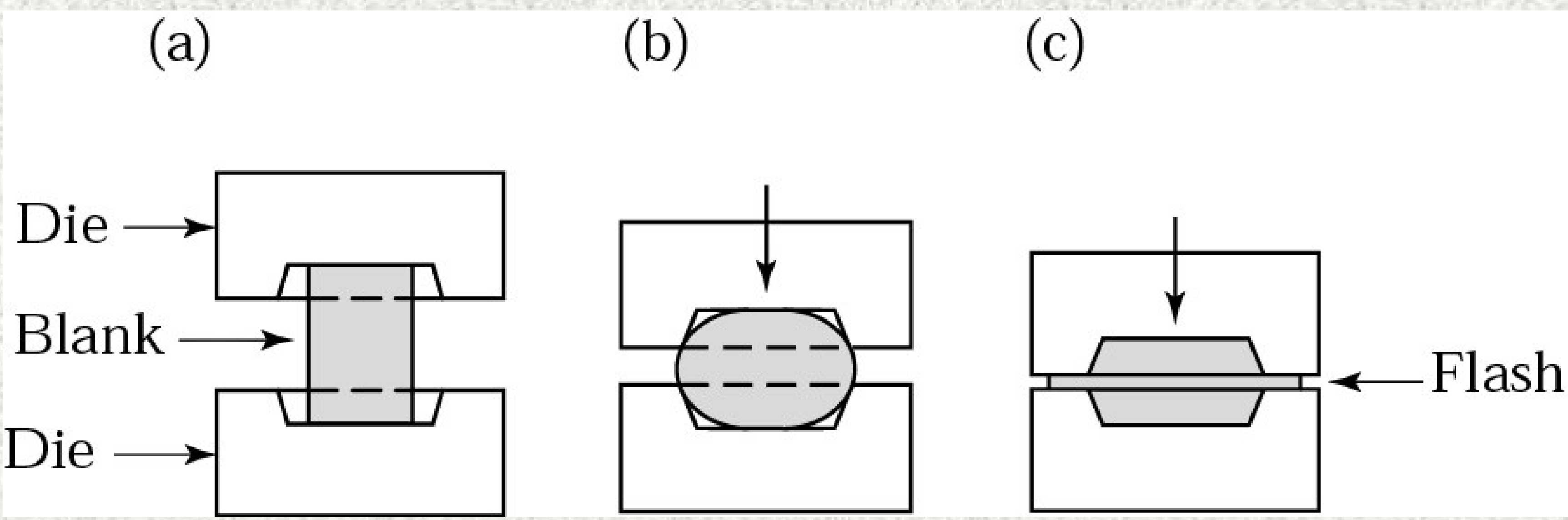
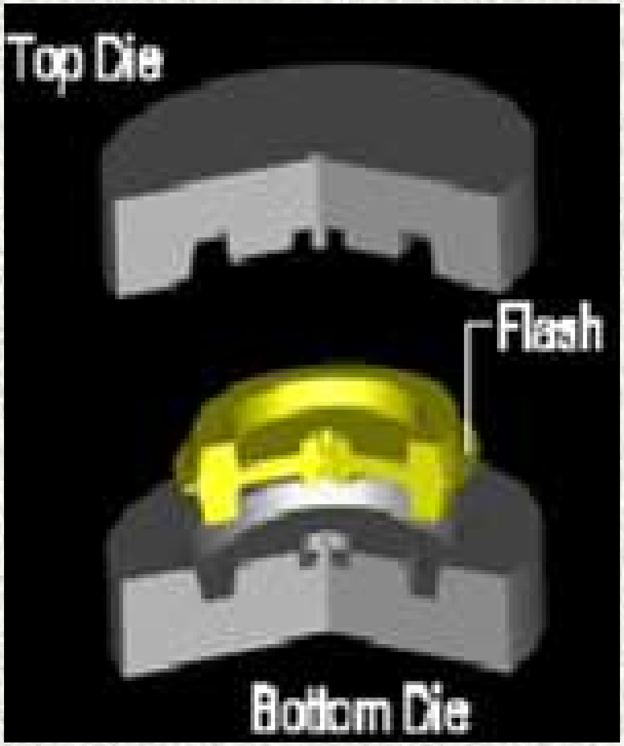
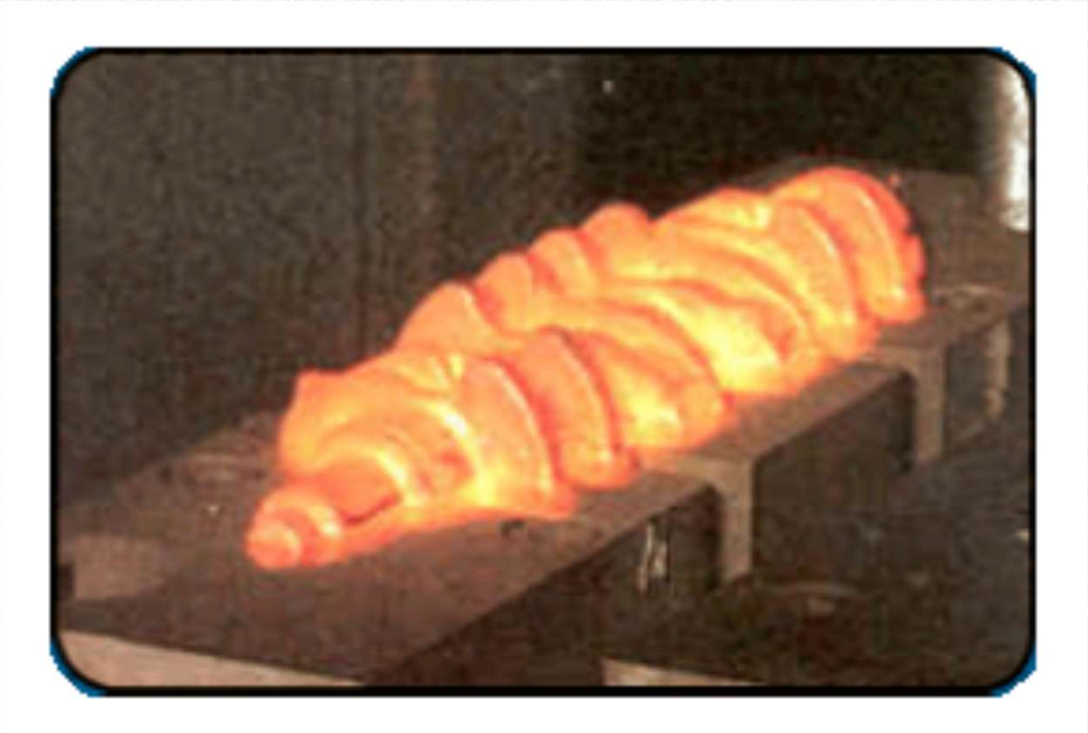


Figure 14.6 Stages in impression-die forging of a solid round billet. Note the formation of flash, which is excess metal that is subsequently trimmed off (see Fig. 14.8).

Closed Die Forging





Forging a Connecting Rod

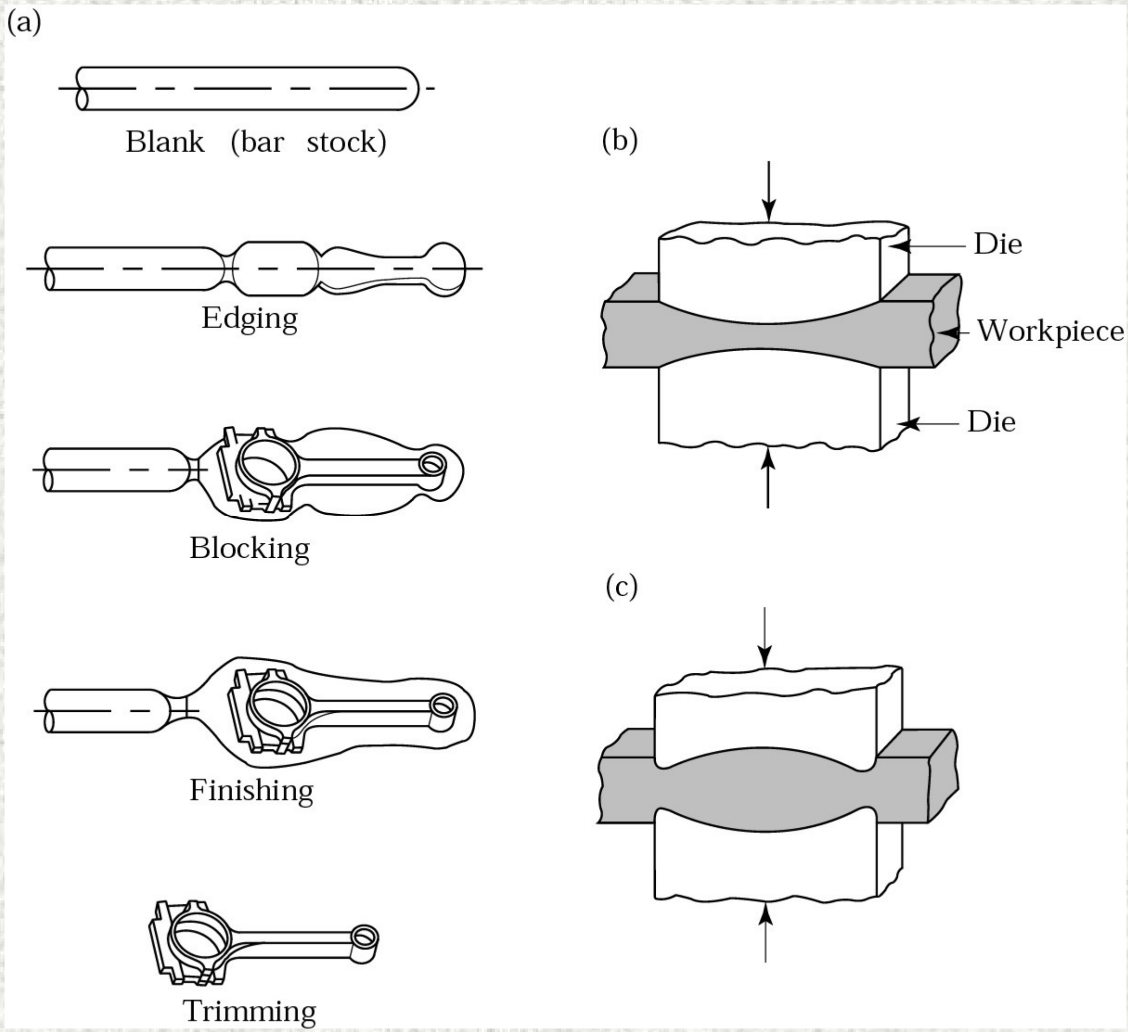
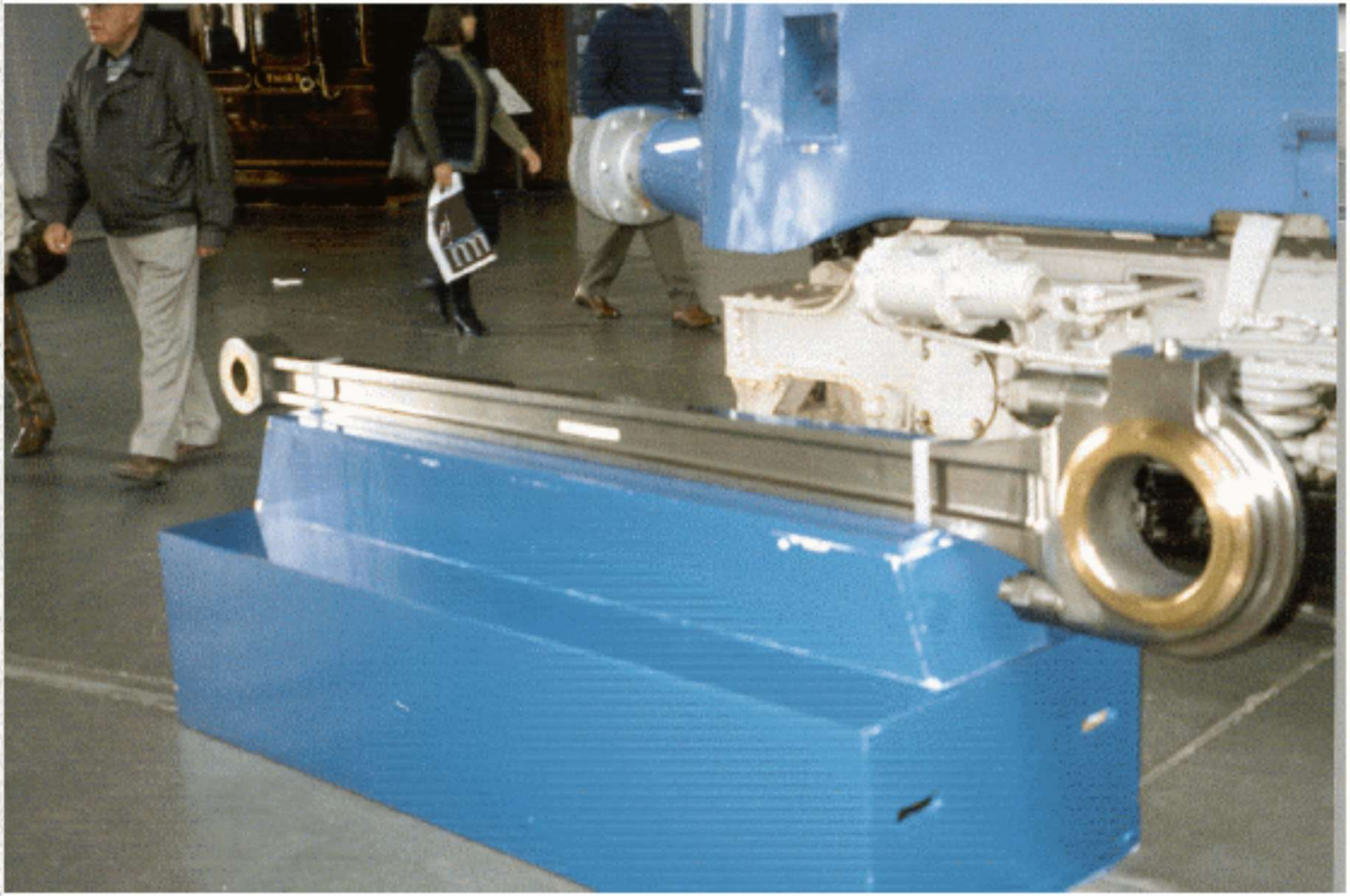


Figure 14.7 (a) Stages in forging a connecting rod for an internal combustion engine. Note the amount of flash required to ensure proper filling of the die cavities. (b) Fullering, and (c) edging operations to distribute the material when preshaping the blank for forging.

Railroad engine connecting rod



Aircraft landing gear

Trimming Flash from a Forged Part

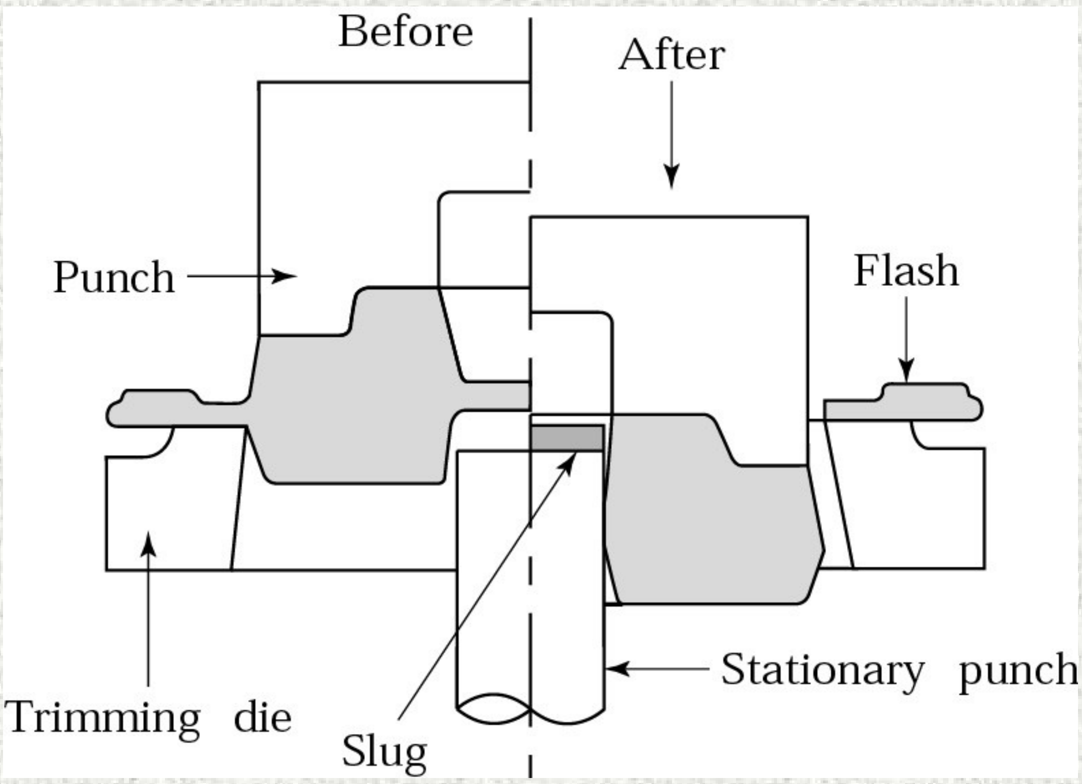


Figure 14.8 Trimming flash from a forged part. Note that the thin material at the center is removed by punching.

Comparison of Forging With and Without Flash

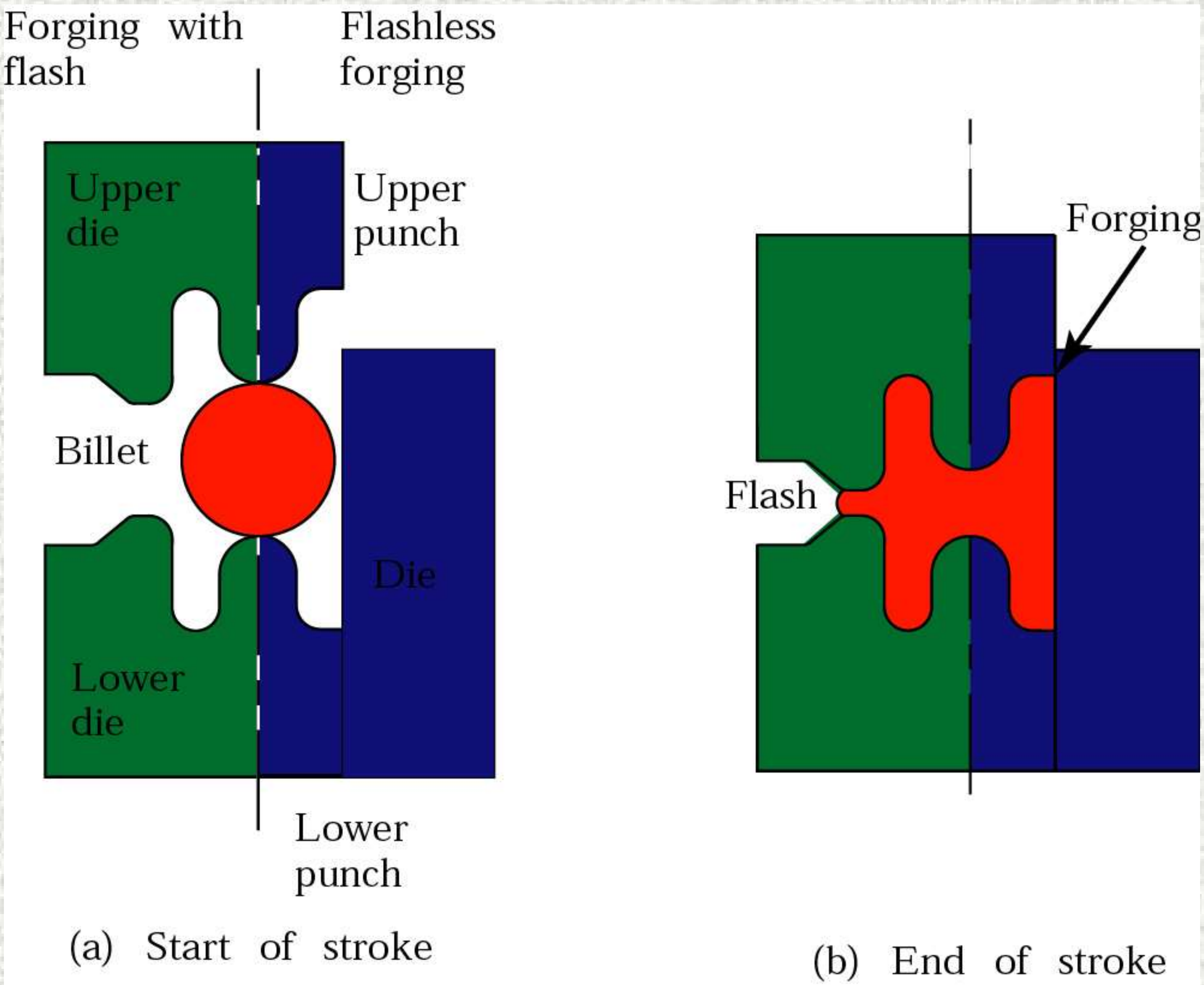
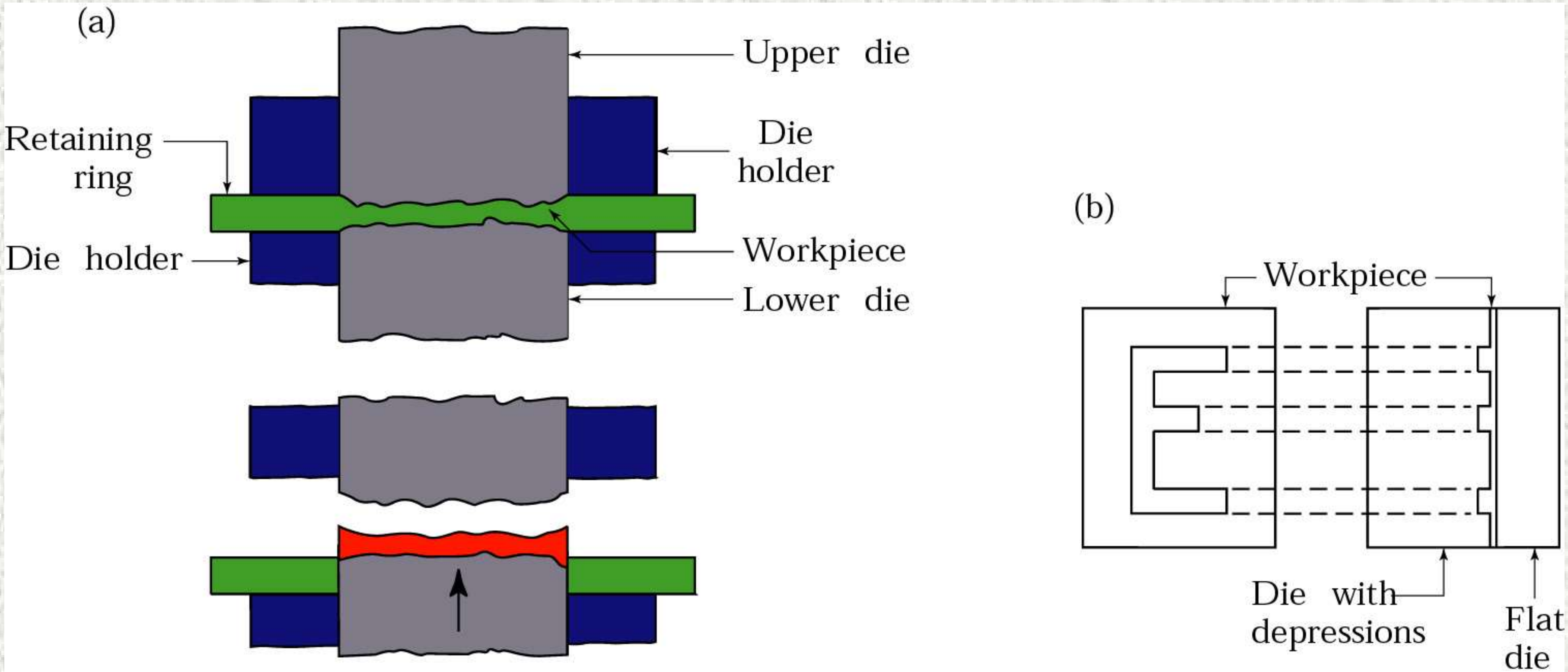


Figure 14.9 Comparison of closed-die forging to precision or flashless forging of a cylindrical billet. *Source*: H. Takemasu, V. Vazquez, B. Painter, and T. Altan.

Coining

Figure 14.10 (a) Schematic illustration of the coining process. the earliest coins were made by open-die forging and lacked sharp details. (b) An example of a coining operation to produce an impression of the letter E on a block of metal.



Range of *k* Values for Equation $F=kY_fA$

TABLE 14.2

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

Heading/Upset Forging

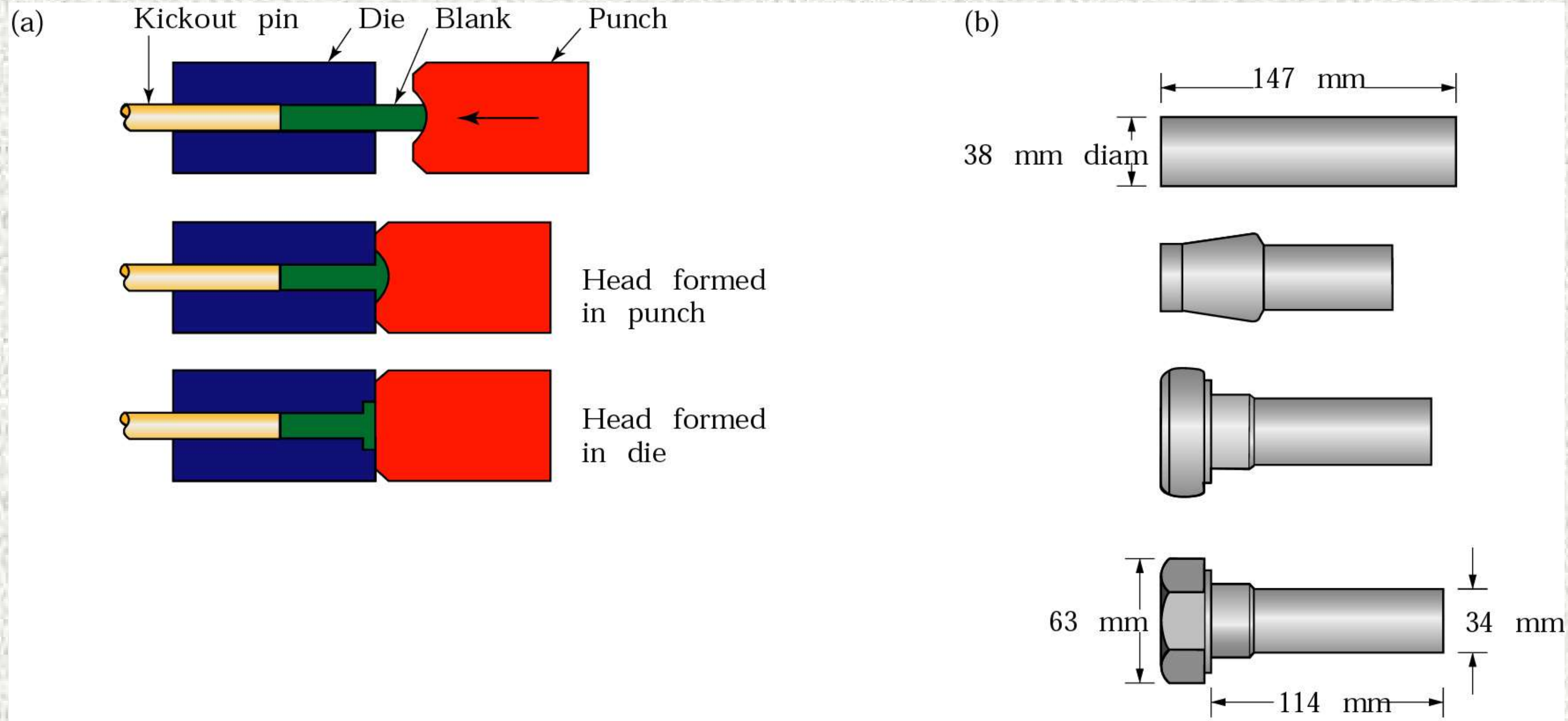


Figure 14.11 (a) Heading operation, to form heads on fasteners such as nails and rivets. (b) Sequence of operations to produce a bolt head by heading.

Grain Flow Pattern of Pierced Round Billet

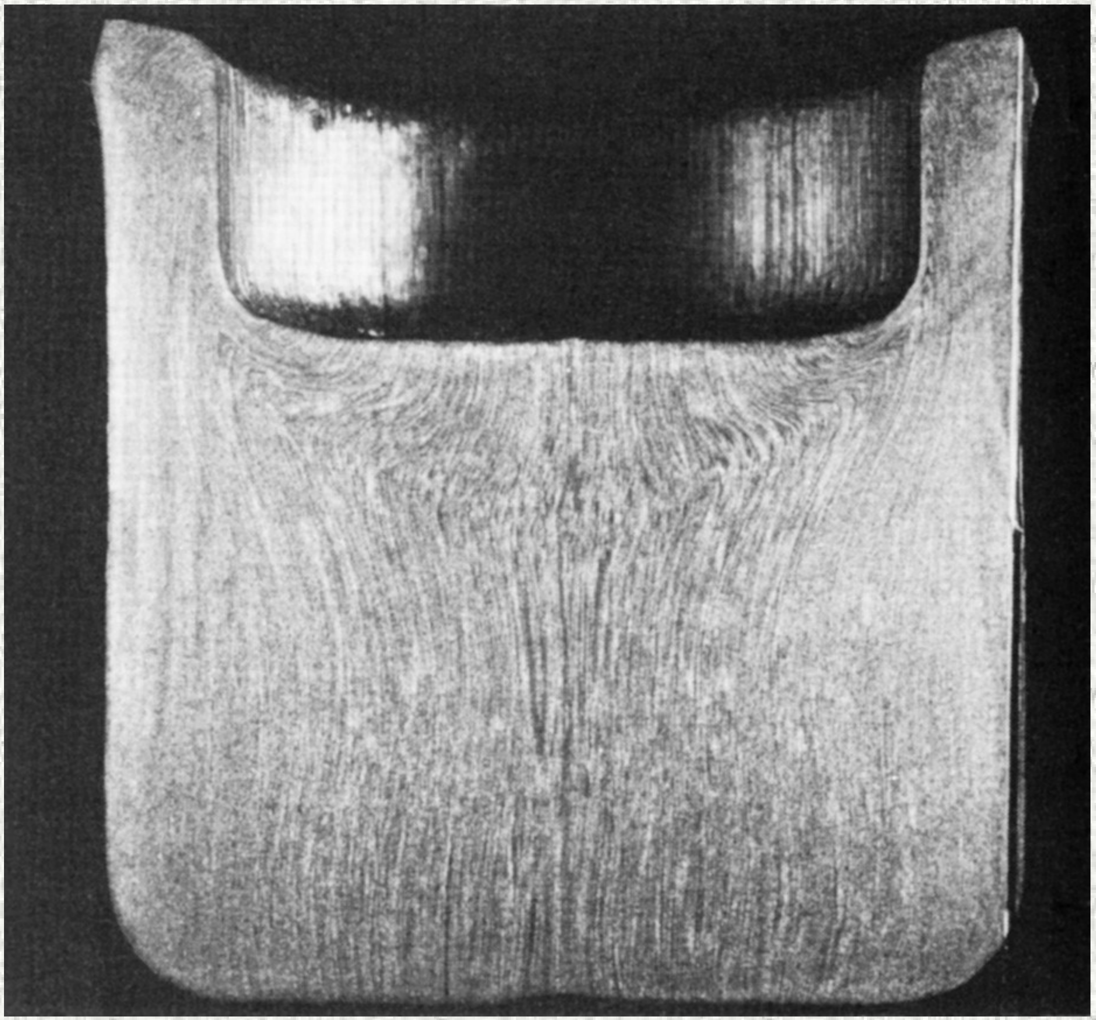


Figure 14.12 A pierced round billet, showing grain flow pattern. *Source*: Courtesy of Ladish Co., Inc.

Grain Flow Lines

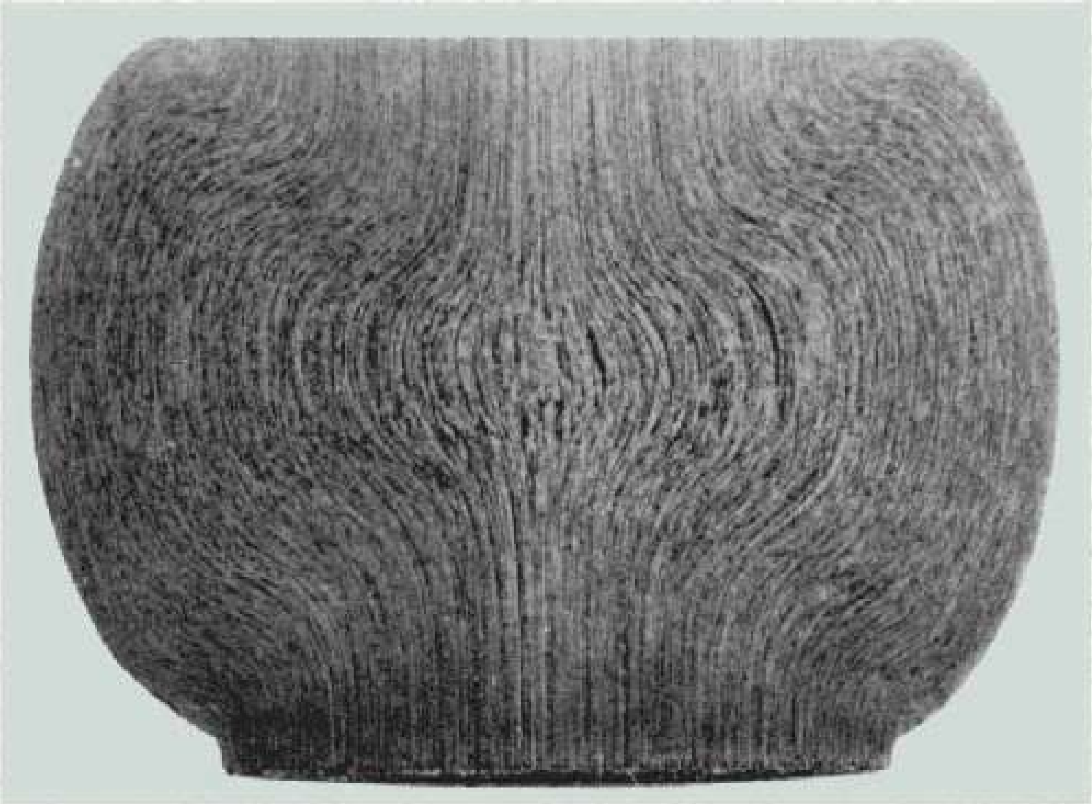
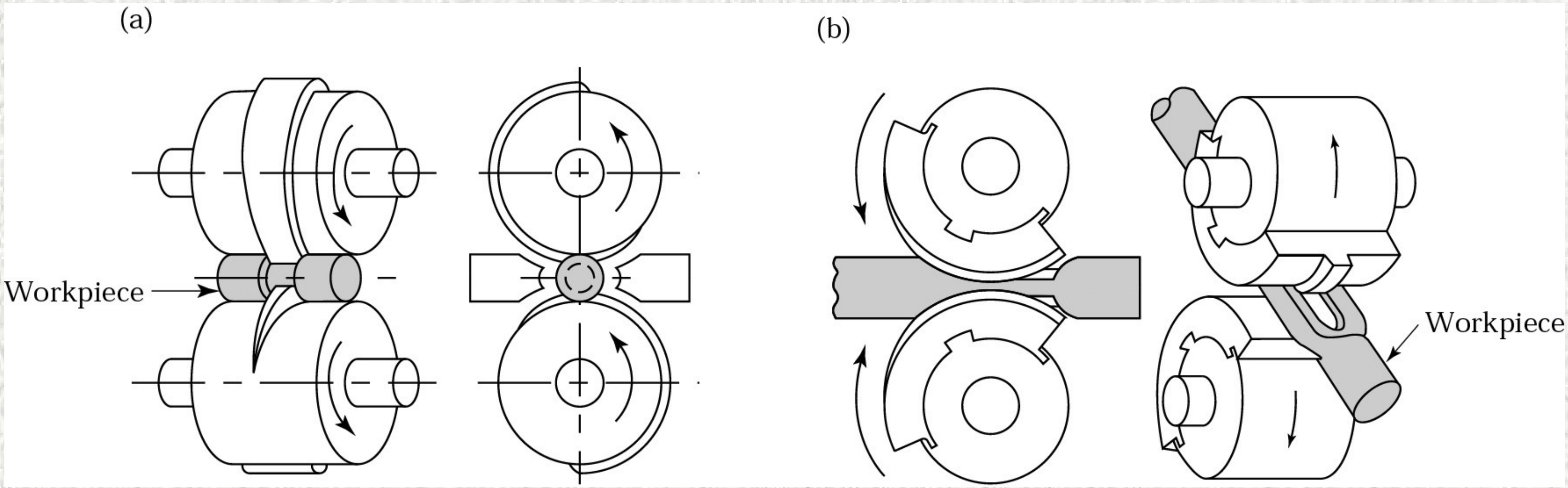


FIGURE 6.2 Grain flow lines in upsetting a solid steel cylinder at elevated temperatures. Note the highly inhomogenous deformation and barreling. The differnet shape of the botte, section of the specemen (as compared with the top) results from the hot specimenresting on the lower, cool die before deformation proceeded. The bottom surface was chilled; thus it exhibits greater strength and hence deforms less than the top surface. *Source*: J. A. Schey et al., IIT Research Institute.

Roll-Forging

Figure 14.13 Two examples of the roll-forging operation, also known as *cross-rolling*. Tapered leaf springs and knives can be made by this process. *Source*: (a) J. Holub; (b) reprinted with permission of General Motors Corporation.



Production of Bearing Blanks

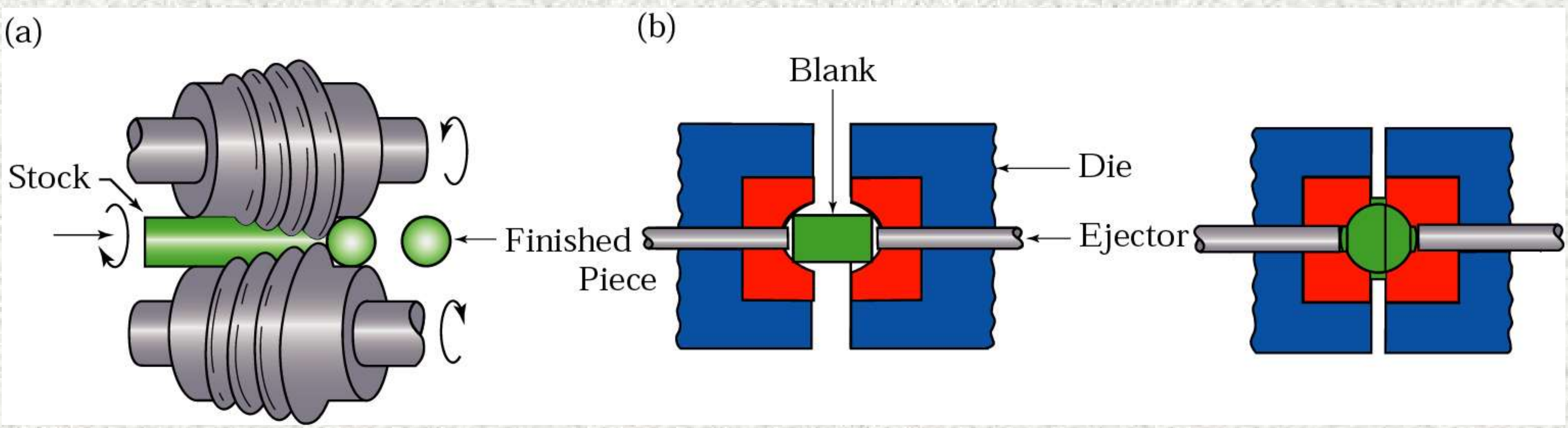
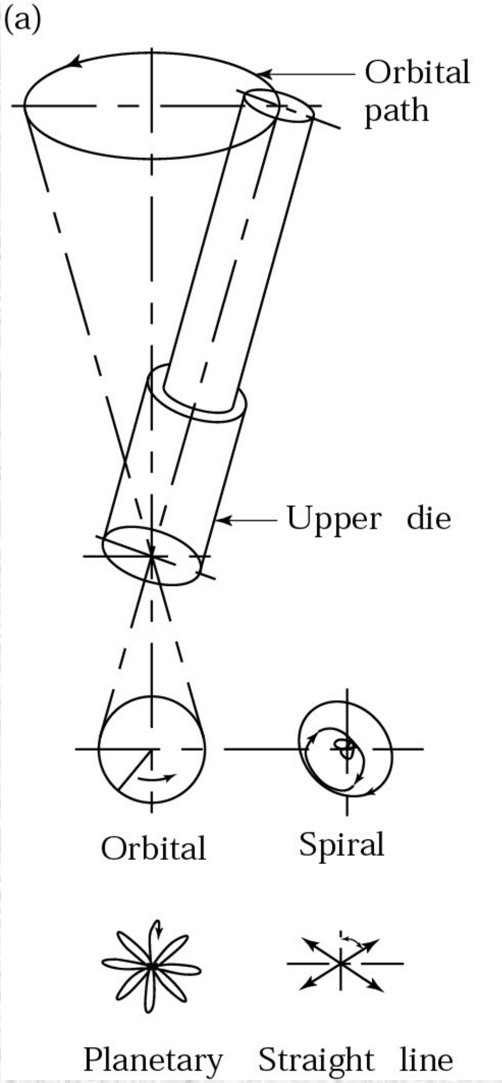


Figure 14.14 (a) Production of steel balls by the skew-rolling process. (b) Production of steel balls by upsetting a cylindrical blank. Note the formation of flash. The balls made by these processes are subsequently ground and polished for use in ball bearings (see Sections 25.6 and 25.10).

Orbital Forging



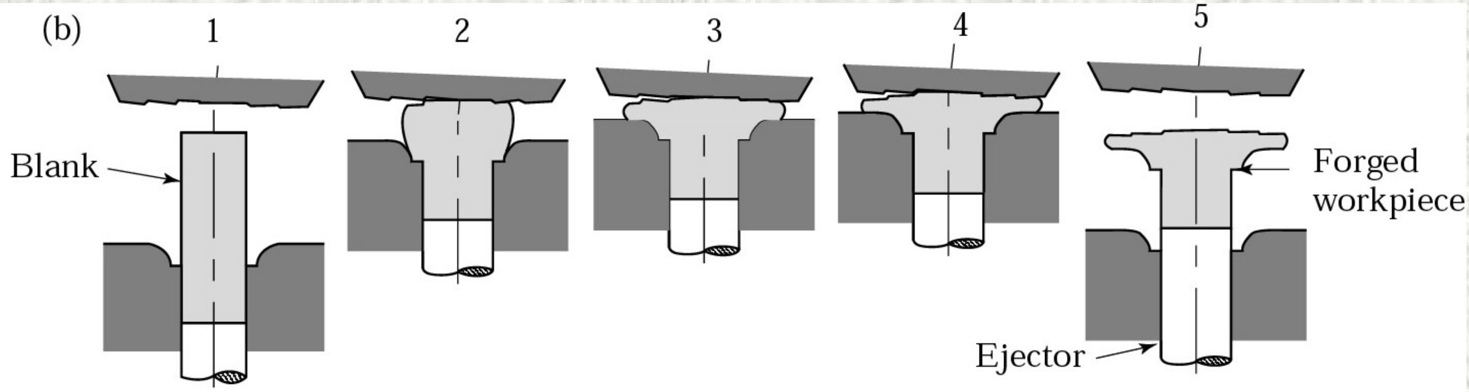


Figure 14.15 (a) Various movements of the upper die in orbital forging (also called rotary, swing, or rocking-die forging); the process is similar to the action of a mortar and pestle. (b) An example of orbital forging. Bevel gears, wheels, and rings for bearings can be made by this process.

Swaging

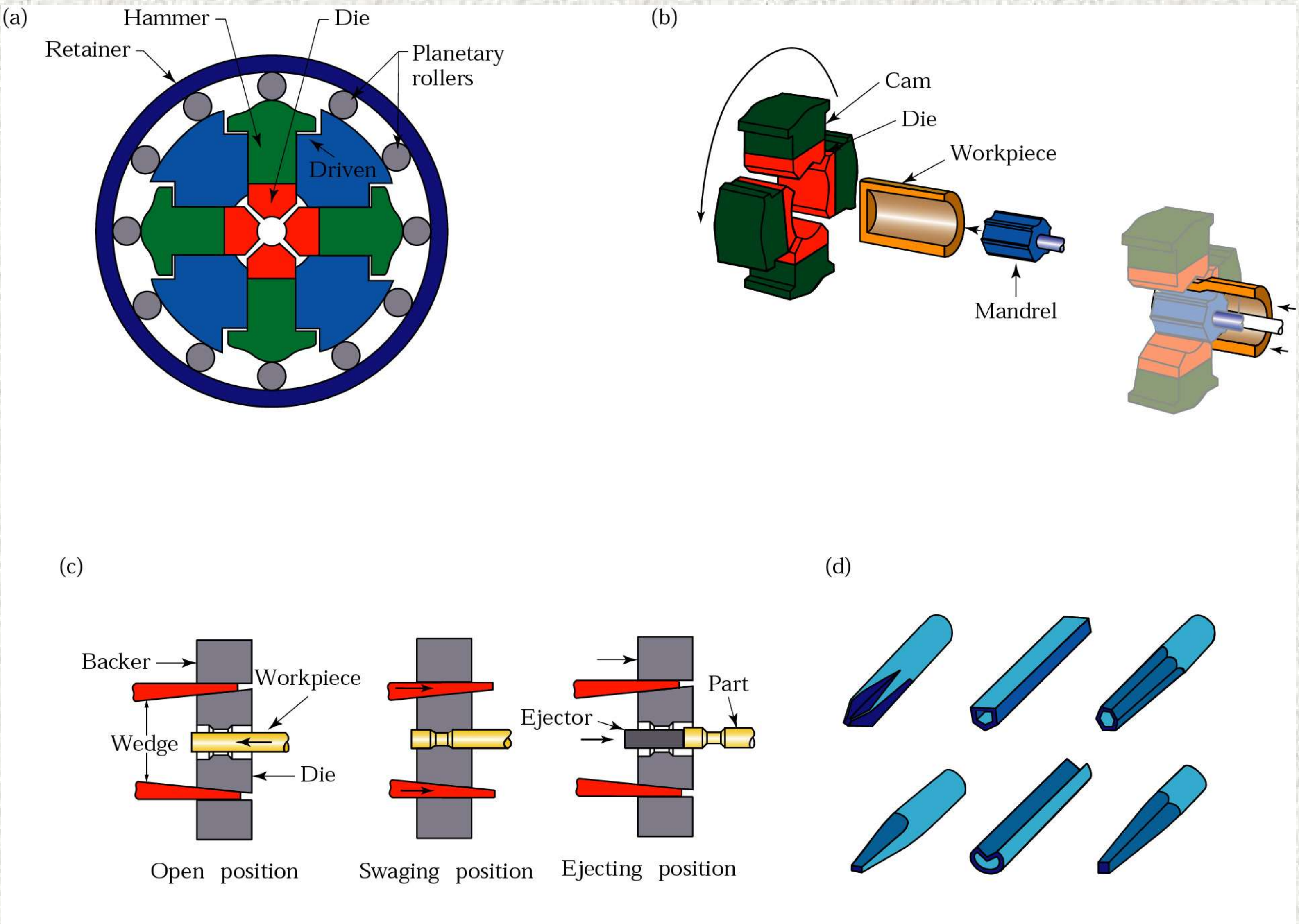


Figure 14.16 (a) Schematic illustration of the rotary-swaging process. (b) Forming internal profiles on a tubular workpiece by swaging. (c) A die-closing type swaging machine, showing forming of a stepped shaft. (d) Typical parts made by swaging.

Swaging of Tubes With and Without a Mandrel

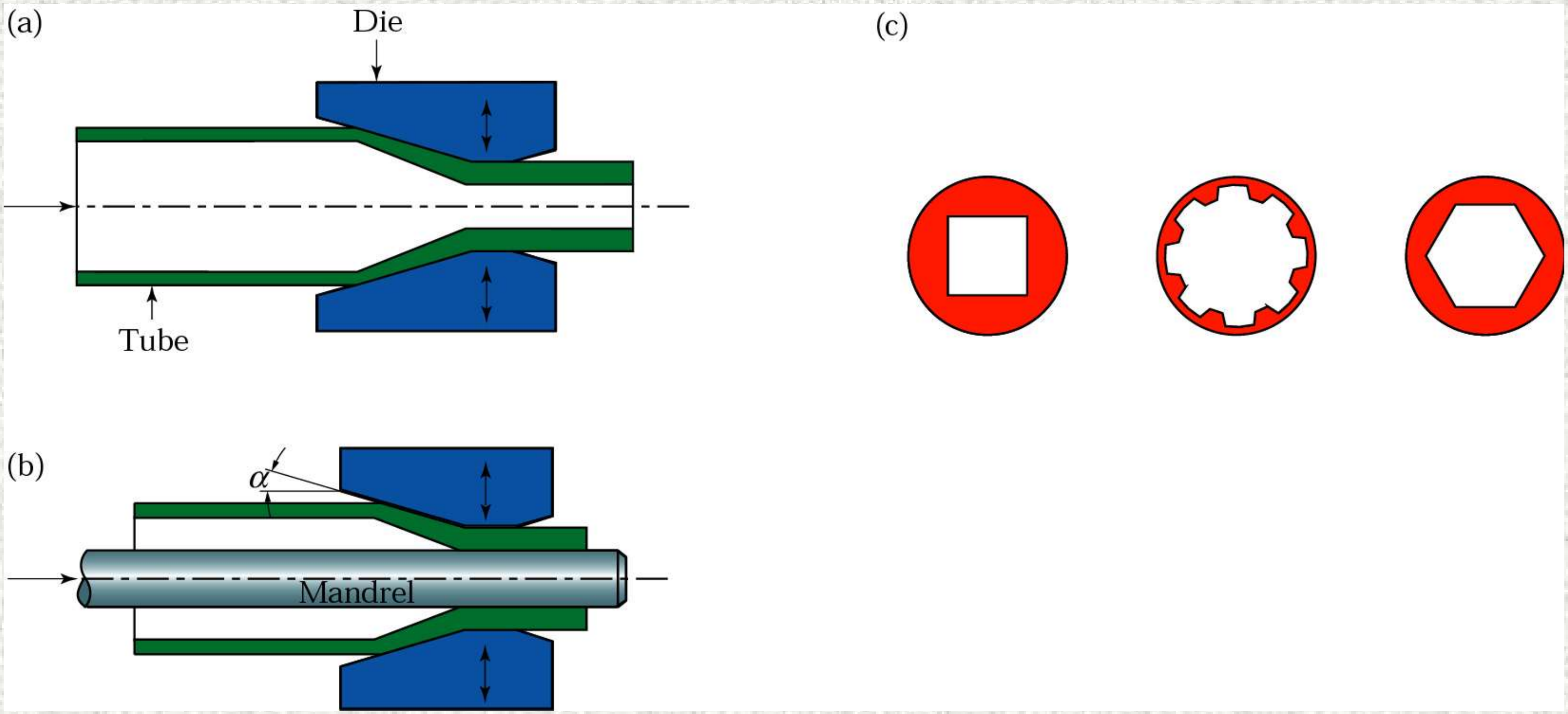


Figure 14.17 (a) Swaging of tubes without a mandrel; not the increase in wall thickness in the die gap. (b) Swaging with a mandrel; note that the final wall thickness of the tube depends on the mandrel diameter. (c) Examples of cross-sections of tubes produced by swaging on shaped mandrels. Rifling (spiral grooves) in small gun barrels can be made by this process.

Impression-Forging Die and Die Inserts

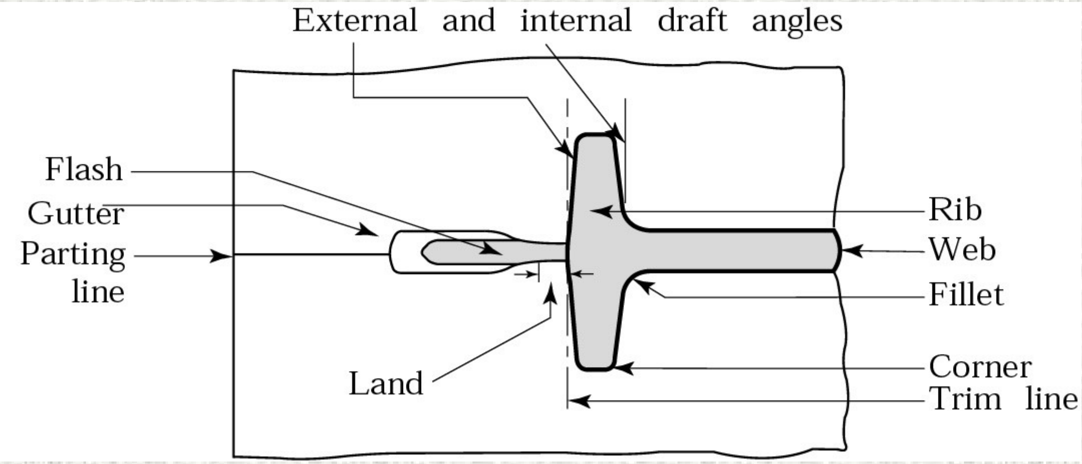


Figure 14.18 Standard terminology for various features of a typical impression-forging die.

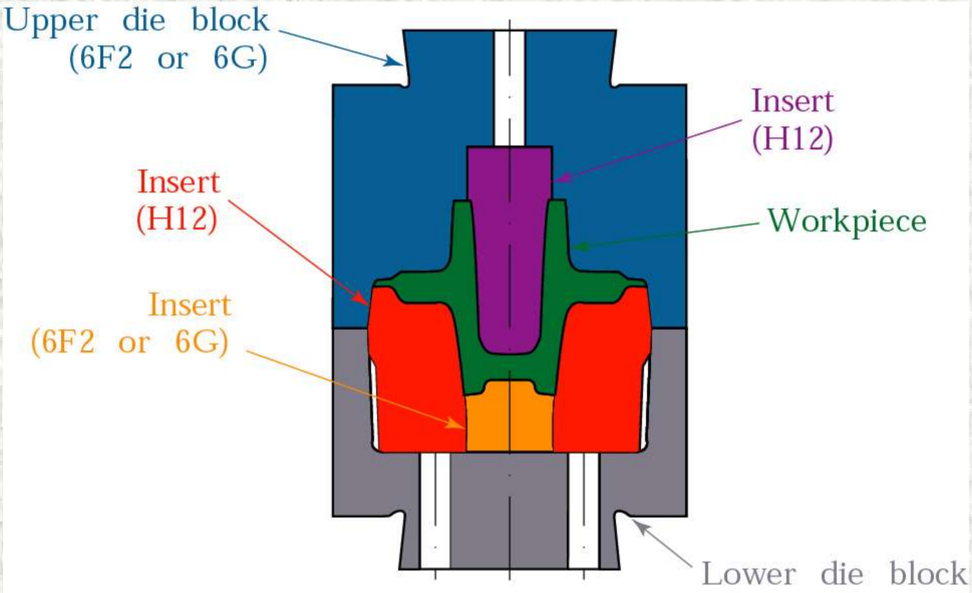


Figure 14.19 Die inserts used in dies for forging an automotive axle housing. (See Tables 5.5 to 5.7 for die materials.) *Source*: *Metals Handbook, Desk Edition*. ASM International, Metals Park, Ohio, 1985. Used with permission.

Classification of Metals in Decreasing Order of Forgeablilty

TABLE 14.3

Metal or alloy	Approximate range of hot forging temperature (°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-base superalloys	1050–1180
Cobalt-base superalloys	1180–1250
Tantalum alloys	1050–1350
Molybdenum alloys	1150–1350
Nickel-base superalloys	1050–1200
Tungsten alloys	1200–1300

Defects in Forged Parts

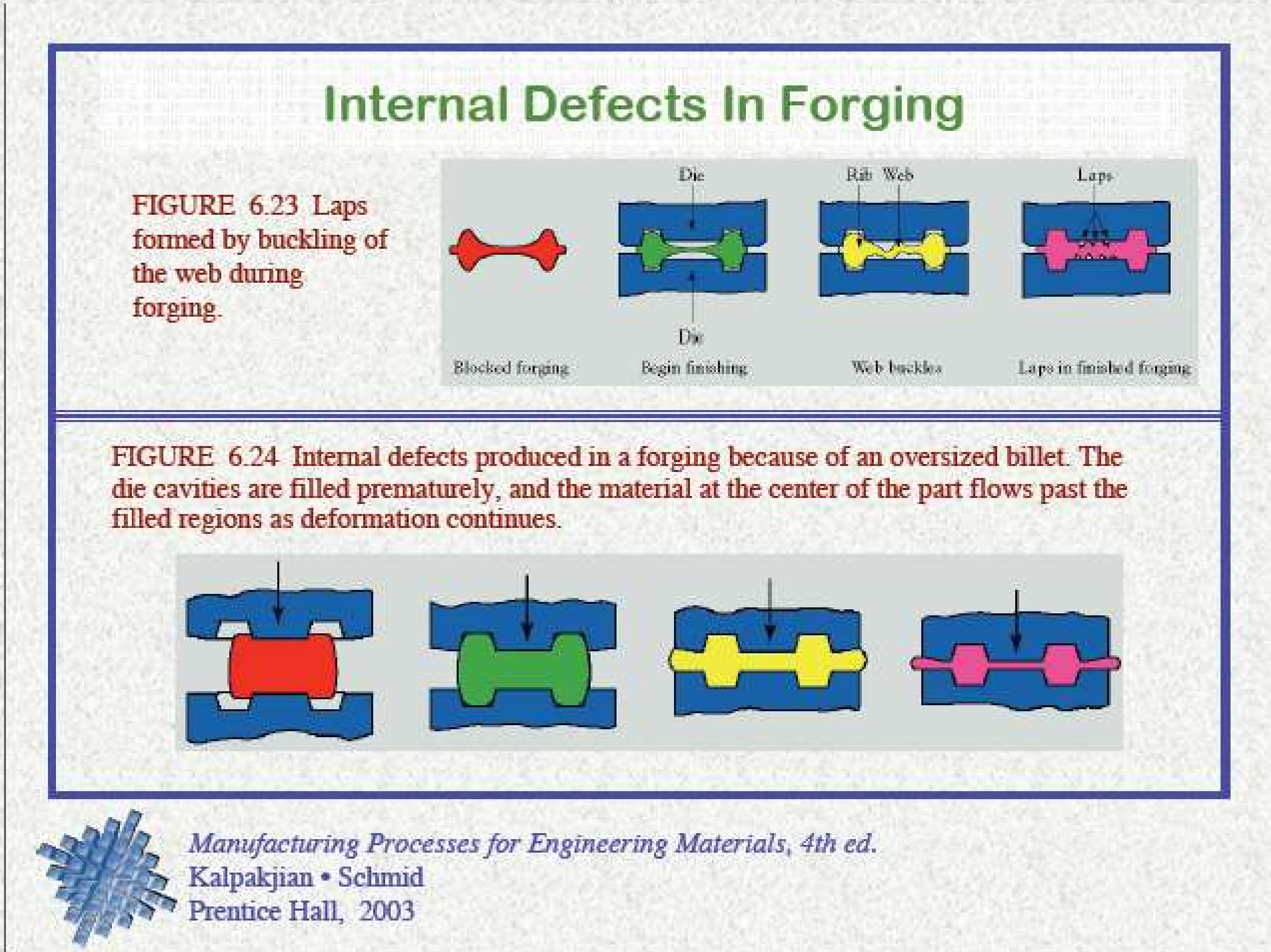


Figure 14.20 Examples of defects in forged parts. (a) Laps formed by web buckling during forging; web thickness should be increased to avoid this problem. (b) Internal defects caused by oversized billet; die cavities are filled prematurely, and the material at the center flows past the filled regions as the dies close.

Defect Formation In Forging

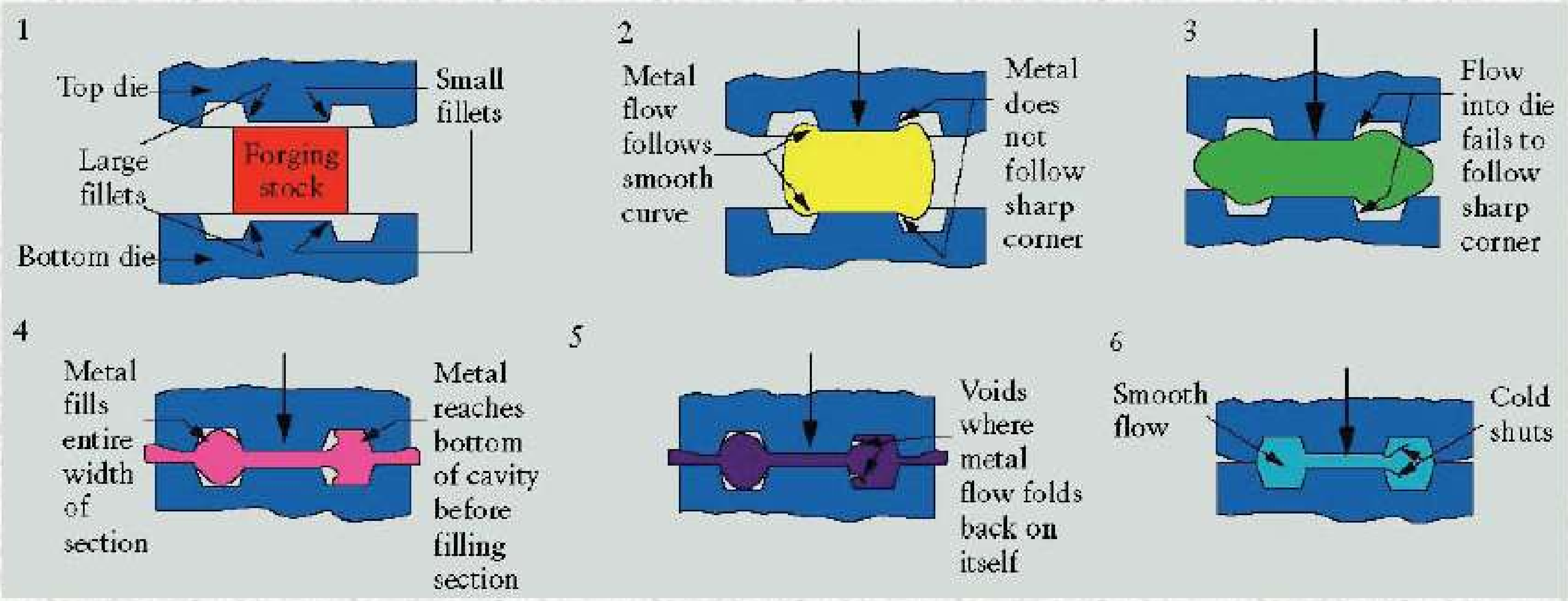


FIGURE 6.25 Effect of fillet radius on defect formation in forging. Small fillets (right side of drawings) cause the defects. *Source*: Aluminum Company of America.

Speed Range of Forging Equipment

TABLE 14.4

Equipment	m/s
Hydraulic press	0.06–0.30
Mechanical press	0.06–1.5
Screw press	0.6–1.2
Gravity drop hammer	3.6–4.8
Power drop hammer	3.0–9.0
Counterblow hammer	4.5–9.0

Principles of Various Forging Machines

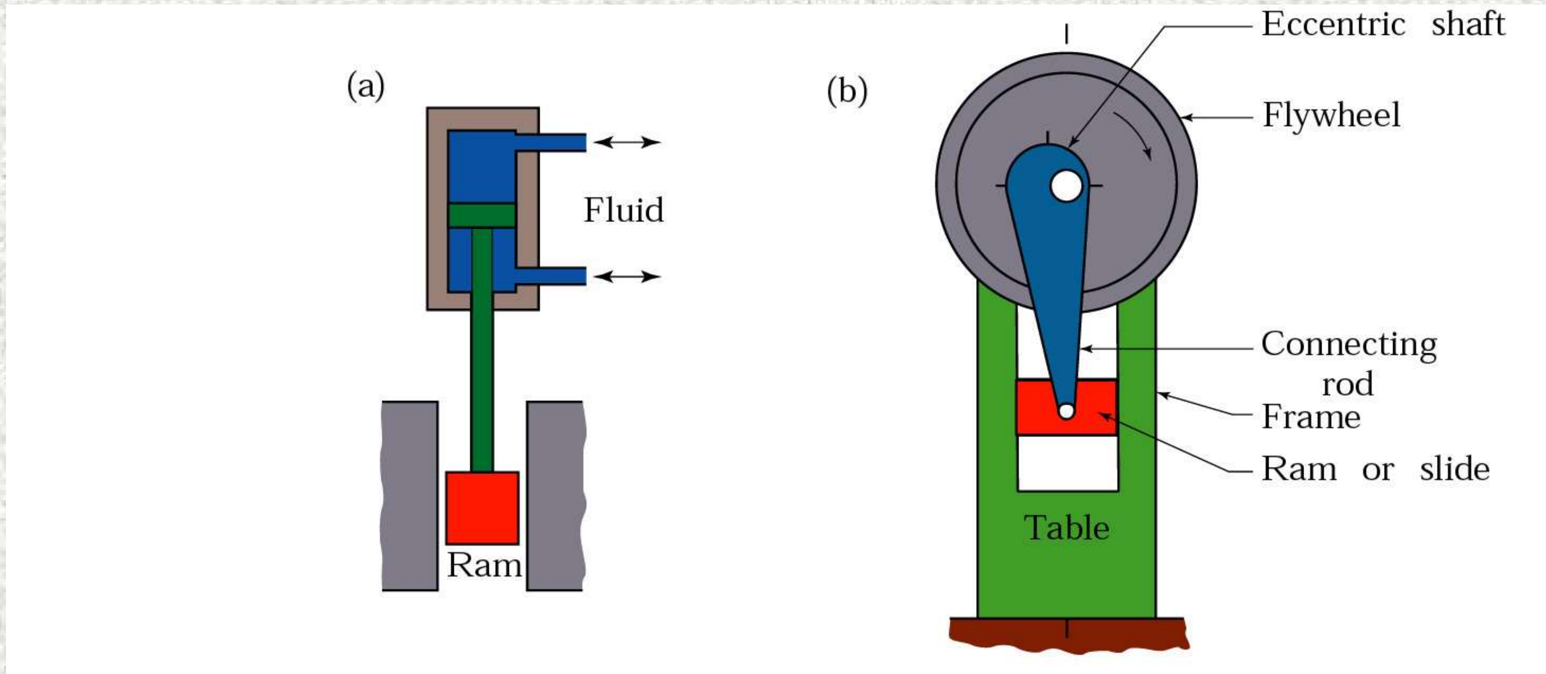


Figure 14.21 Schematic illustration of the principles of various forging machines. (a) Hydraulic press. (b) Mechanical press with an eccentric drive; the eccentric shaft can be replaced by a crankshaft to give the up-and-down motion to the ram. (continued)

Principles of Various Forging Machines (cont.)

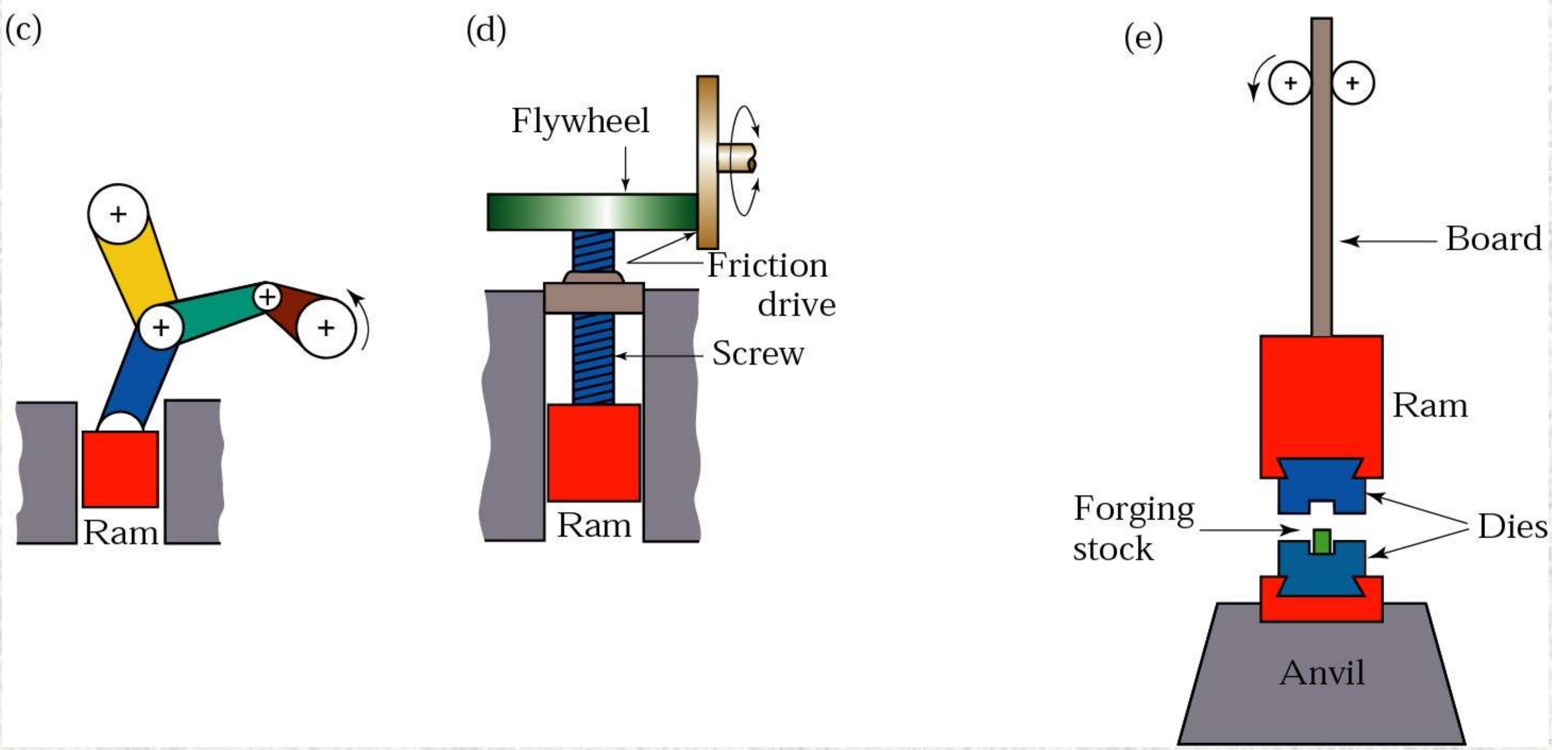


Figure 14.21 (continued) Schematic illustration of the principles of various forging machines. (c) Knuckle-joint press. (d) Screw press. (e) Gravity drop hammer.

Forging hammer capabilities

	Moving mass (kg)	Energy at strike (J)
Gravity drop hammers	500 - 5,000	6,000 - 75,000
Power drop hammers	500 - 18,000	18,000 - 600,000
High energy rate forming		500,000 - 5,000,000

Forging press parameters

	Load capacity	Strokes per minute	Power (kW)
Mechanical presses			
Open-back, inclinable	150 - 1,250 kN	200 - 100	3 - 15
High-speed, straight side	300 - 2,000 KN	2000 - 200	
Larger straight side	1 - 6 MN	100 - 20	10 - 60
Transfer presses	2 - 40 MN	50 - 10	
Forging presses	3 - 80 MN	100 - 30	20 - 500
Hydraulic presses			
Universal	4 - 25 MN		
Forging presses	2 - 500 MN		150 - 1000

Unit Cost in Forging

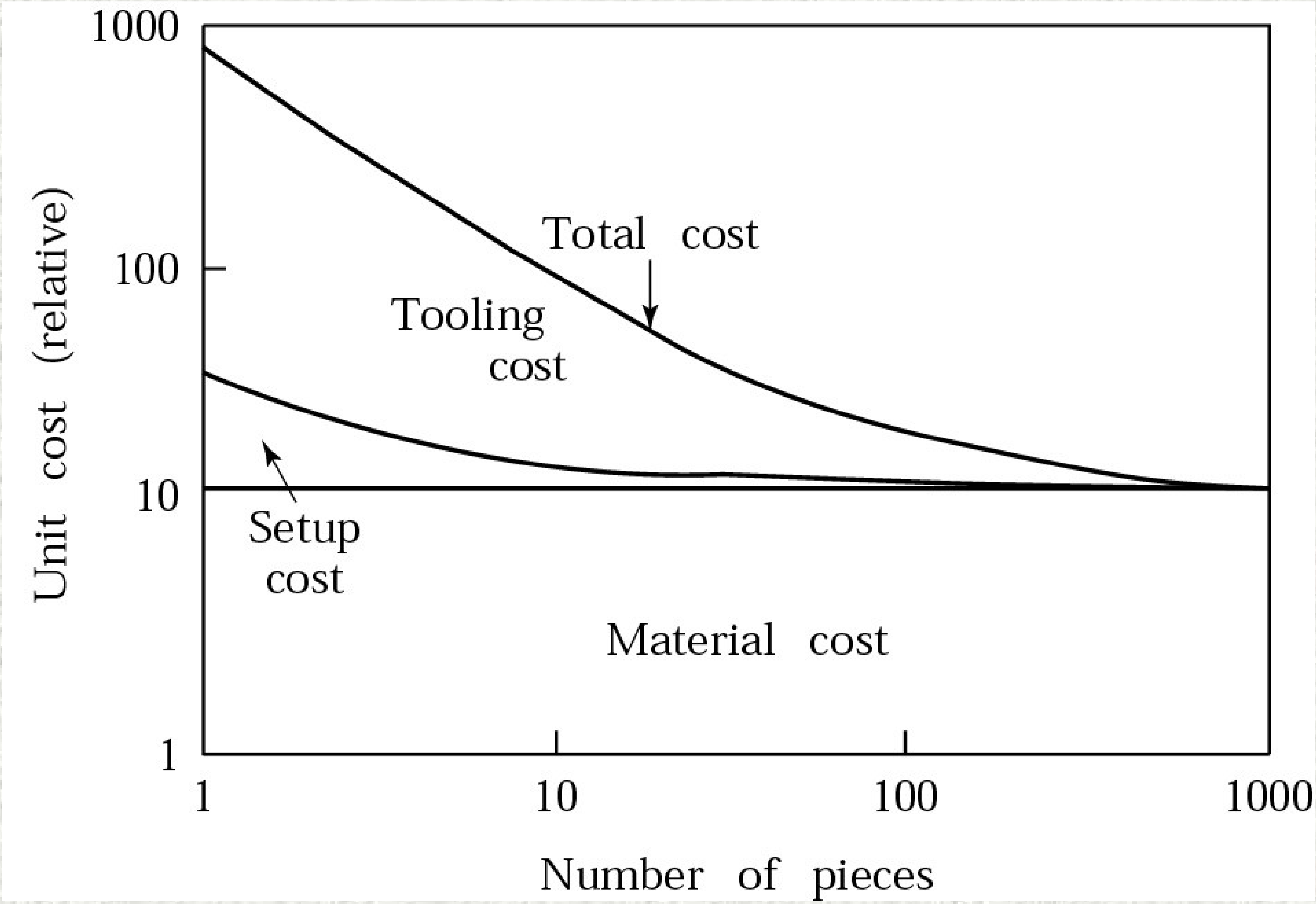


Figure 14.22 Typical unit cost (cost per piece) in forging; note how the setup and the tooling costs per piece decrease as the number of pieces forged increases, if all pieces use the same die.

Relative Unit Costs of a Small Connecting Rod

Figure 14.23 Relative unit costs of a small connecting rod made by various forging and casting processes. Note that, for large quantities, forging is more economical. Sand casting is the more economical process for fewer than about 20,000 pieces.