Manufacturing Engineering Technology in SI Units, 6th Edition

Chapter 11:

Metal Casting Processes and Equipment

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Chapter Outline

- Introduction
- Expendable-mold, Permanent-pattern Casting Processes
- Expendable-mold, Expendable-pattern Casting Processes
- Permanent-mold Casting Processes
- Casting Techniques for Single-crystal Components
- Rapid Solidification
- Inspection of Castings
- Melting Practice and Furnaces
- Foundries and Foundry Automation

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Introduction

- Various casting processes developed over time to meet specific design requirements

Summary of Casting Processes

Process	Advantages	Limitations
Sand	Almost any metal can be cast; 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 can be cast, with no limit to size; complex part shapes	Patterns have low strength and can be costly for low quantities
Plaster mold	Intricate part shapes; good dimensional accuracy and surface 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-tolerance parts; good surface finish	Limited part size
Investment	Intricate part shapes; excellent surface finish and accuracy; almost any metal can be 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

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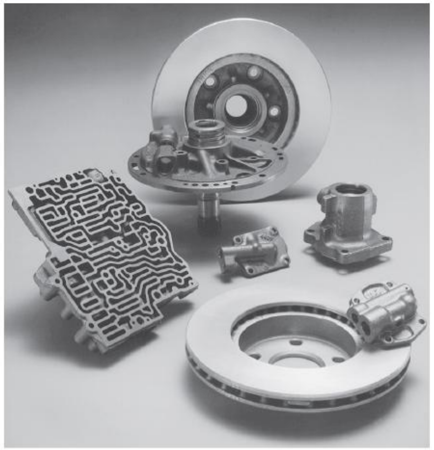
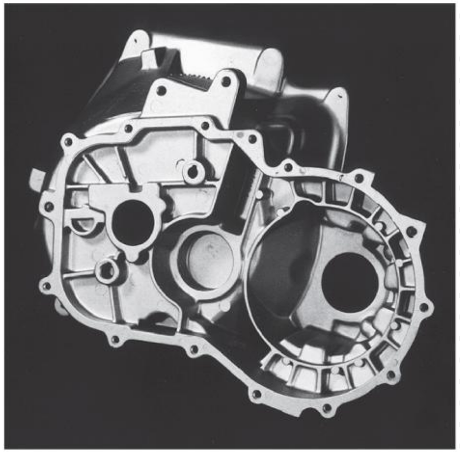
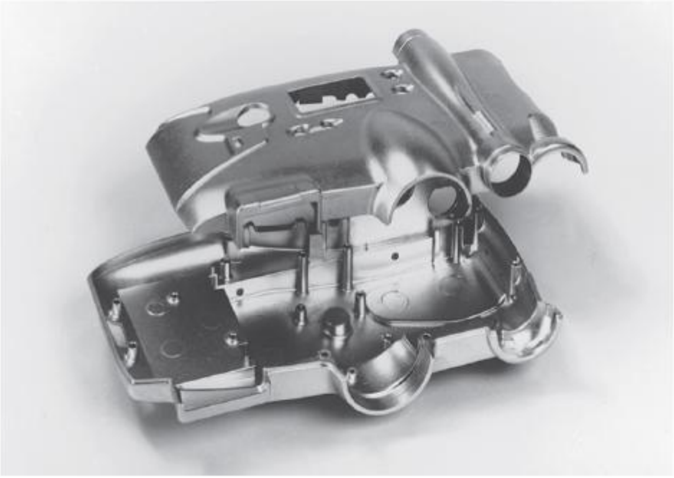
Introduction

- Molding categories:

1. **Expendable molds**
2. **Permanent molds**
3. **Composite molds**







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Introduction

- General characteristics of sand casting and casting processes are summarized

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	<0.01	0.01
Maximum	No limit	100+	100+	50+	100+	300	50	5000+
Typical 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
Typical dimensional tolerance (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
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 to 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. Minimum quantity is 1 when applying rapid prototyping.
Source: Data taken from J.A. Schey, *Introduction to Manufacturing Processes*, 3d ed., McGraw-Hill, 2000.

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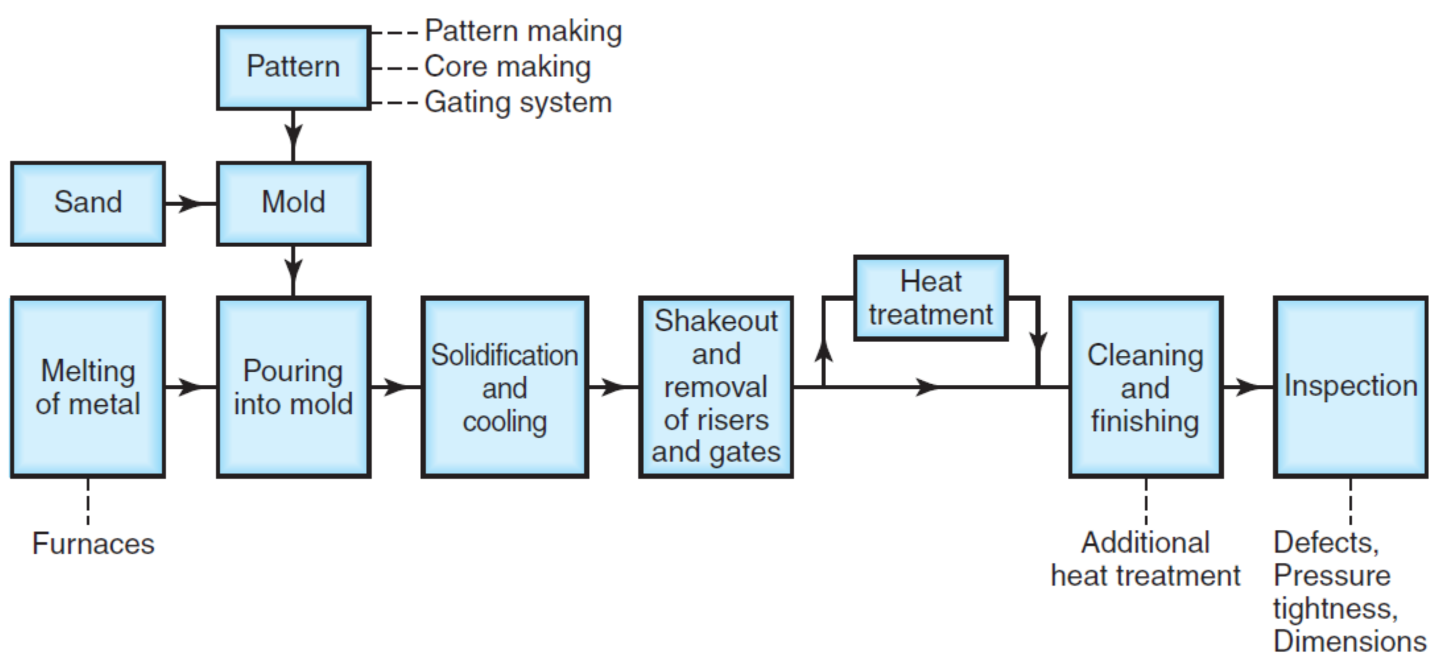
Expendable-mold, Permanent-pattern Casting Processes: Sand Casting

- Most prevalent form of casting
- Application for machine bases, large turbine impellers, propellers, plumbing fixtures



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Expendable-mold, Permanent-pattern Casting Processes: Sand Casting

Sand

- Sand-casting operations use silica sand as the mold material
- Sand is inexpensive and suitable high melting point process
- 2 types of sand: **naturally bonded** (*bank sand*) and **synthetic** (*lake sand*)
- Fine grained sand enhances mold strength and lower mold *permeability*

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Expendable-mold, Permanent-pattern Casting Processes: Sand Casting

Types of Sand Molds

3 basic types:

1. **Green-sand mold**
   Sand in the mold is moist or damp while the metal is being poured into it
2. **Cold-box mold**
   Organic and inorganic *binders* are blended into the sand to bond the grains chemically
3. **No-bake mold**
   Synthetic liquid resin is mixed with the sand and allow to hardens at room temperature

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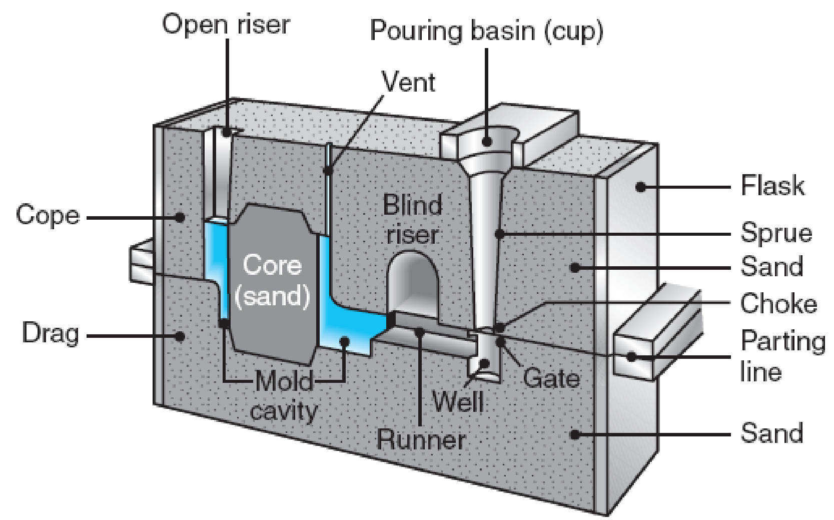
Expendable-mold, Permanent-pattern Casting Processes: Sand Casting

Major features of molds in sand casting

Tim hieu cac chuc nang cua cac thanh phan

- **Flask**
- **Cope** on top and a **drag** on the bottom
- **Pouring basin / Pouring cup**
- **Sprue**
- **Runner system, gates**
- **Risers**
- **Cores**
- **Vents**



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Expendable-mold, Permanent-pattern Casting Processes: Sand Casting

Pattern

Can cu vao chi tiet

- *Patterns* are used to mold the sand mixture into the shape of the casting
- Selection of a pattern material depends on the

1. Size and shape of the casting
2. Dimensional accuracy
3. Quantity of castings required
4. Molding process

Mau thuong lon hon chi tiet vi sau khi dong dac vat lieu co lai

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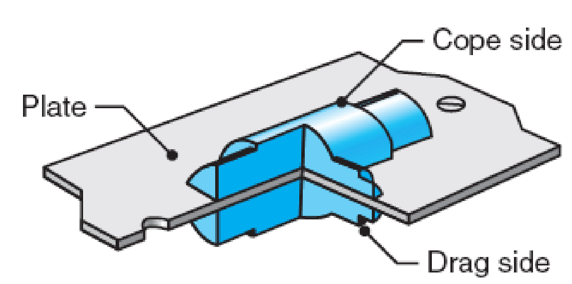
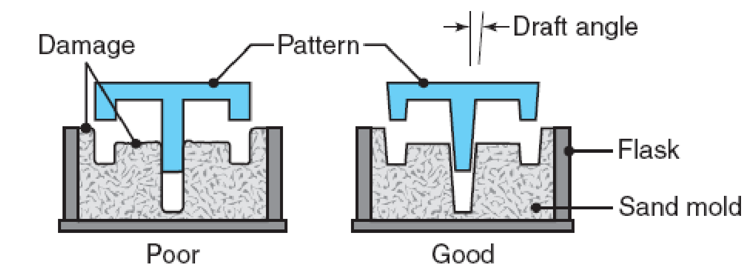
Expendable-mold, Permanent-pattern Casting Processes: Sand Casting

Pattern

- **Match-plate patterns**
  2 patterns are constructed by securing each half of one or more split patterns to the opposite sides of a single plate



- Pattern design should provide for **metal shrinkage** to allow the pattern to be easily removed



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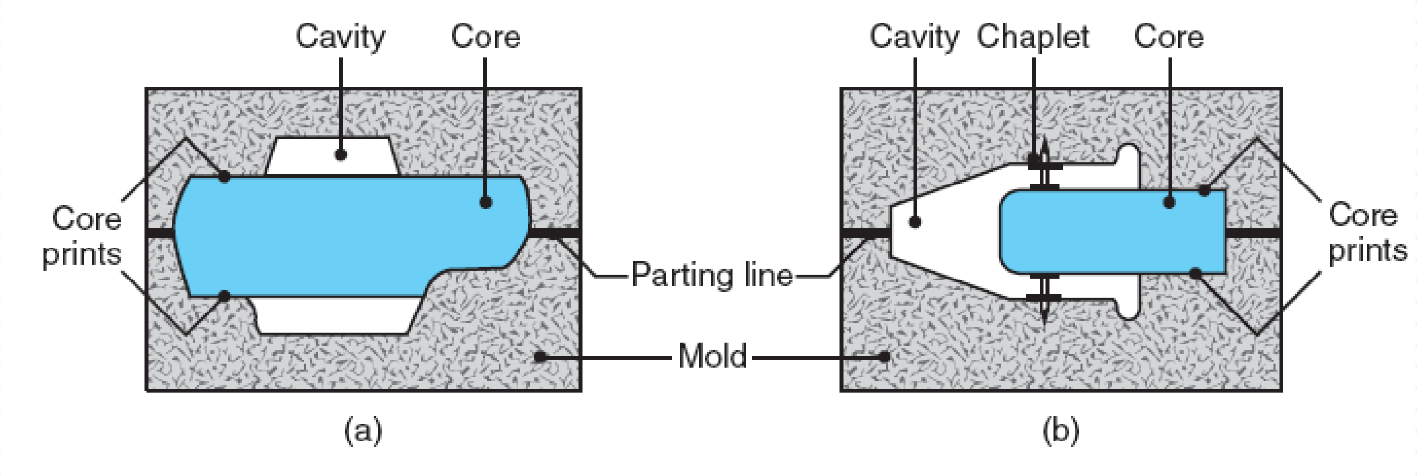
Expendable-mold, Permanent-pattern Casting Processes: Sand Casting

Cores

- Cores are placed in the mold cavity to form the interior surfaces of the casting
- It is removed from the finished part during shakeout and further processing



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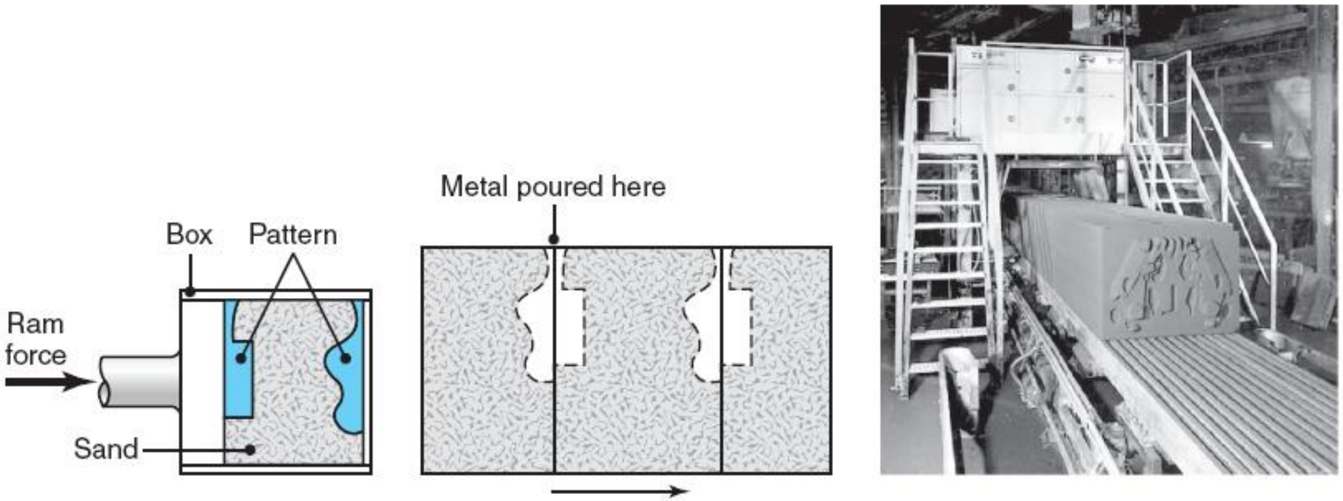
Sand-molding Machines

- In **vertical flaskless molding**, the halves of the pattern form a vertical chamber wall against which sand is blown and compacted



(a) (b) (c)

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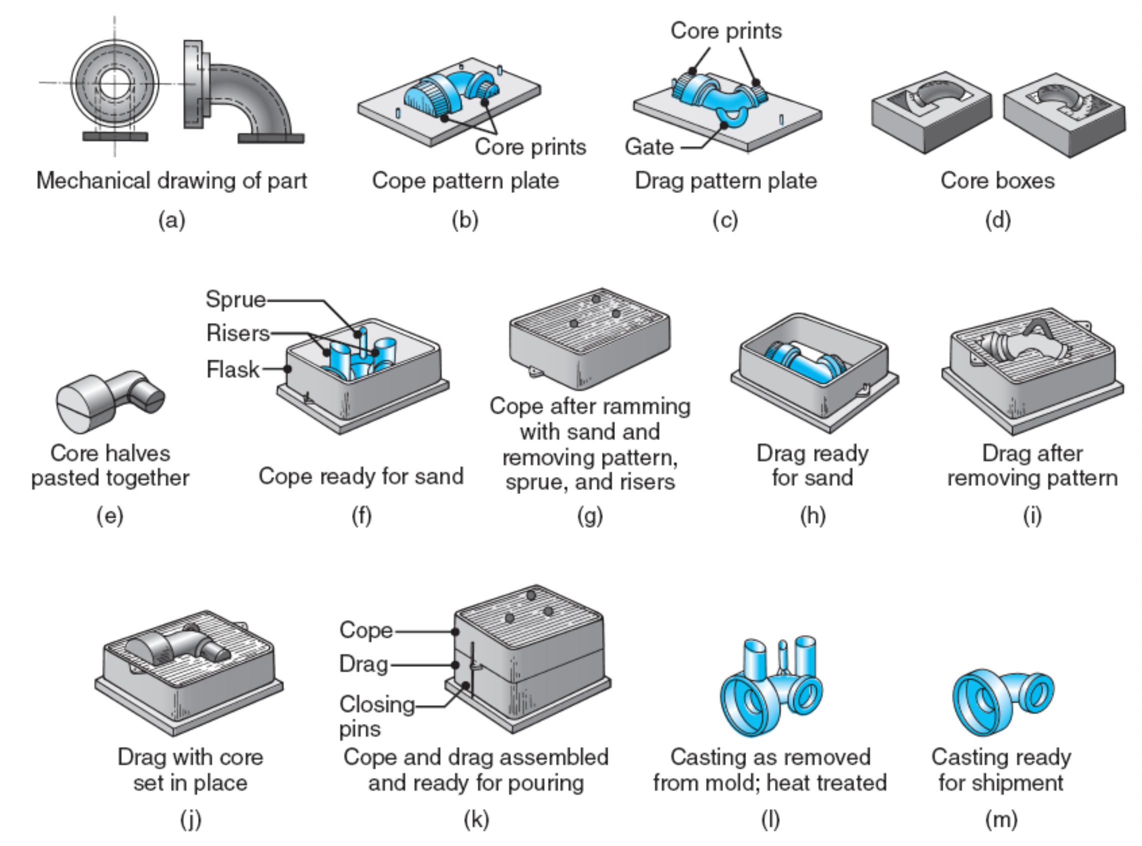
Expendable-mold, Permanent-pattern Casting Processes: Sand Casting

The Sand-casting Operation



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Expendable-mold, Permanent-pattern Casting Processes: Sand Casting

The Sand-casting Operation

- *Finishing operations* may involve machining, straightening, or forging with dies (sizing) to obtain final dimensions
- *Inspection* is carried out to ensure that the casting meets all design and quality-control requirements

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Expendable-mold, Permanent-pattern Casting Processes: Shell Molding

- *Shell molding* can produce many types of castings with close dimensional tolerances and a good surface finish at low cost
- Applications include small mechanical parts requiring high precision such as gear housings
- Shell sand has lower permeability than sand used for green-sand molding
- Complex shapes can be produced with less labor since it can be automated easily

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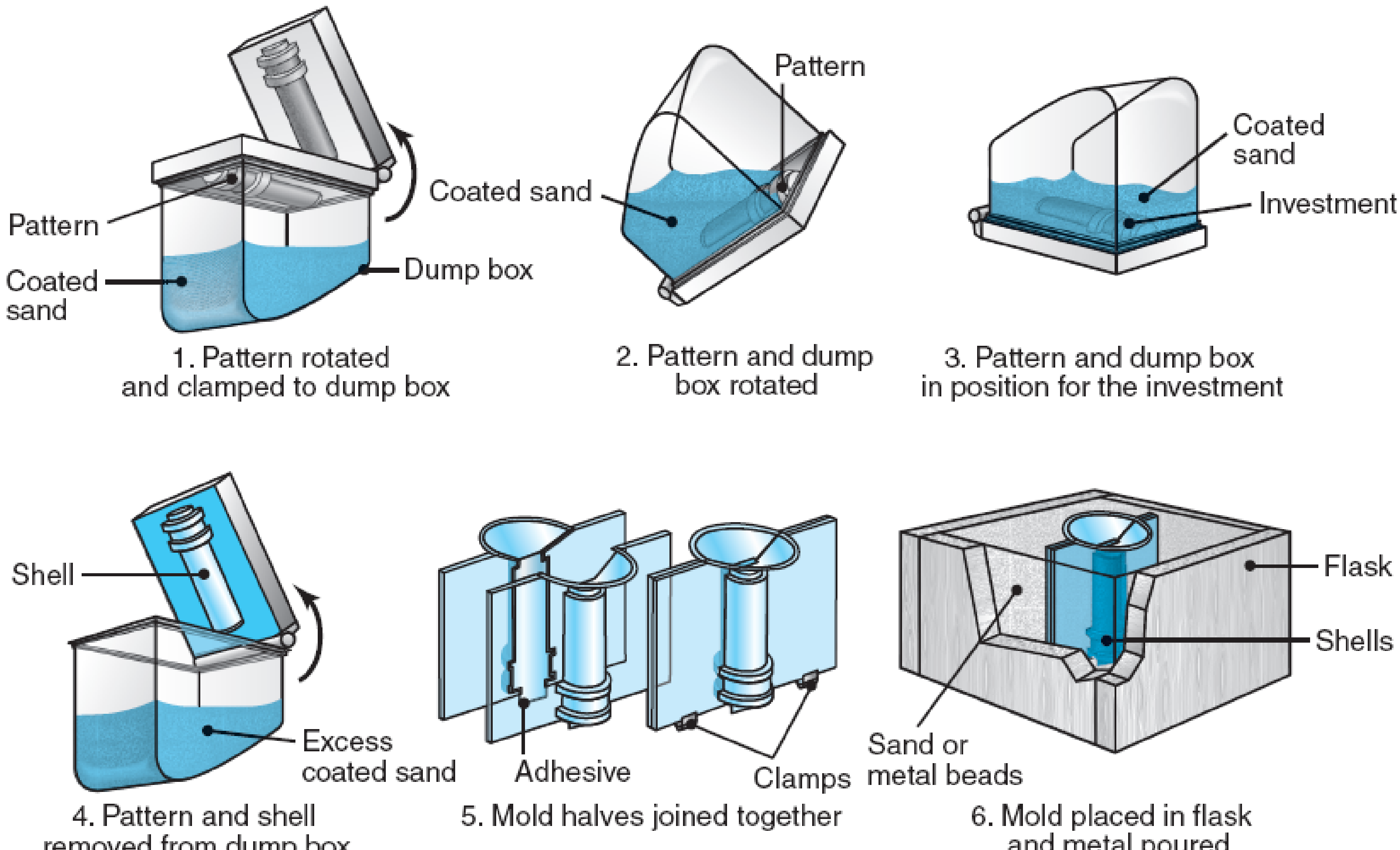
Expendable-mold, Permanent-pattern Casting Processes: Shell Molding



1. Pattern rotated and clamped to dump box
2. Pattern and dump box rotated
3. Pattern and dump box in position for the investment
4. Pattern and shell removed from dump box
5. Mold halves joined together
6. Mold placed in flask and metal poured

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Expendable-mold, Permanent-pattern Casting Processes: Plaster-mold Casting

- **Precision casting** produce high dimensional accuracy and good surface finish products
- Typical parts made are lock components, gears, valves, fittings, tooling, and ornaments
- In *plaster-molding* process, the mold is made of plaster of paris with the addition of talc and silica flour to improve strength

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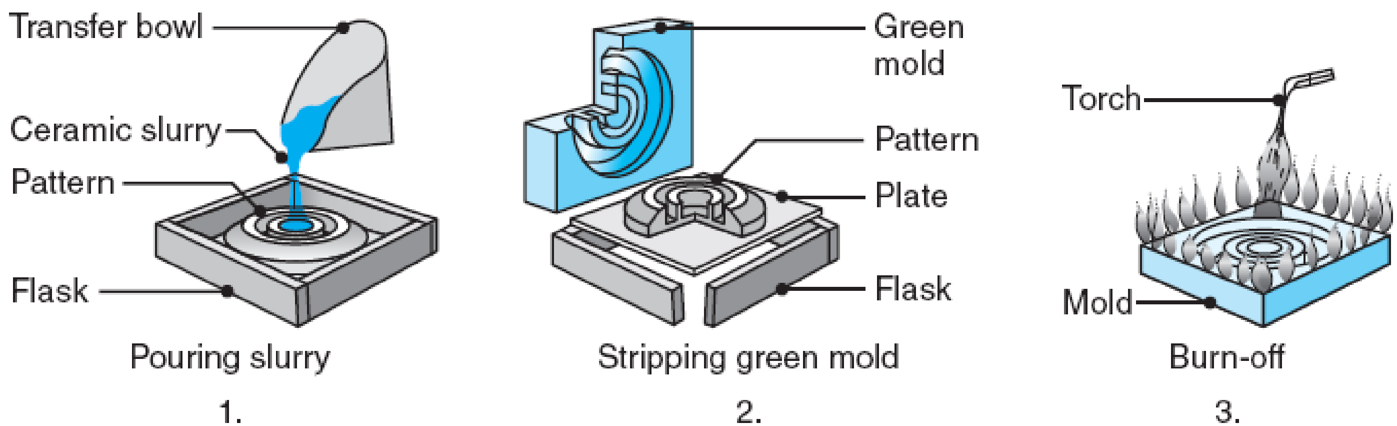
Expendable-mold, Permanent-pattern Casting Processes: Ceramic-mold Casting

- *Ceramic-mold casting* process is similar to the plaster-mold process but uses refractory mold materials suitable for high-temperature applications



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Expendable-mold, Expendable-pattern Casting Processes: Evaporative-pattern Casting (Lost-foam Process)

- *Evaporative-pattern casting* process uses a polystyrene pattern, which evaporates upon contact with molten metal to form a cavity for the casting
- Used for ferrous and nonferrous metals which is applicable to automotive industry
- The advantages are:

1. Simple
2. Inexpensive flasks and polystyrene
3. Minimal finishing and cleaning operations
4. Process can be automated

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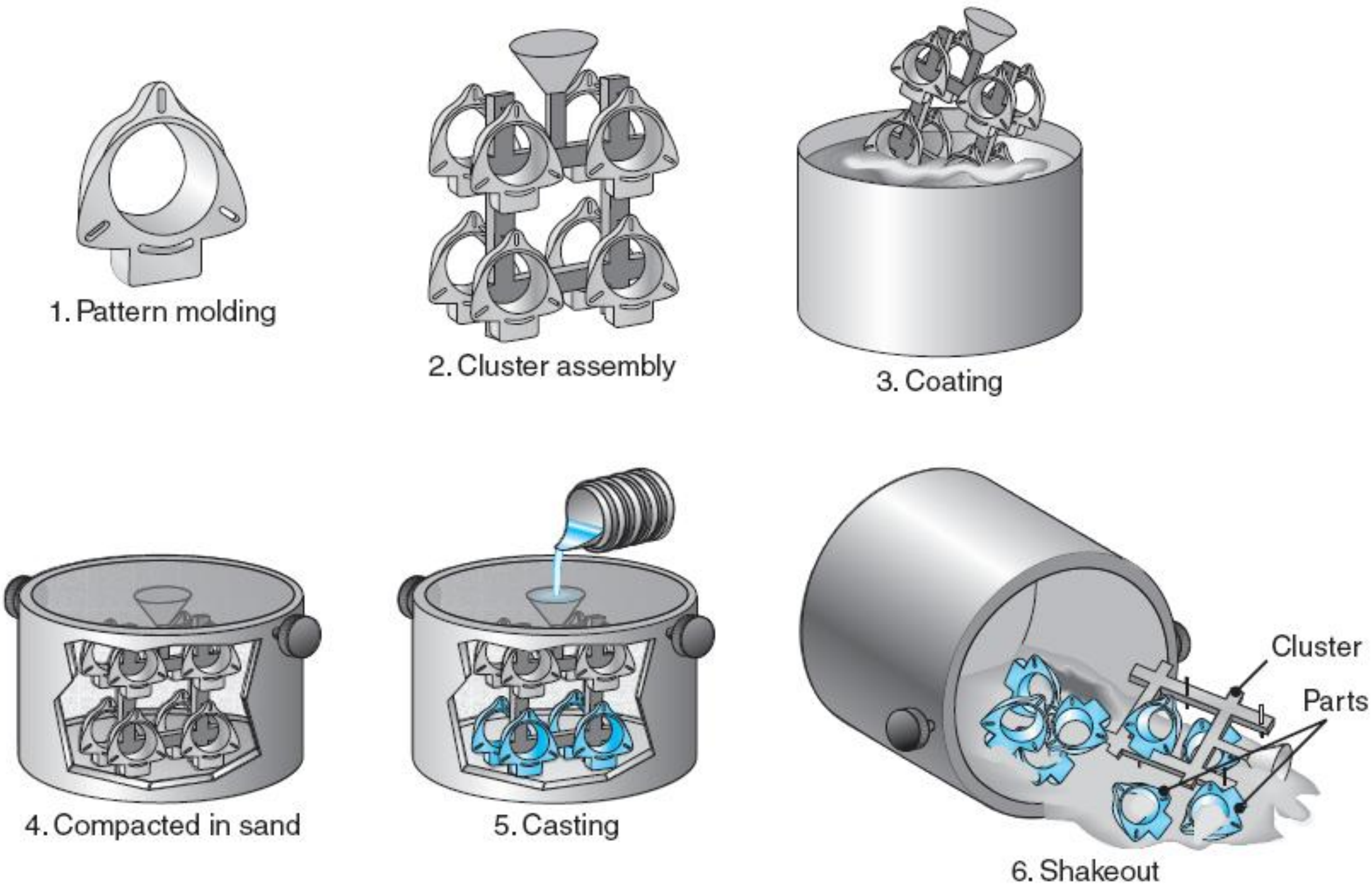
Expendable-mold, Expendable-pattern Casting Processes: Evaporative-pattern Casting (Lost-foam Process)



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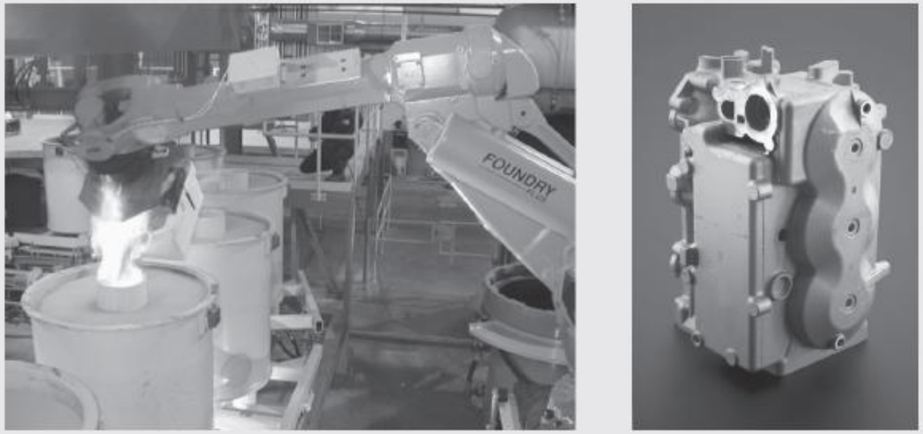
Expendable-mold, Expendable-pattern Casting Processes: Evaporative-pattern Casting (Lost-foam Process)

CASE STUDY 11.1

Lost-foam Casting of Engine Blocks

a) Metal is poured into a mold for lost-foam casting of a 60-hp, three-cylinder marine engine

b) Finished engine block



(a) (b)

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Expendable-mold, Expendable-pattern Casting Processes: Investment Casting

- Also called **lost-wax process**
- Used to make office equipment, and mechanical components such as gears
- Pattern is invested (surrounded) with the refractory material
- Mold is heated up to drive off the water of crystallization and to burn off any residual wax
- Process is capable of producing intricate shapes from ferrous and nonferrous metals and alloys

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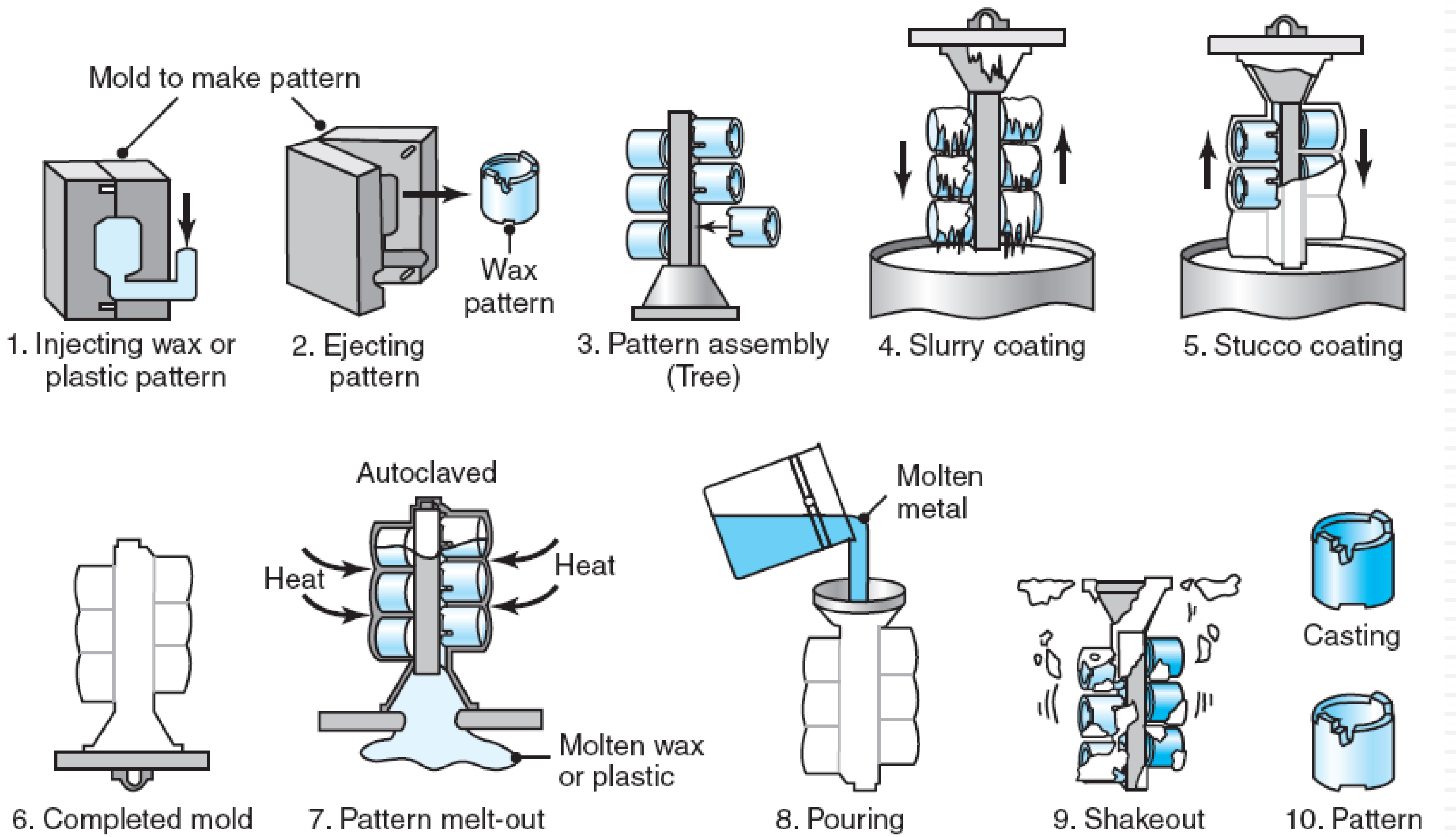
Expendable-mold, Expendable-pattern Casting Processes: Investment Casting



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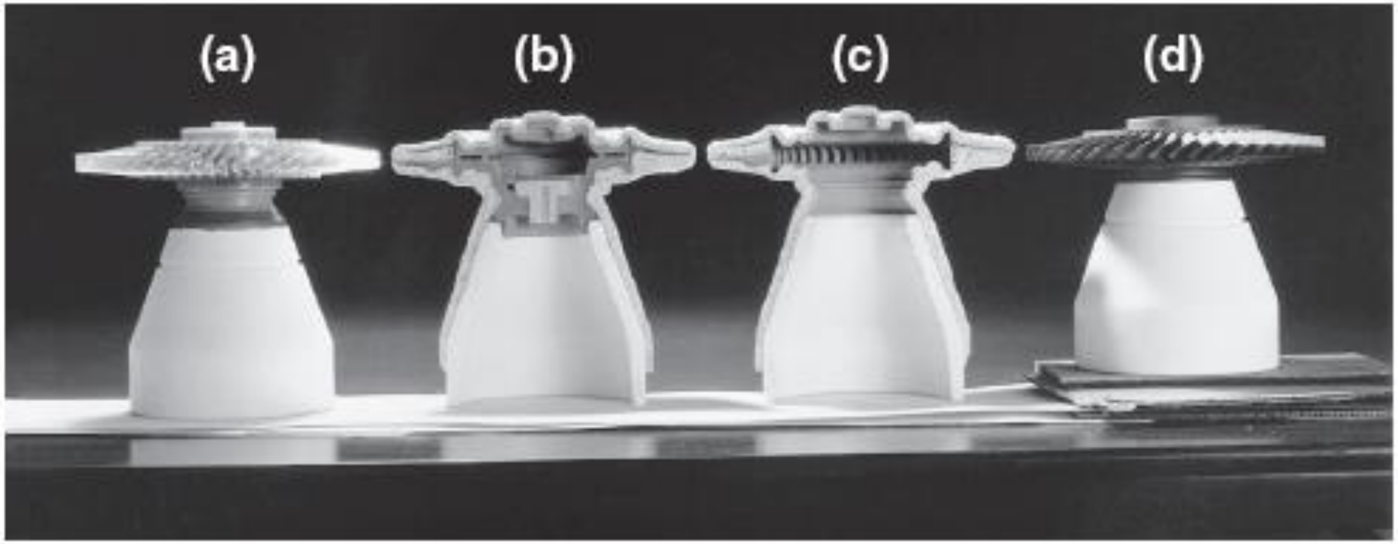
Expendable-mold, Expendable-pattern Casting Processes: Investment Casting

Ceramic-shell Investment Casting

- Process is economical and is used for the precision casting of steels and high-temperature alloys



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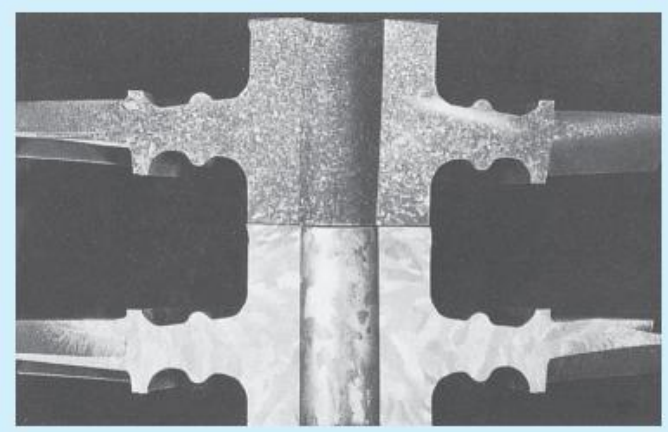
Expendable-mold, Expendable-pattern Casting Processes: Investment Casting

EXAMPLE 11.1

Investment-cast Superalloy Components for Gas Turbines

- Figure shows a cross section and microstructure of two rotors:

1. (Top) Investment cast
2. (Bottom) Conventionally cast



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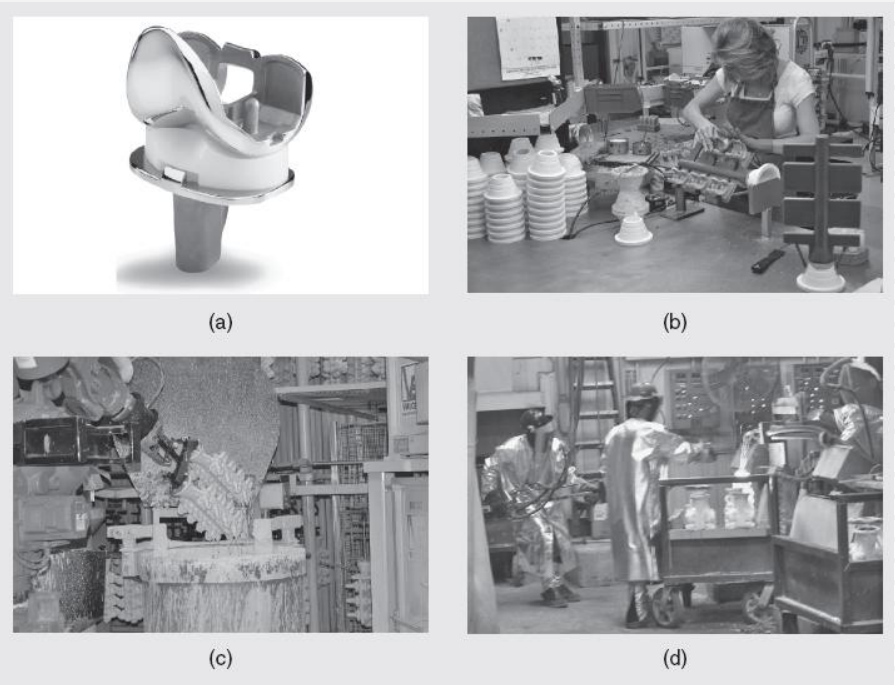
CASE STUDY 11.2

Investment Casting of Total Knee Replacements

- Manufacture of total knee replacements



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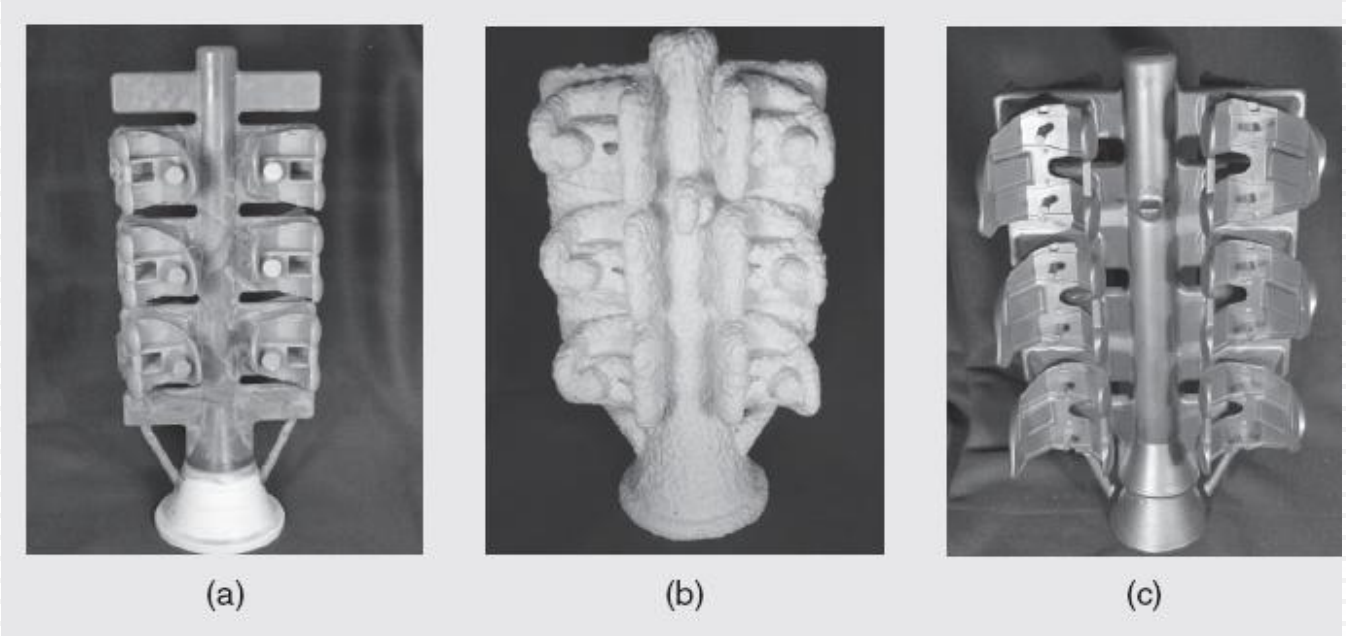
Expendable-mold, Expendable-pattern Casting Processes: Investment Casting

CASE STUDY 11.2

Investment Casting of Total Knee Replacements

- Progression of the tree



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Permanent-mold Casting Processes: Permanent-mold Casting

- 2 halves of a mold are made from materials with high resistance to erosion and thermal fatigue
- In order to increase the life of permanent molds, the surfaces of the mold cavity are coated with a refractory slurry or sprayed with graphite
- Equipment costs is high but labor costs are kept low through automation
- Not economical for small production runs

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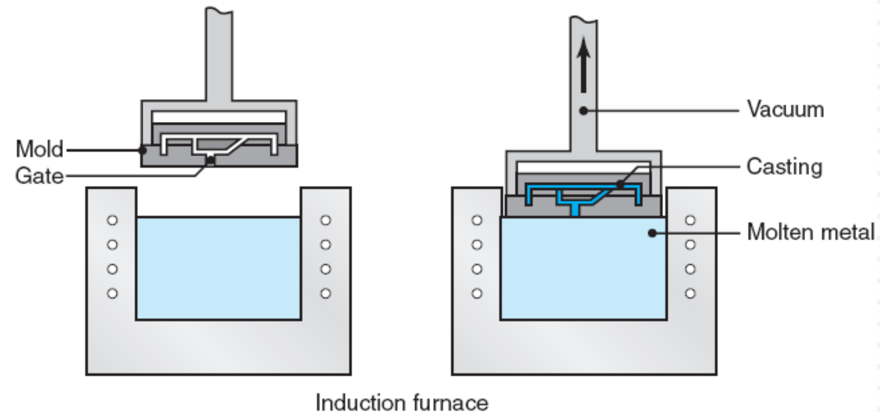
Permanent-mold Casting Processes: Vacuum Casting

- Vacuum casting is an alternative to other casting and is suitable for thin-walled complex shapes with uniform properties
- A mixture of fine sand and urethane is molded over metal dies and cured with amine vapor
- Automated and production costs are similar green-sand casting



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Permanent-mold Casting Processes: Die Casting

- *Die-casting* process is a further example of permanent-mold casting
- 2 basic types of die-casting machines:

1. **Hot-chamber process** use a piston to forces a certain volume of metal into the die cavity through a gooseneck and nozzle
2. **Cold-chamber process** is where molten metal is poured into the injection cylinder (*shot chamber*)

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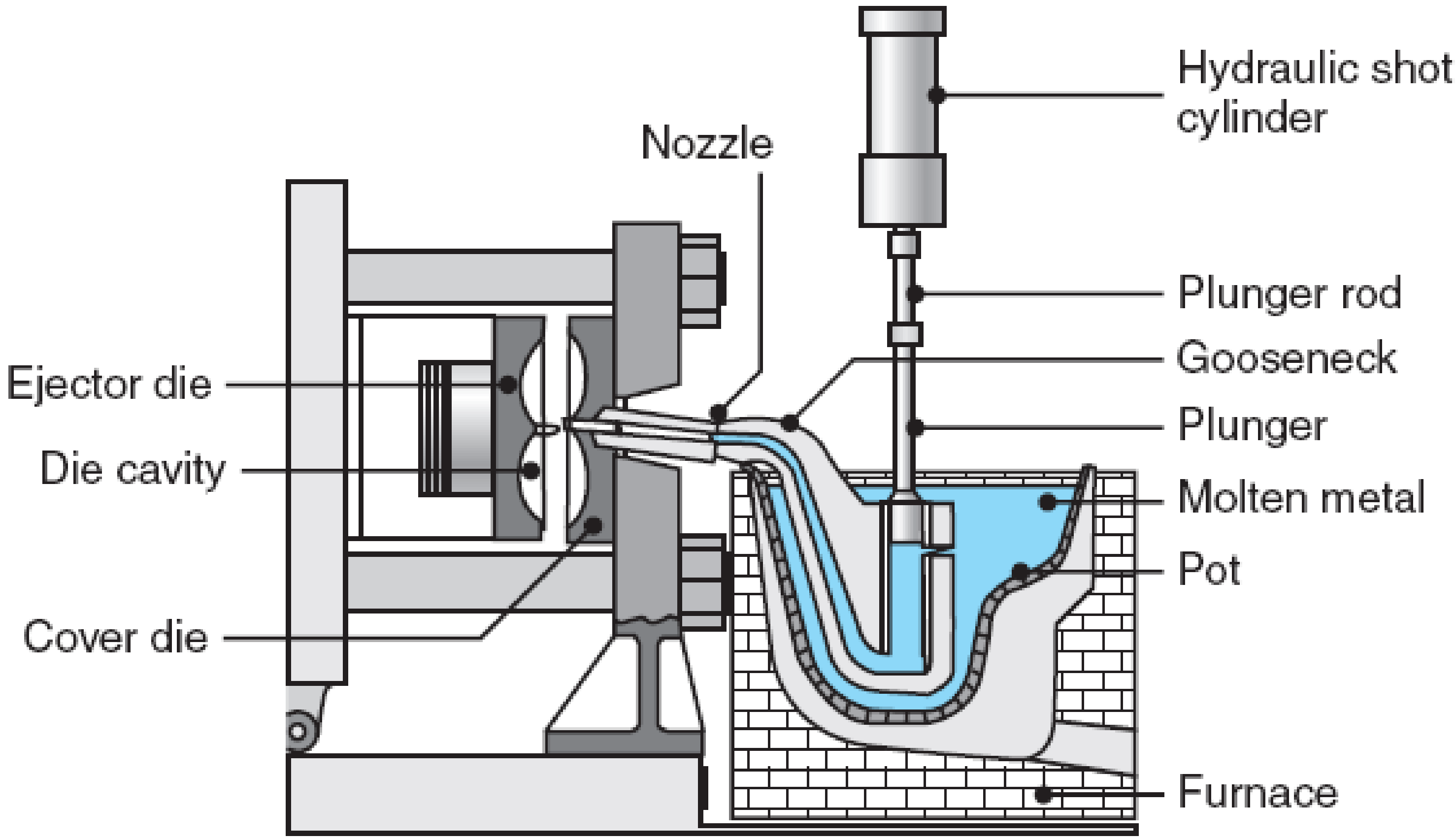
Permanent-mold Casting Processes: Die Casting (*Hot Chamber*)



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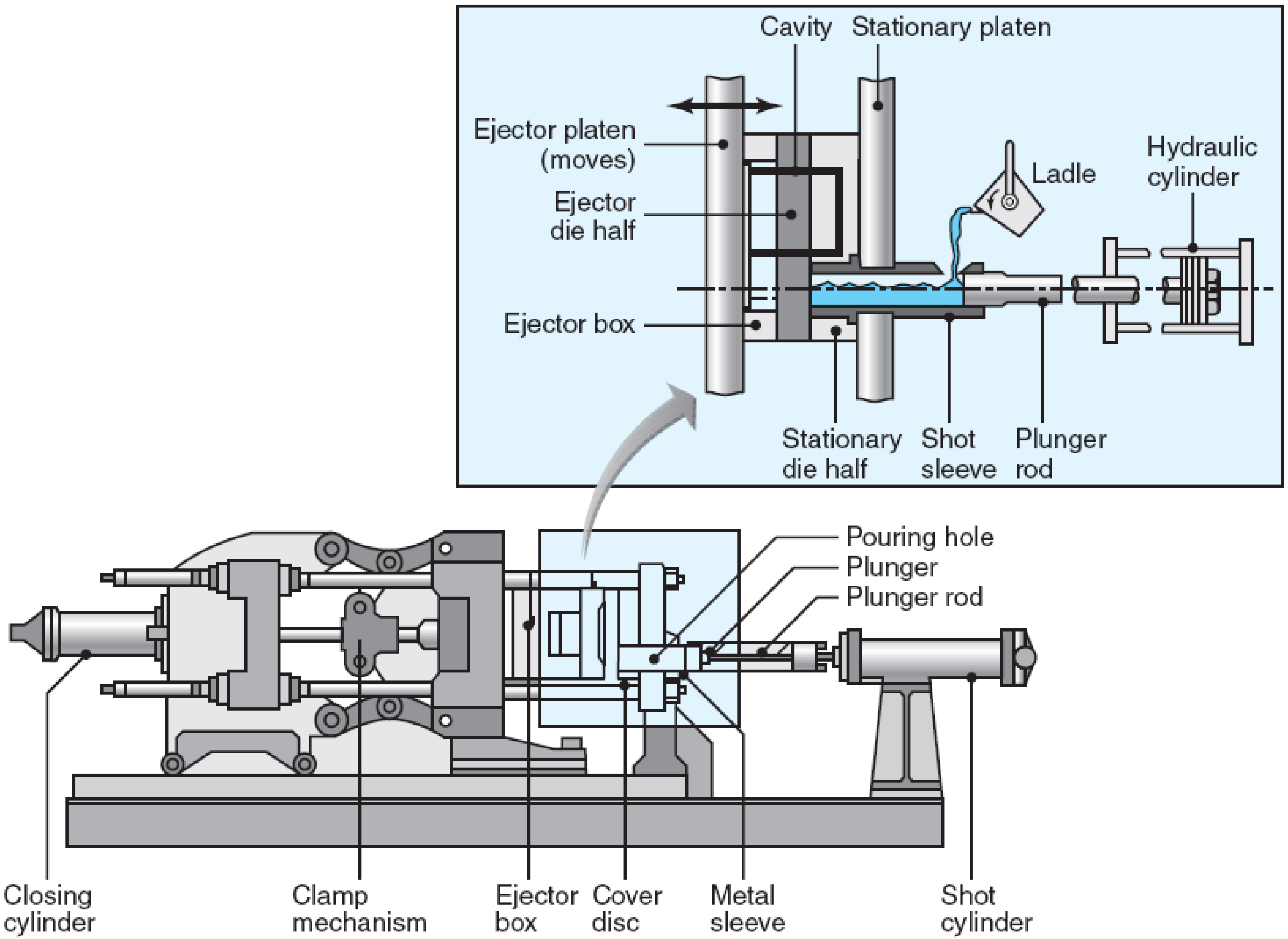
Permanent-mold Casting Processes: Die Casting (*Cold Chamber*)



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Permanent-mold Casting Processes: Die Casting

Process Capabilities and Machine Selection

- Die casting is able to produce strong and high-quality parts with complex shapes
- Also produces good dimensional accuracy and surface details
- Strength-to-weight ratio of die-cast parts increases with decreasing wall thickness

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Permanent-mold Casting Processes: Die Casting

Process Capabilities and Machine Selection

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 AZ91 B (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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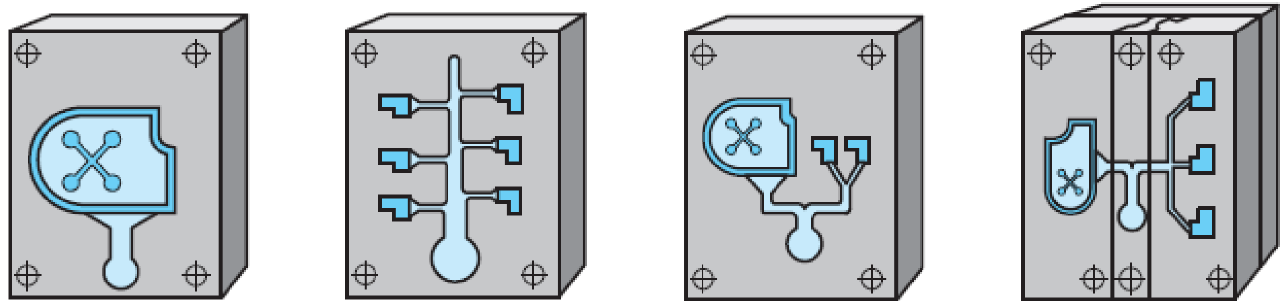
Permanent-mold Casting Processes: Die Casting

Process Capabilities and Machine Selection

- Die-casting dies can be

1. *Single cavity*
2. *Multiple cavity* (several identical cavities)
3. *Combination cavity* (several different cavities)
4. *Unit dies*



Single-cavity die (a) Multiple-cavity die (b) Combination die (c) Unit die (d)

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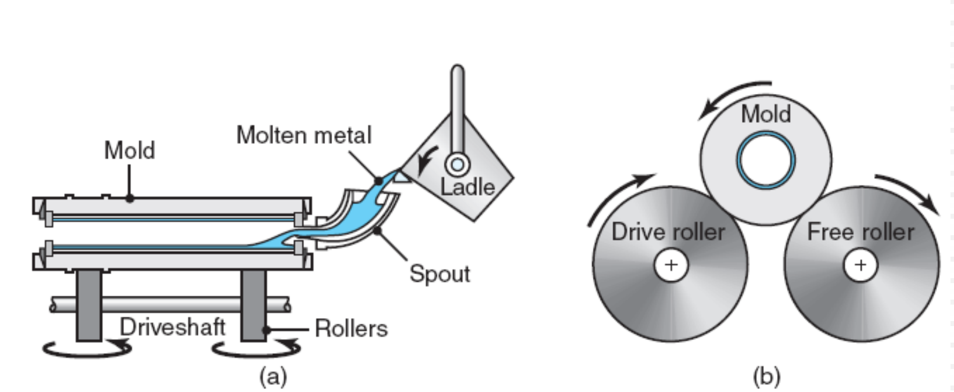
Permanent-mold Casting Processes: Centrifugal Casting

- *Centrifugal-casting* process utilizes inertial forces to distribute the molten metal into the mold cavities

True Centrifugal Casting

- Cylindrical parts (such as pipes, gun barrels) are produced by the technique



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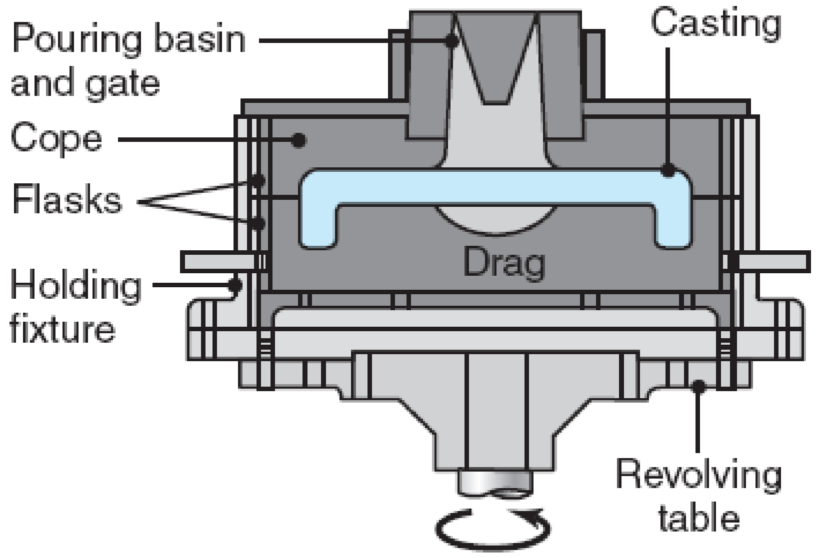
Permanent-mold Casting Processes: Centrifugal Casting

Semicentrifugal Casting

- Used to cast parts with rotational symmetry, such as a wheel with spokes.



(a)

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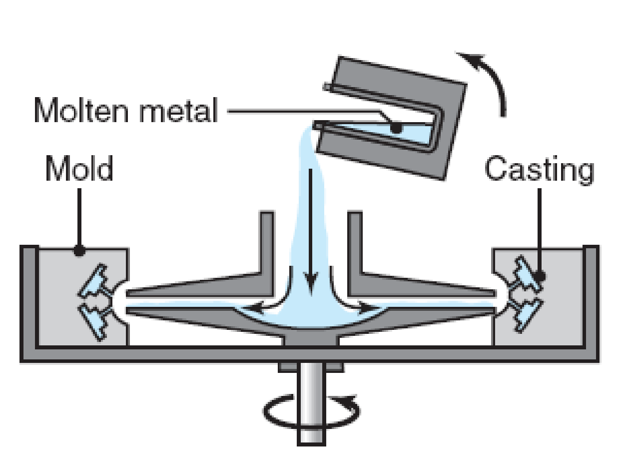
Permanent-mold Casting Processes: Centrifugal Casting

Centrifuging

- Mold cavities of any shape are placed at a certain distance from the axis of rotation
- Properties of the castings can vary by distance from the axis of rotation, as in true centrifugal casting



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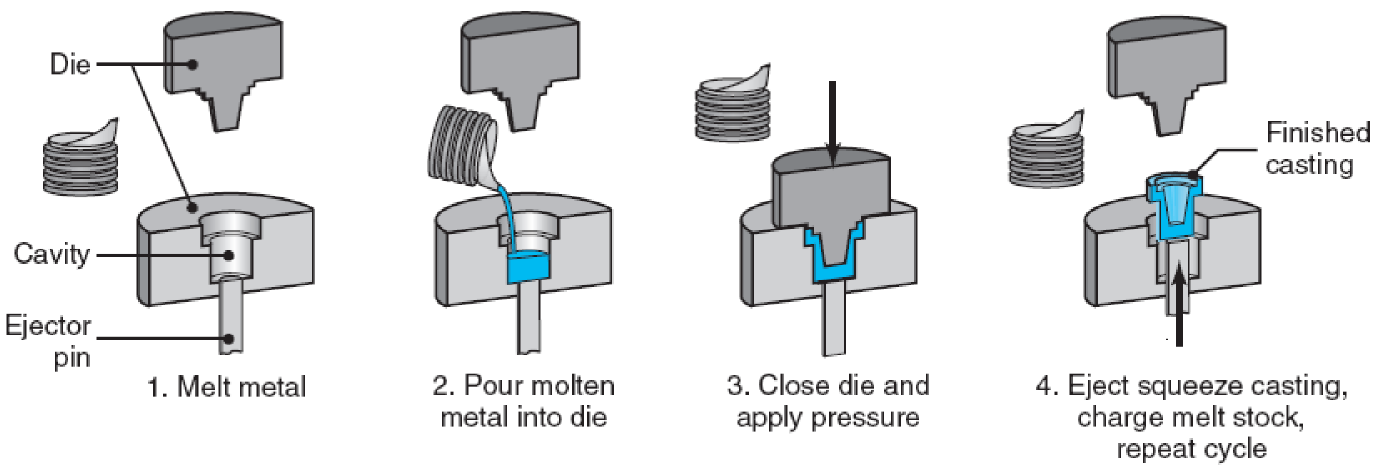
Permanent-mold Casting Processes: Squeeze Casting and Semisolid-metal Forming

Squeeze Casting

- Involves the solidification of molten metal under high pressure
- Products made are automotive components and mortar bodies



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Permanent-mold Casting Processes: Composite-mold Casting Operations

- *Composite molds* are made of two or more different materials
- Used for casting complex shapes such as impellers for turbines
- Composite molds

1. Increase the strength of the mold
2. Improve the dimensional accuracy and surface finish
3. Help reduce overall costs and processing time

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Casting Techniques for Single-crystal Components

Conventional Casting of Turbine Blades

- Uses a ceramic mold
- Molten metal is poured into the mold and solidify at the ceramic walls
- Grain structure developed is polycrystalline
- Grain boundaries cause structure to creep and cracking along the boundaries

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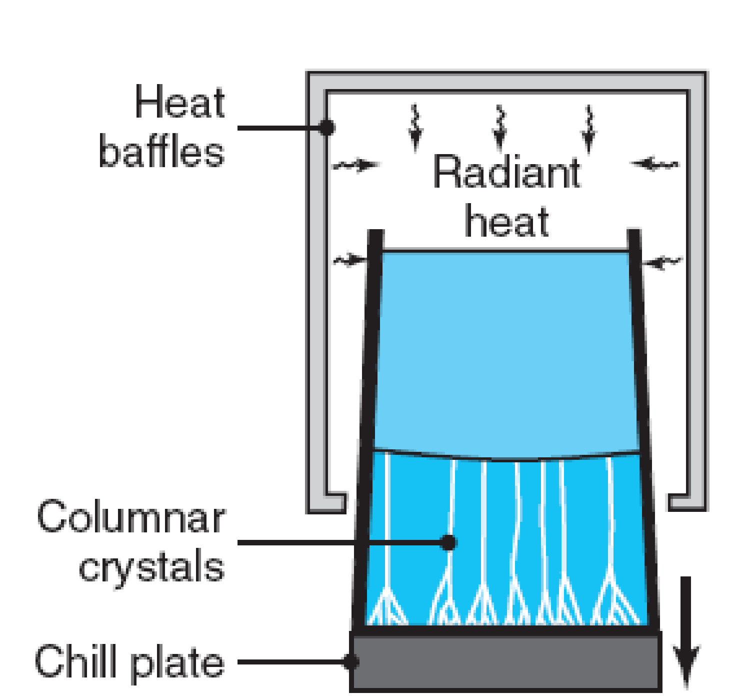
Casting Techniques for Single-crystal Components

Directionally Solidified Blades

- Ceramic mold is preheated by radiant heating
- Metal is poured into the mold and allow crystals to grow



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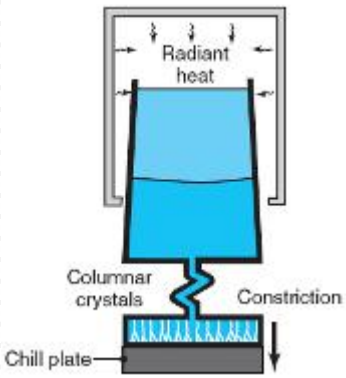
Casting Techniques for Single-crystal Components

Single-crystal Blades

- The mold has a constriction in the shape of a corkscrew or helix
- Only the most favourably oriented crystals are able to grow through the helix
- Blades are more expensive, lack of grain boundaries has resistant to creep and thermal shock
- Longer and more reliable service life



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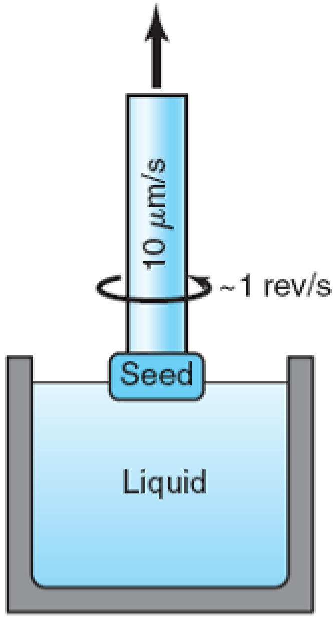
Casting Techniques for Single-crystal Components

Single-crystal Growing

- 2 basic methods of crystal growing:

1. **Czochralski** (CZ) **process**
   - a seed crystal is dipped into the molten metal and then pulled out slowly while being rotated
   - liquid metal solidify on the seed and crystal structure of the seed is continued throughout



(a)

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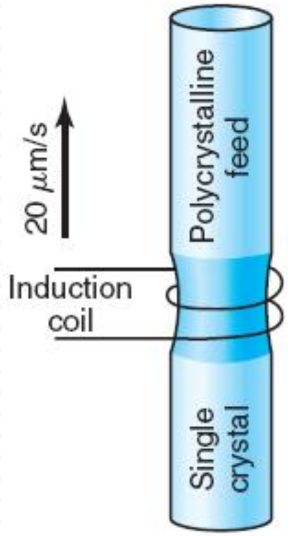
Casting Techniques for Single-crystal Components

Single-crystal Growing

2. **Floating-zone method**

- a rod of polycrystalline silicon resting on a single crystal
- induction coil heats these two pieces while the coil moves slowly upward
- single crystal grows upward while maintaining its orientation



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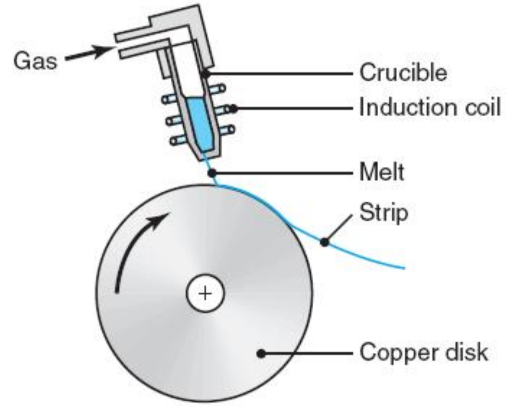
Rapid Solidification

- Technique for making *amorphous alloys* involves cooling the molten metal at high rates
- Thus does not have sufficient time to crystallize
- For **melt spinning**, the alloy is melted by induction in a ceramic crucible and propelled under high gas pressure against a rotating copper disk



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Inspection of Castings

- Control of all casting stages is essential to maintaining good quality
- Castings can be inspected *visually* or *optically* for surface defects
- In *destructive* testing, specimens are determined for the presence, location, and distribution of porosity and defects
- *Pressure tightness* of cast components is determined by sealing the openings in the casting and pressurizing it with water, oil, or air

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Melting Practice and Furnaces

- Melting practice has a direct bearing on the quality of castings
- Fluxes are inorganic compounds that refine the molten metal by removing dissolved gases and various impurities
- Added manually or injected automatically into the molten metal

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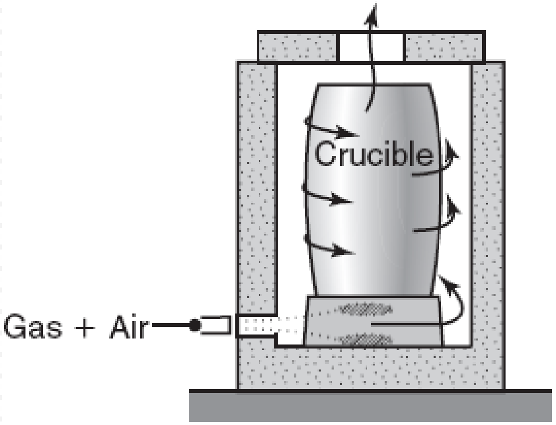
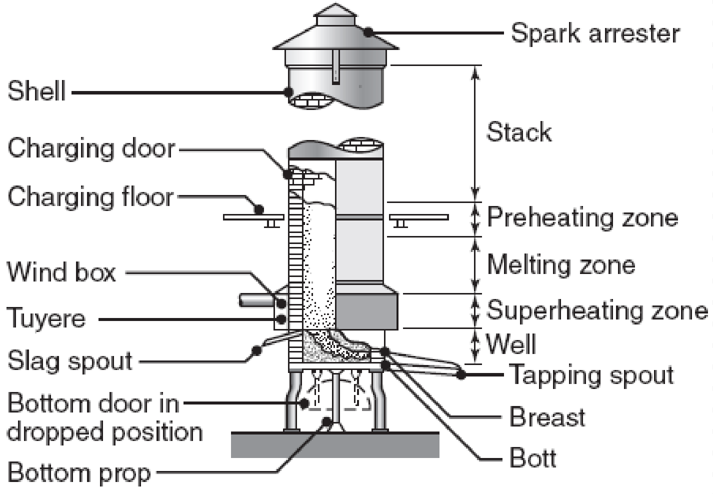
Melting Practice and Furnaces

Melting Furnaces

- Commonly used melting furnaces:

1. **Electric-arc** furnaces
2. **Induction** furnaces
3. **Crucible** furnaces
4. **Cupolas**
5. **Levitation melting**





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Foundries and Foundry Automation

- Casting operations usually are carried out in foundries
- Modern foundries have automated and computer-integrated facilities for all aspects of their operations
- Automation minimizes labor, reduces the possibility of human error, increases the production rate and attains higher quality level

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