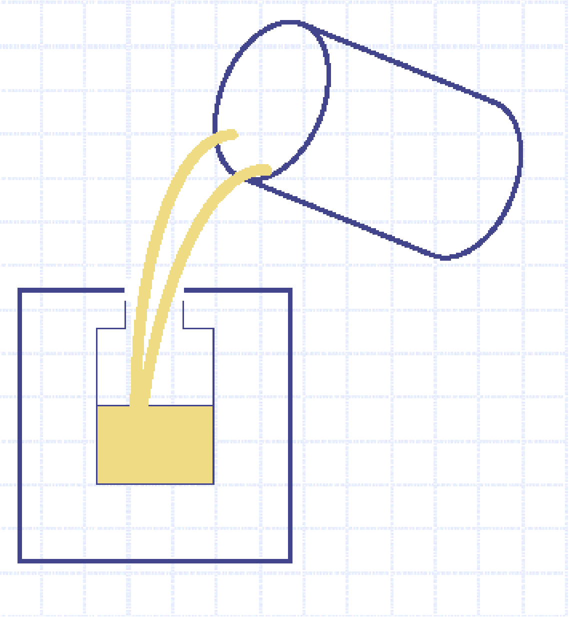
Metal casting



Casting Methods

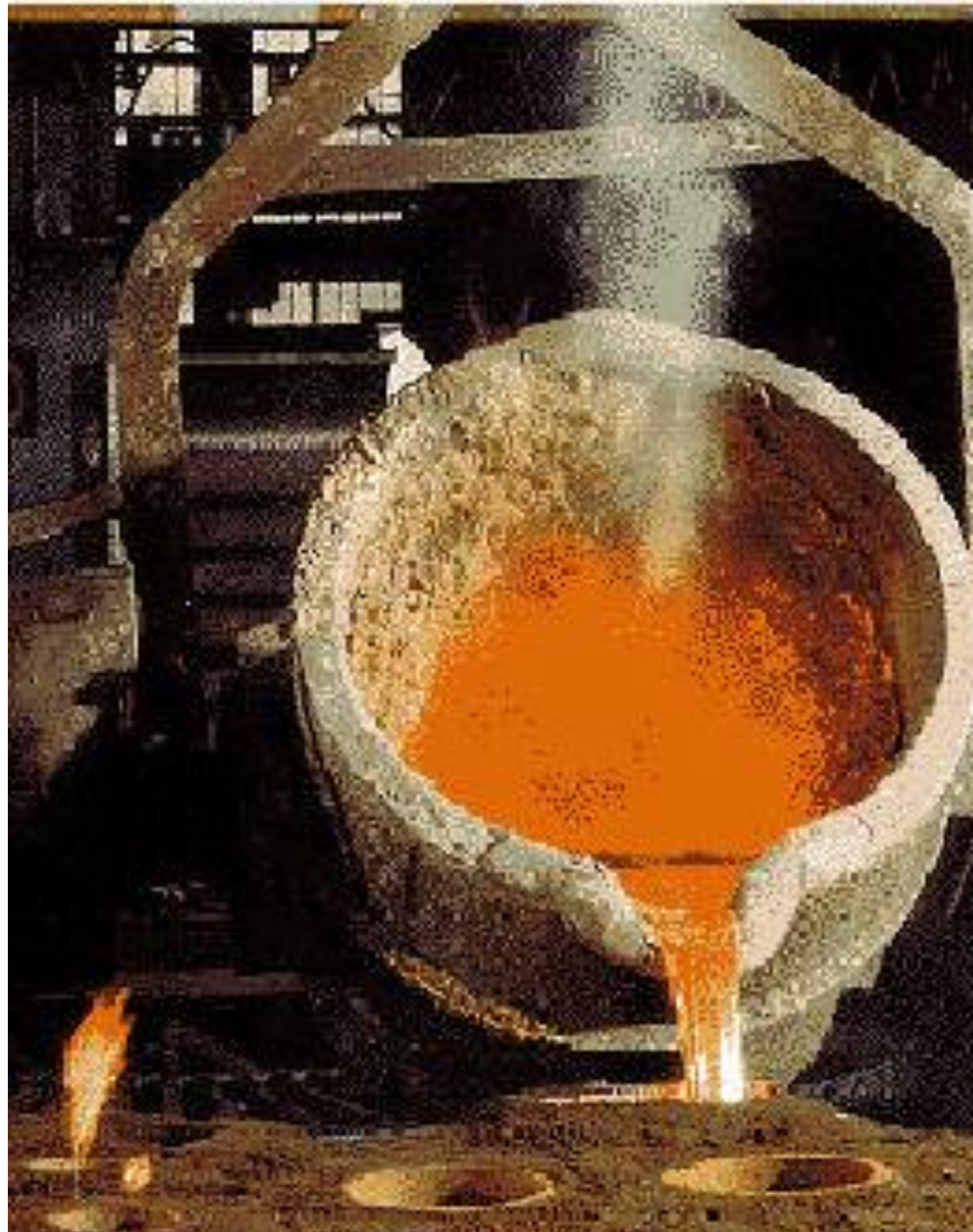
• Sand Casting
High Temperature Alloy,
Complex Geometry,
Rough Surface Finish

• Investment Casting
High Temperature Alloy,
Complex Geometry,
Moderately Smooth Surface Finish

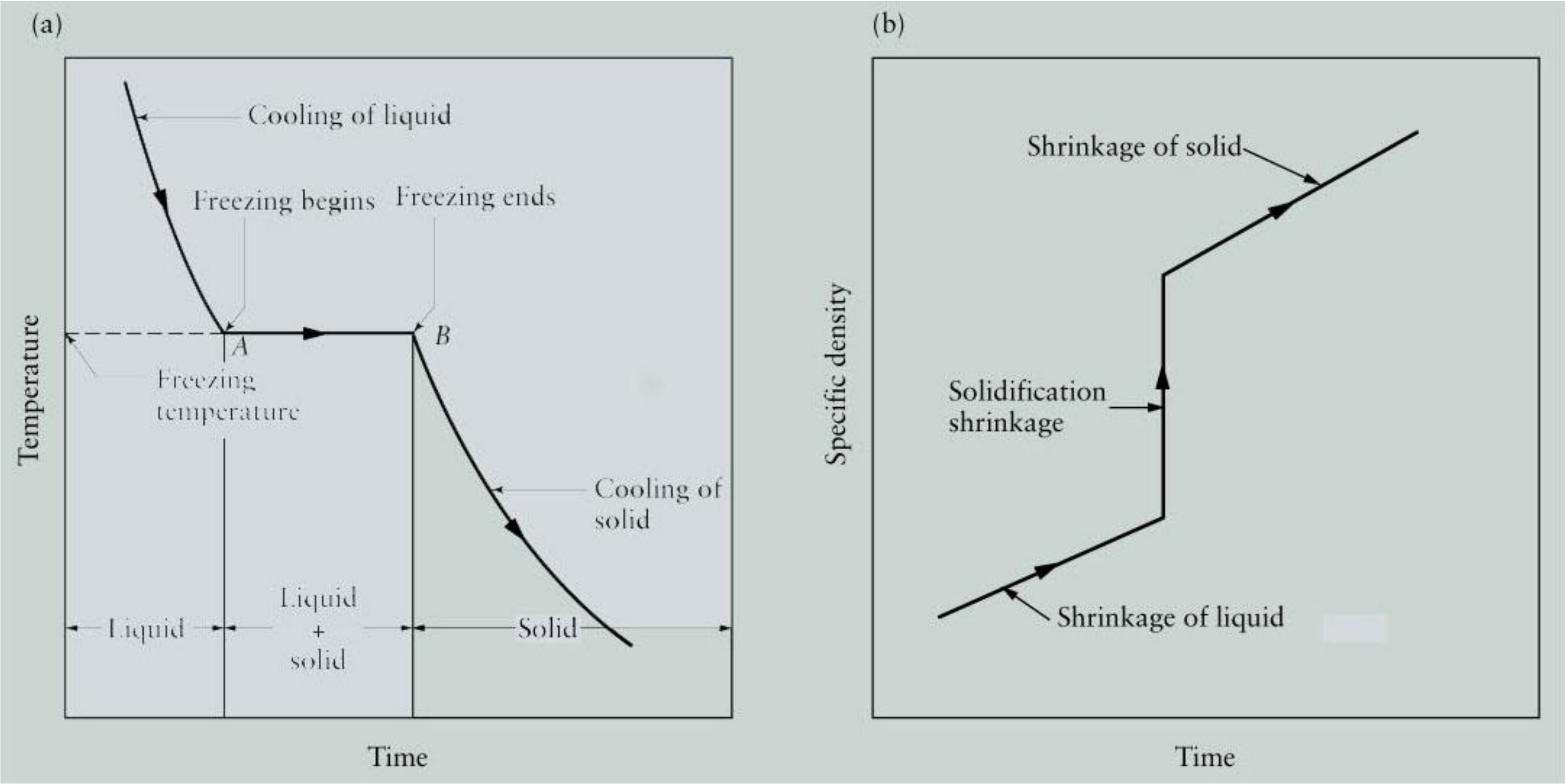
• Die Casting
High Temperature Alloy,
Moderate Geometry,
Smooth Surface

Sand Casting

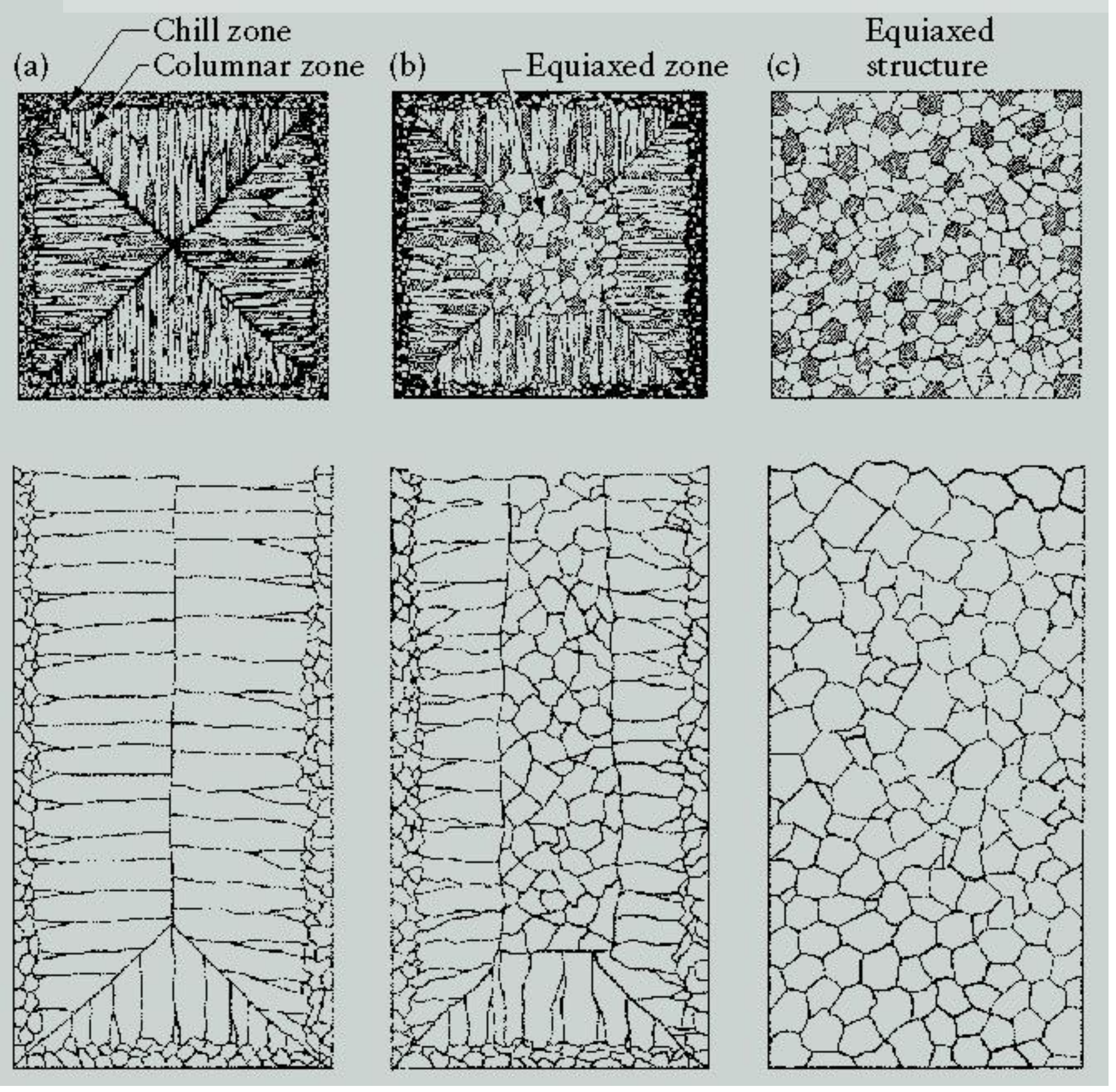
Metals: Most castable metals.
Size Range: Limitation depends on foundry capabilities. Ounces to many tons.
Tolerances:
Non-Ferrous ± 1/32^2 to 6^2
Add ± .003^2 to 3^2, ± 3/64^2 from 3^2 to 6^2.
Across parting line add ± .020^2 to ± .090^2 depending on size.
(Assumes metal patterns)
Surface Finish:
Non-Ferrous: 150-350 RMS
Ferrous: 300-700RMS
Minimum Draft Requirements:
1° to 5°
Cores: 1° to 1 1/2°
Normal Minimum Section Thickness:
Non-Ferrous: 1/8^2 - 1/4^2
Ferrous: 1/4^2 - 3/8^2



Solidification of Pure Metals

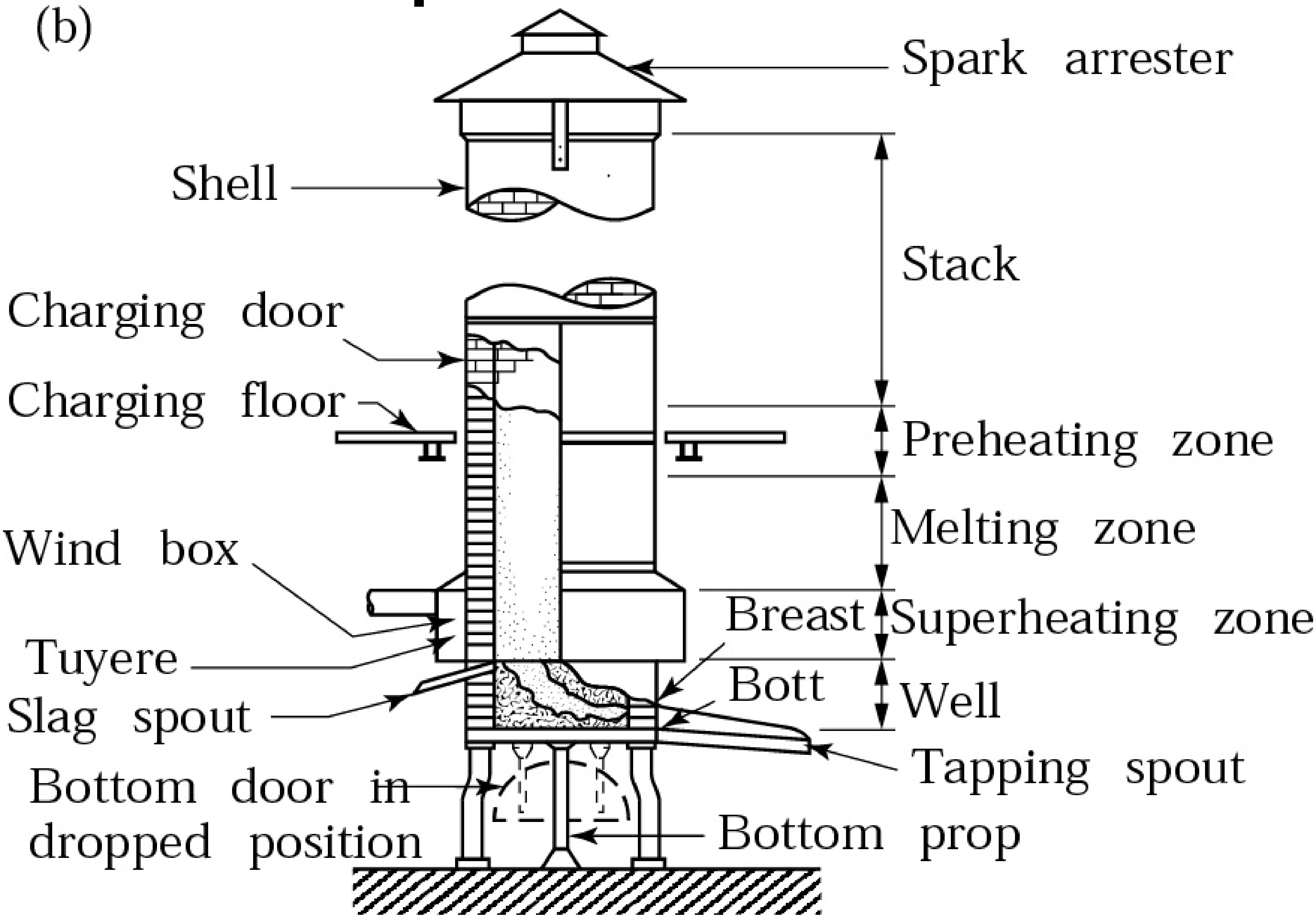


Three Cast Structures of Solidified Metals

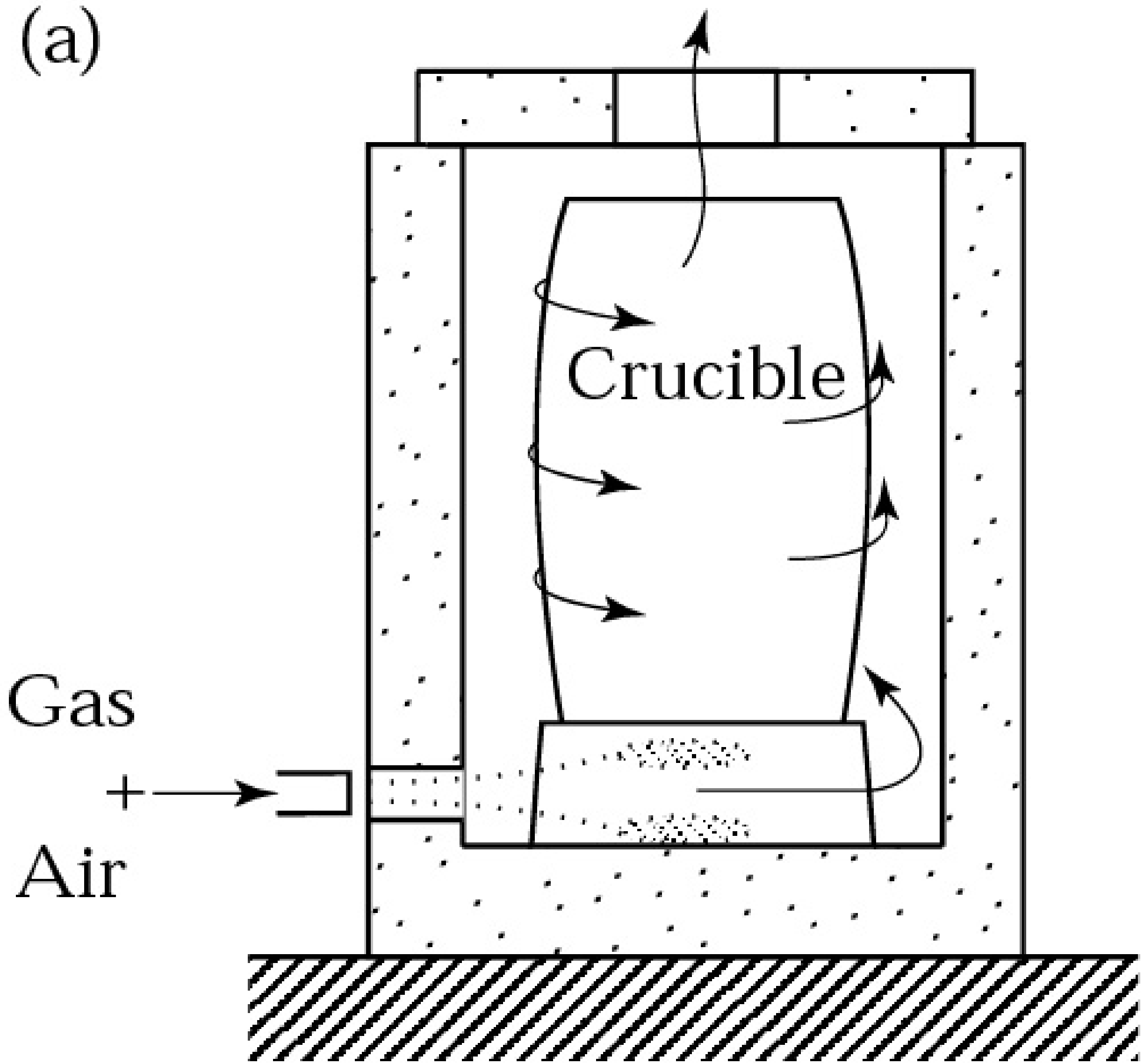


- Schematic illustration of three cast structures of metals solidified in a square mold:
- (a) pure metals;
- (b) solid-solution alloys; and
- (c) the structure obtained by heterogeneous nucleation of grains, using nucleating agents.

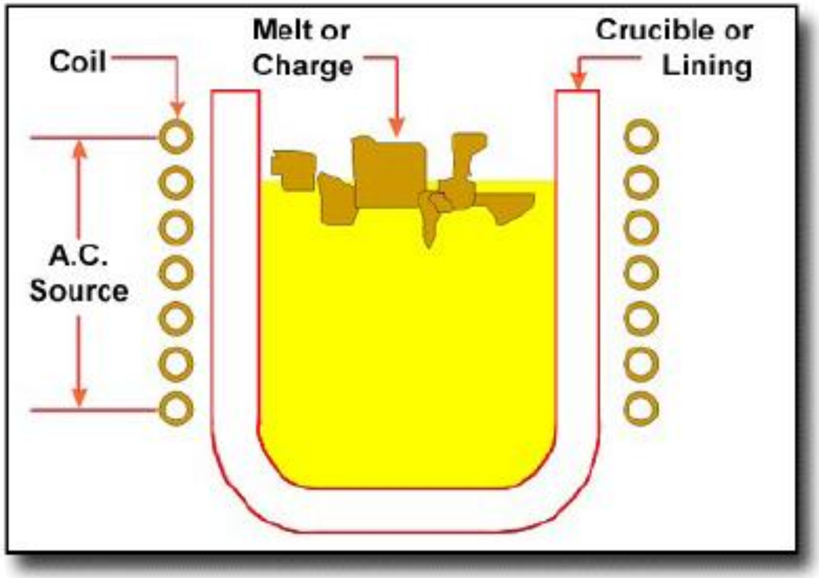
Cupola furnace

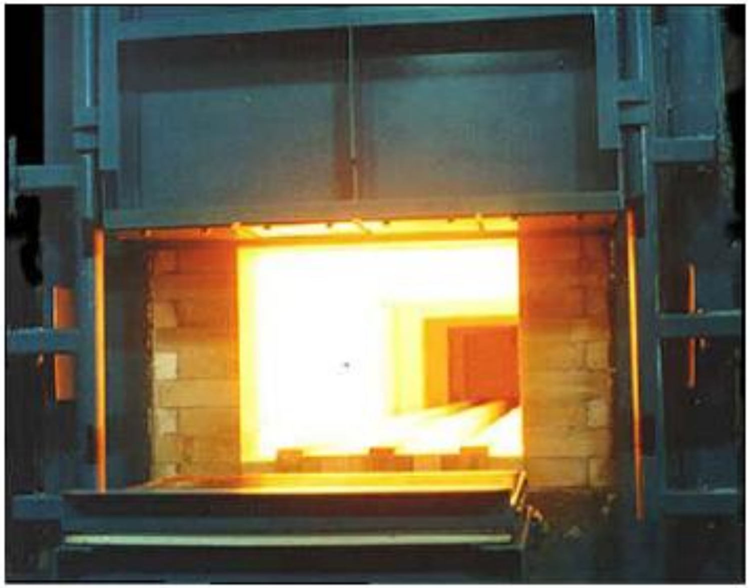


Crucible furnace



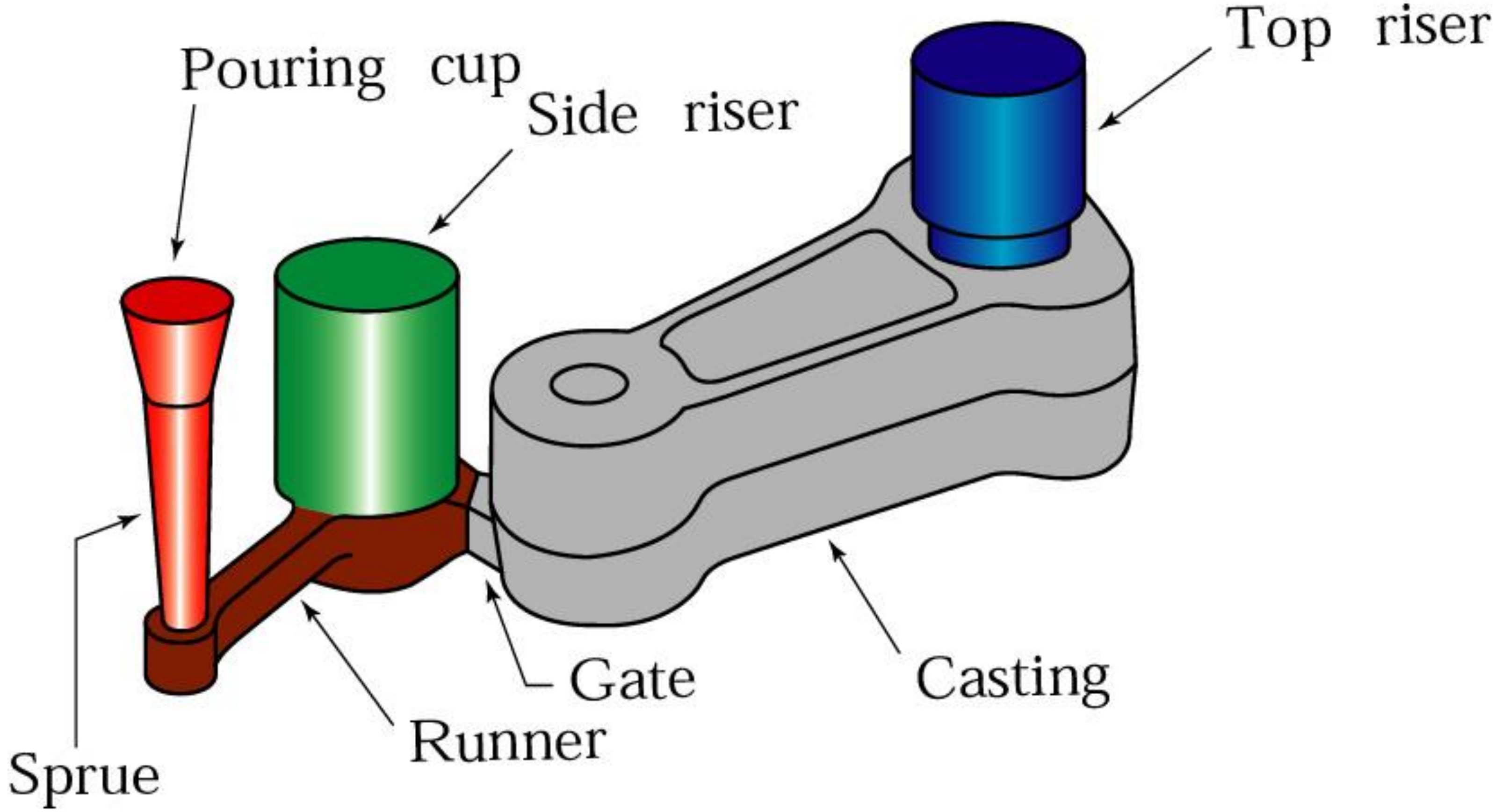
Electric Furnaces



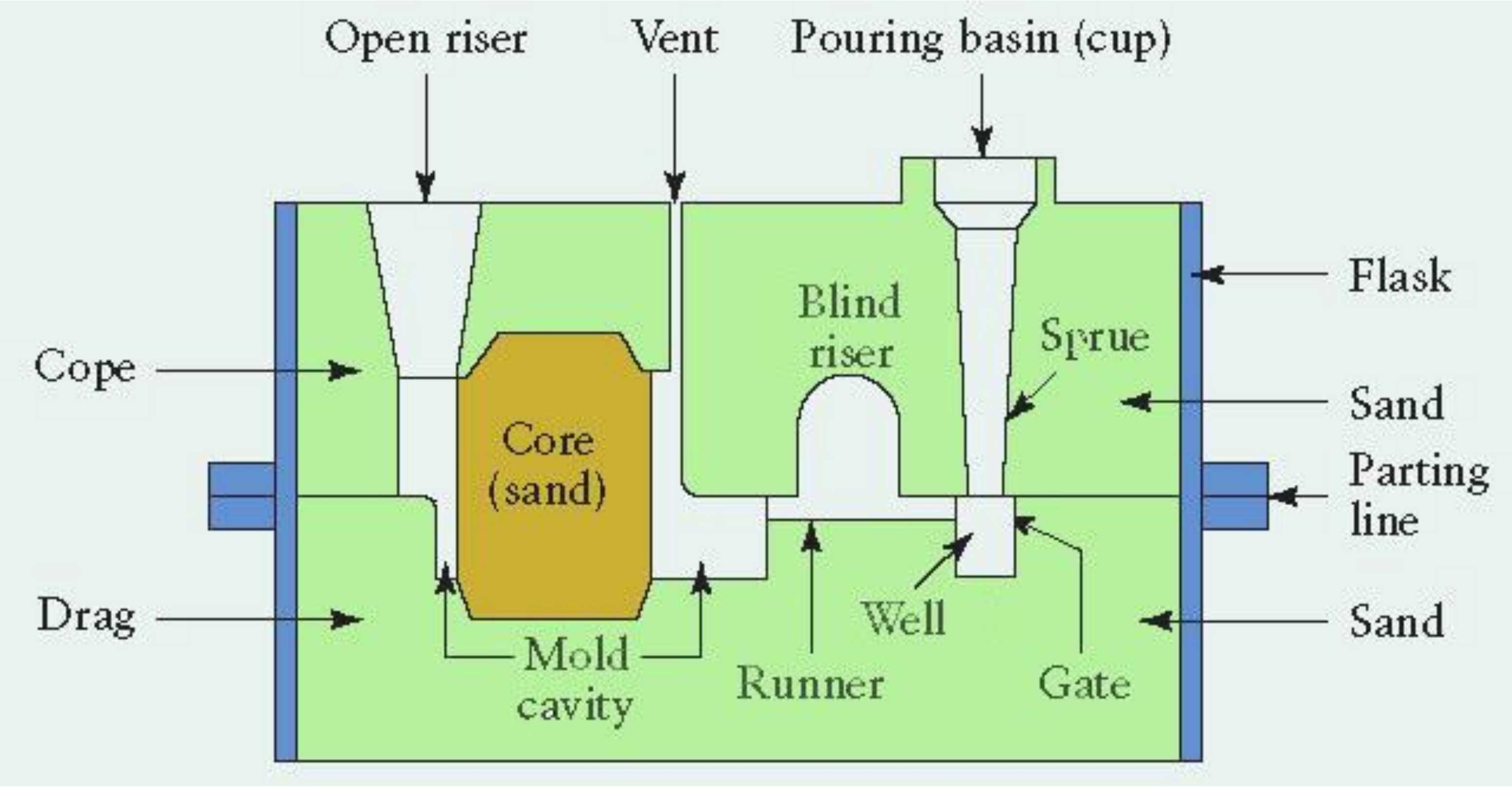


Induction Furnace

Electric Furnace


Pouring cup
Side riser
Top riser
Sprue
Runner
Gate
Casting

Features of a Sand Mold



- **Schematic illustration of a sand mold, showing various features.**

Steps in Sand Casting

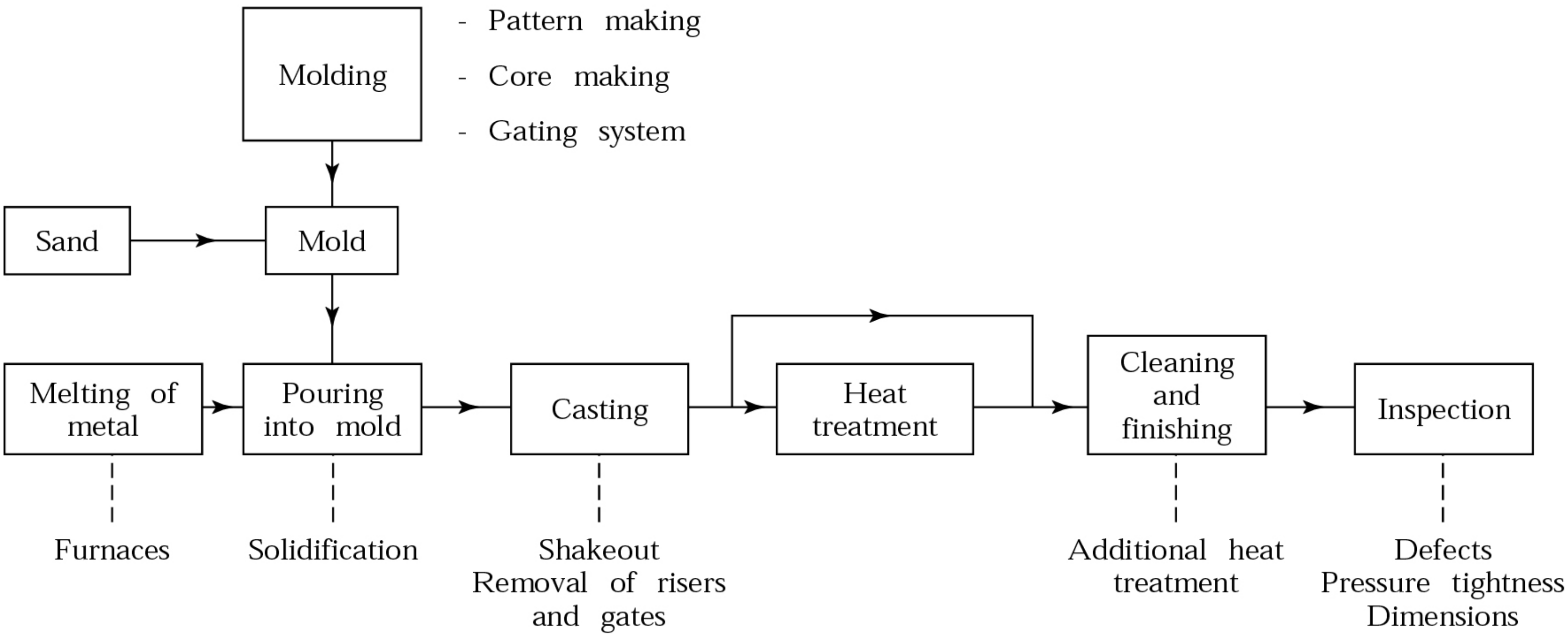
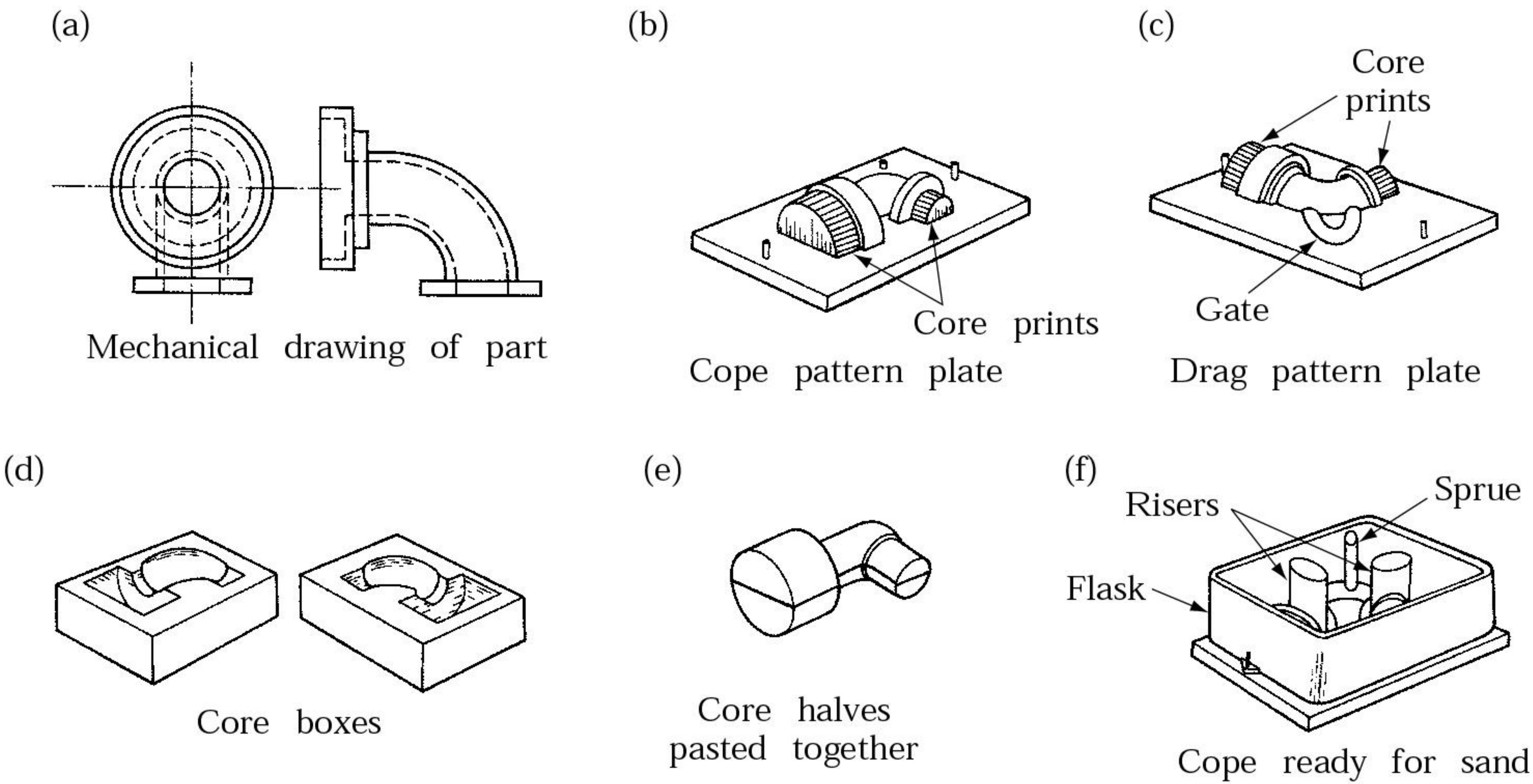


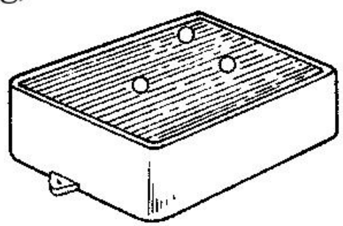
Figure 11.5 Outline of production steps in a typical sand-casting operation.

Steps in Sand Casting



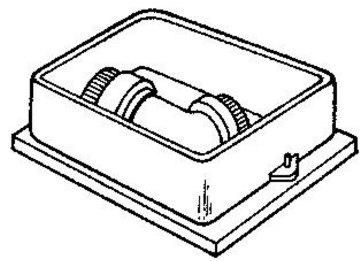
Steps in Sand Casting

(g)



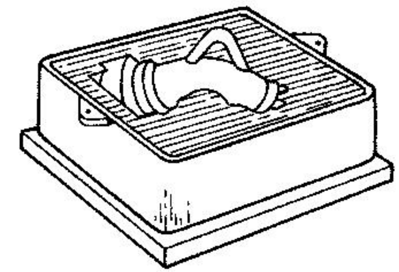
Cope after ramming with sand and removing pattern, sprue, and risers

(h)



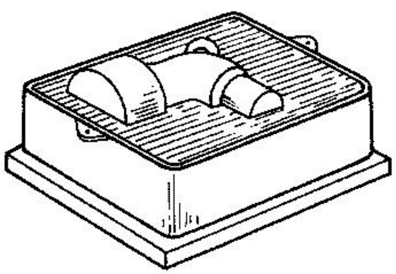
Drag ready for sand

(i)



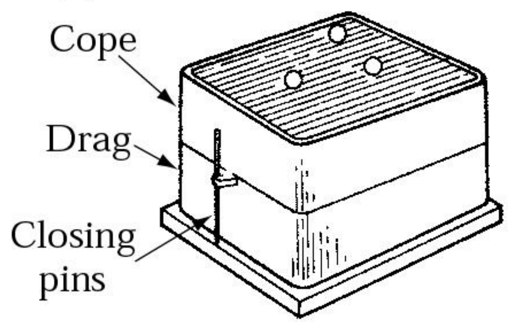
Drag after removing pattern

(j)



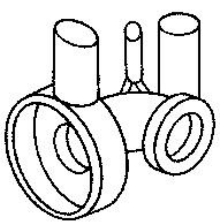
Drag with core set in place

(k)



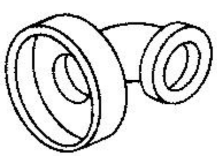
Cope and drag assembled ready for pouring

(l)



Casting as removed from mold; heat treated

(m)



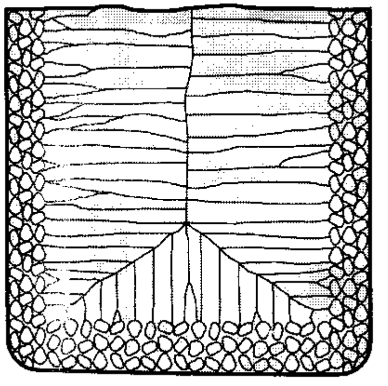
Casting ready for shippement

Sand Casting Process

- *Pattern* (oversized to allow for shrinkage)
- Ramming sand around *Pattern* in a *Flask*
- Compacting / jolting sand (green sand, skin dried or, loam moulded)
- Withdraw *Pattern*, add *Core*
- Reassemble *Mould*, with *Gating*, *Runner*, *Riser*, and *Sprue*
- Weight and ready for pouring.

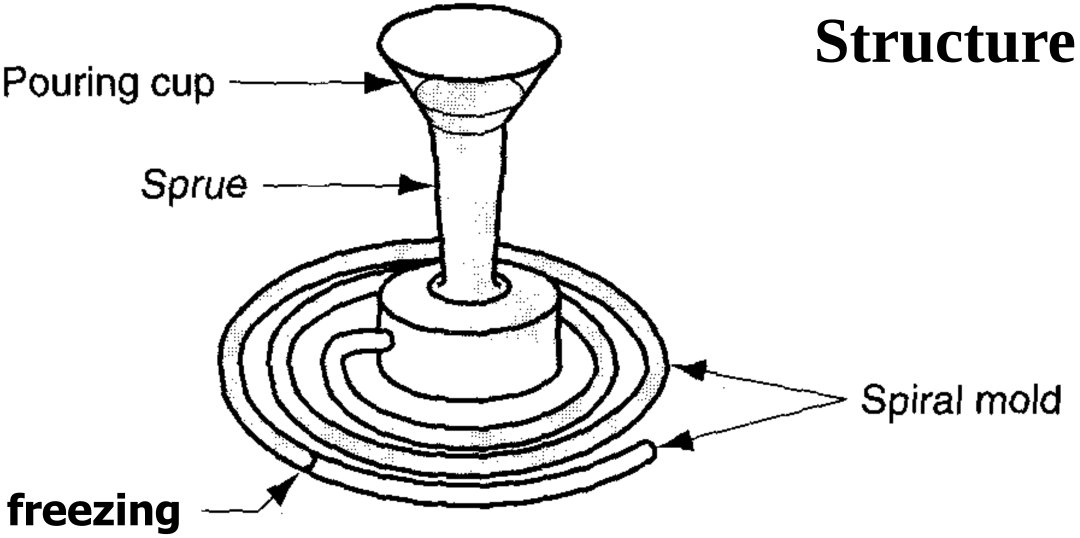
Process Parameters

- Pouring Temperature
- Cooling rate
- Fluidity (viscosity)



Grain Structure

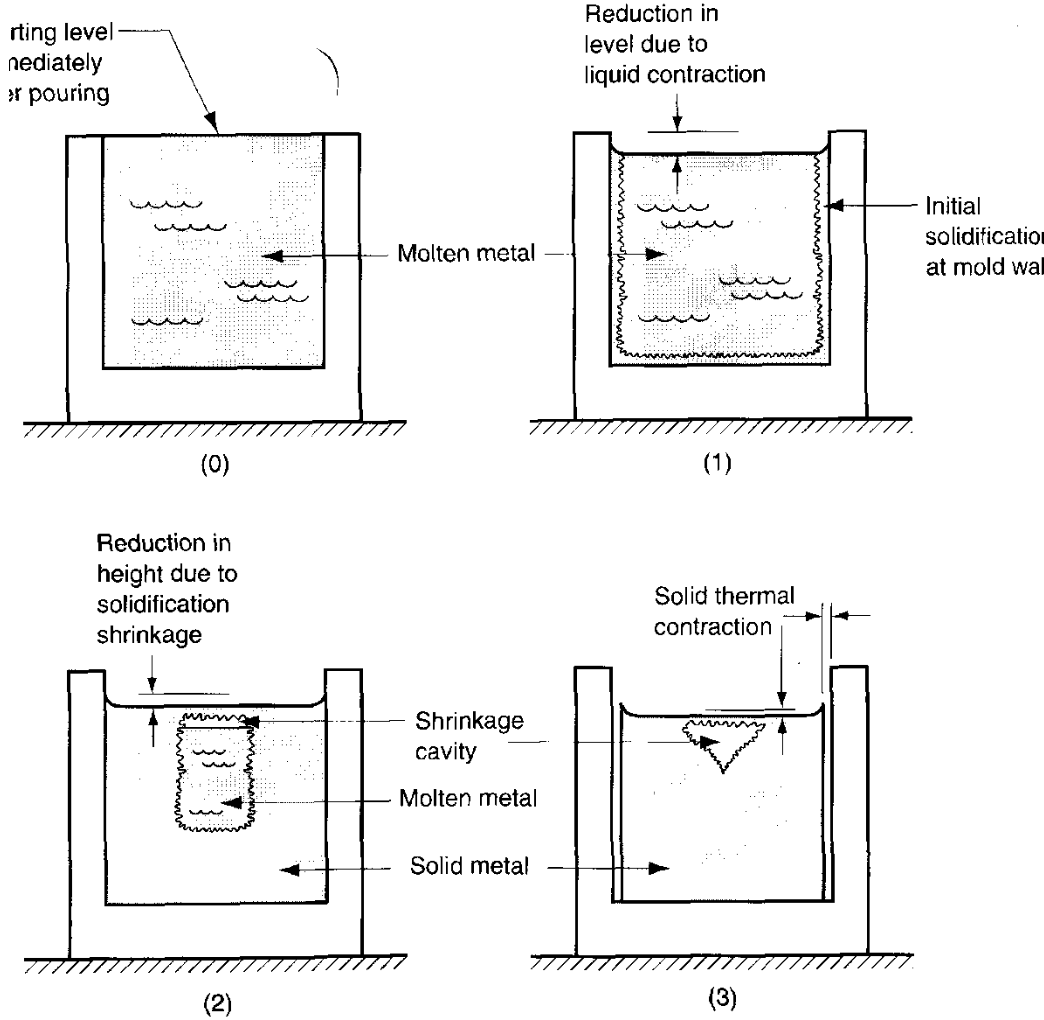
Spiral mould



Limit of flow before freezing

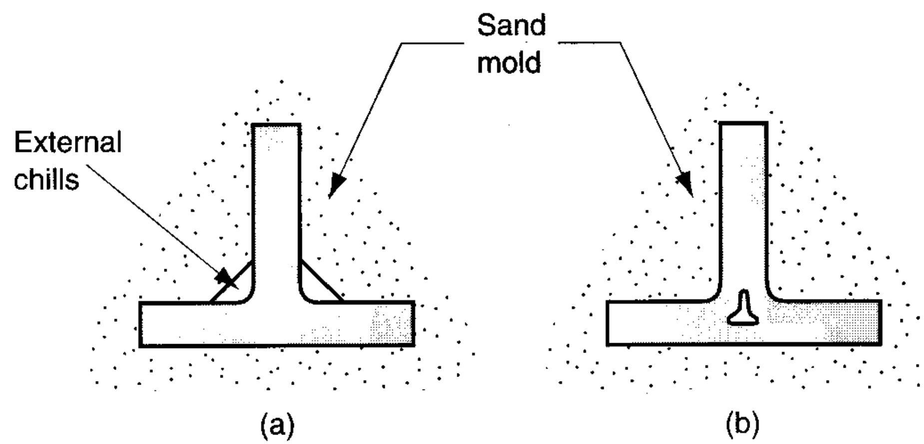
Shrinkage

- Liquid contraction
- Solidification shrinkage
- Solid thermal contraction



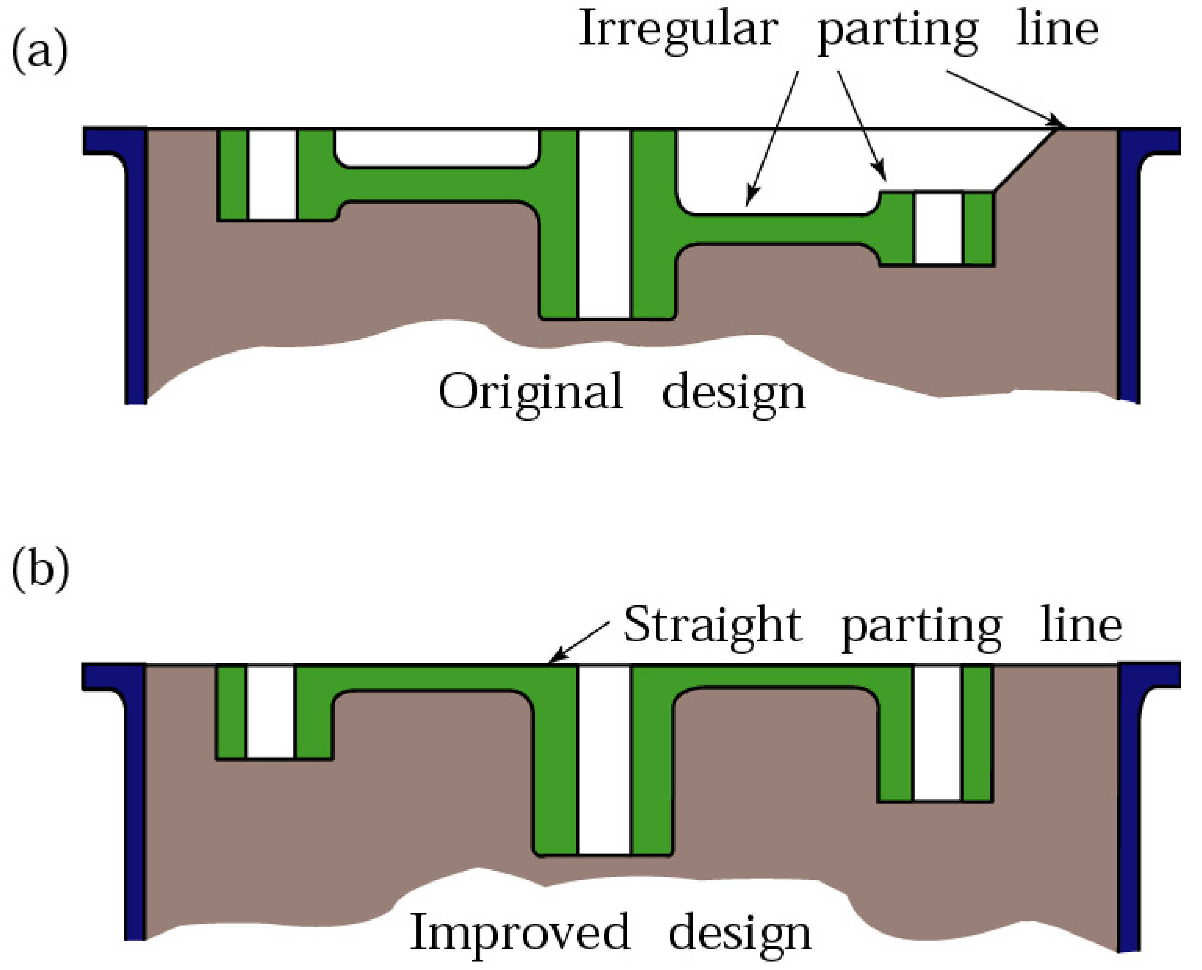
Shrinkage

Directional shrinkage



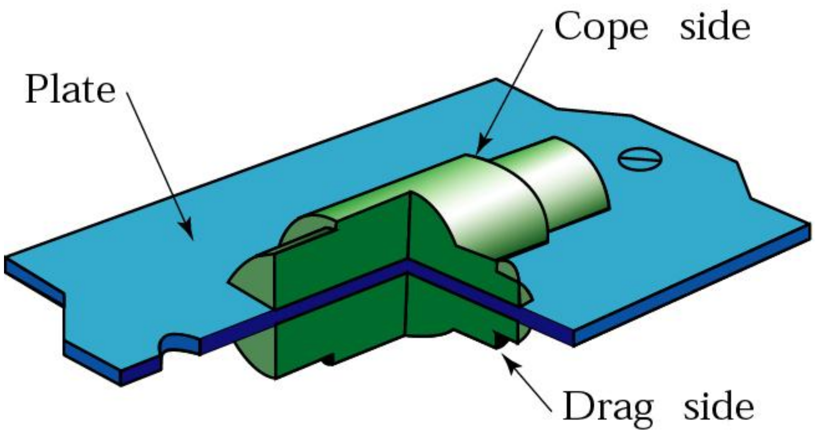
Metal	Volumetric contraction due to: Solidification shrinkage, %	Solid thermal contraction, %
Aluminum	7.0	5.6
Aluminum alloy (typical)	7.0	5.0
Gray cast iron	1.8	3.0
Gray cast iron, high carbon	0	3.0
Low carbon cast steel	3.0	7.2
Copper	4.5	7.5
Bronze (Cu–Sn)	5.5	6.0

Parting Line

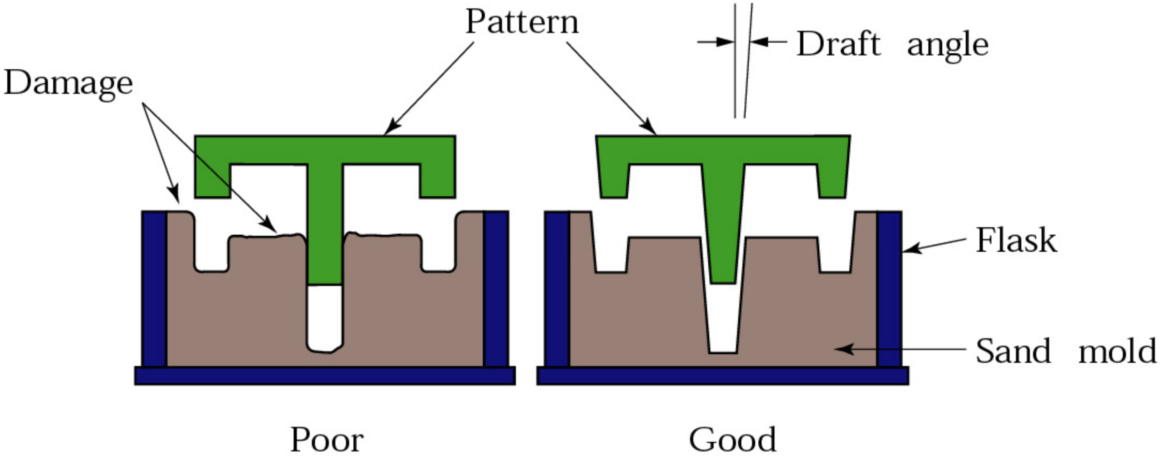


Redesign of a casting by making the parting line straight to avoid defects..

Patterns for Sand Casting



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



Taper on patterns for ease of removal from the sand mold.

Pattern Material Characteristics

TABLE 11.3					
			Rating[a]		
Characteristic	*Wood*	*Aluminum*	*Steel*	*Plastic*	*Cast iron*
Machinability	E	G	F	G	G
Wear resistance	P	G	E	F	E
Strength	F	G	E	G	G
Weightb	E	G	P	G	P
Repairability	E	P	G	F	G
Resistance to:					
Corrosionc	E	E	P	E	P
Swellingc	P	E	E	E	E

aE, Excellent; G, good; F, fair; P, poor.

bAs a factor in operator fatigue.

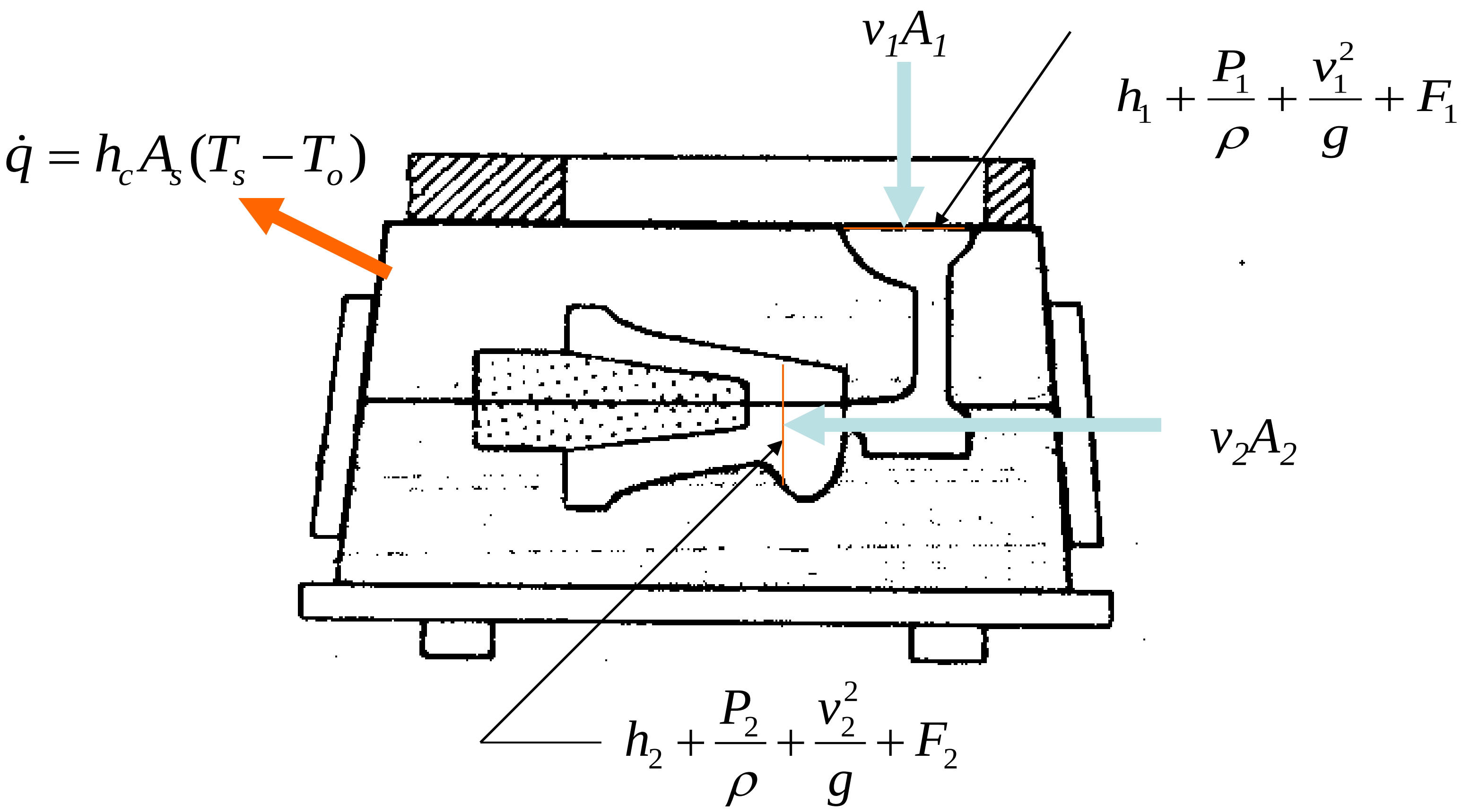
cBy water.

Source: D.C. Ekey and W.R. Winter, *Introduction to Foundry Technology*. New York. McGraw-Hill, 1958.

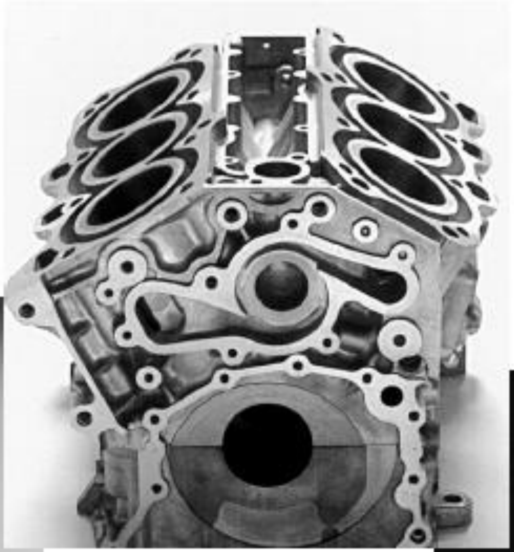
Design of Casting

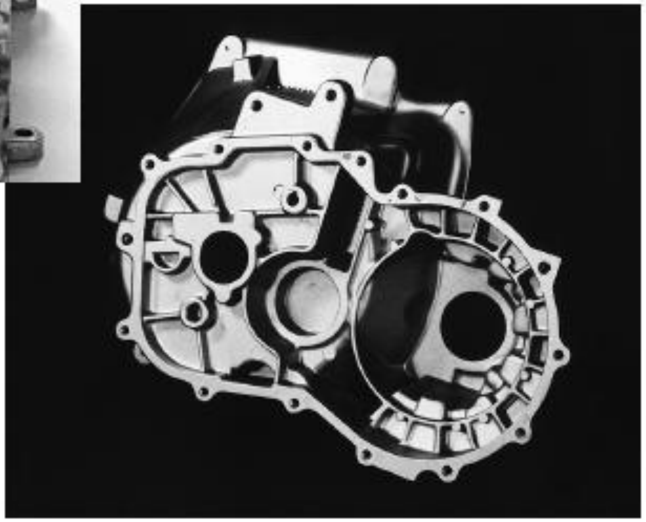
- Geometry
- Machining allowance
- Finishing
- Shrinkage factor
- Wall thickness, Fillet radius
- Runner, gating, sprue system
- Grain size
- Mechanical properties

Casting Design

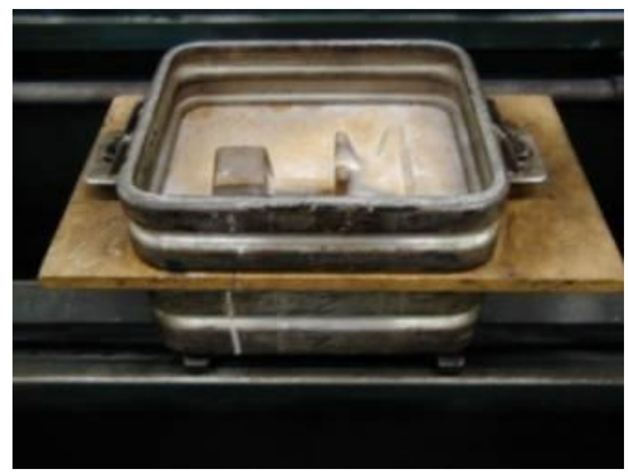


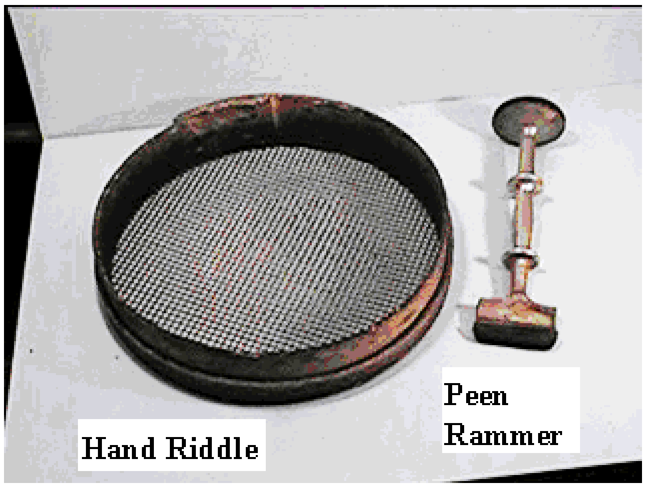
Sand Cast Parts



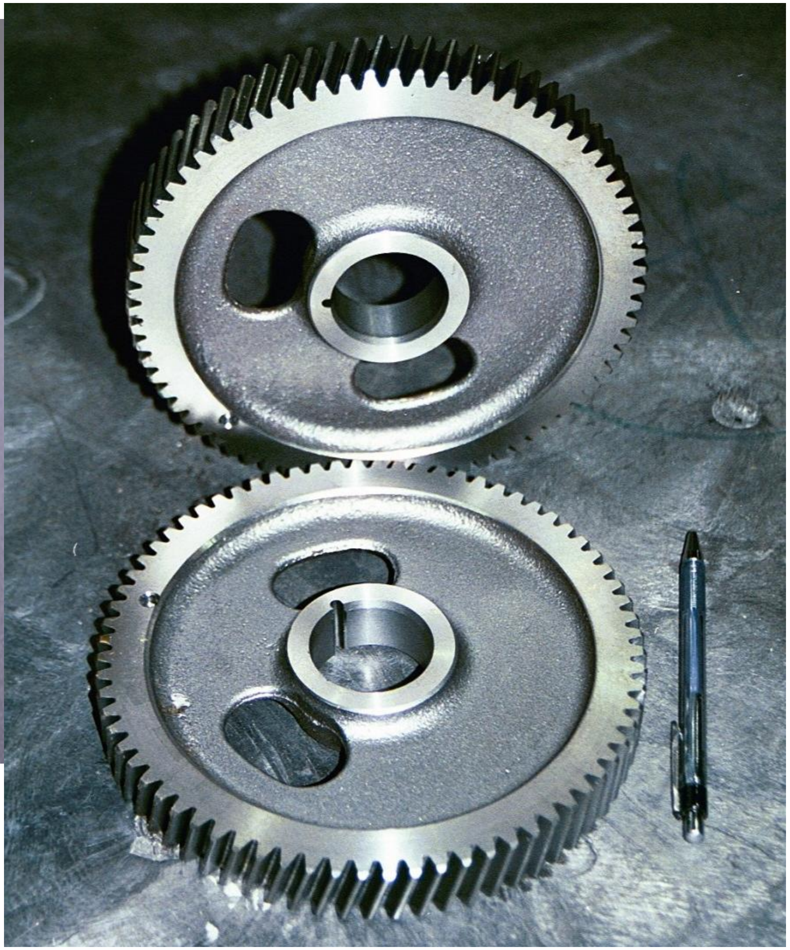


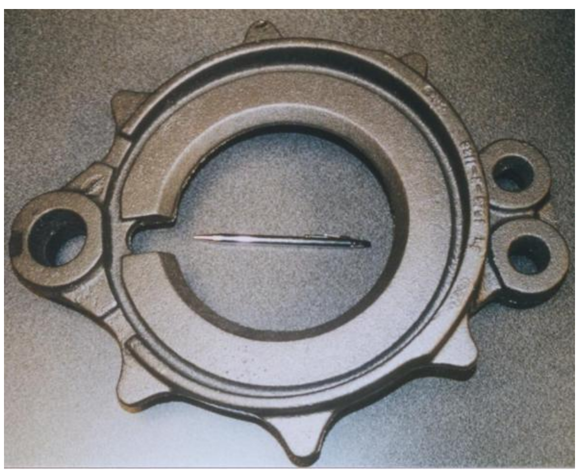



3583


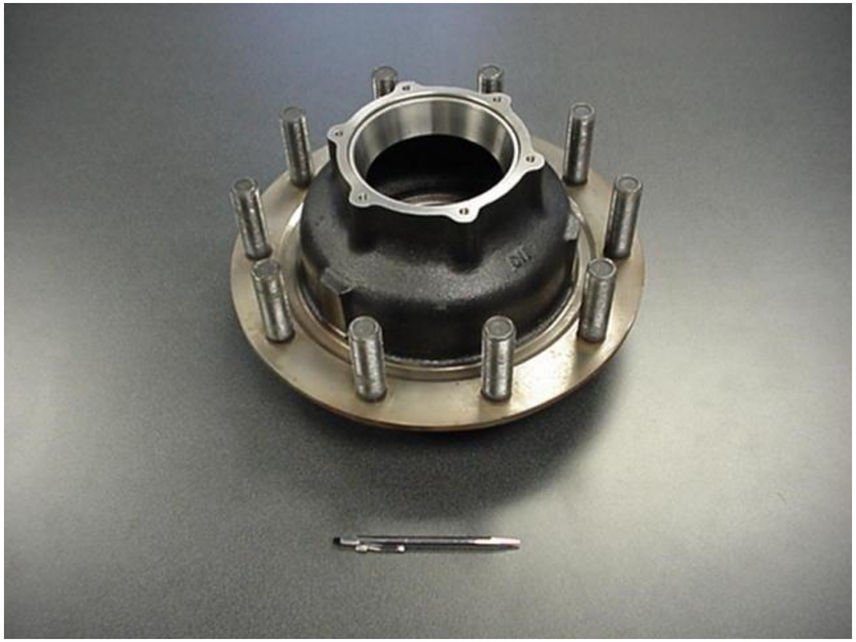

Peen
Rammer
Hand Riddle

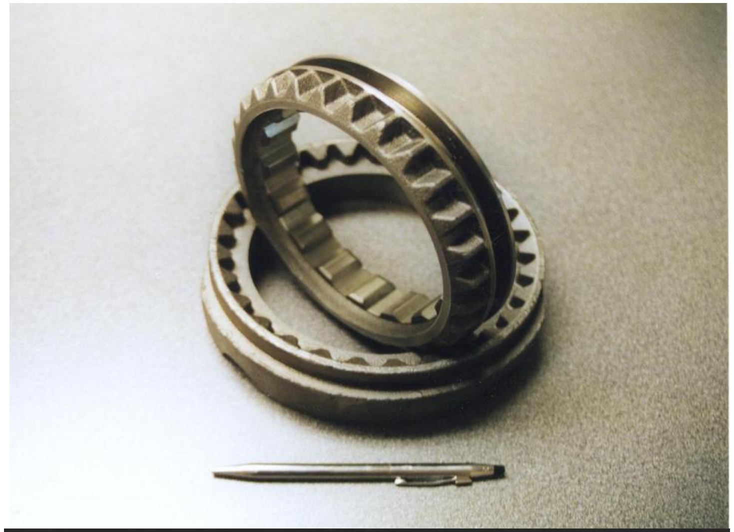

Molders Trowel
Strike Off Bar
Slick






ap
APPLIED PROCESS
ONE INCH






77 LB
ADI
PUMP
IMPELLER

Sand Casting - Pros

- Produce parts with complex geometries, both internally and externally.
- Possible to net shape with no further manufacturing required.
- Large parts can be produced.
- Wide choice of metals.
- Suitable for mass production.

Sand Casting - Cons

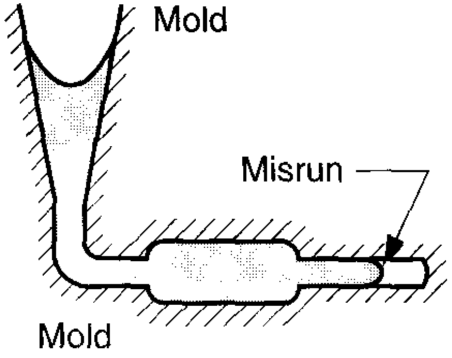
- Porosity
- Poor dimensional control for some processes
- Poor surface finish for some processes
- Limitation on mechanical properties
- Safety hazard
- Environmental hazard

Other Casting Processes

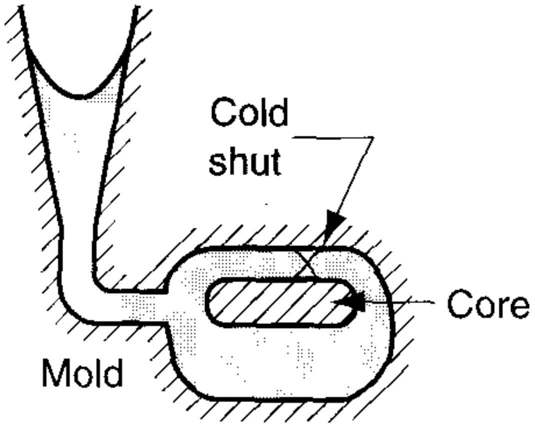
- Casting Quality
- Product Design Considerations

Casting Quality - Defects

- Misruns - unfilled region exists
  - insufficient fluidity of melt
  - low pouring temperature
  - slow pouring
  - cross-section too thin
- Cold shut - premature freezing at fusion point. Similar reason as misrun



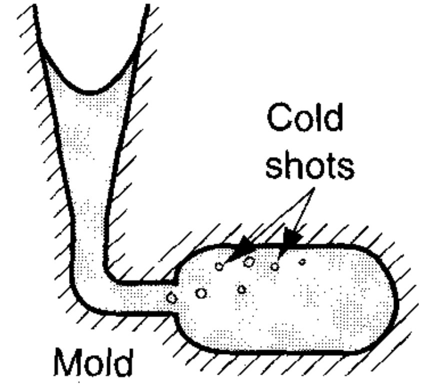
(a)



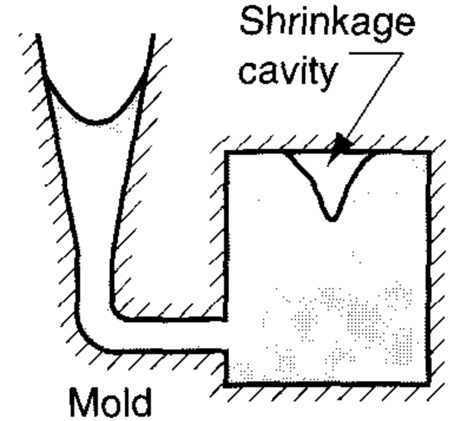
(b)

Casting Quality - Defects

- Cold shots - Splattering during pouring forming solid globules. Redesign of pouring procedure or gating system is needed.
- Shrinkage cavity - depression or internal void caused by solidification shrinkage. Solved by proper riser design.

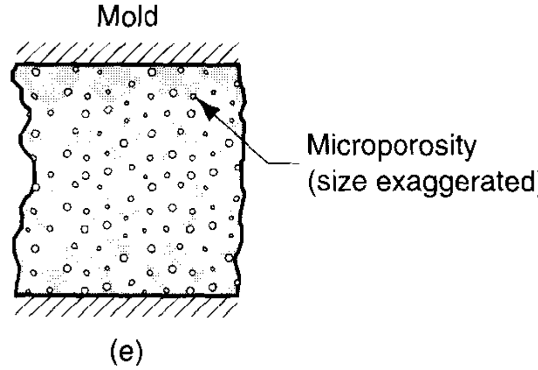


(c)

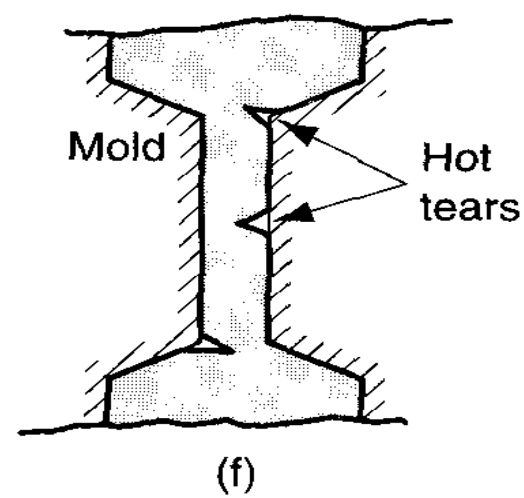


(d)

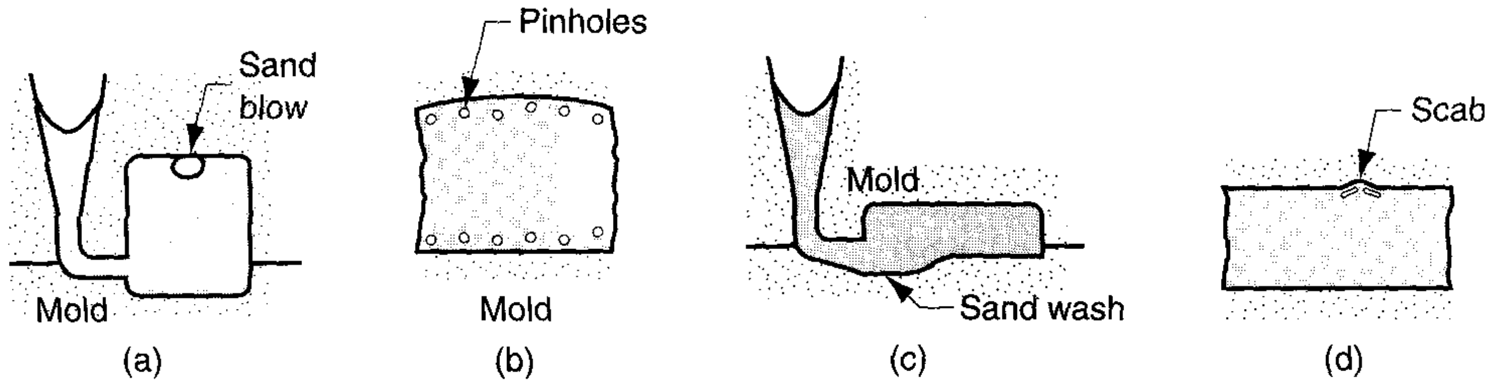
Casting Quality - Defects



- Microporosity -Network of small voids caused by localised solidification shrinkage. Caused by the freezing manner of the alloy.
- Hot tearing - Occurs at location with high stress due to inability to shrink naturally. Resolve by mold collapsing or removing from the mold immediately after freezing.

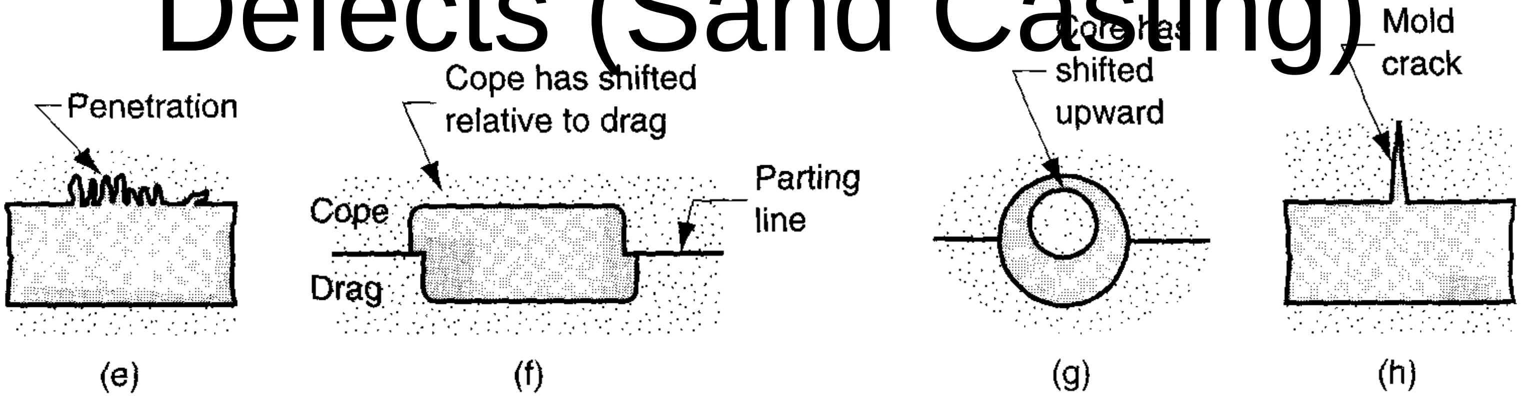


Casting Quality - Defects (Sand Casting)



- Sand blow - cavity caused by mold gas during pouring. Low permeability, poor venting or high moisture content.
- Pin holes - small gas cavities.
- Sand wash - erosion of sand mold during pouring.
- Scabs - mold surface locally flakes off and embedded in the casting during solidification

Casting Quality - Defects (Sand Casting)

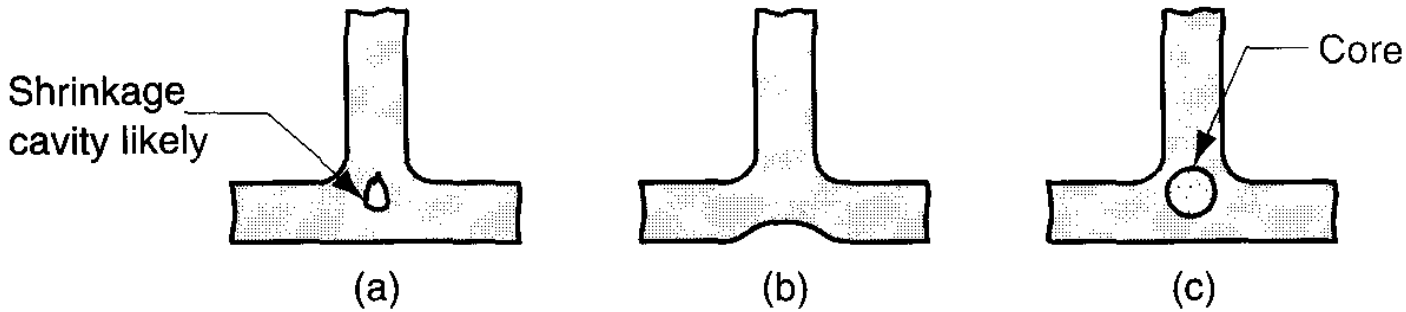


- Penetration - penetration of molten metal into the sand. Harder packing of sand is needed.
- Mold shift - shift of the cope relative to the drag.
- Core shift - shift of the core, usually vertical.
- Mold crack - mold strength insufficient, liquid metal form a fin of the final casting.

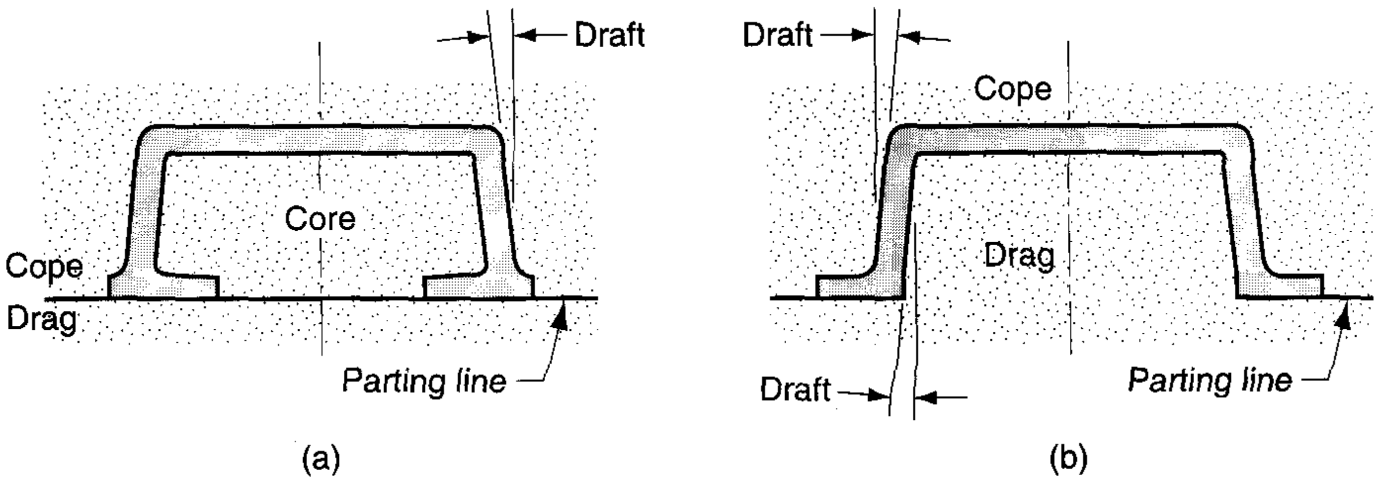
Product Design Considerations

- **Geometric simplicity - Avoid unnecessary complexity.**
- **Corners - Avoid sharp corners, generous fillet radius.**
- **Section thickness - Uniform section thickness to avoid shrinkage cavities and hot spots.**
- **Draft - Facilitate removal of parts from mold. (1 deg. For sand and 2/3 deg. for permanent)**
- **Use of cores - minimize the use of core**
- **Dimensional tolerance and surface finish - proper choice of casting method.**
- **Machining allowances - For assembly purposes, typically 1.5 to 6 mm.**

Product Design Considerations



Shrinkage, hot spot



Draft and core elimination

Product Design Considerations

Casting process	Part size	Tolerance in.	(mm)	Surface roughness μin.	μm
Sand casting [a]				250–1000	(6–25)
Aluminum [b]	Small	±0.020	(±0.5)		
Cast iron	Small	±0.040	(±1.0)		
	Large	±0.060	(±1.5)		
Copper alloys	Small	±0.015	(±0.4)		
Steel	Small	±0.050	(±1.3)		
	Large	±0.080	(±2.0)		
Shell molding				250	(6.4)
Aluminum [b]	Small	±0.010	(±0.25)		
Cast iron	Small	±0.020	(±0.5)		
Copper alloys	Small	±0.015	(±0.4)		
Steel	Small	±0.030	(±0.8)		
Plaster mold	Small	±0.005	(±0.12)	30	(0.75)
	Large	±0.015	(±0.4)		
Permanent mold				125	(3.2)
Aluminum [b]	Small	±0.010	(±0.25)		
Cast iron	Small	±0.030	(±0.8)		
Copper alloys	Small	±0.015	(±0.4)		
Steel	Small	±0.020	(±0.5)		
Die casting				40–100	(1–2.5)
Copper alloys	Small	±0.005	(±0.12)		
Aluminum [b]	Small	±0.005	(±0.12)		
Investment				30–100	(0.75–2.5)
Aluminum [b]	Small	±0.005	(±0.12)		
Cast iron	Small	±0.010	(±0.25)		
Copper alloys	Small	±0.005	(±0.12)		
Steel	Small	±0.010	(±0.25)		

Compiled from [5], [11], and other sources.

[a] Values of surface roughness are for greensand molding; for other sand mold processes, surface finish is better.

[b] Values for aluminum also apply to magnesium.

Other Casting Processes

Other Casting Processes

- Expendable Mold Casting Processes
  - Shell mold
  - Vacuum mold
  - Expanded polystrene mold
  - Investment casting
  - Plaster mold and ceramic mold
- Permanent Mold Casting Processes
  - Basic permanent mold
  - Variations of permanent mold
  - Die casting
  - Centrifugal casting

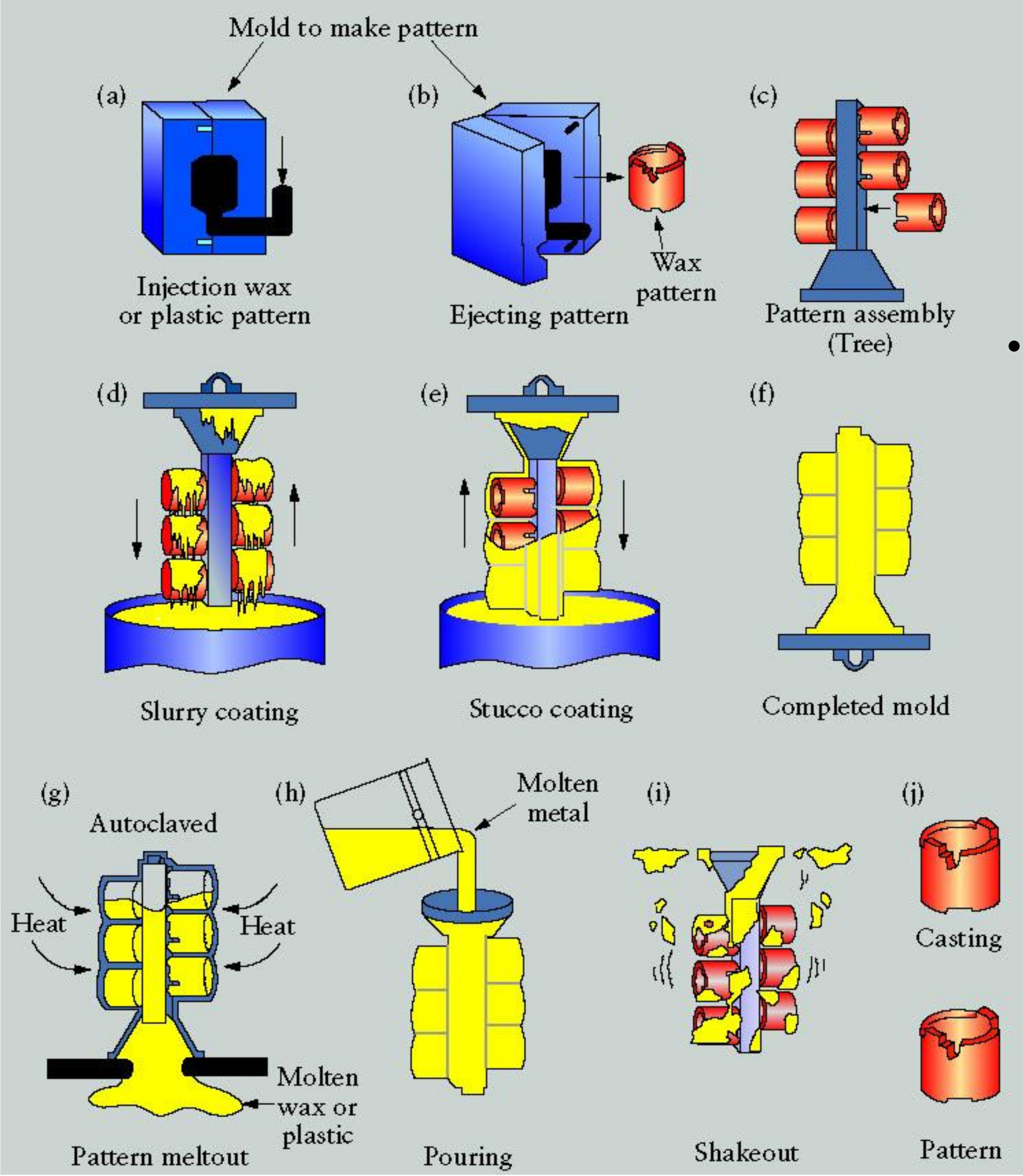
Processes

1. Sand casting
2. Shell casting
3. Carbon dioxide casting
4. Fluid sand casting
5. Composite mold casting
6. Plaster mold casting
7. Slush casting
8. Evaporative pattern casting (EPC)
9. Die casting
10. Permanent mold casting
11. Ceramic mold casting
12. Investment casting (lost-wax process)

Considerations

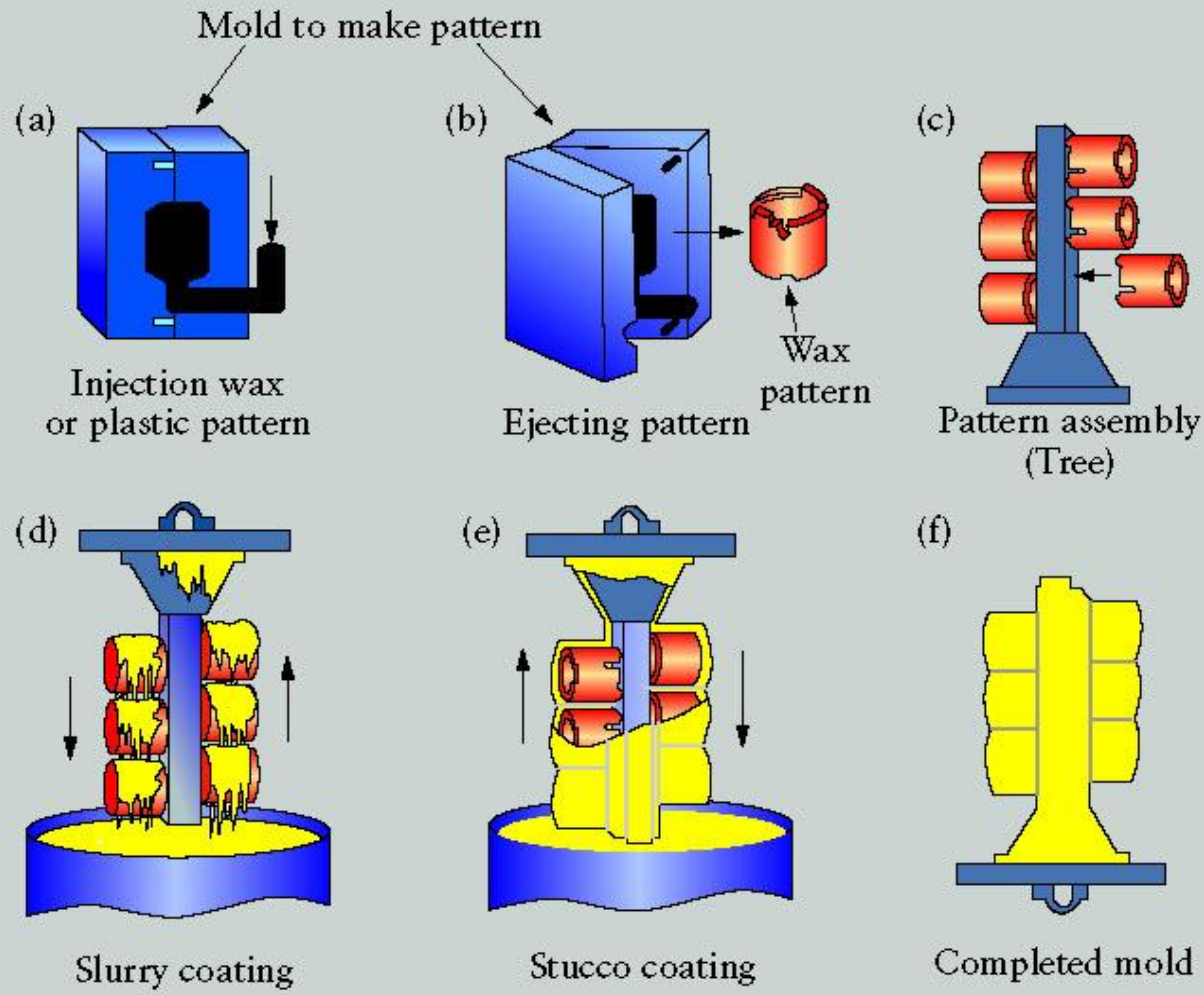
- Type of metal to be cast
- Size of part to be cast
- Required cast accuracy of the part
- Economics
- Required secondary operations such as machining, hardening, welding, and plating

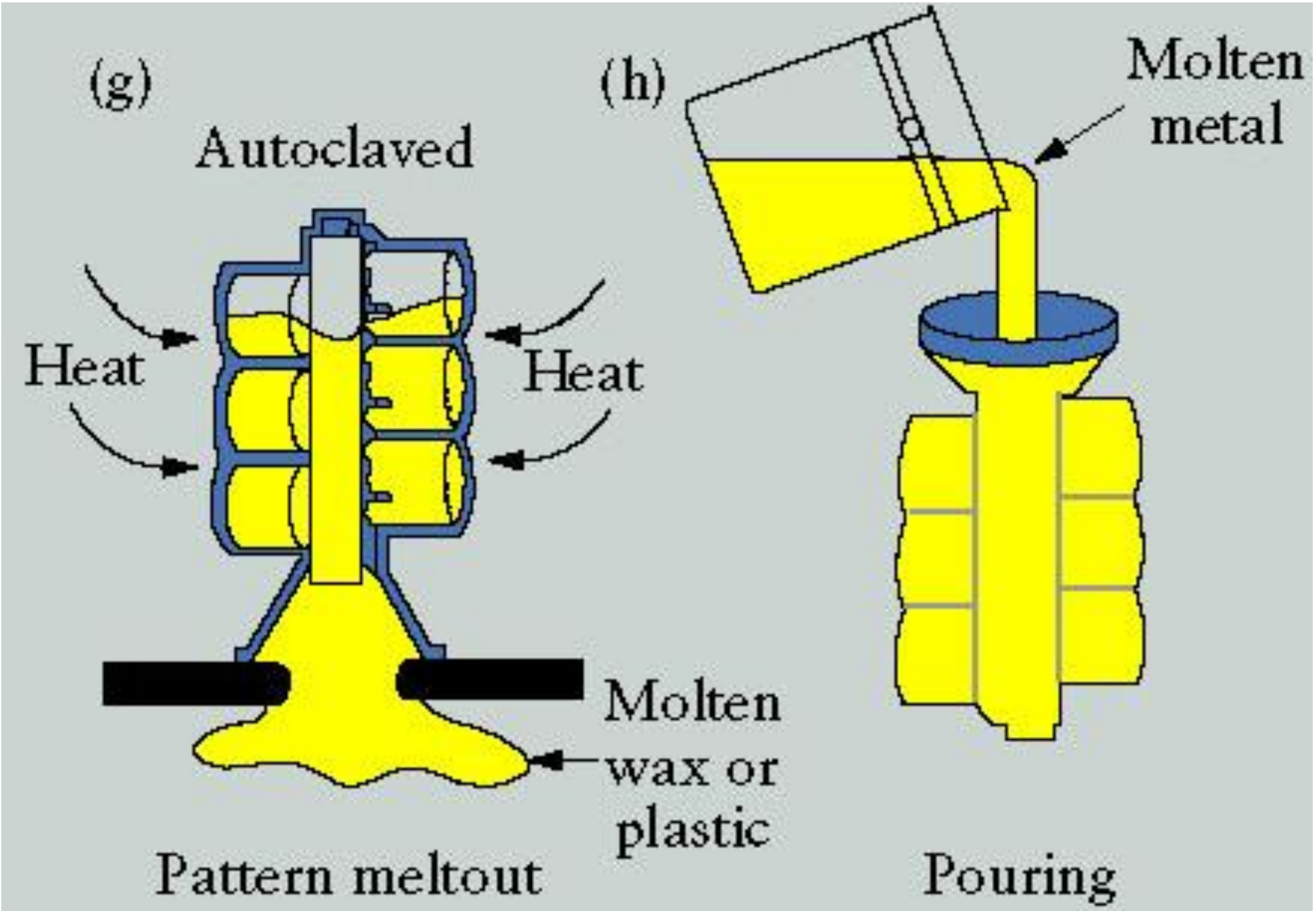
	Sand	Shell	Evaporative pattern	Plaster	Investment	Permanent mold	Die	Centrifugal
Typical materials cast	All	All	All	Nonferrous (Al, Mg, Zn, Cu)	All	All	Nonferrous (Al, Mg, Zn, Cu)	All
Weight (kg): minimum maximum	0.01 No limit	0.01 100+	0.01 100+	0.01 50+	0.001 100+	0.1 300	<0.01 50	0.01 5000+
Typ. surface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

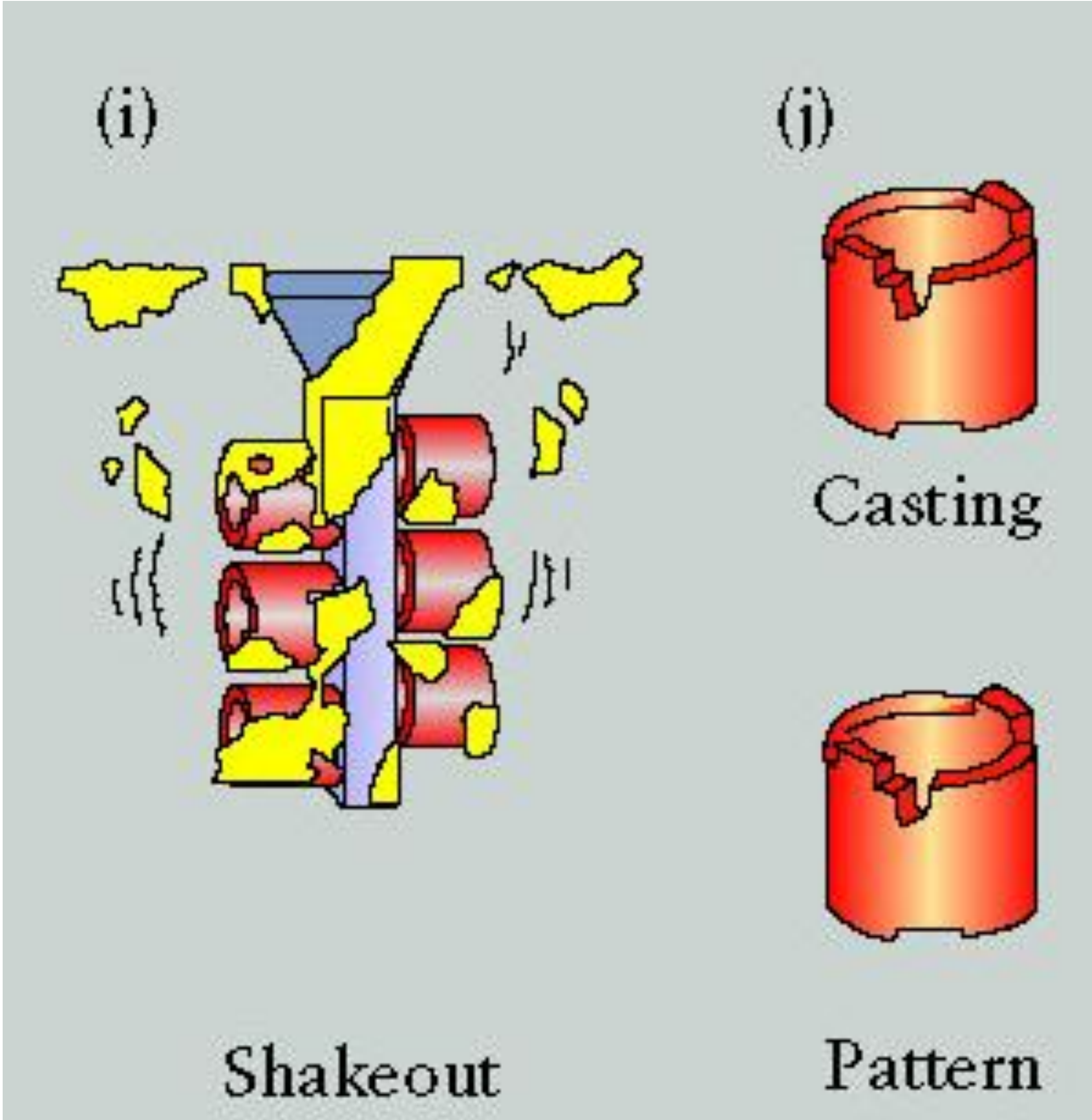


Investment Casting

- 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*: Steel Founders' Society of America.


Mold to make pattern
(a)
Injection wax
or plastic pattern
(b)
Wax
pattern
Ejecting pattern
(c)
Pattern assembly
(Tree)
(d)
Slurry coating
(e)
Stucco coating
(f)
Completed mold


(g)
Autoclaved
Heat
Heat
Molten
wax or
plastic
Pattern meltout
(h)
Molten
metal
Pouring


(i)
(j)
Casting
Shakeout
Pattern

Expendable Mold Casting - Investment Casting

Pros:

- Capability to cast parts with great complexity and intricacy.
- Close dimensional control ($\pm$ 0.076 μm tolerance).
- Good surface finish.
- Wax can be recovered and reuse.
- Additional machining normally not required.

Cons:

- Normally cater for smaller parts.
- Relatively expensive

Expendable Pattern Casting

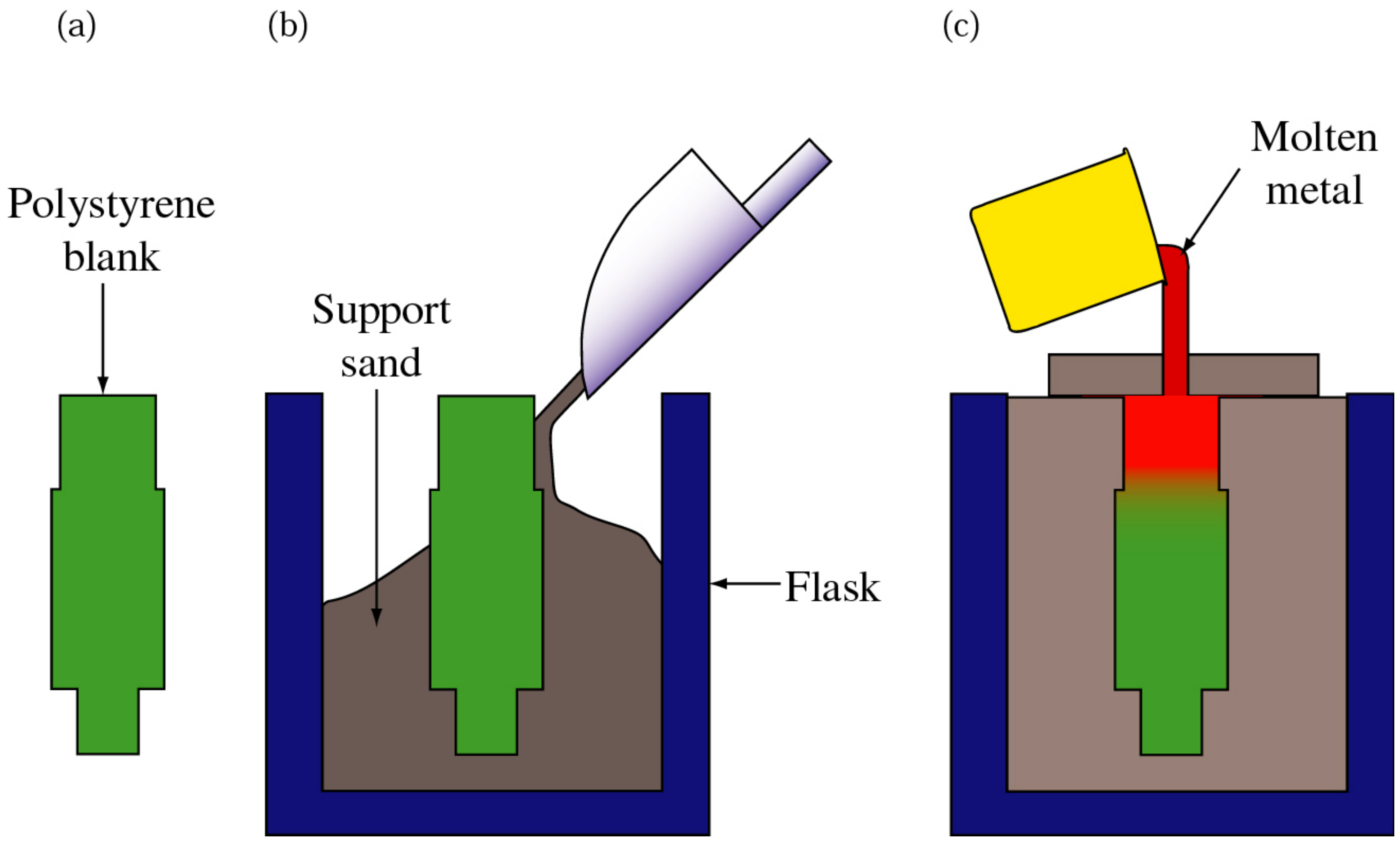
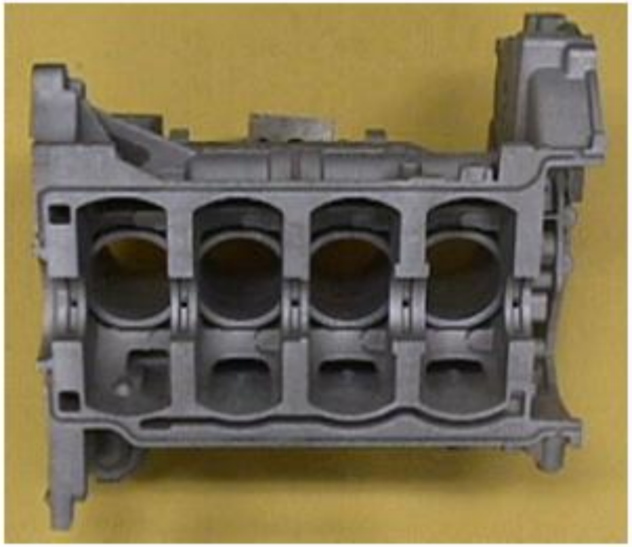


Figure 11.15 Schematic illustration of the expendable pattern casting process, also known as lost foam or evaporative casting. Pattern made from Polystrene and vaporized when in contact with molten metal. The pattern can include the sprue and runner. No cope / drag is needed.

Lost Foam Castings



Expendable Mold Casting - Expanded Polystrene Mold

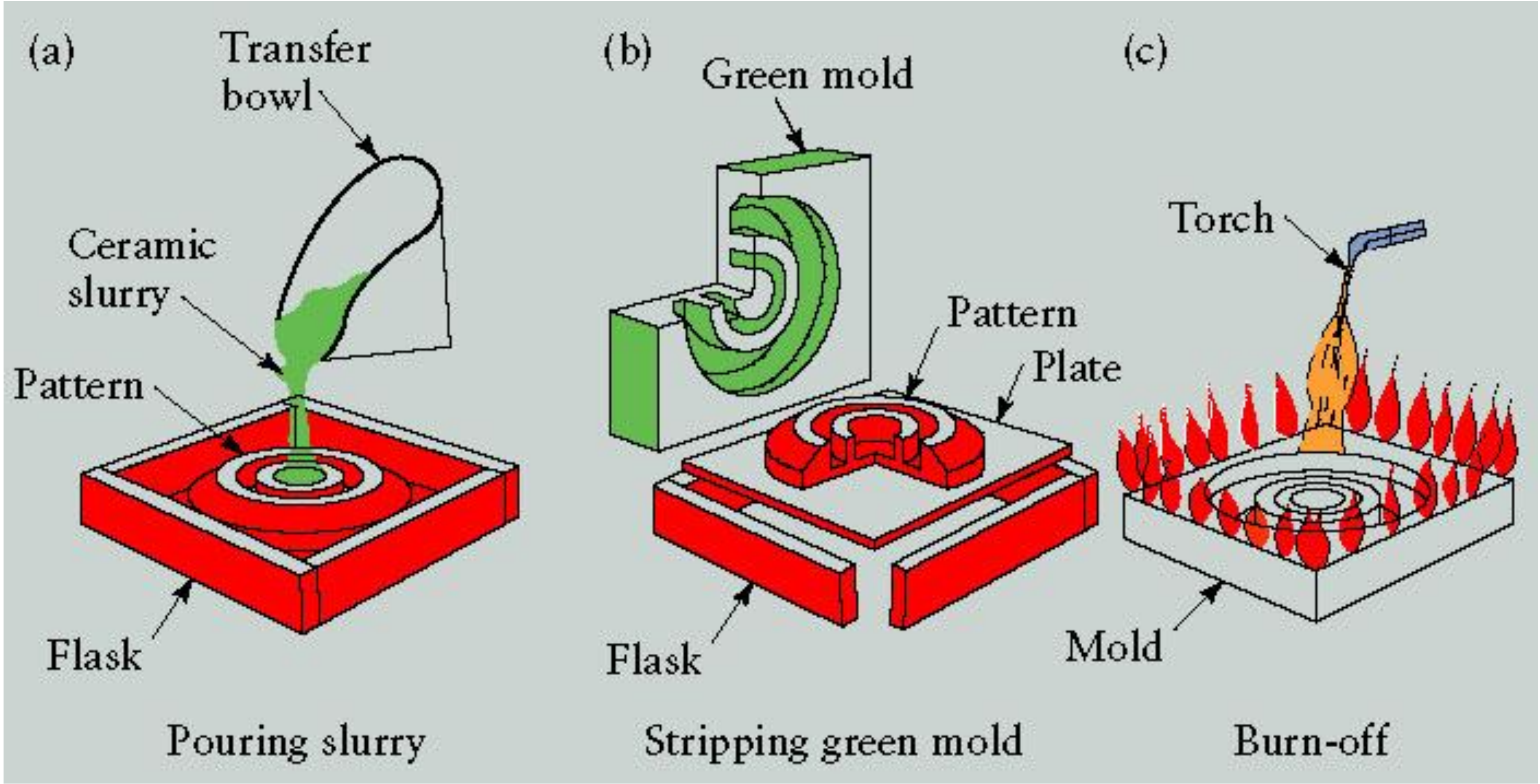
Pros:

- Pattern need not be removed.
- No cope /drag is needed, all features are built into the pattern.
- Possibility for automated production.

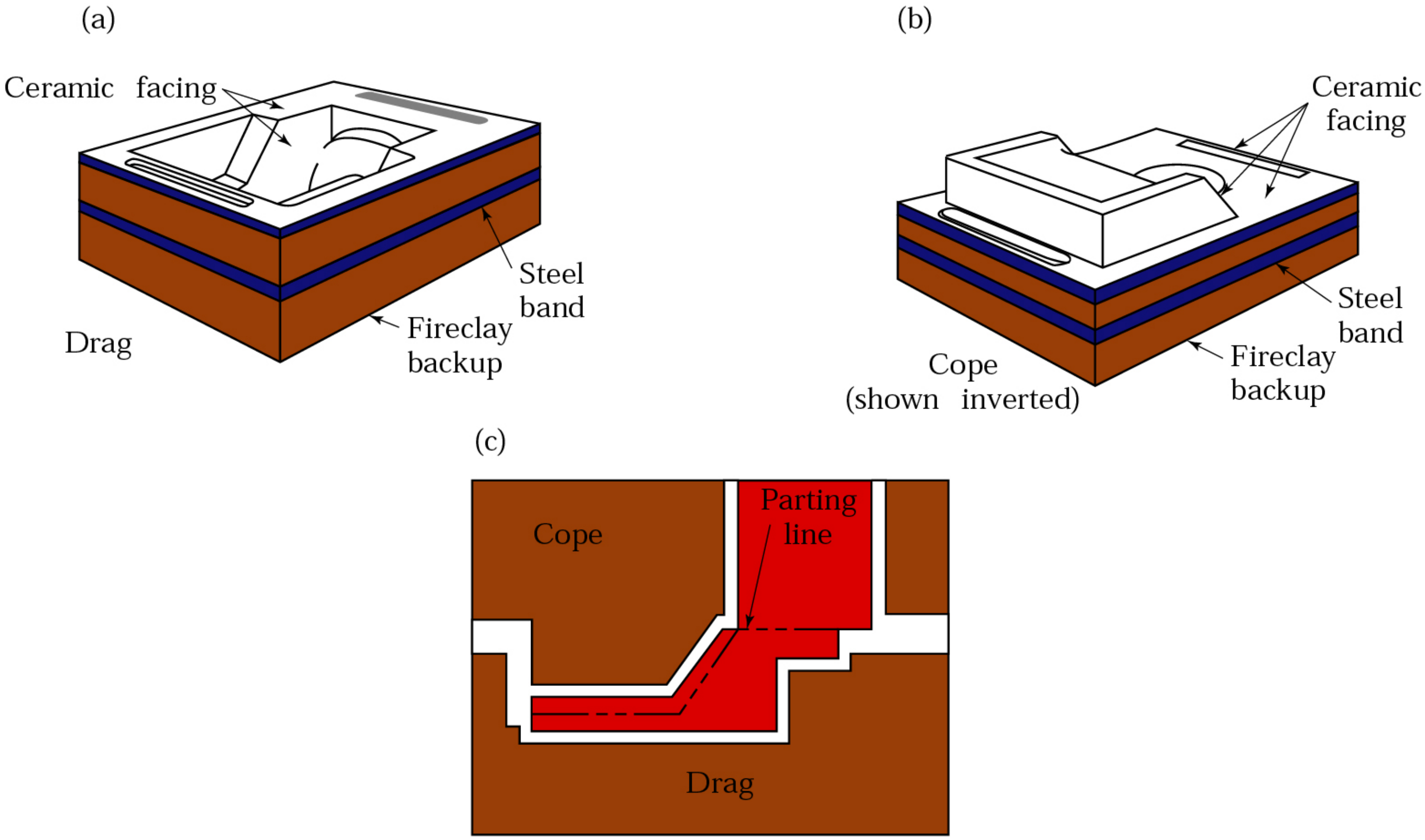
Cons:

- The pattern is not reusable.

Operation Sequence of Making a Ceramic Mold



- Sequence of operations in making a ceramic mold.



Fireclay backup
Ceramic facing

A typical ceramic mold (Shaw process) for casting steel dies used in hot forging.

Expendable Mold Casting - Plaster Mold and Ceramic Mold

- **Similar to sand casting in terms of process.**
- **Plaster mold is for lower temperature alloys while ceramic mold is for higher temperature alloys.**

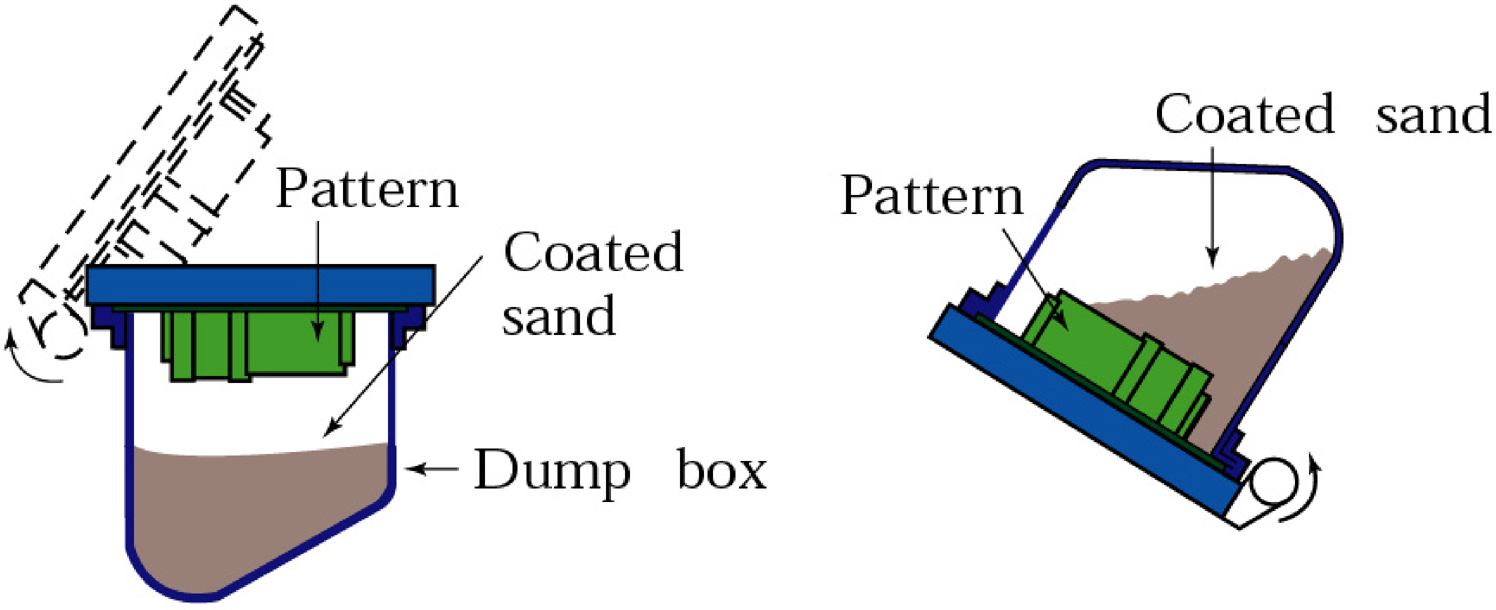
Pros:

- **Good surface finish and dimensional control.**
- **Capability to make thin cross sections.**

Cons:

- **Curing takes too long to render it unsuitable for volume production.**

Shell Casting
Dump-Box Technique



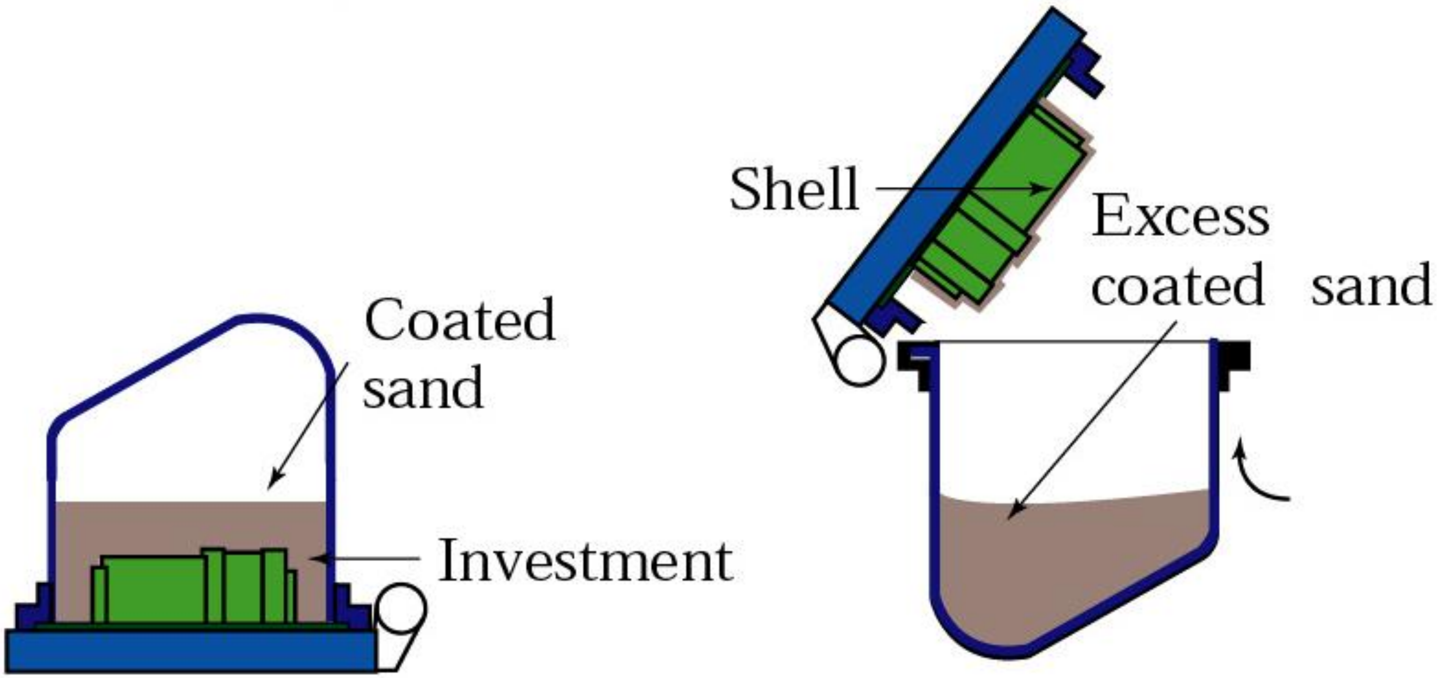
(a) Pattern rotated and clamped to dump box

(b) Pattern and dump box rotated

A common method of making shell molds. Called *dump-box* technique, the limitations are the formation of voids in the shell and peelback (when sections of the shell fall off as the pattern is raised). *Source*: ASM International.

Shell Casting

Dump-Box Technique



(c) Pattern dump box in position for the investment

(d) Pattern and shell removed from dump box

Expendable Mold Casting - Shell Mold

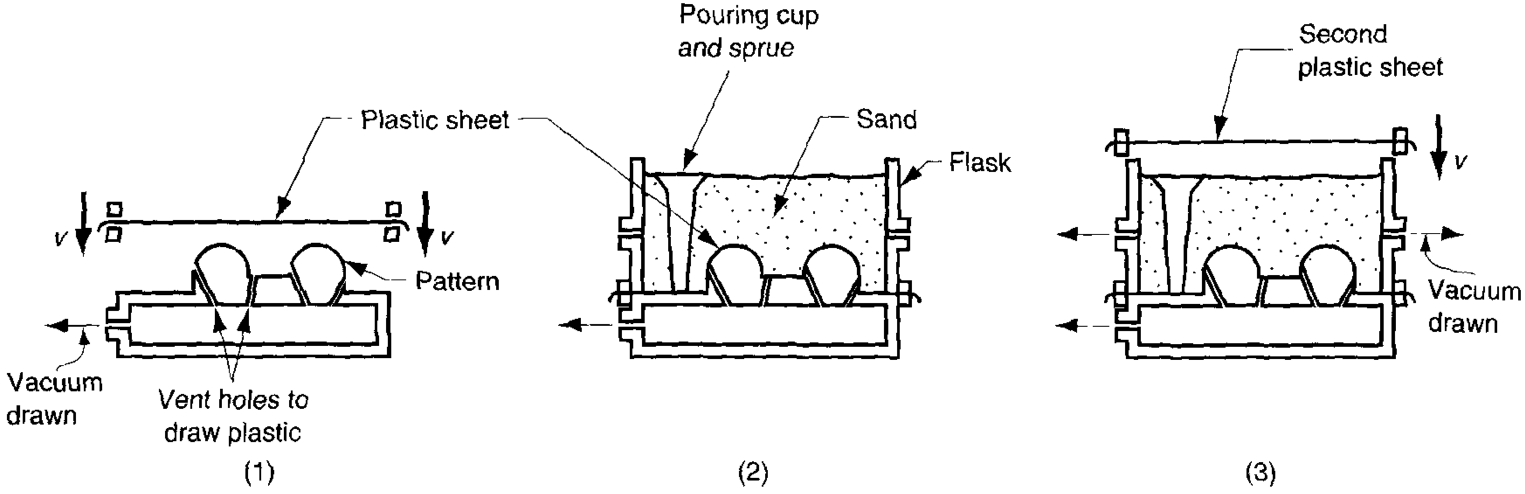
Pros:

- Smoother surface finish than sans casting.
- Surface finish of 2.5 μm can be obtained.
- Good dimensional accuracy $\pm$ 0.25 mm on small to medium size parts.
- No further machining is needed.
- Capability for automation lowers the cost for larger quantities.

Cons:

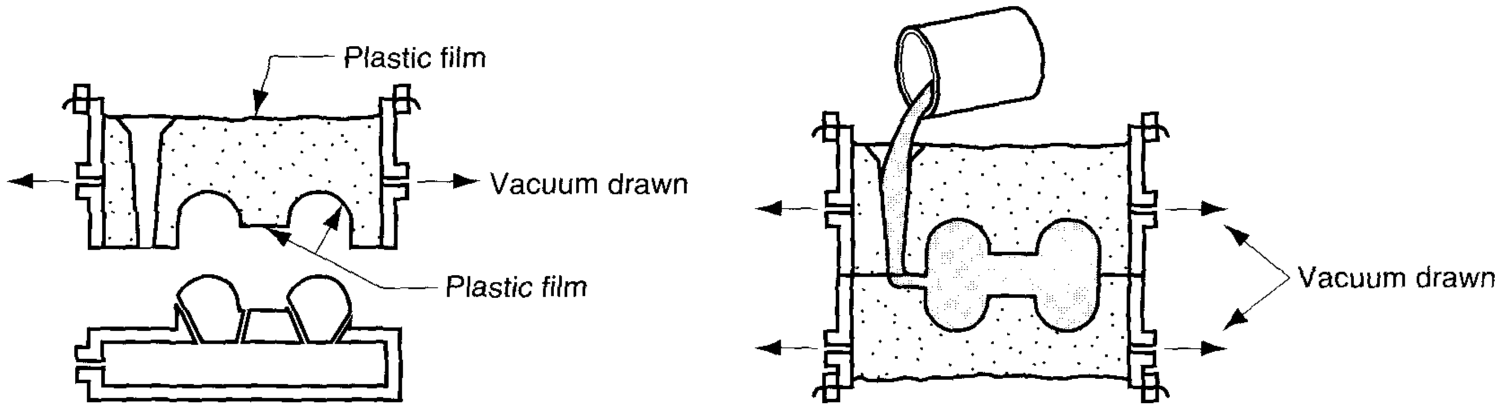
- More expensive metal pattern, especially for small batch.

Expendable Mold Casting - Vacuum Mold



1. Thin pre-heated plastic sheet sucks onto the vacuum vented pattern surface.
2. Special flask with vents and filled with sand is placed over the pattern.
3. Another plastic sheet covers the sand and vacuum is drawn.

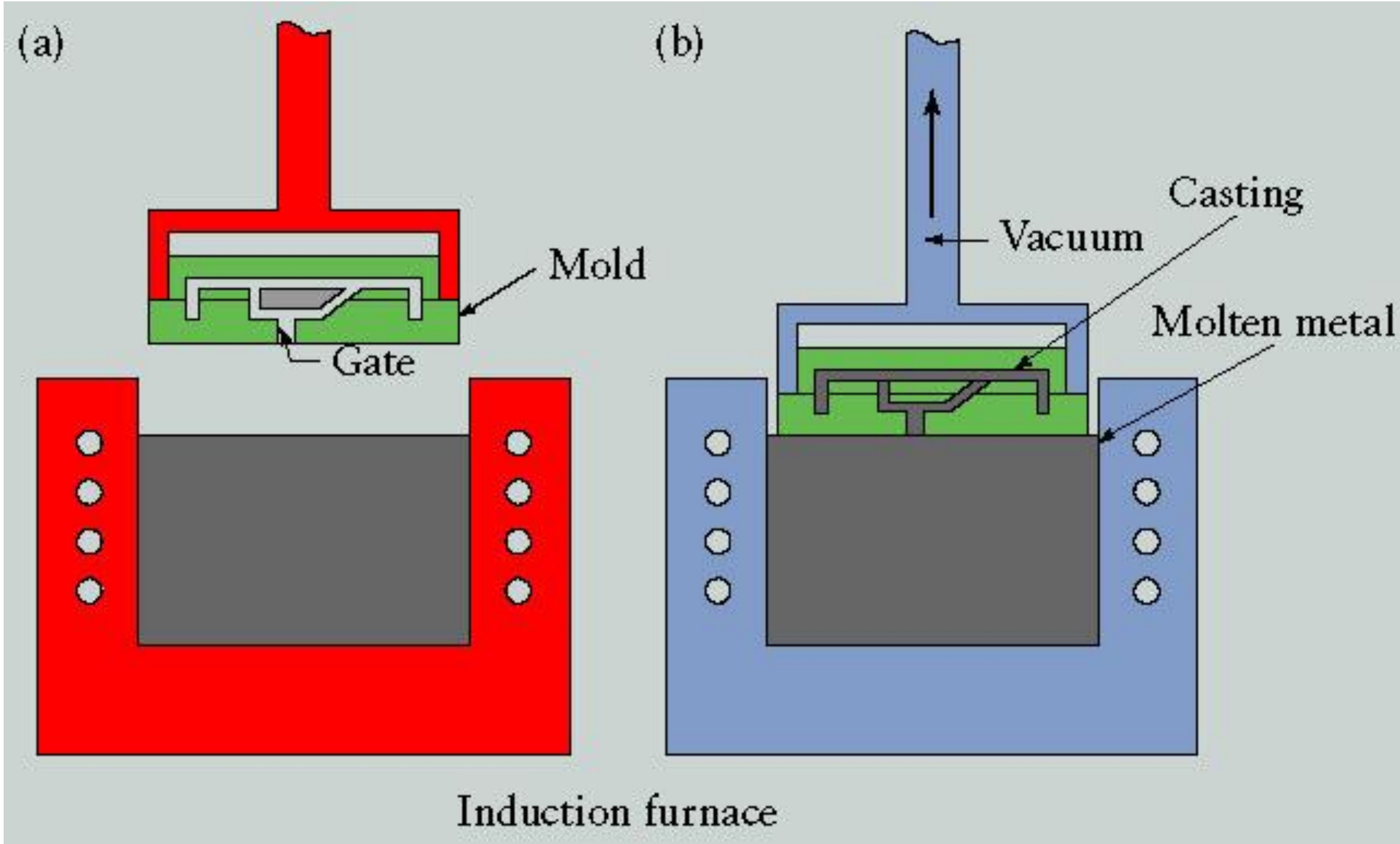
Expendable Mold Casting - Vacuum Mold



(4) (5)

4. Vacuum on the pattern is released to free the sand mold.
5. Cope and drag is assembled to form the complete mold. The plastic sheet is burnt away when in contact with the molten metal.

Vacuum-Casting Process



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

Expendable Mold Casting - Vacuum Mold

Sand held together by vacuum pressure.

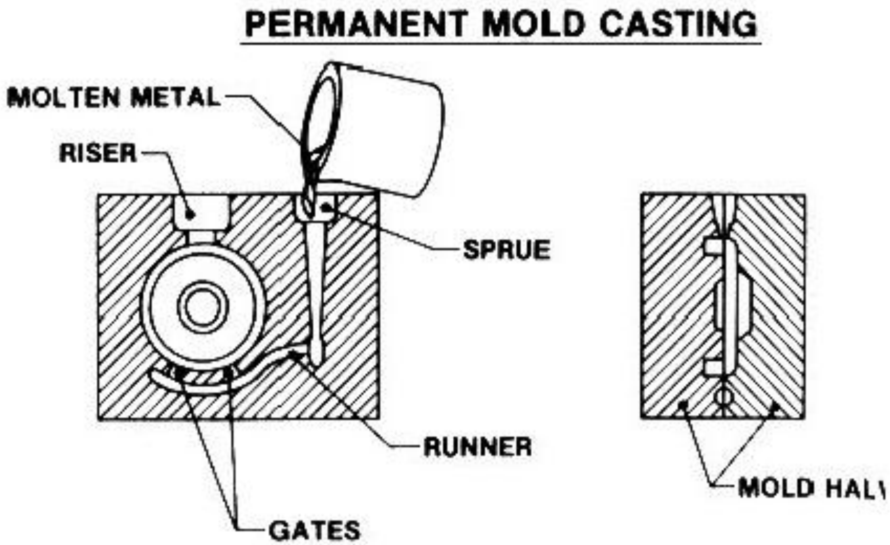
Pros:

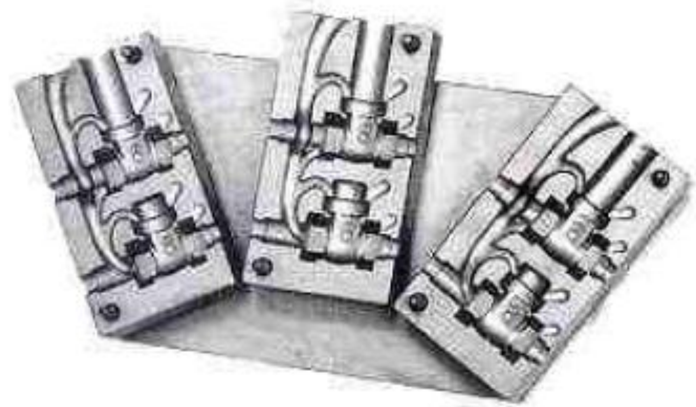
- Sand can be recovered unlike shell mold.
- No chemical binder, and therefore no special treatment for the sand.
- No water mixed with the sand and therefore no moisture related problems

Cons:

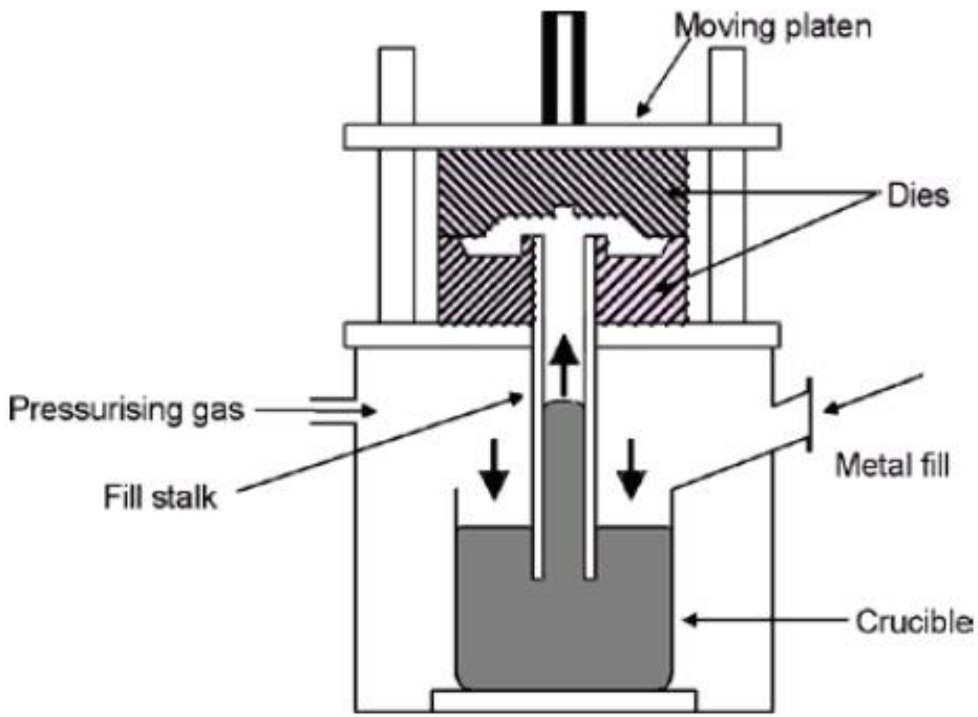
- Relative slow
- Not readily adaptable to mechanization.

Permanent Mold Casting

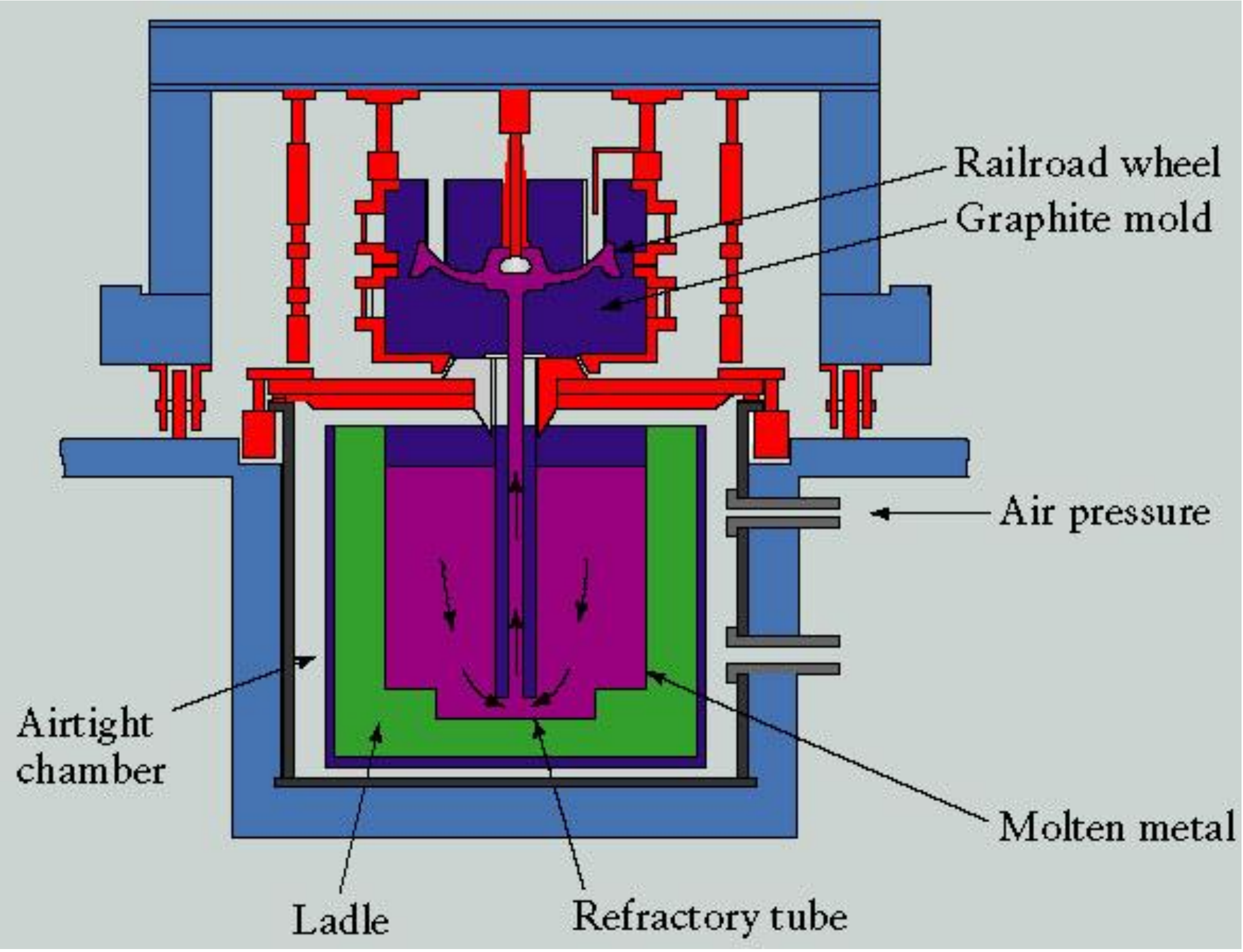




Low Pressure Casting



Pressure-Casting Process



- **The pressure-casting process uses graphite molds for the production of steel railroad wheels. *Source*: Griffin Wheel Division of Amsted Industries Incorporated.**

Permanent Mold Casting - Basic Permanent Mold

Pros:

- Good surface finish and close dimensional control.
- More rapid solidification, finer grain structure, stronger castings.

Cons:

- Generally limited to lower melting point metals.
- Simpler part geometries as mold is permanent.
- Mold cost is expensive and thus cater for volume production.

Permanent Mold Casting - Die Casting

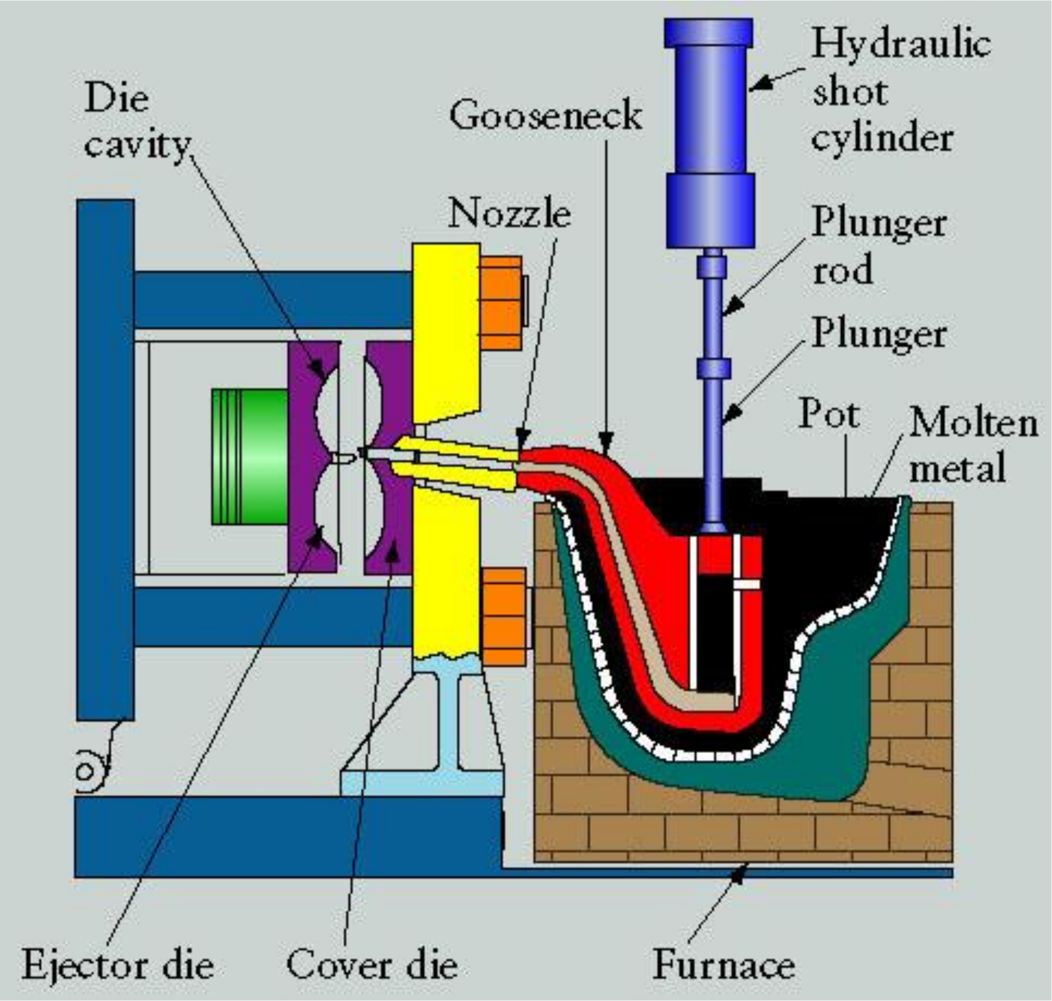
Hot-chamber machines :

Metal molten in container attached to machine. Typical injection pressures are 7 to 35 MPa. The piston is subjected to the melting temperature of the metal and thus the process is often used for low melting point metals such as zinc, tin, lead or magnesium alloys.

Cold-chamber machines

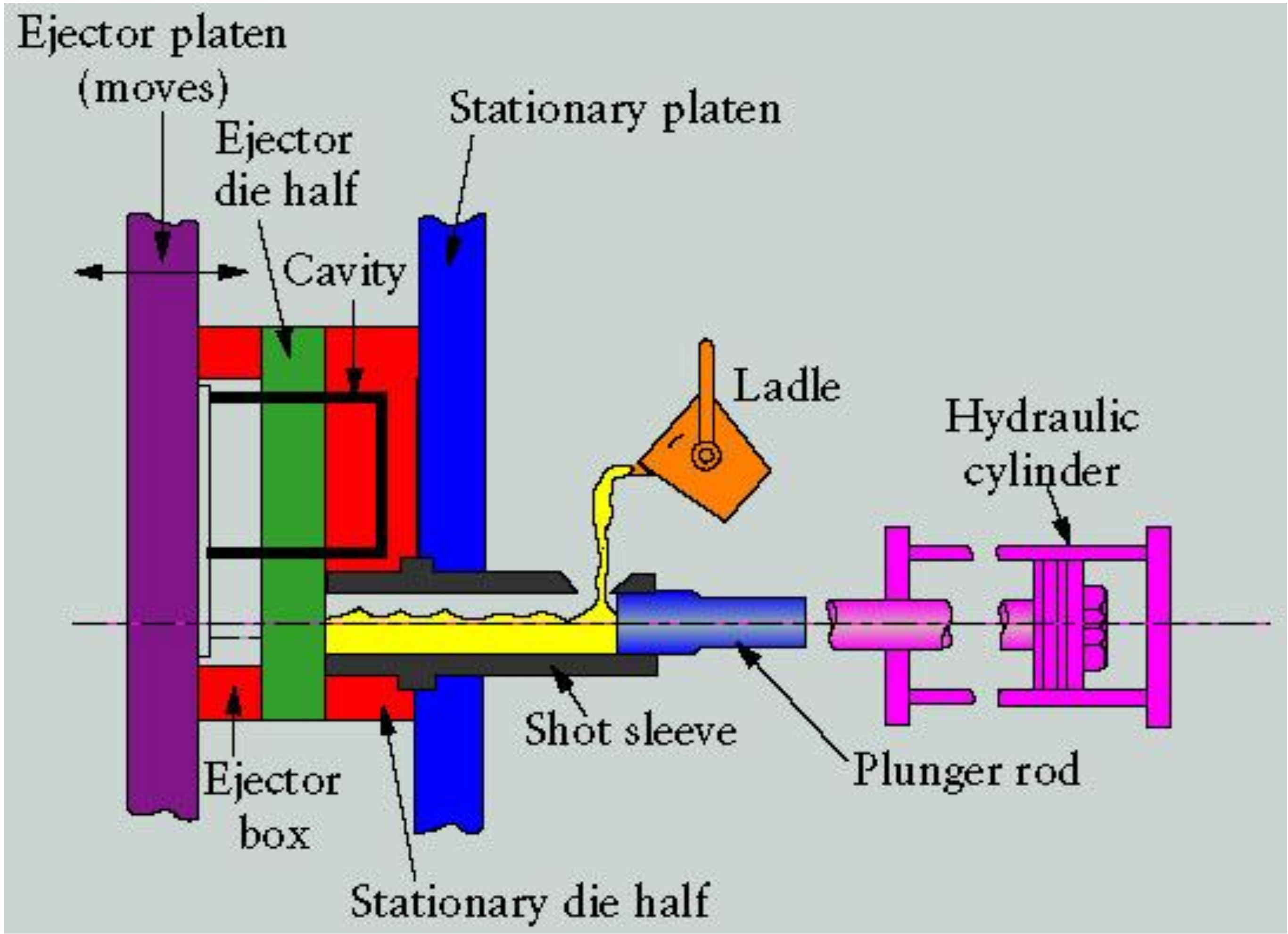
Molten metal is poured into an unheated chamber from an external container. Typical injection pressures are 14 to 140 MPa. Often used for high melting point metal such as aluminum, brass, and magnesium alloys.

Die Casting in Hot-Chamber Process



- **Sequence of steps in die casting of a part in the hot-chamber process. *Source*: Courtesy of Foundry Management and Technology.**

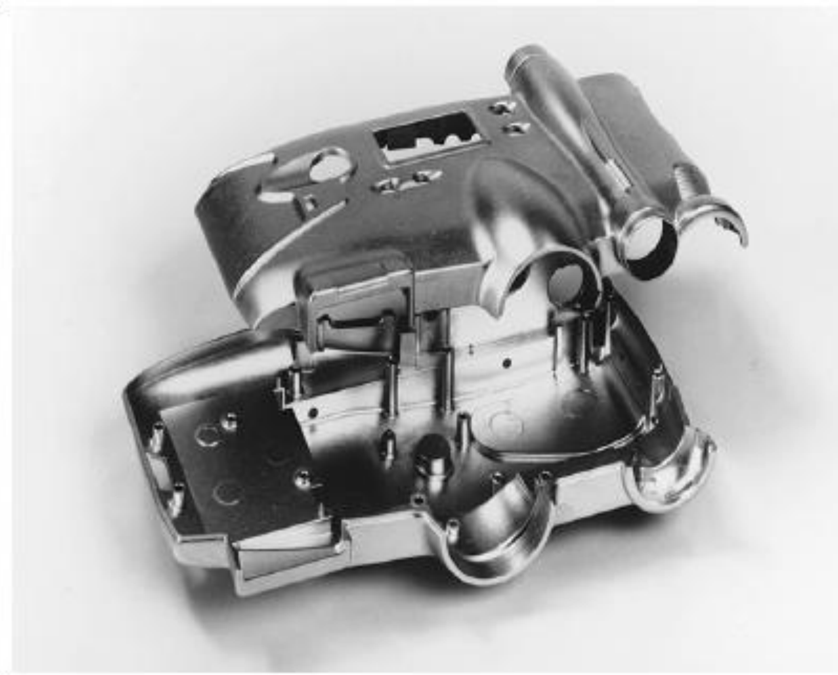
Die Casting in Cold-Chamber Process



- Sequence of operations in die casting of a part in the cold-chamber process.

Die Casting Machine

Die Casting Part Example



Permanent Mold Casting - Die Casting

- **Mold made of tool steel.**
- **Mold opening mechanism to be synchronized with ejector pins.**
- **Venting is needed for air and gas typically at the parting surface.**
- **Flash formation is common.**

Permanent Mold Casting - Die Casting

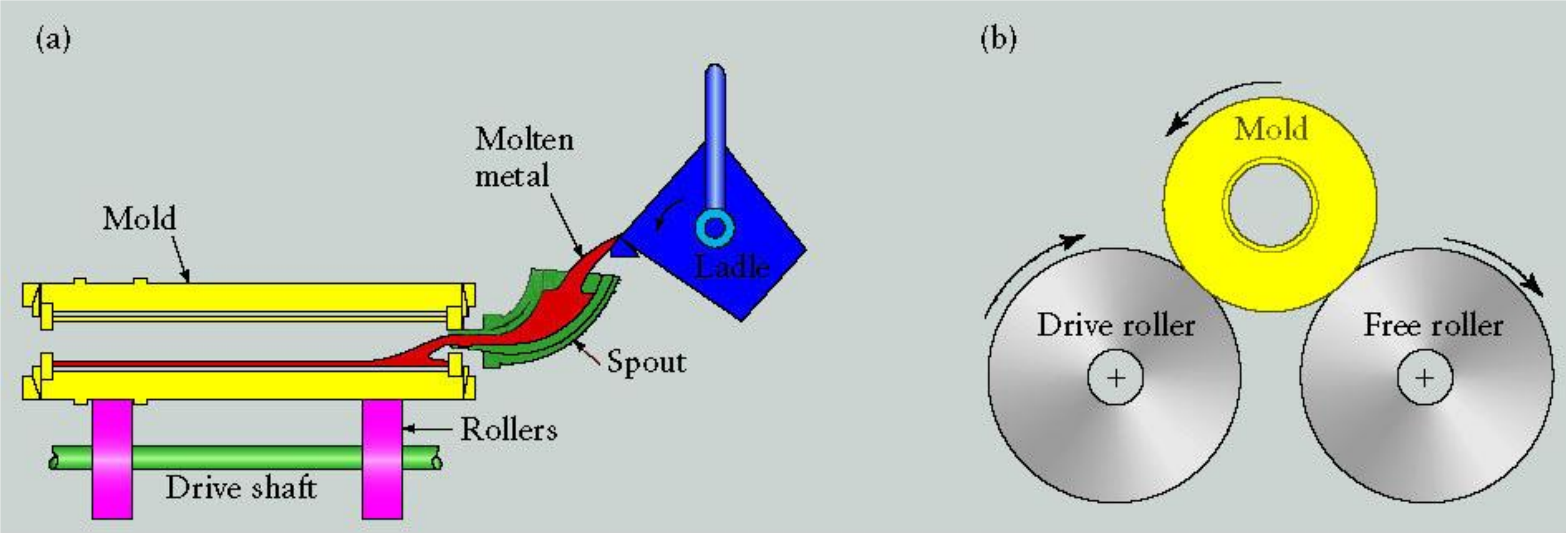
Pros:

- **High production rates are possible.**
- **Economical for large quantities.**
- **Close tolerances are possible (± 0.076 mm).**
- **Good surface finish.**
- **Thin sections are possible (down to 0.5 mm).**
- **Rapid cooling, fine grain, high strength.**

Cons:

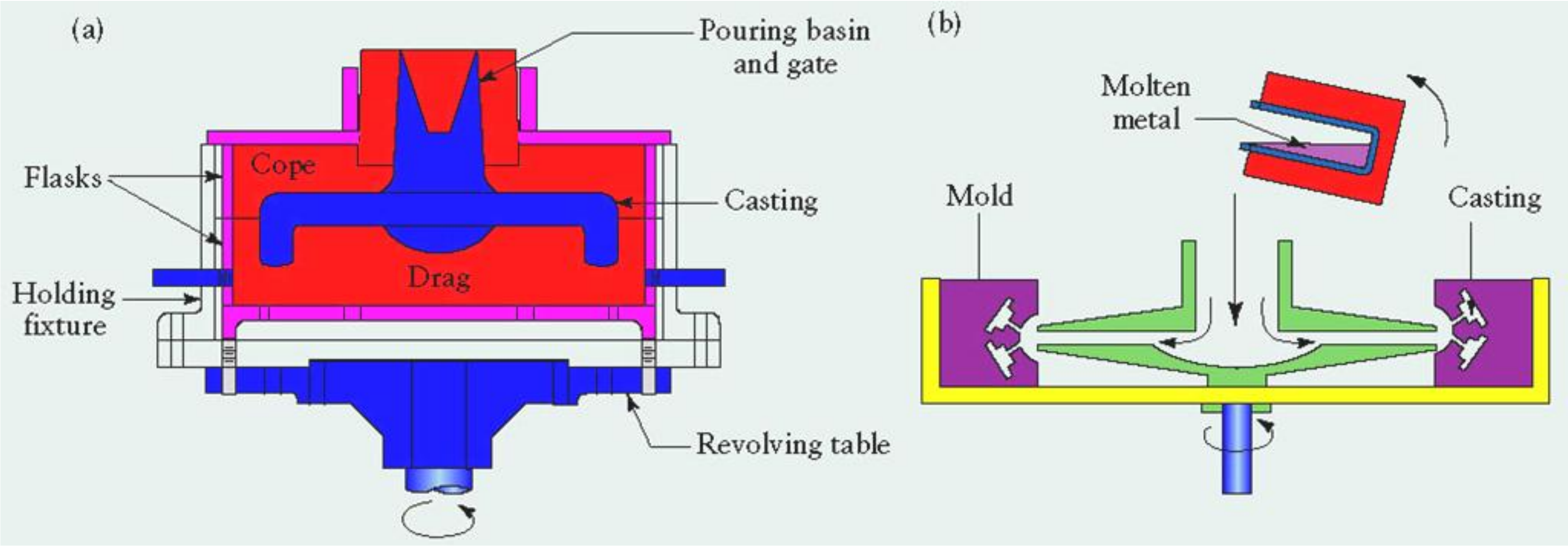
- **melting point of metals.**
- **shape restriction.**

Centrifugal Casting Process



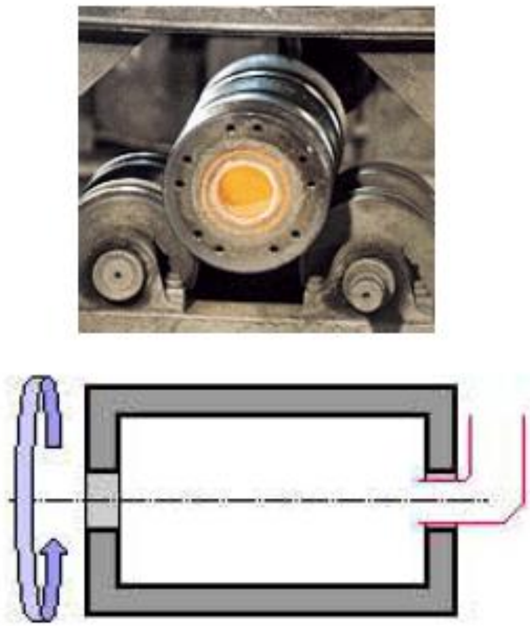
Schematic illustration of the centrifugal casting process. Pipes, cylinder liners, and similarly shaped parts can be cast by this process.

Semicentrifugal Casting Process

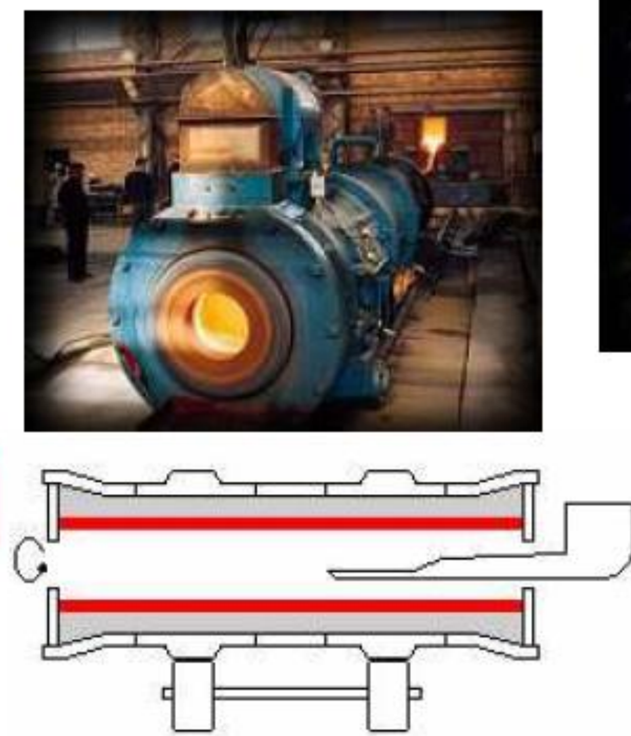


•(a) Schematic illustration of the semicentrifugal casting process. (b) Schematic illustration of casting by centrifuging. The molds are placed at the periphery of the machine, and the molten metal is forced into the molds by centrifugal forces.

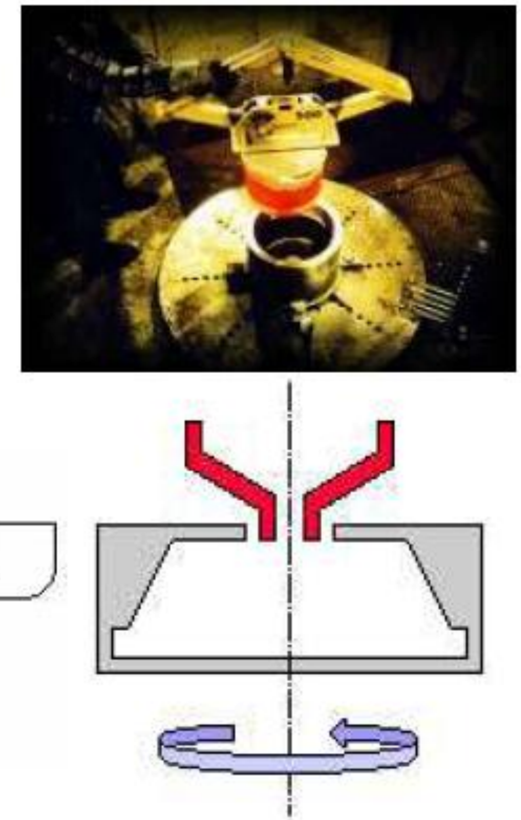
Centrifugal Casting



horizontal

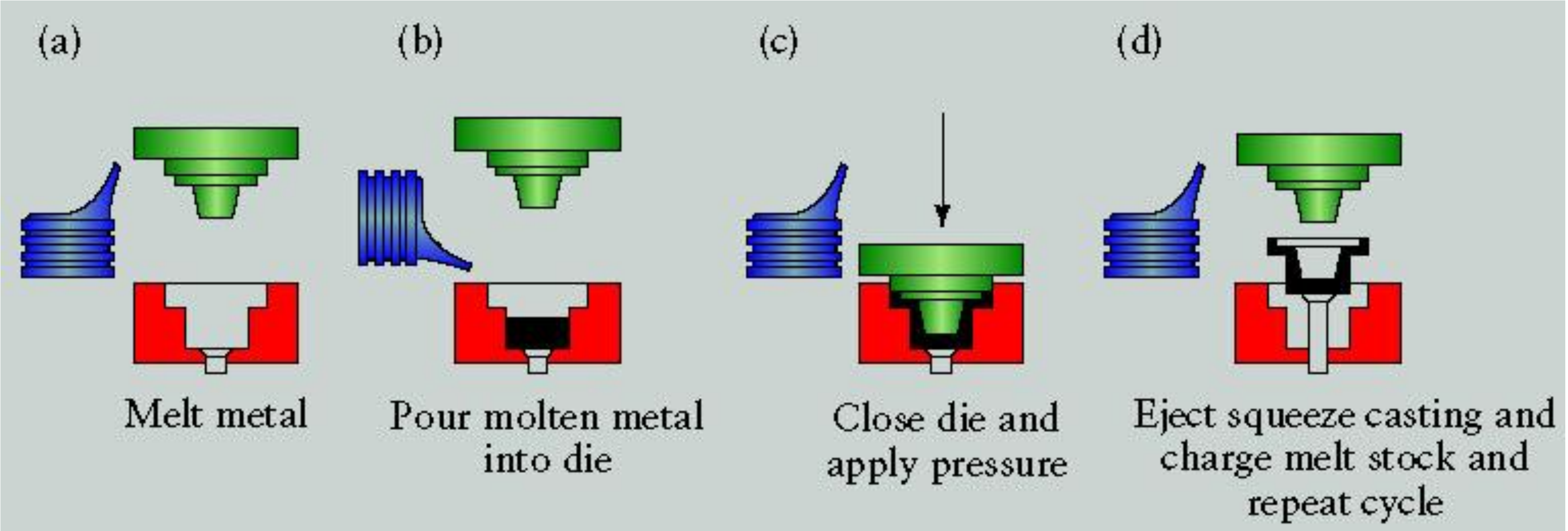


sand-lined mold casting



vertical

Squeeze-Casting Process



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