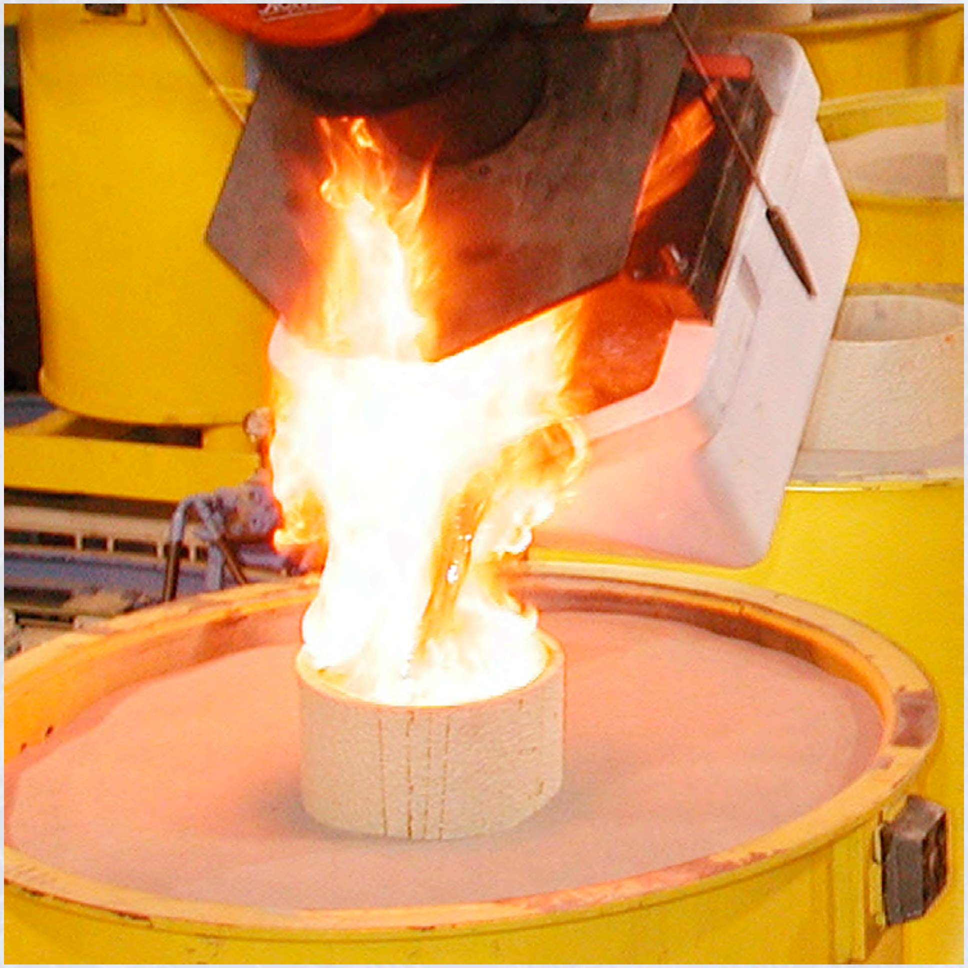
Chapter 11

Metal-Casting Processes



Summary of Casting Processes

TABLE 11.1

Summary of Casting Processes

Process	Advantages	Limitations
Sand	Almost any metal castl no limit to part size, shape or weight; low tooling cost	Some finishing required; relatively coarse surface finish; wide tolerances
Shell mold	Good dimensional accuracy and surface finish; high production rate	Part size limited; expensive patterns and equipment
Evaporative pattern	Most metals cast with no limit to size; complex part shapes	Patterns have low strength and can be costly for low quantitites
Plaster mold	Intricate part shapes; good dimensional accuracy and sutface finish; low porosity	Limited to nonferrous metals; limited part size and volume of production; mold-making time relatively long
Ceramic mold	Intricate part shapes; close-toleranve parts; good surface finish	Limited part size
Investment	Intricate part shapes; excellent surface finish and accuracy; almost any metal cast	Part size limited; expensive patterns, molds and labor
Permanent mold	Good surface finish and dimensional accuracy; low porosity; high production rate	High mold cost; limited part shape and complexity; not suitable for high-melting-point metals
Die	Excellent dimensional accuracy and surface finish; high production rate	High die cost; limited part size; generally limited to nonferrous metals; long lead time
Centrifugal	Large cylindrical or tubular parts with good quality; high production rate	Expensive equipment; limited part shape

Typical Cast Parts

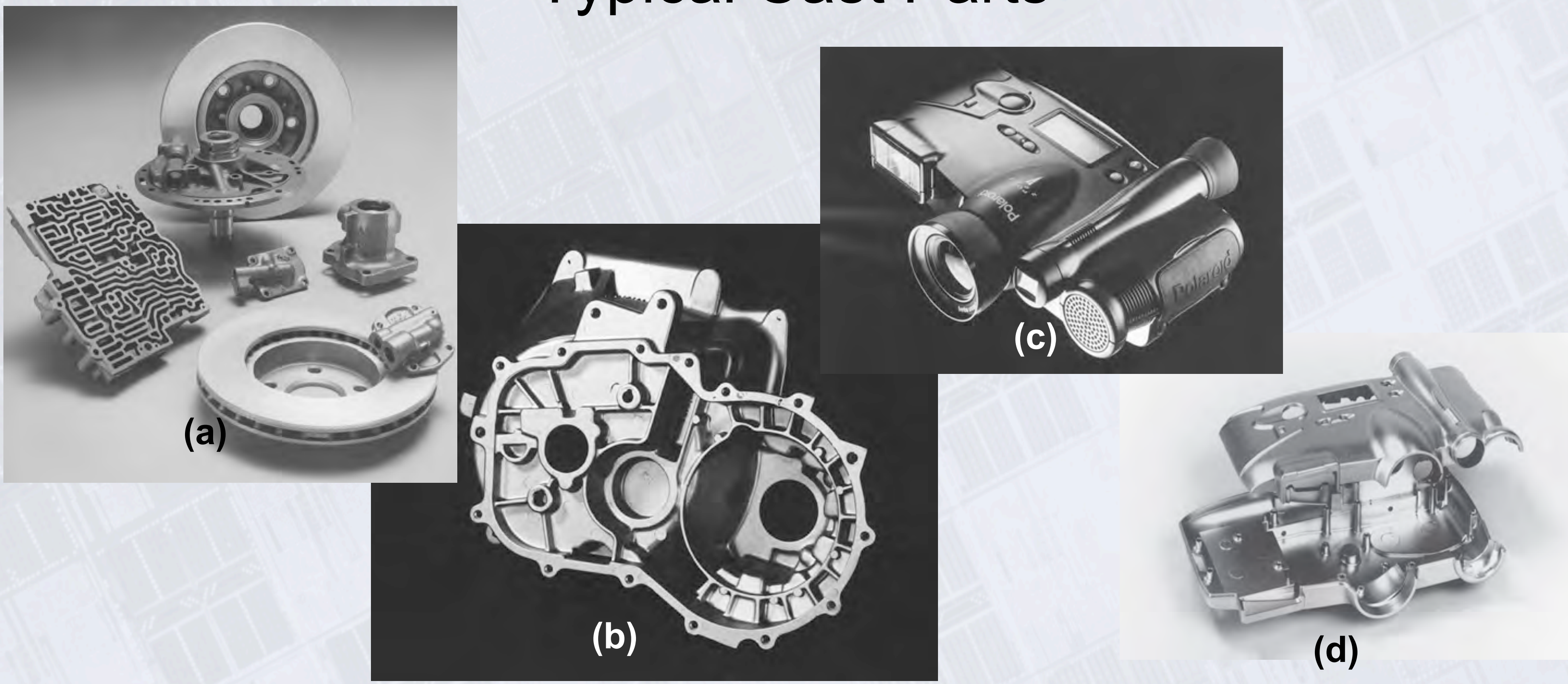


Figure 11.1 (a) Typical gray-iron castings used in automobiles, including the transmission valve body (left) and the hub rotor with disk-brake cylinder (front). *Source*: Courtesy of Central Foundry Division of General Motors Corporation. (b) A cast transmission housing. (c) The Polaroid PDC-2000 digital camera with a AZ191D die-cast high-purity magnesium case. (d) A two-piece Polaroid camera case made by the hot-chamber die-casting process. *Source:* Courtesy of Polaroid Corporation and Chicago White Metal Casting, Inc.

Characteristics of Casting

TABLE 11.2

General Characteristics of Casting Processes

	Sand	Shell	Evaporative pattern	Plaster	Investment	Permanent mold	Die	Centrifugal
Typical materials cast	All	All	All	Nonferrous (Al, Mg, Zn, Cu)	All	All	Nonferrous (Al, Mg, Zn, Cu)	All
Weight (kg):								
minimum	0.01	0.01	0.01	0.01	0.001	0.1	6 0.01	0.01
maximum	No limit	100+	100+	50+	100+	300	50	5000+
Typ. surface finish (R_a in μm)	5–25	1–3	5–25	1–2	0.3–2	2–6	1–2	2–10
Porosity[1]	3–5	4–5	3–5	4–5	5	2–3	1–3	1–2
Shape complexity[1]	1–2	2–3	1–2	1–2	1	2–3	3–4	3–4
Dimensional accuracy[1]	3	2	3	2	1	1	1	3
Section thickness (mm):								
Minimum	3	2	2	1	1	2	0.5	2
Maximum	No limit	—	—	—	75	50	12	100
Typ. dimensional tolerance (mm/mm)	1.6–4 mm (0.25 mm for small parts)	±0.003		±0.005–0.010	±0.005	±0.015	±0.001–0.005	0.015
Cost[1,2]								
Equipment	3–5	3	2–3	3–5	3–5	2	1	1
Pattern/die	3–5	2–3	2–3	3–5	2–3	2	1	1
Labor	1–3	3	3	1–2	1–2	3	5	5
Typical lead time[2]	Days	Weeks	Weeks	Days	Weeks	Weeks	Weeks-months	Months
Typical production rate[2] (parts/mold-hour)	1–20	5–50	1–20	1–10	1–1000	5–50	2–200	1–1000
Minimum quantity[2]	1	100	500	10	10	1000	10,000	10–10,000

Notes: 1. Relative rating, from 1 (best) to 5 (worst). For example, die casting has relatively low porosity, mid to low shape complexity, high dimensional accuracy, high equipment and die costs, and low labor costs. These ratings are only general; significant variations can occur, depending on the manufacturing methods used.
2. Approximate values without the use of rapid prototyping technologies.
Source: Data taken from J. A. Schey, *Introduction to Manufacturing Processes*, 3d. ed., McGraw-Hill 2000.

Production Steps in Sand-Casting

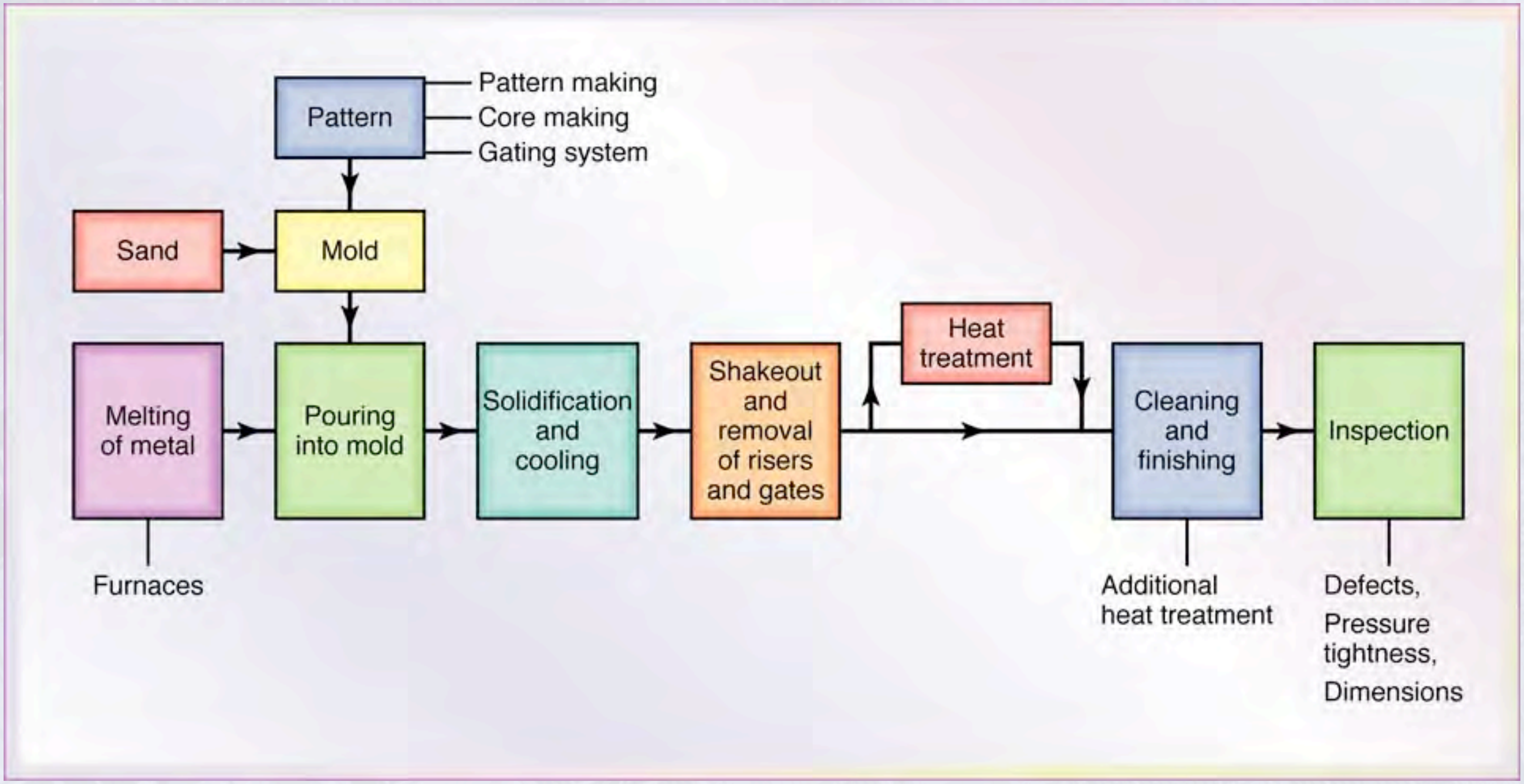


Figure 11.2 Outline of production steps in a typical sand-casting operation.

Sand Mold

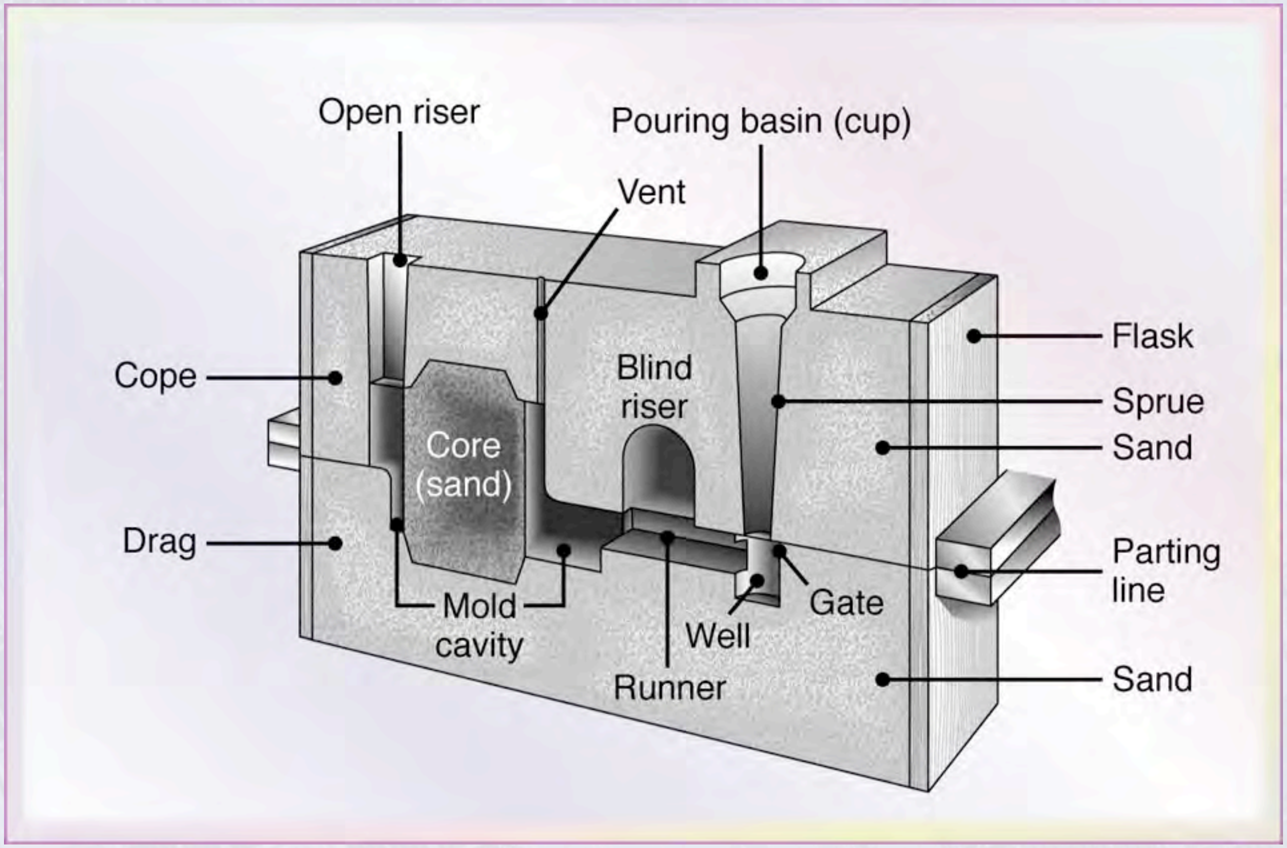


Figure 11.3 Schematic illustration of a sand mold, showing various features.

Pattern Plate

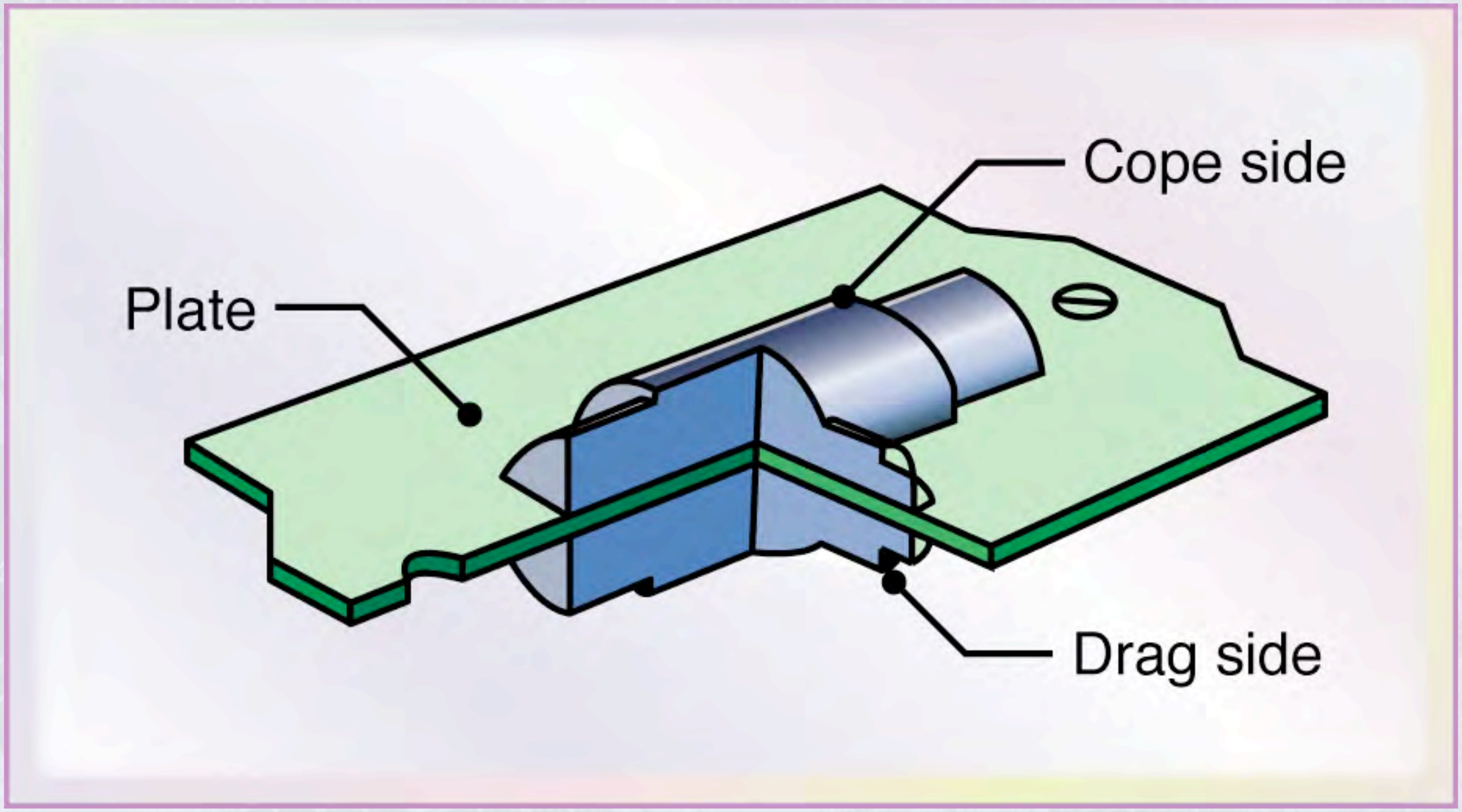


Figure 11.4 A typical metal match-plate pattern used in sand casting.

Design for Ease of Removal from Mold

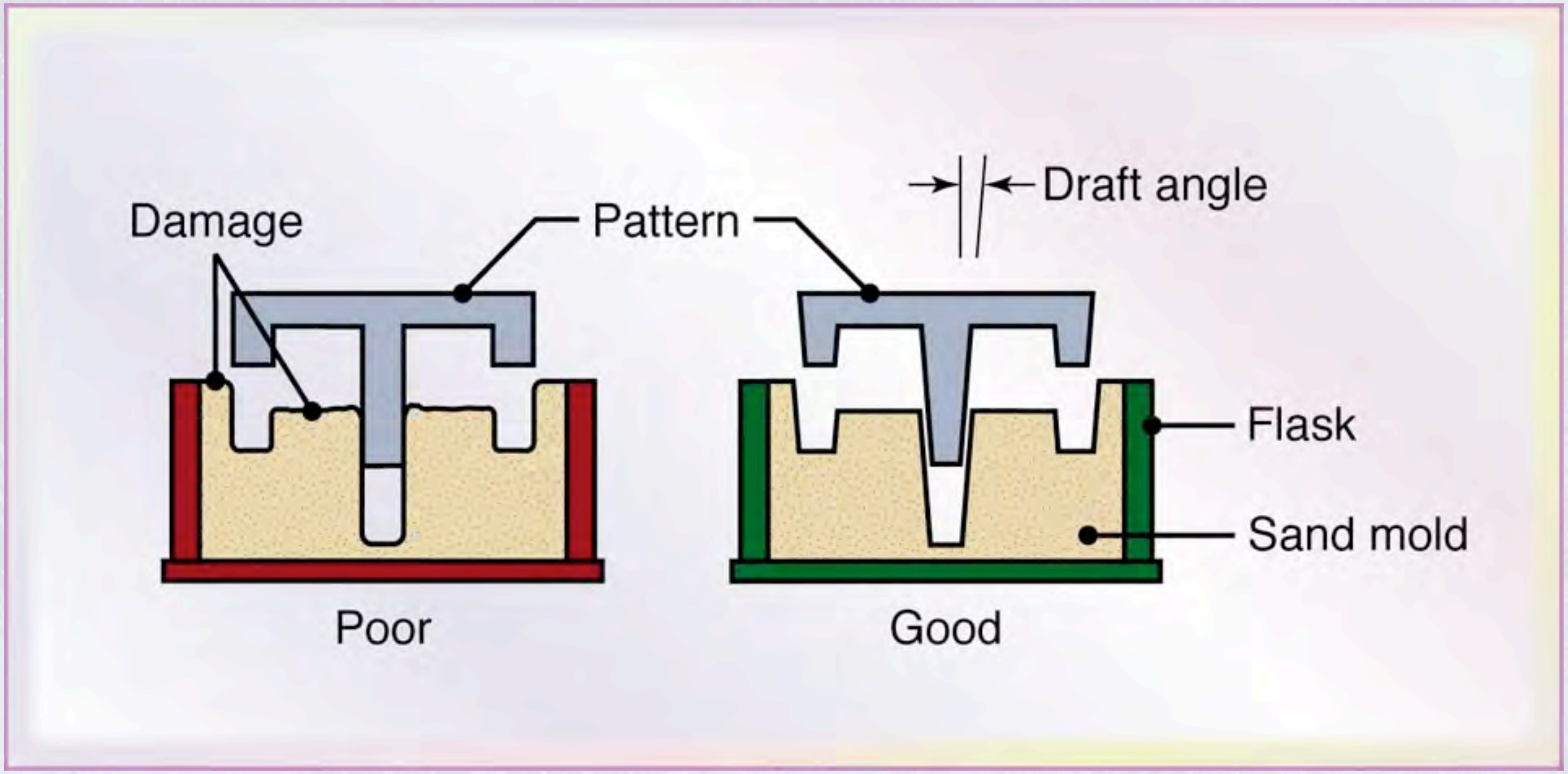


Figure 11.5 Taper on patterns for ease of removal from the sand mold

Sand Cores

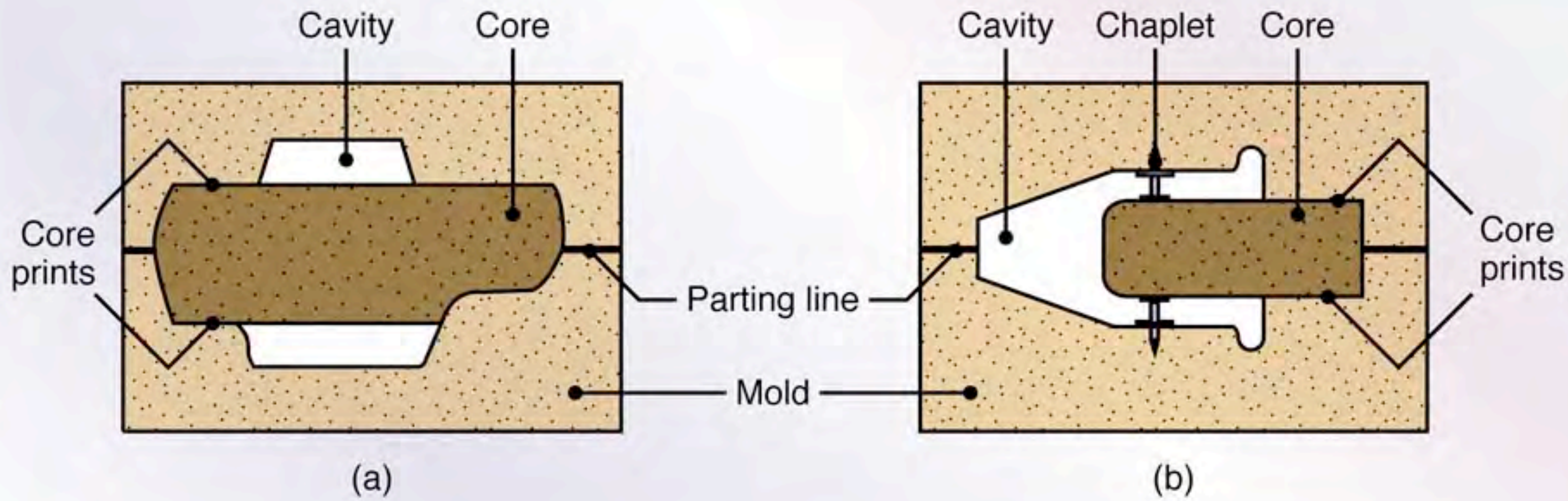


Figure 11.6 Examples of sand cores showing core prints and chaplets to support cores.

Vertical Flaskless Molding

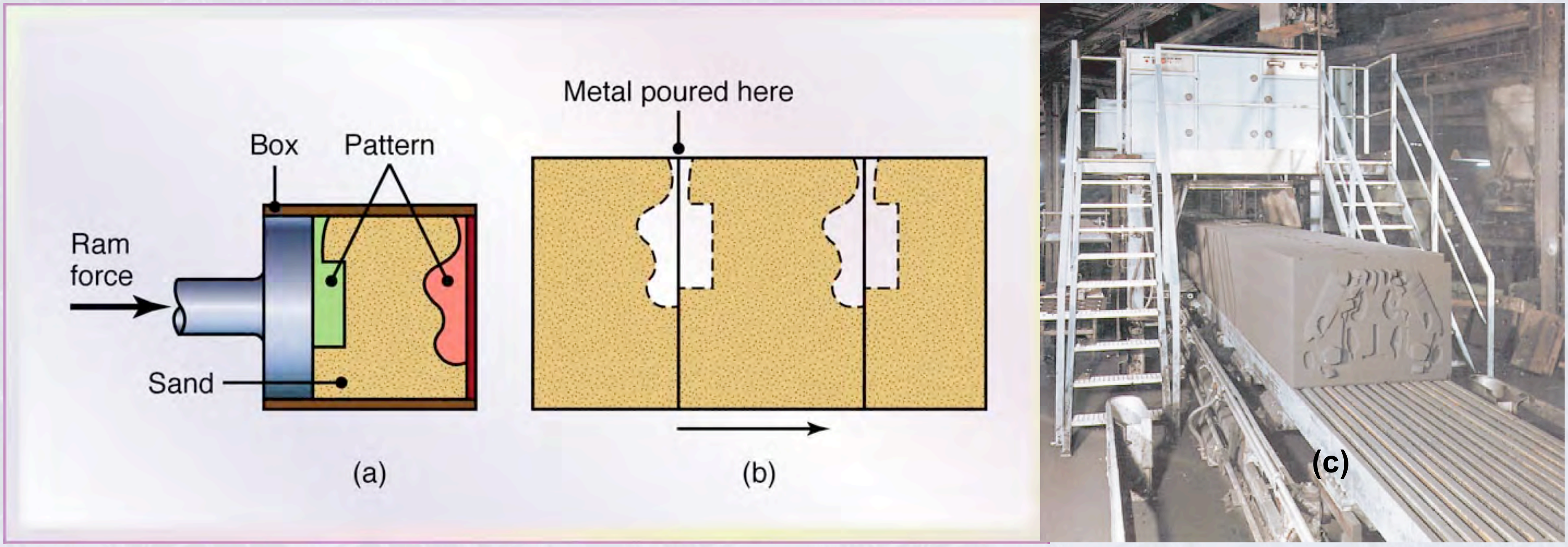
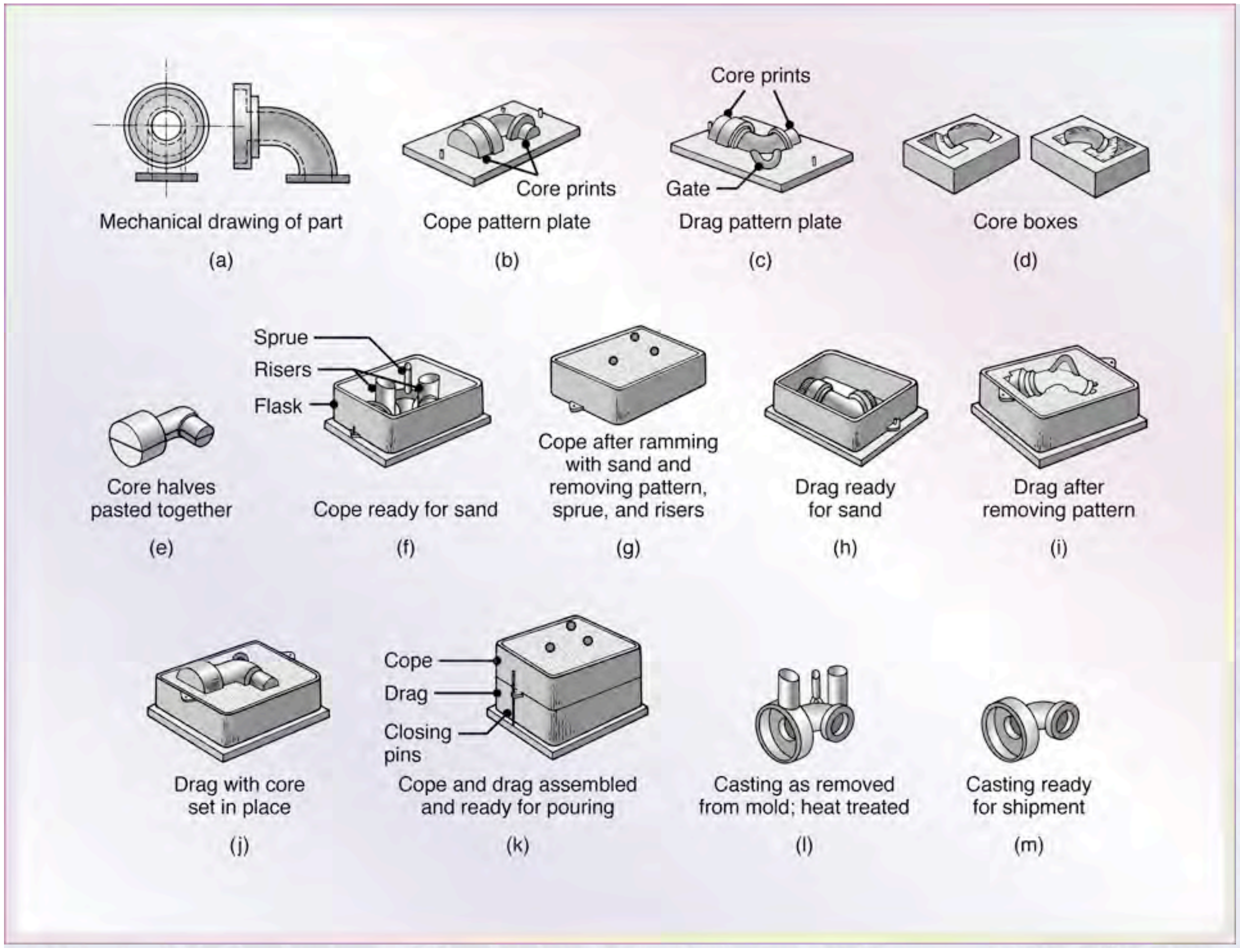


Figure 11.7 Vertical flaskless molding. (a) Sand is squeezed between two halves of the pattern. (b) Assembled molds pass along an assembly line for pouring. (c) A photograph of a vertical flaskless molding line. *Source*: Courtesy of American Foundry Society.



Sequence of Operations for Sand-Casting

Figure 11.8 Schematic illustration of the sequence of operations for sand casting. (a) A mechanical drawing of the part is used to generate a design for the pattern. Considerations such as part shrinkage and draft must be built into the drawing. (b-c) Patterns have been mounted on plates equipped with pins for alignment. Note the presence of core prints designed to hold the core in place. (d-e) Core boxes produce core halves, which are pasted together. The cores will be used to produce the hollow area of the part shown in (a). (f) The cope half of the mold is assembled by securing the cope pattern plate to the flask with aligning pins and attaching inserts to form the sprue and risers. Continued on next slide.

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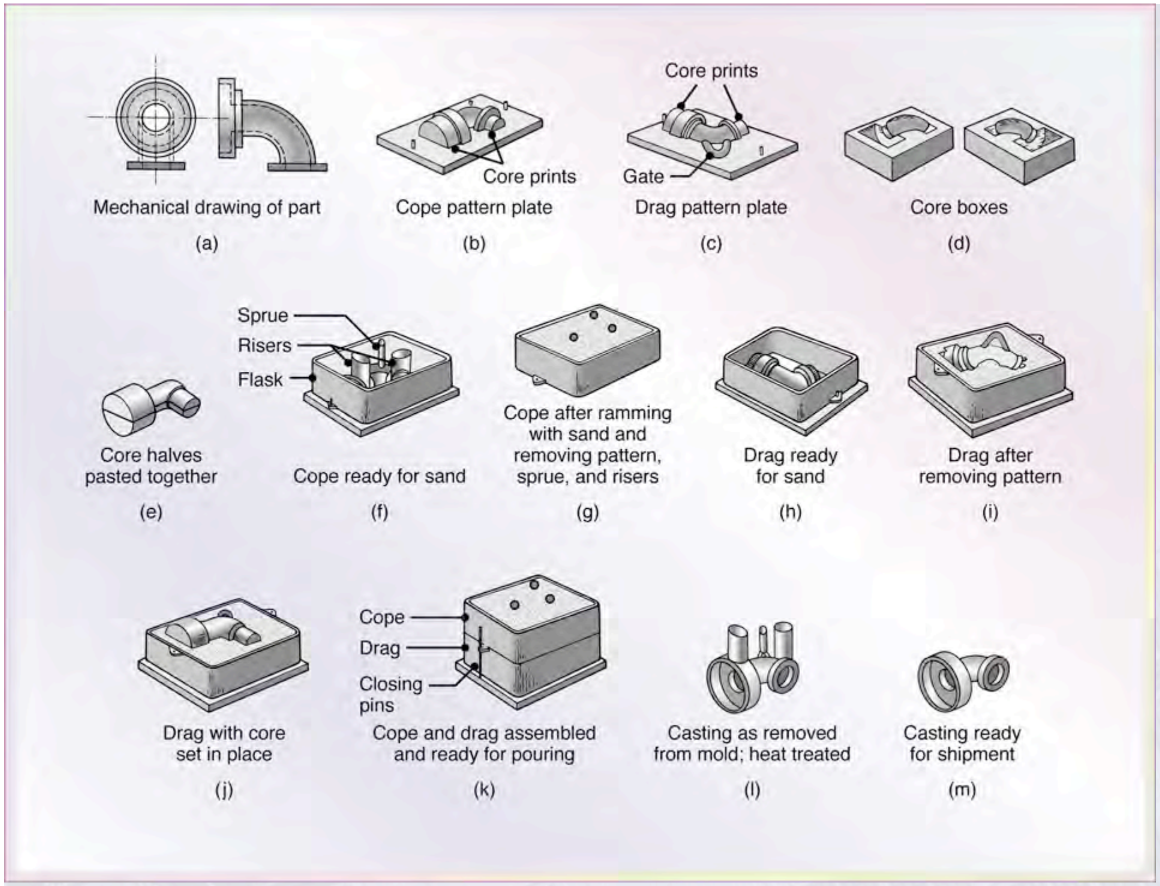


Sequence of Operations for Sand-Casting, Con't.

(g) The flask is rammed with sand and rthe plate and inserts are removed. (h) The drag half is produced in a similar manner with the pattern inserted. A bottom board is placed below the drag and aligned with pins. (i) The pattern , flask, and bottom board are inverted; and the pattern is withdrawn, leaving the appropriate imprint. (j) The core is set in place within the drag cavity. (k) The mold is closed by placing the cope on top of the drag and securing the assembly with pins. The flasks the are subjected to pressure to counteract buoyant forces in the liquid, which might lift the cope. (l) After the metal solidifies, the casting is removed from the mold. (m) The sprue and risers are cut off and recycled, and the casting is cleaned, inspected, and heat treated (when necessary). *Source*: Courtesy of Steel Founder's Society of America

Shell-Molding Process

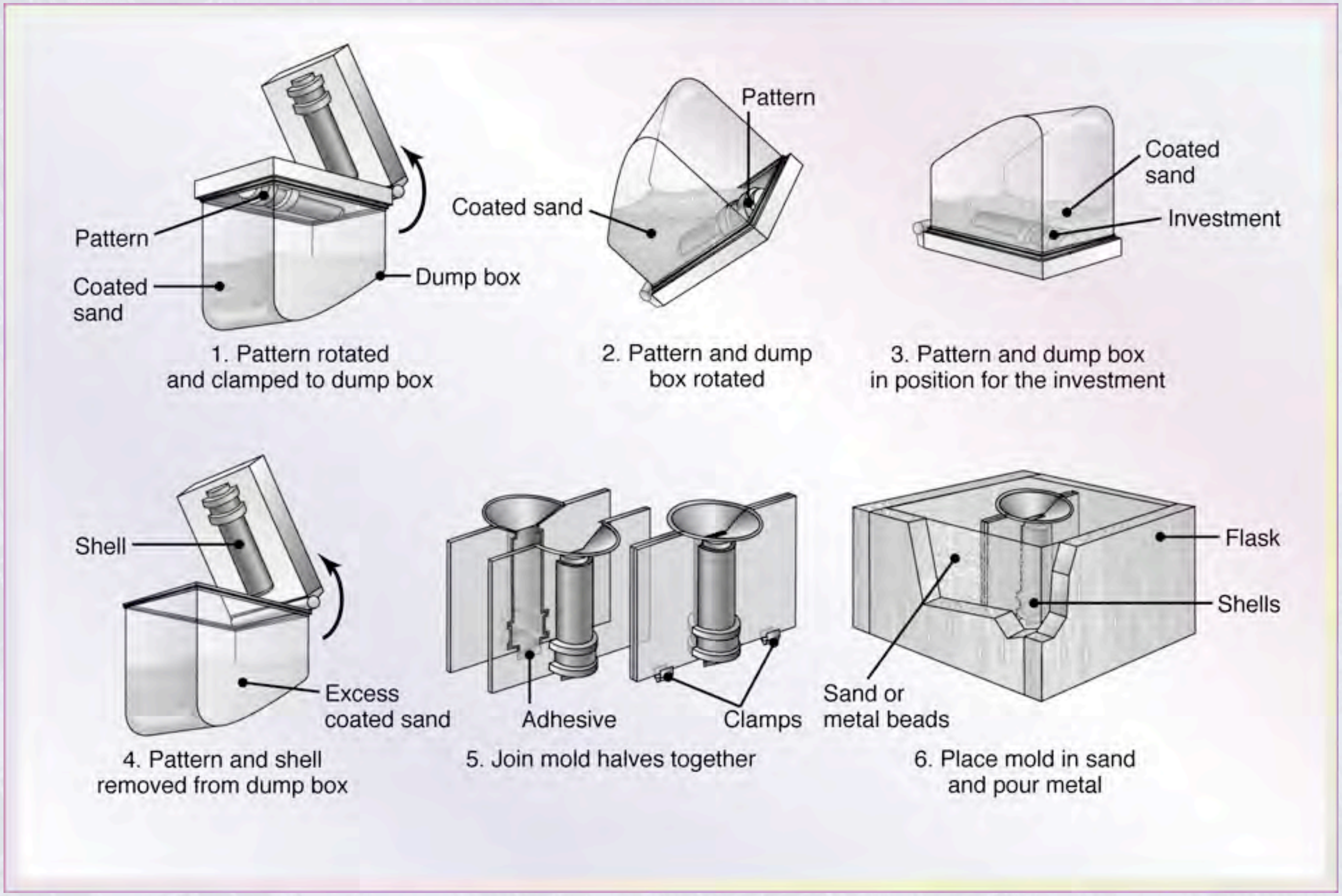


Figure 11.9 The shell-molding process, also called *dump-box* technique.

Sequence of Operations in Making a Ceramic Mold

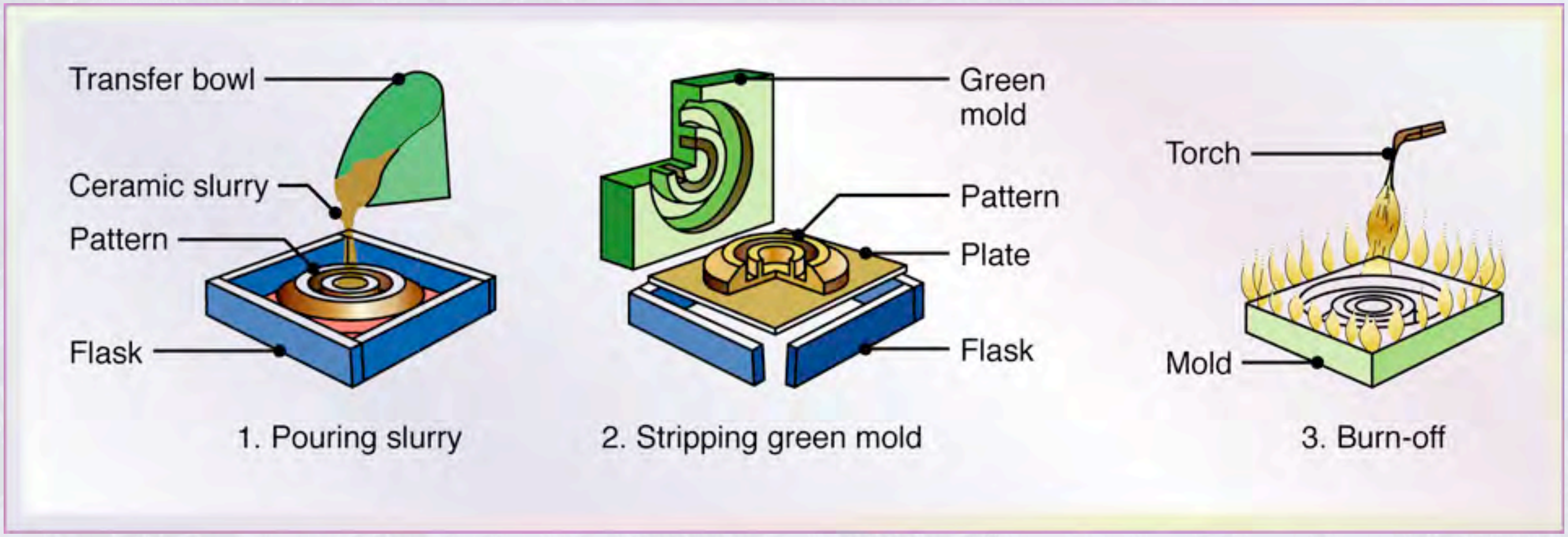


Figure 11.10 Sequence of operations in making a ceramic mold. *Source*: *Metals Handbook,* Vol. 5, 8th ed.

Expandable-Pattern Casting Process

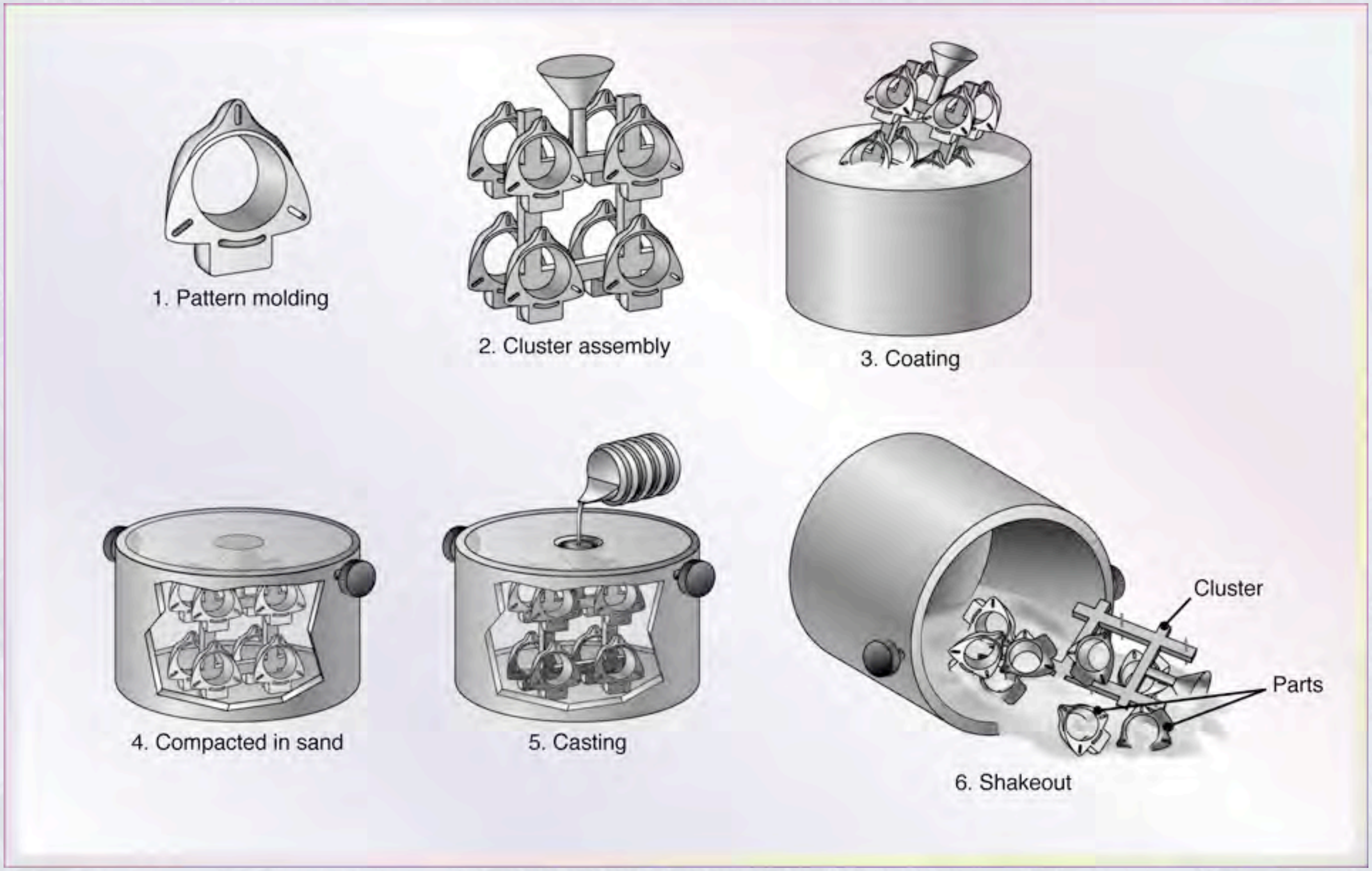
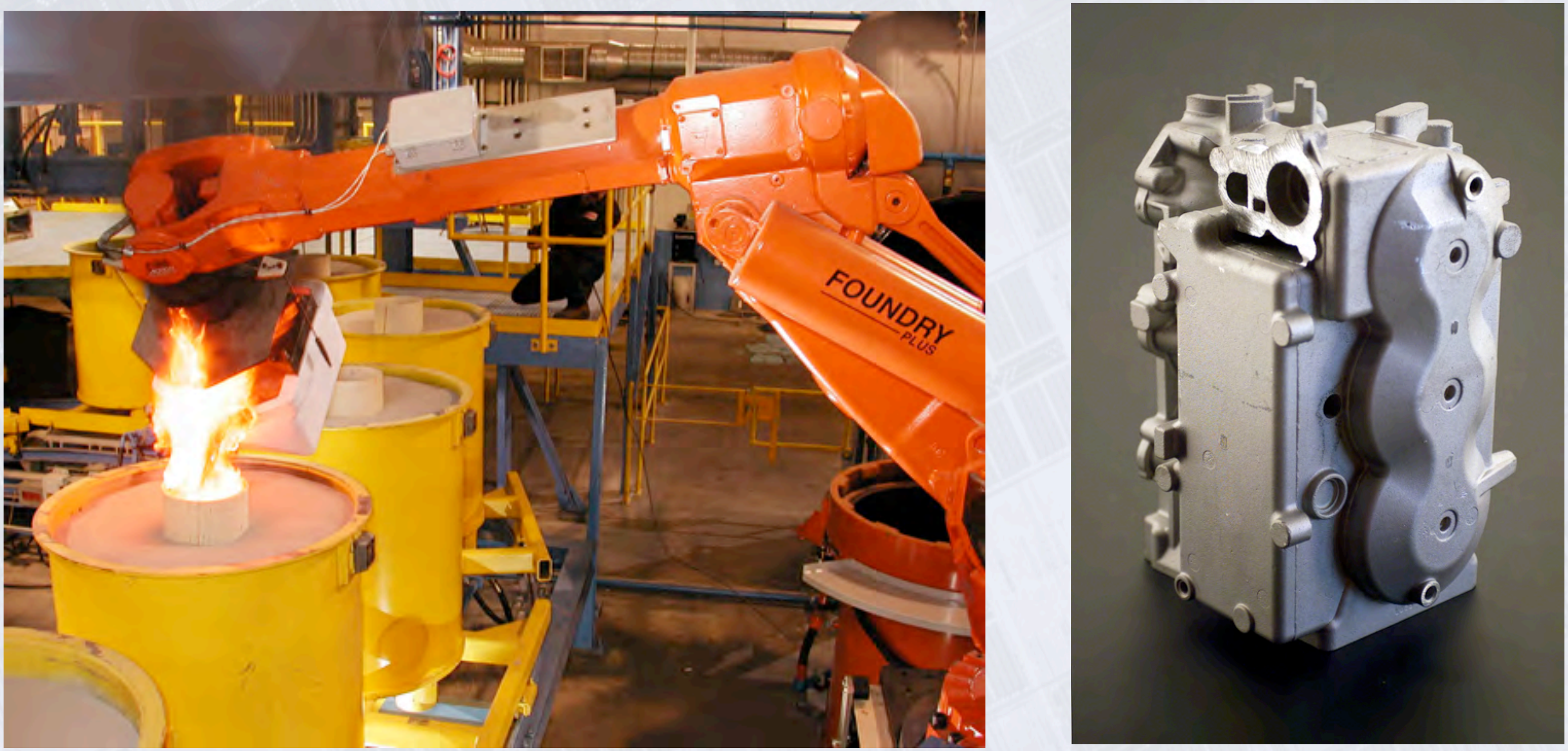


Figure 11.11 Schematic illustration of the expandable-pattern casting process, also known as lost-foam or evaporative casting.

Evaporative Pattern Casting of an Engine Block



(a) (b)

Figure 11.12 (a) Metal is poured into mold for lost-foam casting of a 60-hp. 3-cylinder marine engine; (b) finished engine block. Source: Courtesy of Mercury Marine.

Investment Casting Process

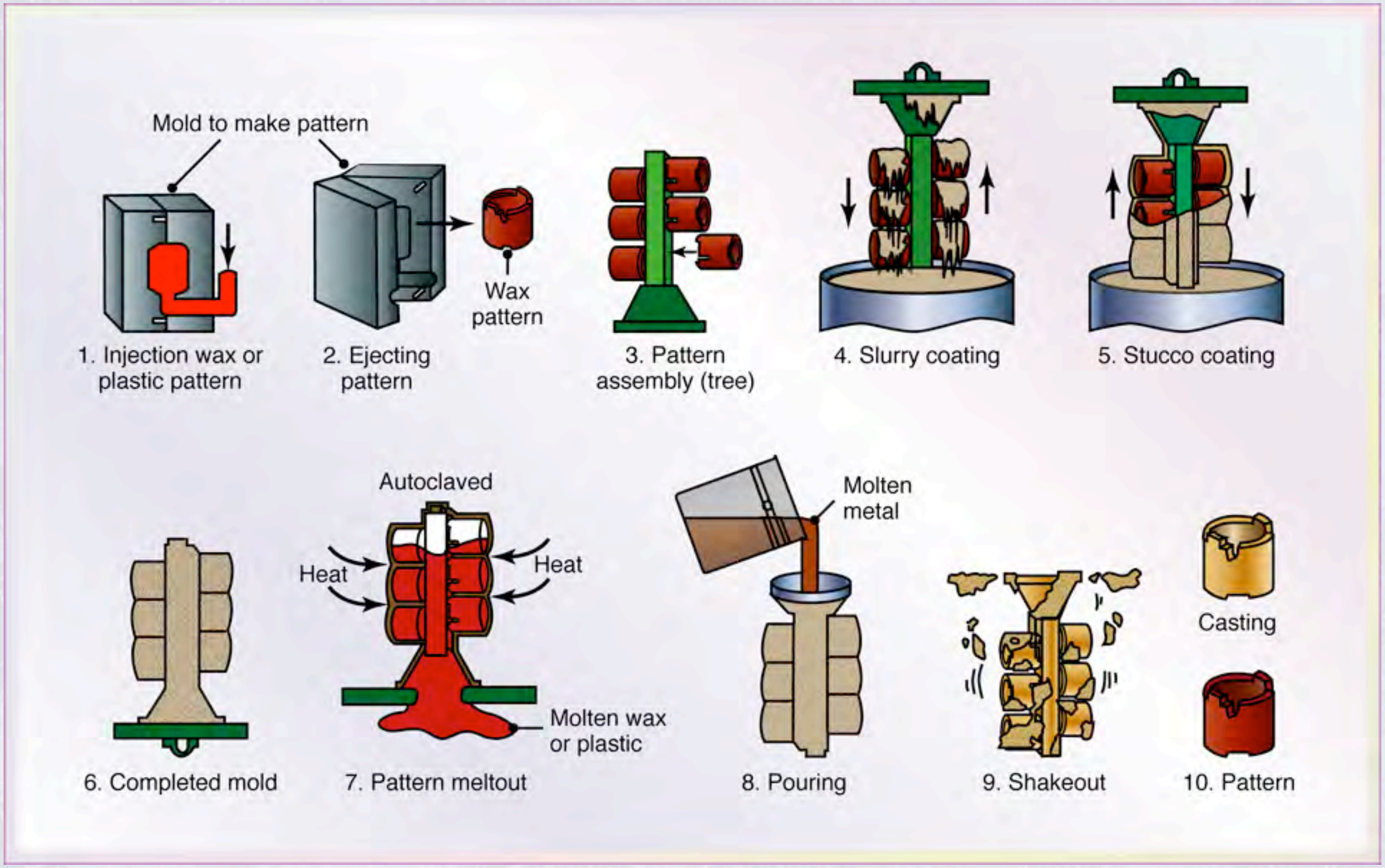


Figure 11.13 Schematic illustration of investment casting (lost-wax) process. Castings by this method can be made with very fine detail and from a variety of metals. *Source*: Courtesy of Steel Founder's Society of America.

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Integrally Cast Rotor for a Gas Turbine

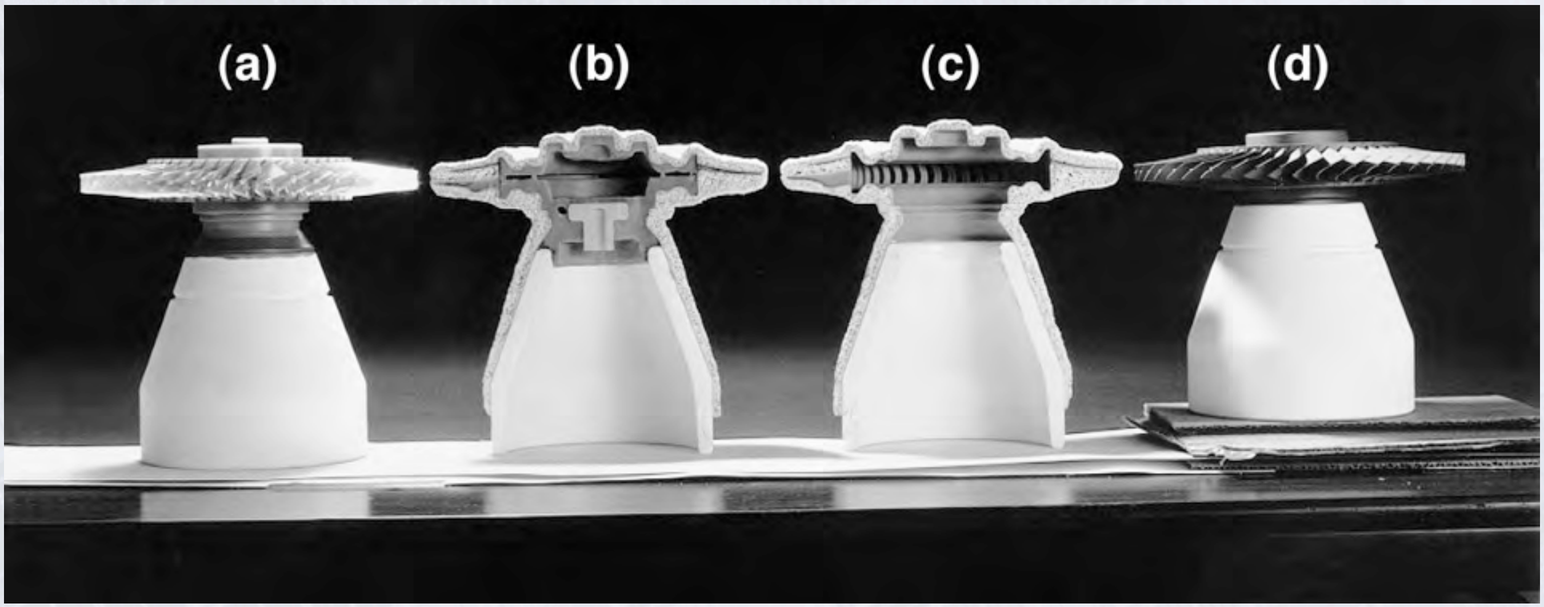

Figure 11.14 Investment casting of an integrally cast rotor for a gas turbine. (a) Wax pattern assembly. (b) Ceramic shell around wax pattern. (c) Wax is melted out and the mold is filled, under a vacuum, with molten superalloy. (d) The cast rotor, produced to net or near-net shape. *Source*: Courtesy of Howmet Corporation.

Comparison of Investment-Cast and Conventionally Cast Rotors

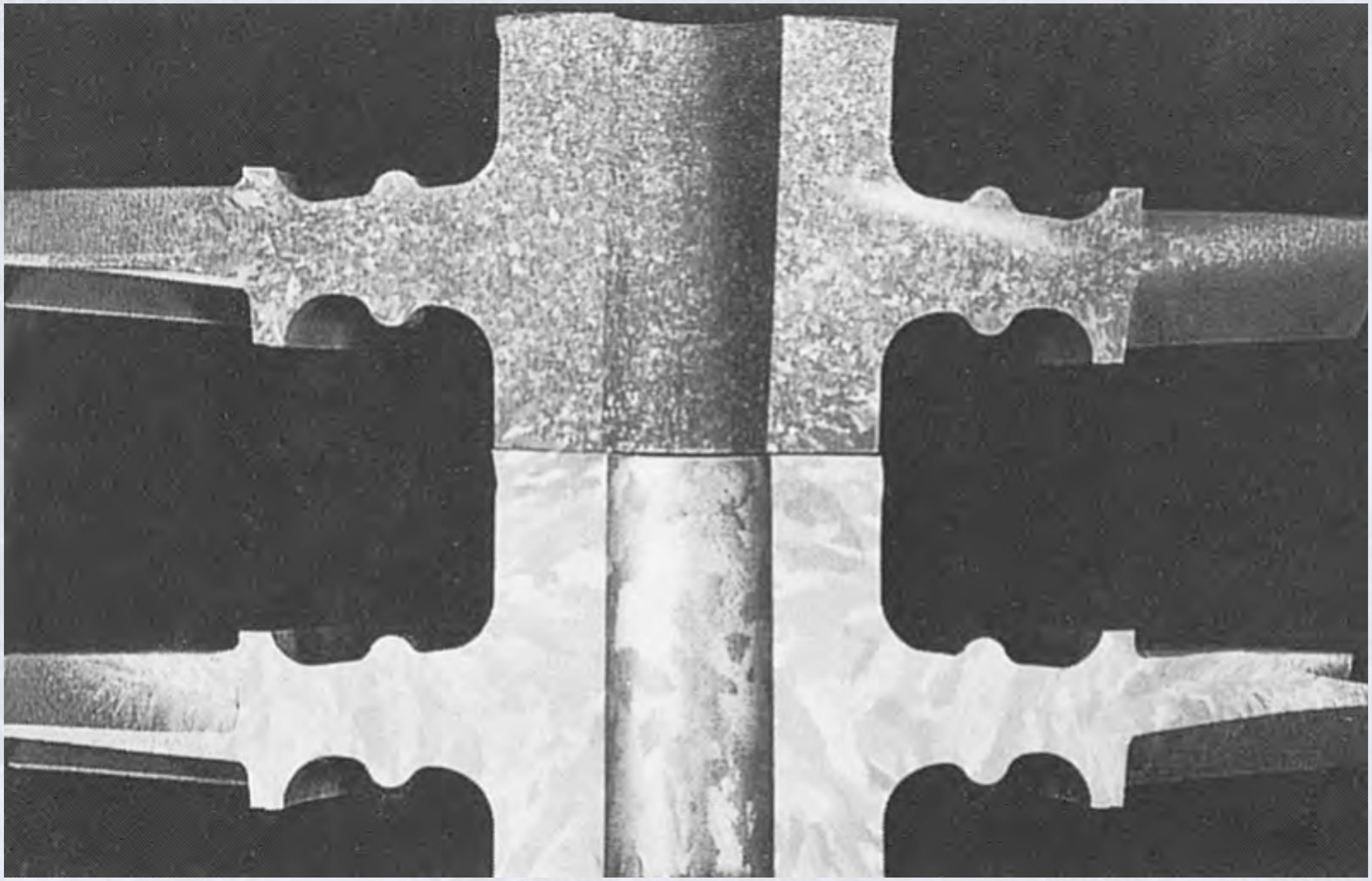

Figure 11.15 Cross-section and microstructure of two rotors: (top) investment-cast; (bottom) conventionally cast. *Source*: *Advanced Materials and Processes*, October 1990, P. 25. ASM International.

Vacuum-Casting

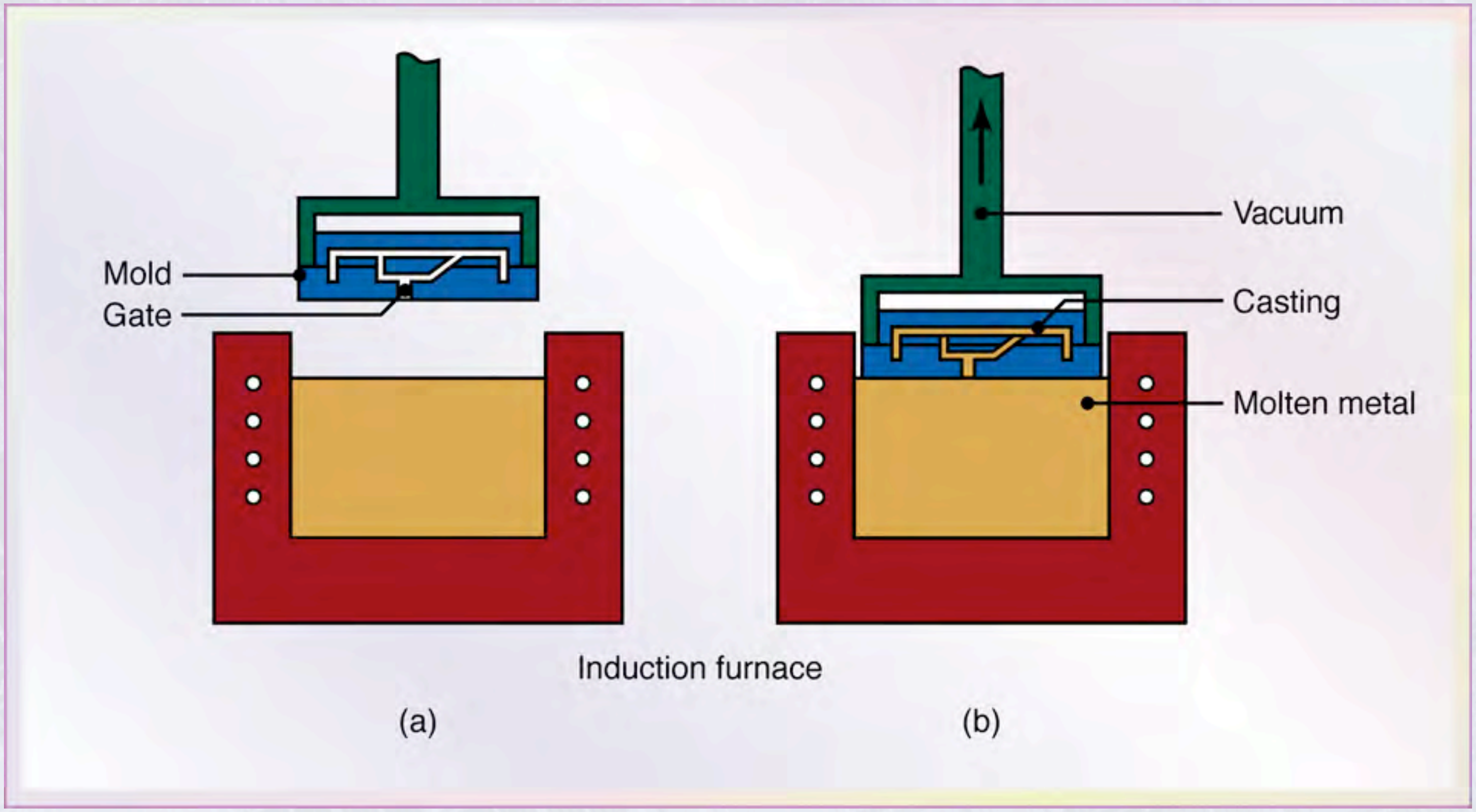

Figure 11.16 Schematic illustration of the vacuum-castin process. Note that the mold has a bottom gate. (a) Before and (b) after immersion of the mold into the molten metal. *Source*: After R. Blackburn.

Hot-Chamber Die-Casting

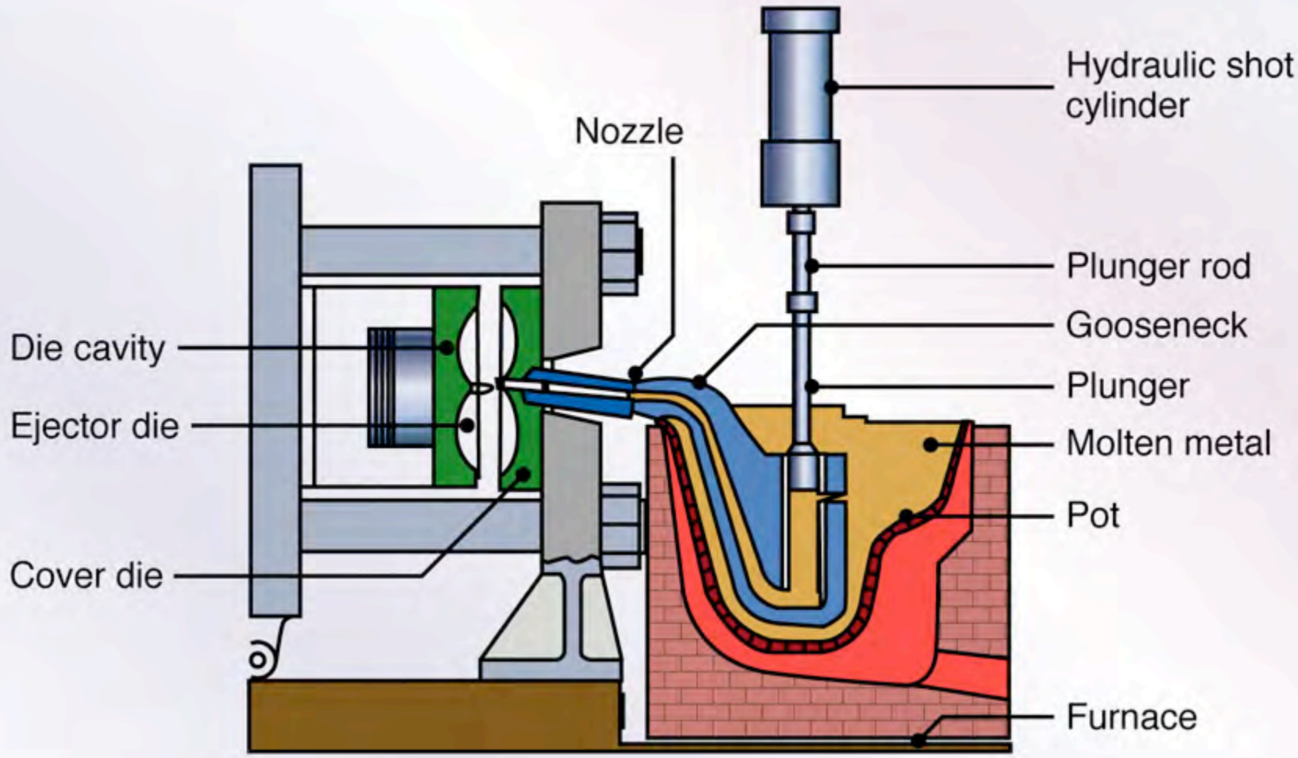

Figure 11.17 Schematic illustration of the hot-chamber die-casting process.

Cold-Chamber Die-Casting

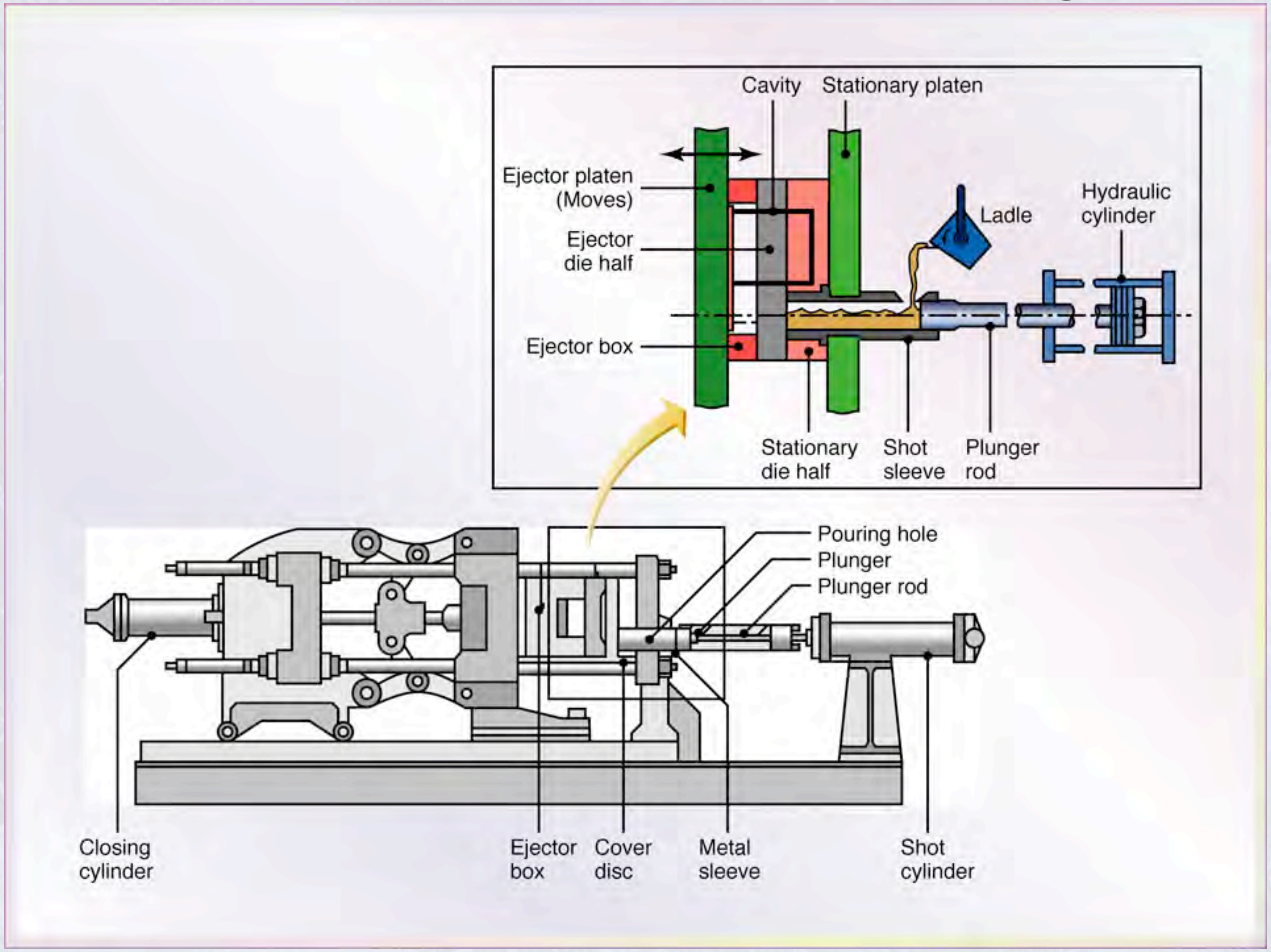

Figure 11.18 Schematic illustration of the cold-chamber die-casting process. These machines are large compared to the size of the casting, because high forces are required to keep the two halves of the dies closed under pressure.

Properties and Applications of Die-Casting Alloys

TABLE 11.3

Properties and Typical Applications of Some Common Die-Casting Alloys

Alloy	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation in 50 mm (%)	Applications
Aluminum 380 (3.5 Cu - 8.5 Si)	320	160	2.5	Appliances, automotive components, electrical motor frames and housings
13 (12 Si)	300	150	2.5	Complex shapes with thin walls, parts requiring strength at elevated temperatures
Brass 858 (60 Cu)	380	200	15	Plumbing fixtures, lock hardware, bushings, ornamental castings
Magnesium AZ91B (9 Al - 0.7 Zn)	230	160	3	Power tools, automotive parts, sporting goods
Zinc No. 3 (4 Al)	280	-	10	Automotive parts, office equipment, household utensils, building hardware, toys
No. 5 (4 Al - 1 Cu)	320	-	7	Appliances, automotive parts, building hardware, business equipment

Source: American Die Casting Institute.

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Types of Cavities in Die-Casting Die

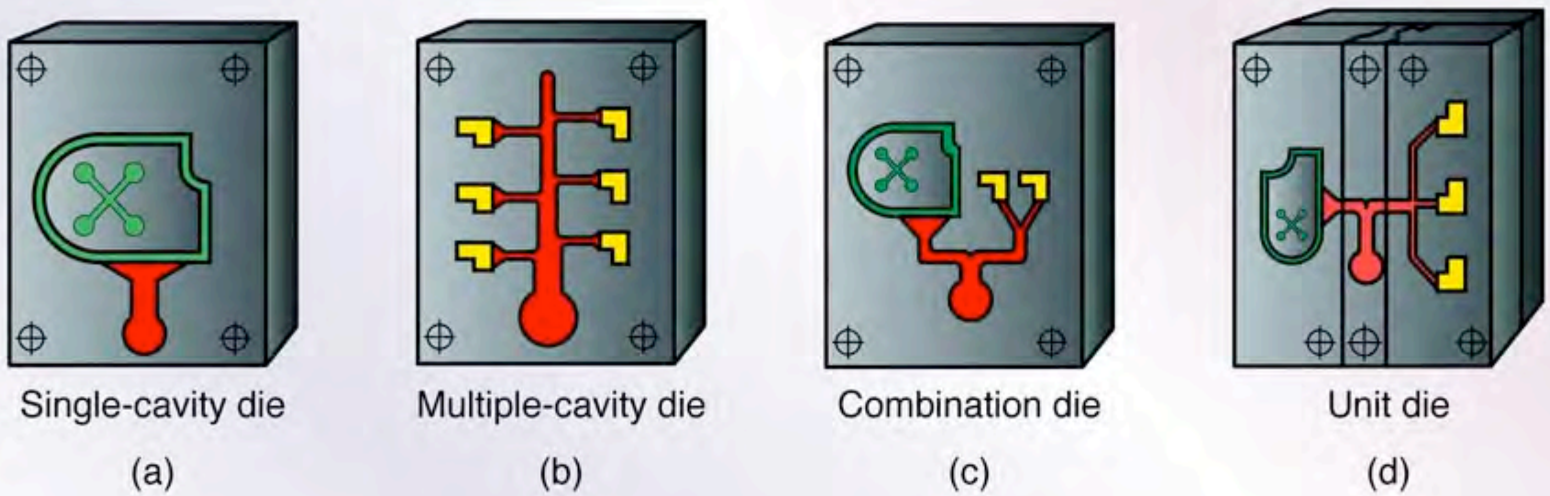


Figure 11.19 Various types of cavities in a die-casting die.
Source: Courtesy of American Die Casting Institute.

Centrifugal-Casting Process

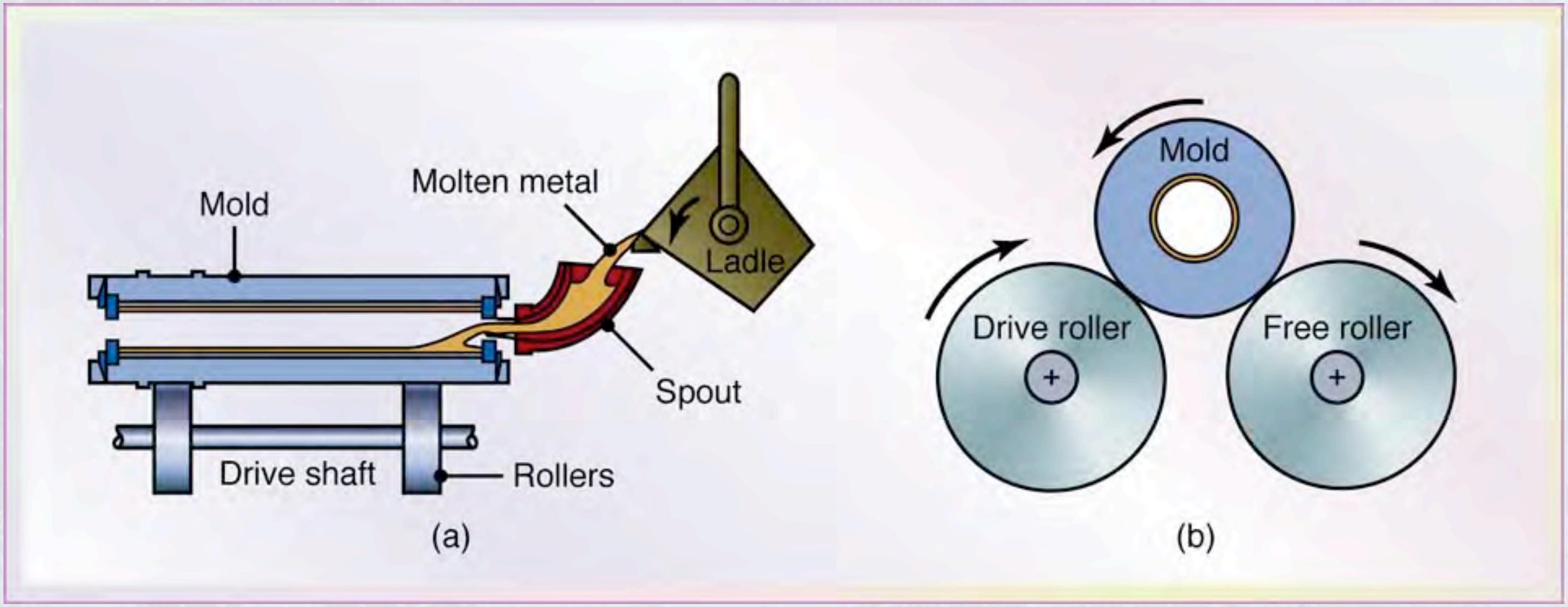


Figure 11.20 (a) Schematic illustration of the centrifugal-casting process. Pipes, cylinder liners, and similarly shaped parts can be cast with this process. (b) Side view of the machine.

Semicentrifugal Casting and Casting by Centrifuging

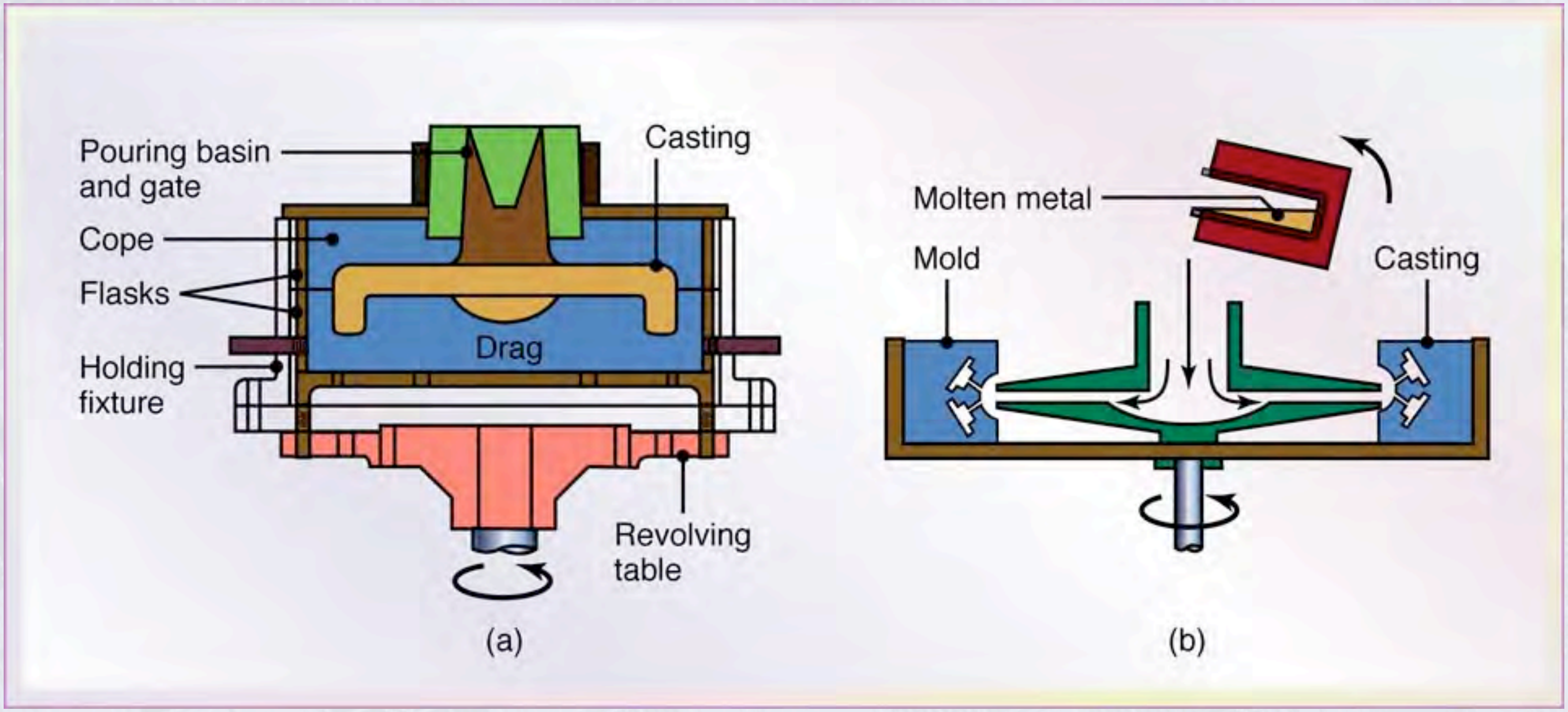


Figure 11.21 (a) Schematic illustration of the semicentrifugal casting process. Wheels with spokes can be cast by this process. (b) Schematic illustration of casting by centrifuging. The molds are placed at the periphery of the machine, and the molten metal is forced into the molds by centrifugal force.

Squeeze-Casting

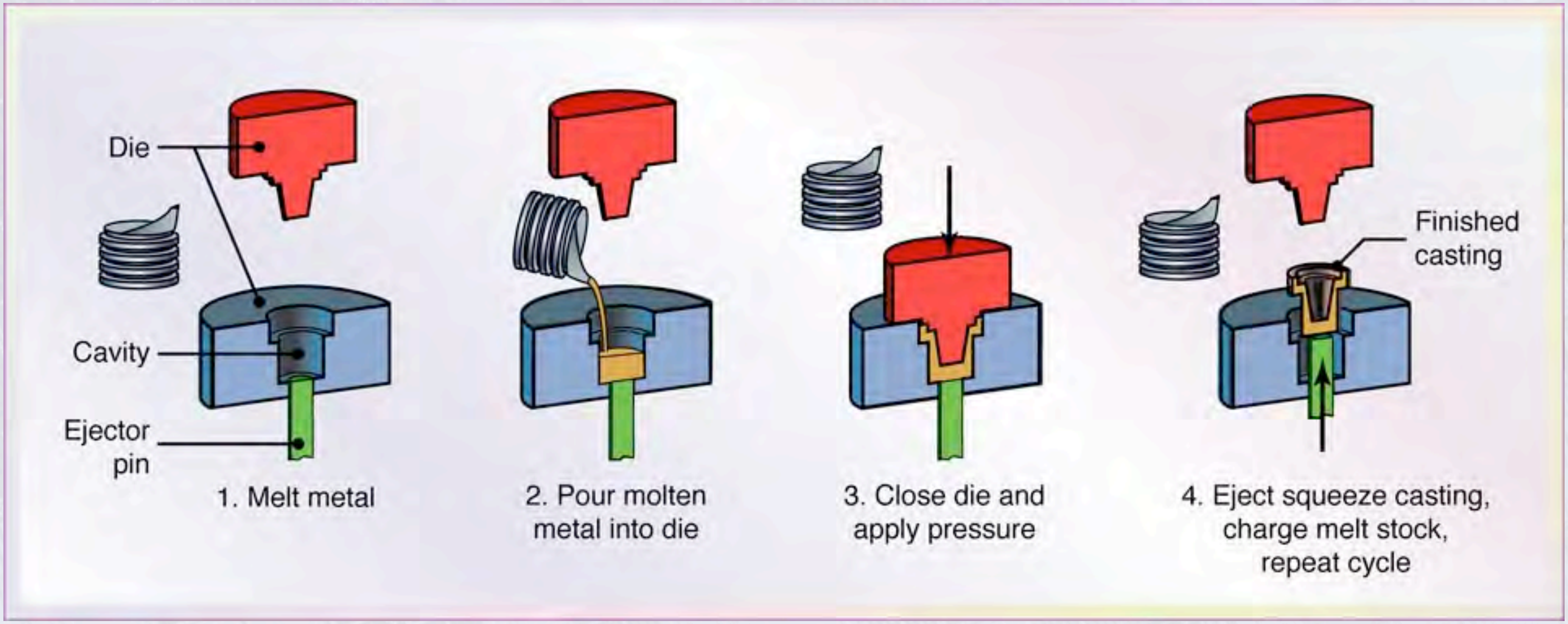


Figure 11.22 Sequence of operations in the squeeze-casting process. This process combines the advantages of casting and forging.

Methods of Casting Turbine Blades

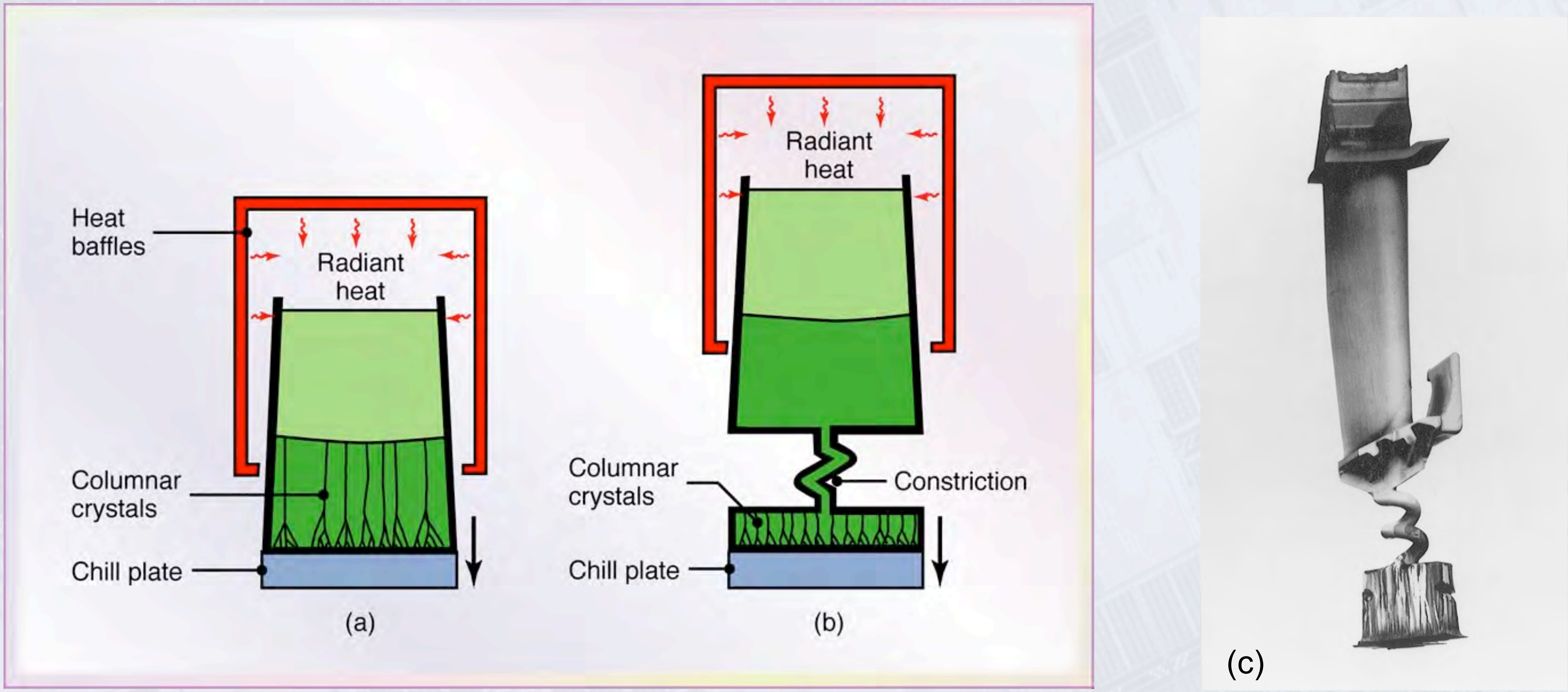


Figure 11.23 Methods of casting turbine blades: (a) directional solidification; (b) method to produce a single-crystal blade; and (c) a single-crystal blade with the constriction portion still attached. *Source:* (a) and (b) After B. H. Kear, (c) Courtesy of ASM International.

Crystal Growing

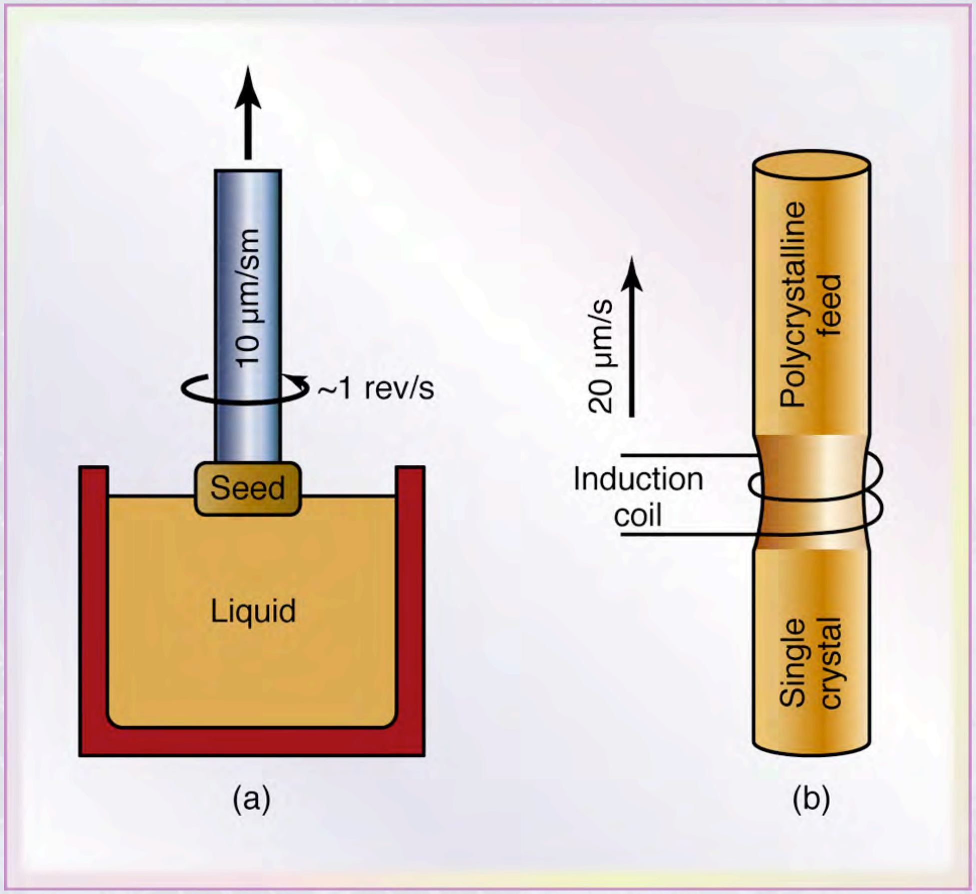
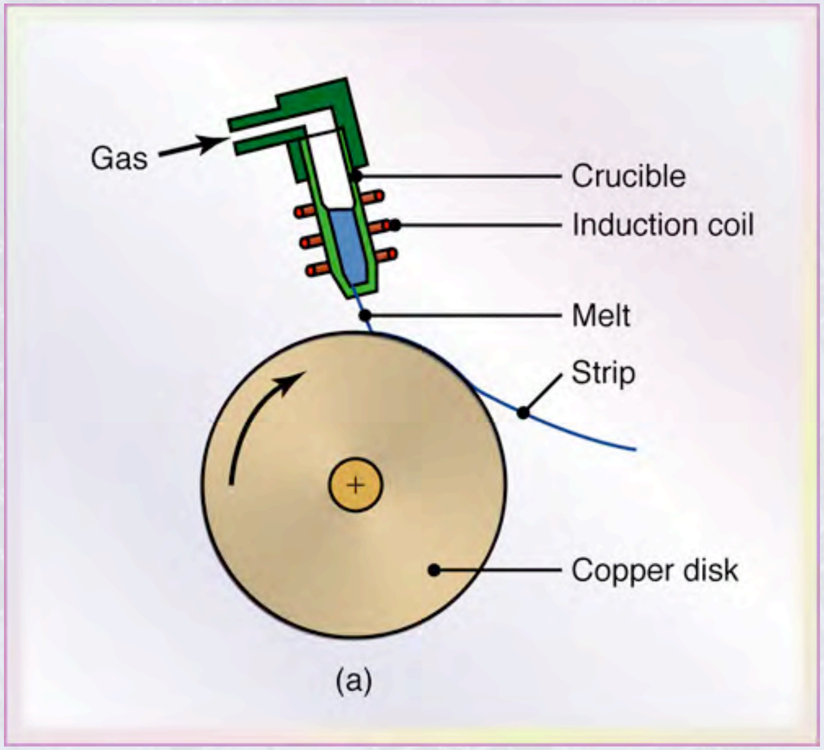


Figure 11.24 Two methods of crystal growing: (a) crystal pulling (Czochralski process) and (b) the floating-zone method. Crystal growing is important especially in the semiconductor industry. (c) A single-crystal ingot produced by the Czochralski process. *Source*: Courtesy of Intel Corp.

Melt-Spinning



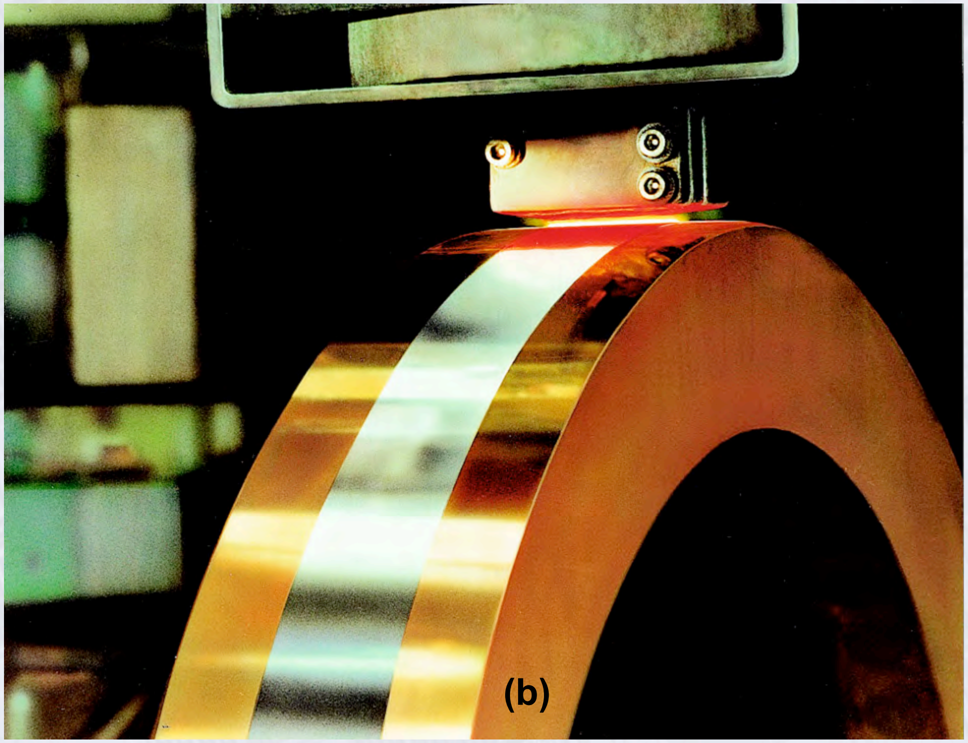


Figure 11.25 (a) Schematic illustration of melt-spinning to produce thin strips of amorphous metal. (b) Photograph of nickel-alloy production through melt-spinning. *Source:* Siemens AG

Types of Melting Furnaces

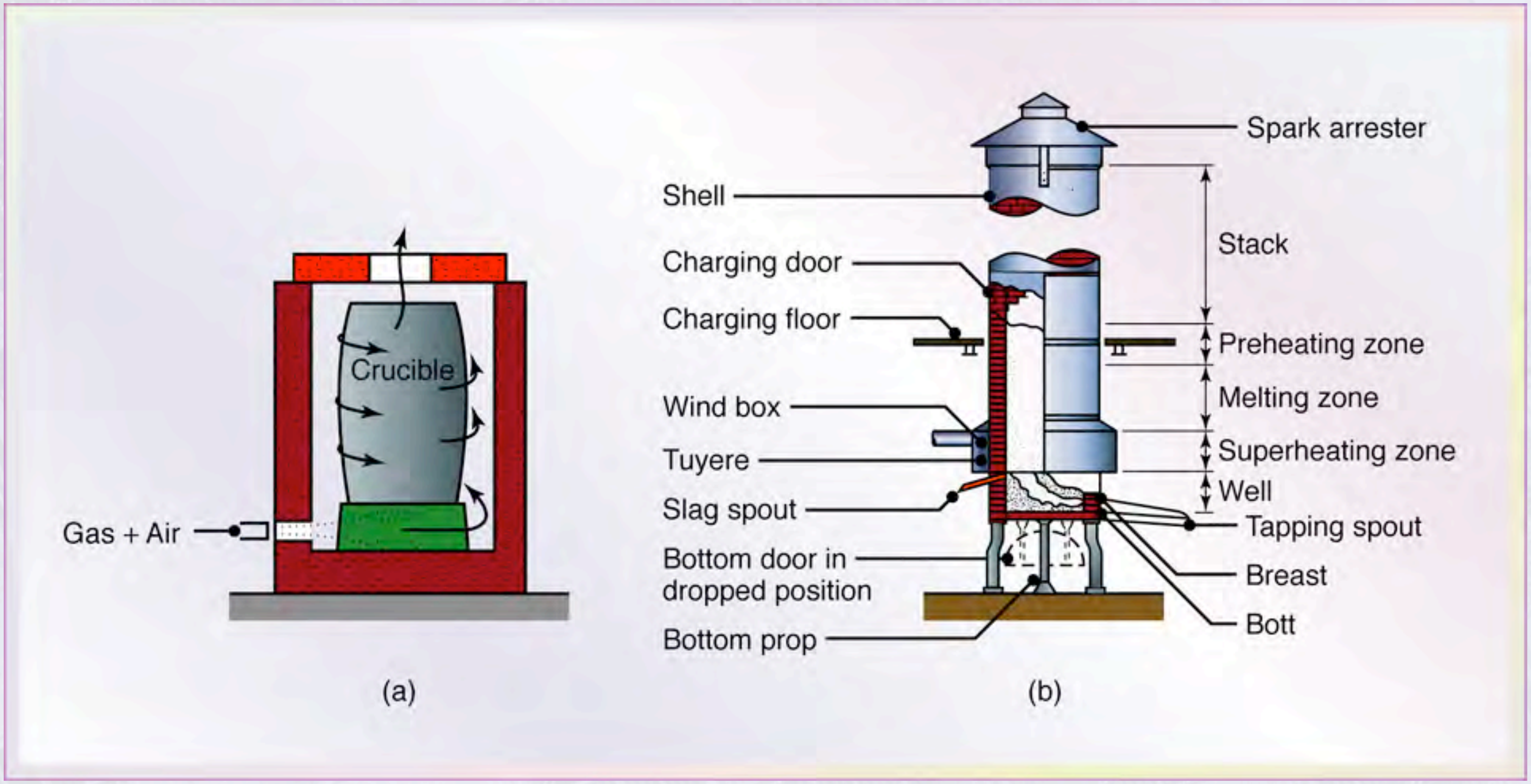


Figure 11.26 Two types of melting furnaces used in foundries:
(a) crucible, and (b) cupola.