CASTING PROCESS - 3

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METAL CASTING PROCESSES

- Sand Casting
- Other Expendable Mold Casting Processes

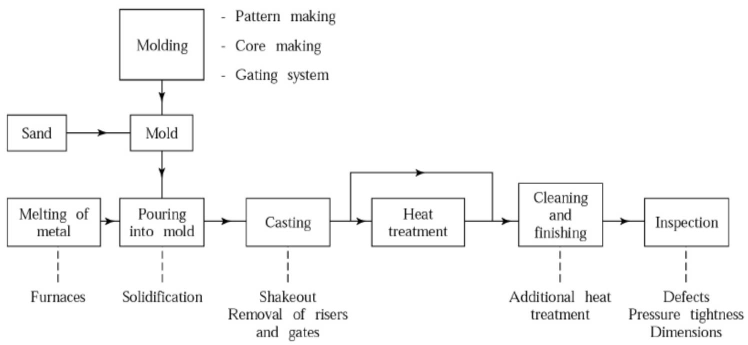
Overview of Sand Casting

- Most widely used casting process, accounting for a significant majority of total tonnage cast
- Nearly all alloys can be sand casted, including metals with high melting temperatures, such as steel, nickel, and titanium
- Parts ranging in size from small to very large
- Production quantities from one to millions

Basic Steps in making sand casting

- There are seven basic steps in making sand castings:
  - Obtaining the casting geometry
  - Patternmaking
  - Coremaking
  - Molding
  - Melting and pouring
  - Cleaning & inspection
  - Heat treatment & post processing

Sand Casting Process



Basic Steps in making sand casting

1. **Obtaining the casting geometry**
   – The traditional method of obtaining the casting geometry is by sending blueprint drawings to the foundry. This is usually done during the request for quotation process. However, more and more customers and foundries are exchanging part geometry via the exchange of computer aided design files.

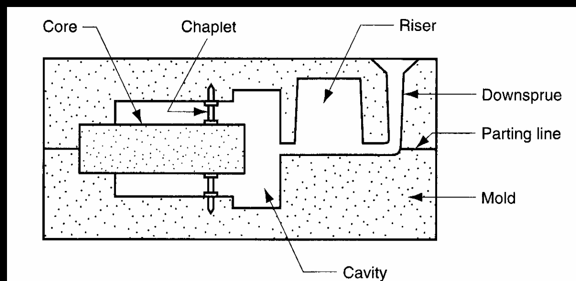
Basic Steps in making sand casting

2. **Patternmaking**
   – The pattern is a physical model of the casting used to make the mold.
   – The mold is made by packing some readily formed aggregate material, such as molding sand, around the pattern. When the pattern is withdrawn, its imprint provides the mold cavity, which is ultimately filled with metal to become the casting.
   – If the casting is to be hollow, as in the case of pipe fittings, additional patterns, referred to as cores, are used to form these cavities.

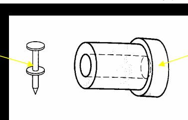
Basic Steps in making sand casting

3. **Coremaking**
   – Cores are forms, usually made of sand, which are placed into a mold cavity to form the interior surfaces of castings. Thus the void space between the core and mold-cavity surface is what eventually becomes the casting.

Sand Casting Process



chaplet

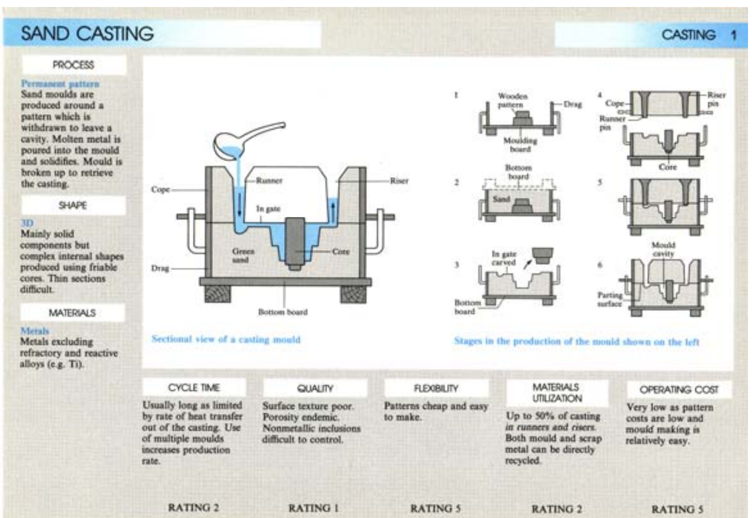


casting

Basic Steps in making sand casting

4. Molding

– Molding consists of all operations necessary to prepare a mold for receiving molten metal. Molding usually involves placing a molding aggregate around a pattern held with a supporting frame, withdrawing the pattern to leave the mold cavity, setting the cores in the mold cavity and finishing and closing the mold.



SAND CASTING — CASTING 1

PROCESS

Permanent pattern
Sand moulds are produced around a pattern which is withdrawn to leave a cavity. Molten metal is poured into the mould and solidifies. Mould is broken up to retrieve the casting.

SHAPE

3D
Mainly solid components but complex internal shapes produced using friable cores. Thin sections difficult.

MATERIALS

Metals
Metals excluding refractory and reactive alloys (e.g. Ti).

Sectional view of a casting mould

Stages in the production of the mould shown on the left

CYCLE TIME	QUALITY	FLEXIBILITY	MATERIALS UTILIZATION	OPERATING COST
Usually long as limited by rate of heat transfer out of the casting. Use of multiple moulds increases production rate.	Surface texture poor. Porosity endemic. Nonmetallic inclusions difficult to control.	Patterns cheap and easy to make.	Up to 50% of casting *in runners and risers.* Both mould and scrap metal can be directly recycled.	Very low as pattern costs are low and mould making is relatively easy.
RATING 2	RATING 1	RATING 5	RATING 2	RATING 5

Basic Steps in making sand casting

5. Melting and Pouring

– The preparation of molten metal for casting is referred to simply as melting. Melting is usually done in a specifically designated area of the foundry, and the molten metal is transferred to the pouring area where the molds are filled.

Basic Steps in making sand casting

6. Cleaning & inspection

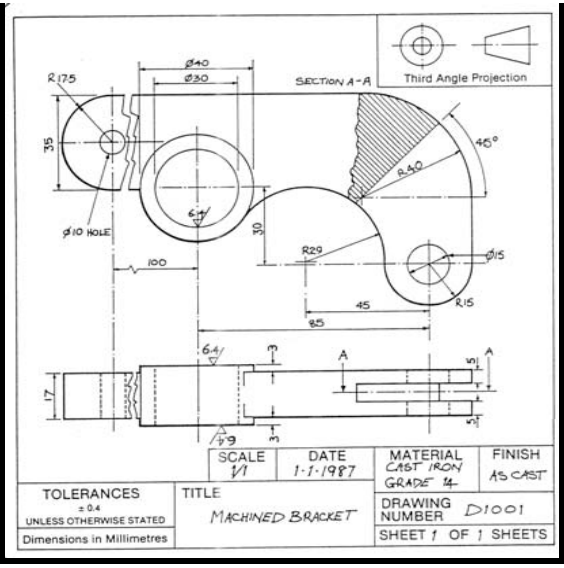
- Cleaning refers to all operations necessary to the removal of sand, scale, and excess metal from the casting. The casting is separated from the mold and transported to the cleaning department. Burned-on sand and scale are removed to improved the surface appearance of the casting. Excess metal, in the form of fins, wires, parting line fins, and gates, is removed. Castings may be upgraded by welding or other procedures.
- Inspection of the casting for defects and general quality is performed.

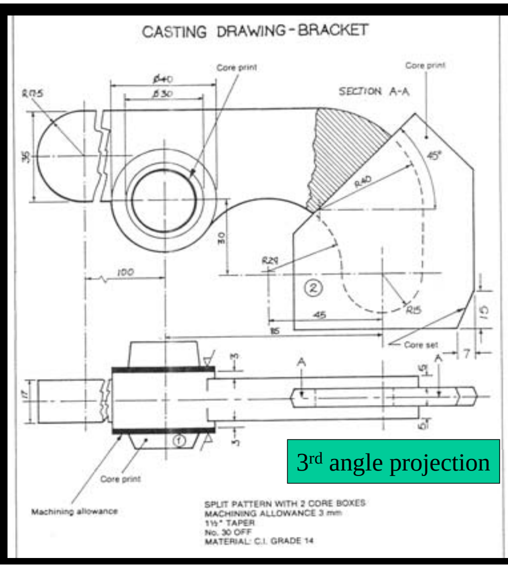
Basic Steps in making sand casting

7. Heat treatment and post processing

- Before shipment, further processing such as heat-treatment, surface treatment, additional inspection, or machining may be performed as required by the customer's specifications.

1. Obtaining the casting geometry





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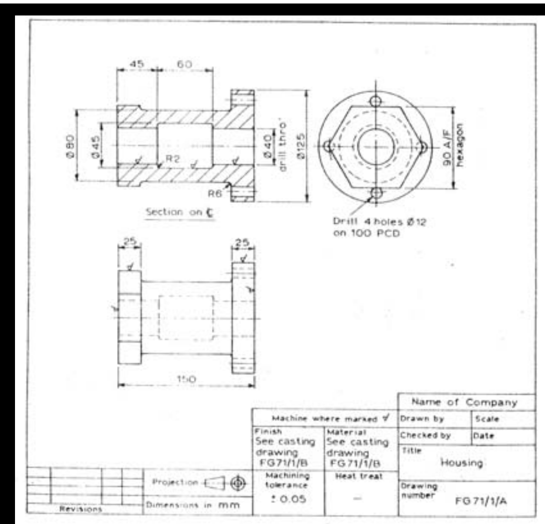

Rajah 1 : Lukisan kejuruteraan

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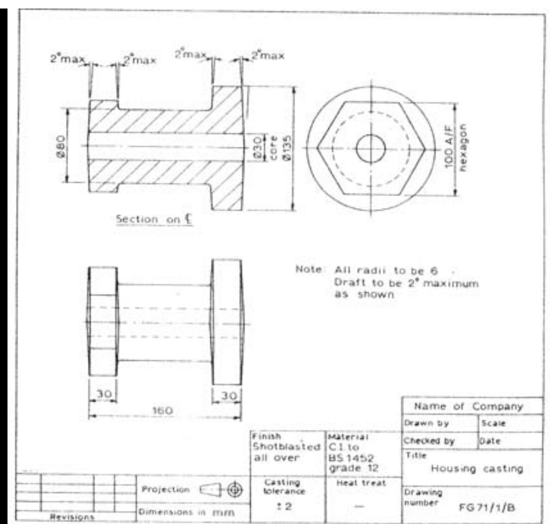

Rajah 2 : Lukisan tuangan

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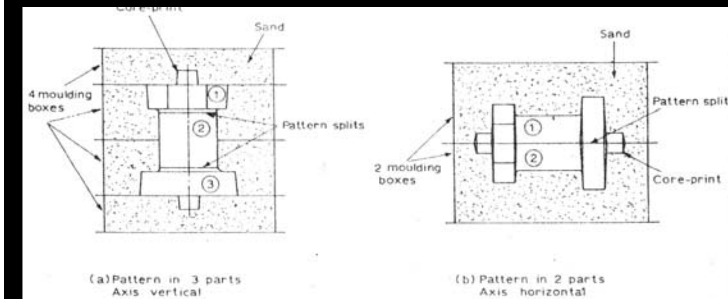
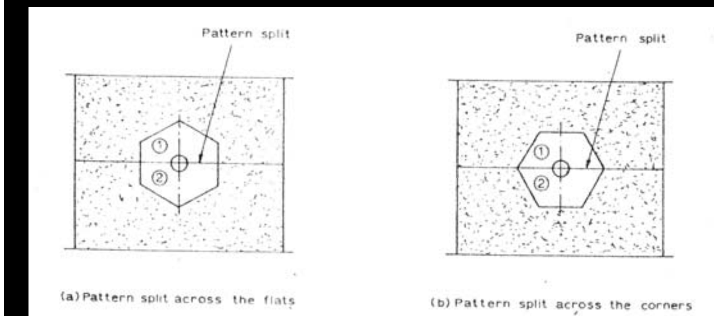
2. Pattern making



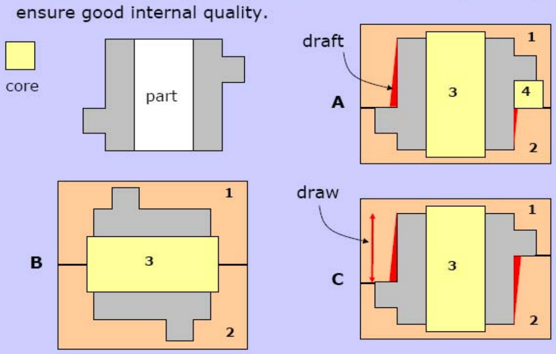
Rajah 3 : Kaedah pengacuanan



Rajah 4 : Kaedah pengacuanan

Parting and Draw Direction - Selection

- Goal: *Minimise the number* and *complexity* of mould elements to create the casting cavity *closest* to the desired geometry, and ensure good internal quality.



Pattern Design

- **Cored holes:** eliminate cored holes and add core print
- **Shrinkage allowance:** to compensate for solid phase contraction
  Depends on part shape (open, hindered), and casting metal:
  Aluminum: 13 mm/m, Copper: 16 mm/m, Grey Iron: 20 mm/m
- **Machining allowance:** based on part size, dimensional variation, sub-surface quality (orientation), machining (manual/automatic).
  1 mm for small die cast parts to 20 mm for large sand cast parts
- **Distortion allowance:** special type of machining allowance to compensate for shape distortion: mainly in iron castings
- **Draft:** to facilitate removal of pattern from mold or part from die
  Depends on distance of face from parting; length of face, internal or external; mold roughness and type of molding.
- **Fillets:** to facilitate molding and filling.

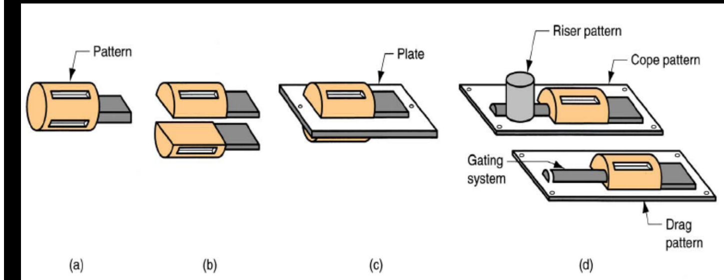
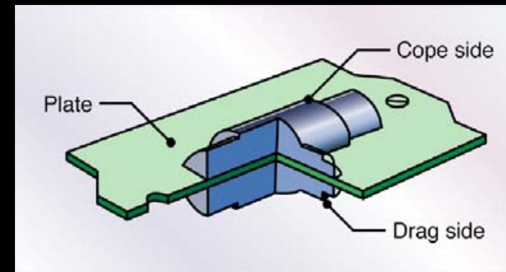


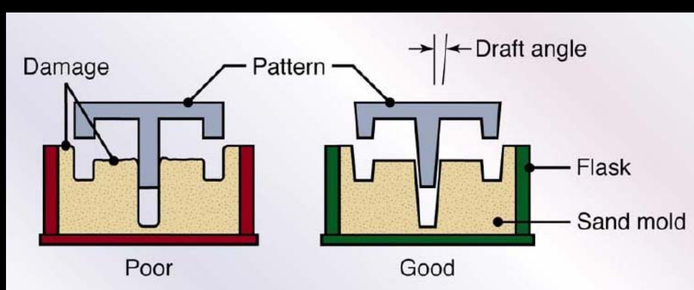
Figure 11.3 - Types of patterns used in sand casting:
(a) solid pattern
(b) split pattern
(c) match-plate pattern
(d) cope and drag pattern



Pattern Considerations/Allowances

- Shrinkage Allowance (Why?)
- Machining Allowance (?)
- Draft Allowance (?)
- Round corners (?)

- Demonstration of draft allowance

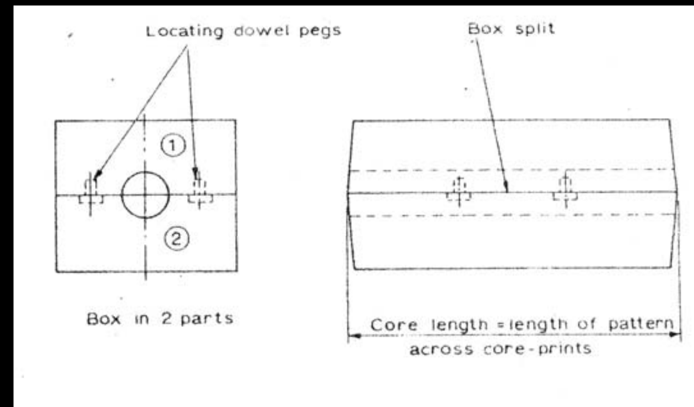


Pattern Material Characteristics

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
Weight[b]	E	G	P	G	P
Repairability	E	P	G	F	G
Resistance to:					
Corrosion[c]	E	E	P	E	P
Swelling[c]	P	E	E	E	E

[a]E, Excellent; G, good; F, fair; P, poor.
[b]As a factor in operator fatigue.
[c]By water.
Source: D.C. Ekey and W.R. Winter, *Introduction to Foundry Technology*. New York. McGraw-Hill, 1958.

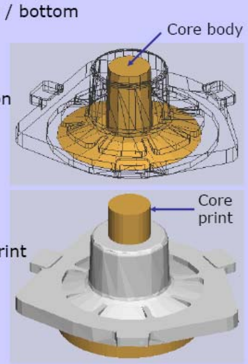
3. Core making



Rajah 5 : Kotak teras

Core design

- **Types of cores:**
  - Horizontal: simply supported / overhanging
  - Vertical: doubly supported / hanging / bottom
- **Core Design:**
  - Avoid thin cores in thick sections
  - High length/dia ratio causes distortion
  - Minimum core-core distance.
- **Print Design:**
  - Horizontal overhanging core: print must balance the body (print weight >= body weight)
  - Compressive stress on mould near print
  - Allow transfer of heat and gases.



Sand Cores

- Cores are used for internal cavities and passages
- Removed from the finished part during shakeout
- Must be strong, collapsible, permeable, heat resistant
- Made in a similar manner to mold making

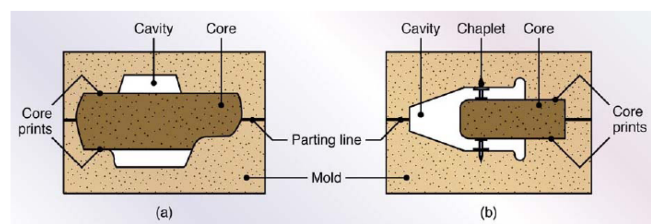
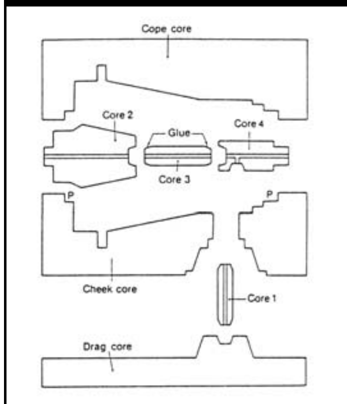
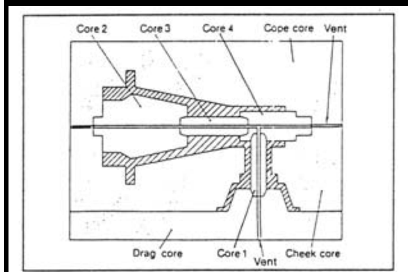


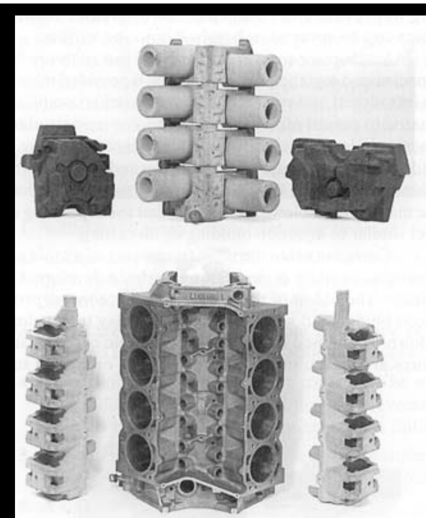
Figure 11.6 Examples of sand cores showing core prints and chaplets to support cores.

Multiple cores



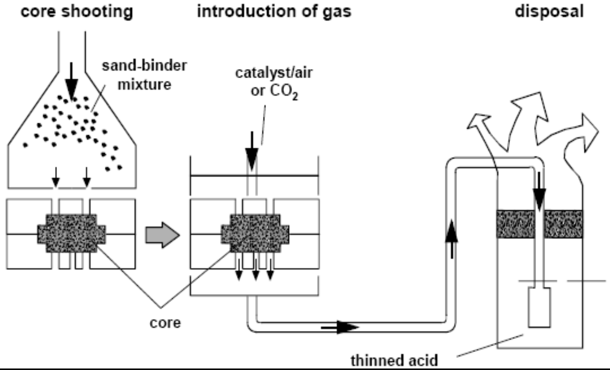


- The cope core is now carefully lined up with, and closed onto the cheek core.



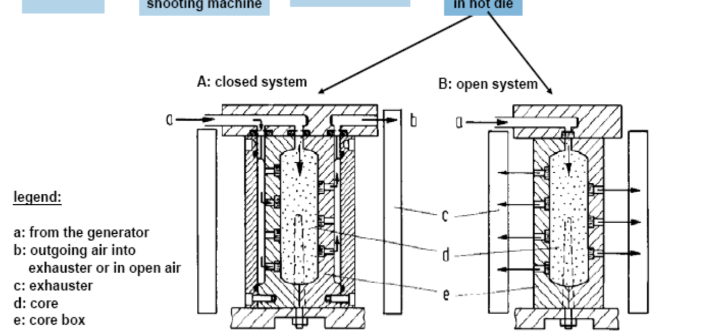
Core production using cold-box method

The cold-box process is a core production method, at which humid, pourable moulding material is cured (baked) in very short times at room temperature in cold core boxes.

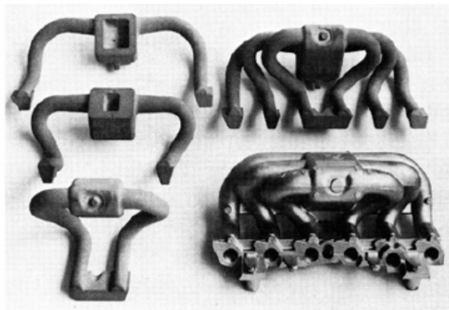


Core production using hot-box method

core sand dressing → transport of core sand to the core shooting machine → core shooting in in heated core box → curing of moulding material in hot die → unloading the core → post-cure



Examples for hot-box cores on furan resin basis

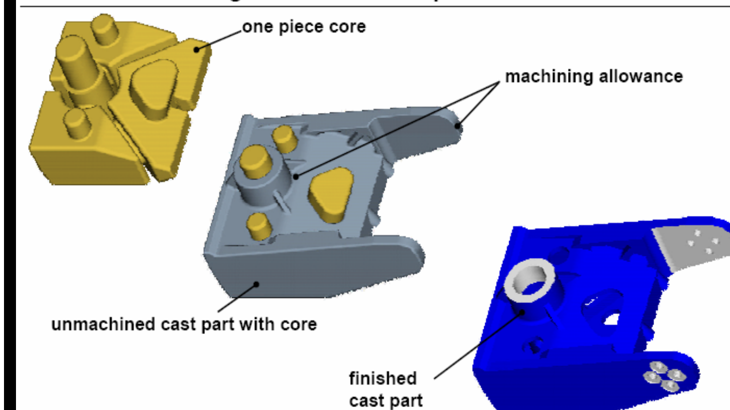


single cores and assembled cores for an aluminium suction system of a 6-cylinder injection engine

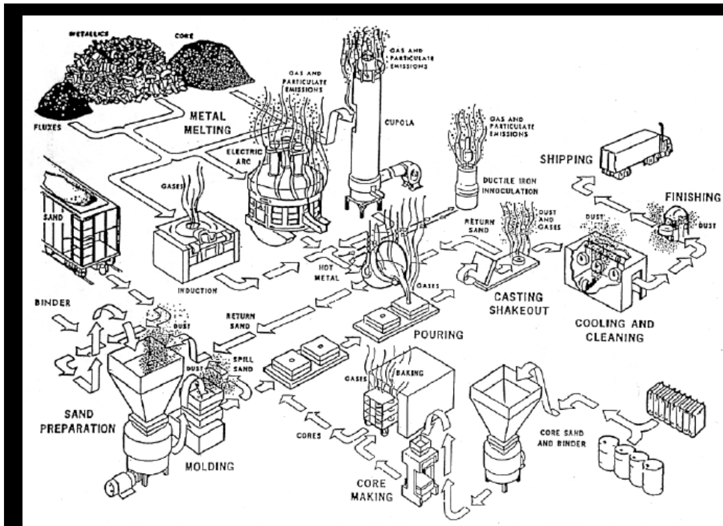
unloading the cores out of the core shooter

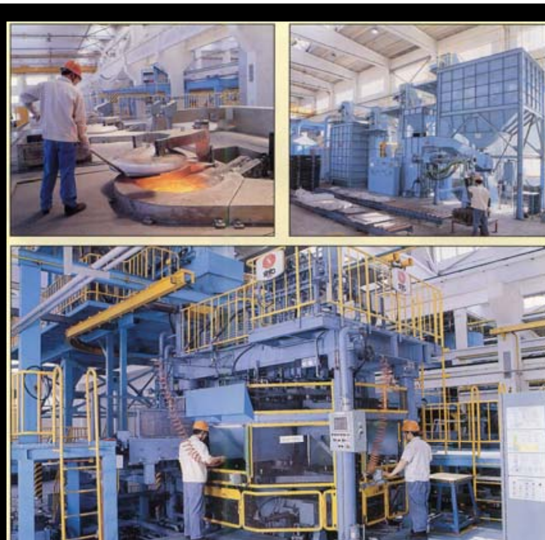
core setting

Cores and machining allowance at cast part



4. Molding





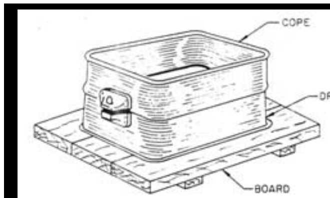


Fig. 14-1 Assembled flask

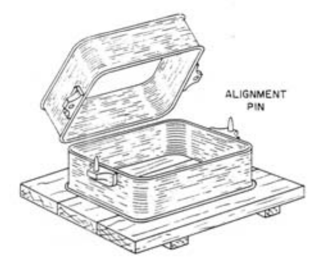


Fig. 14-2 Opened flask

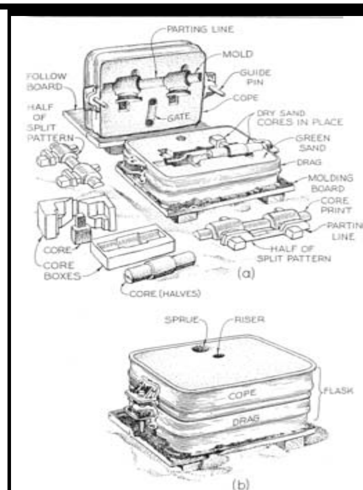
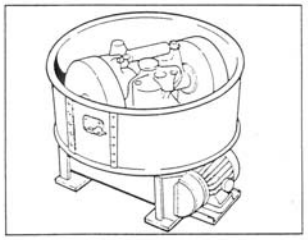
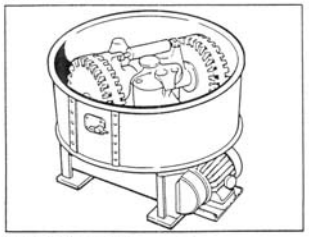


Fig. 12.2 Sand Molding of Table Bracket.

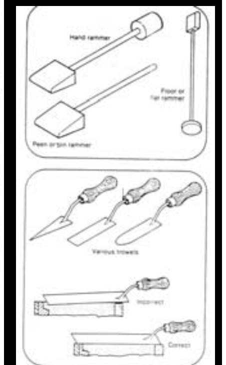
Sand mixers



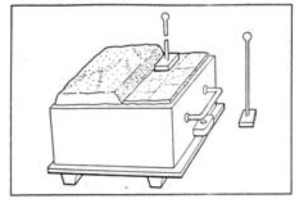
Solid wheels mill.



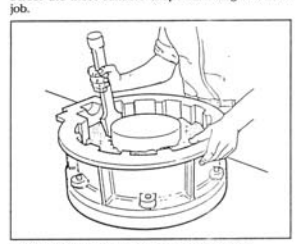
Toothed wheeled mill.



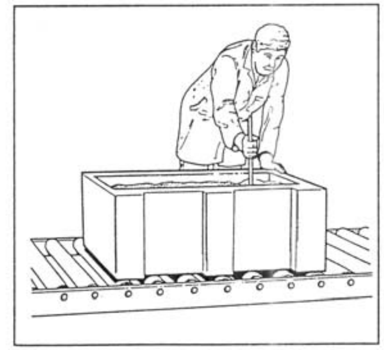
Hand rammer (flat)



Flat ram to complete ramming of mould.
Select the most suitable shape and weight for the job.



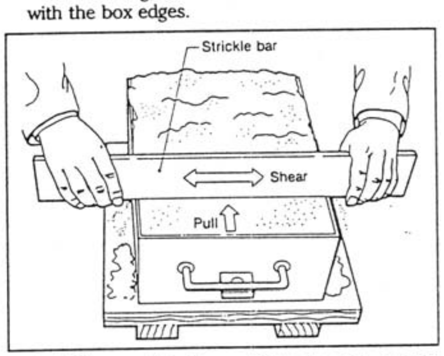
Hand ramming corebox with 'dolly' rammer.



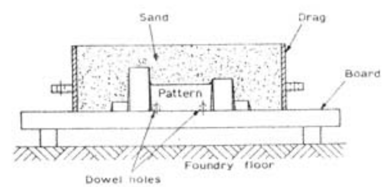
For ramming under particular patterns and coreboxes, shaped rod rammers are used.

Strickling

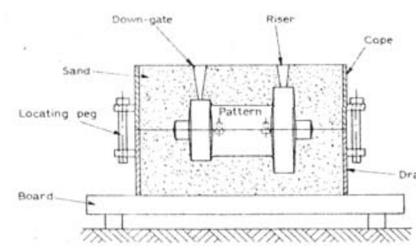
- Removes excess sand from top of mould and core.
- After strickling, the sand surface should be level with the box edges.



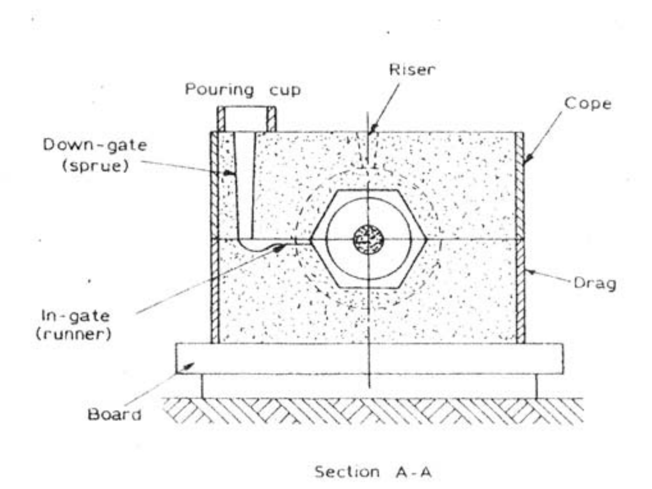
- Strickling mould with a strickle bar (or straight edge), made of steel or wood.

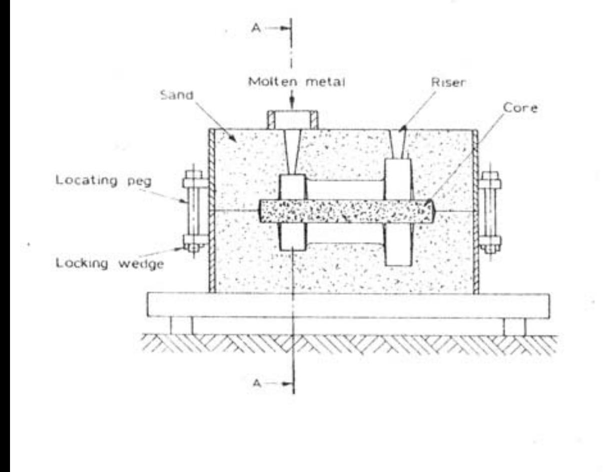


Rajah 6 : Kotak acuan bawah yang telah dipadatkan



Rajah 7 : Kotak acuan bawah dan atas yang telah dipadatkan





Rajah 8 : Acuan lengkap sedia untuk dituang dengan logam lebur

Sequence of Operations for Sand Casting

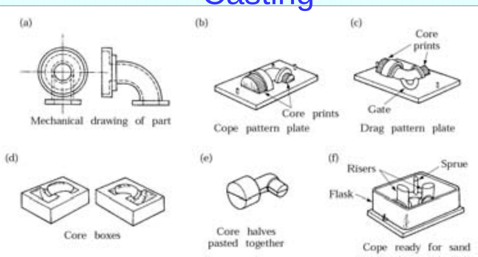


Figure 11.11 Schematic illustration of the sequence of operations for sand casting. *Source*: Steel Founders' Society of America. (a) A mechanical drawing of the part is used to generate a design for the pattern. Considerations such as part shrinkage and draft must be built into the drawing. (b-c) Patterns 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)

Sequence of Operations for Sand Casting (cont.)

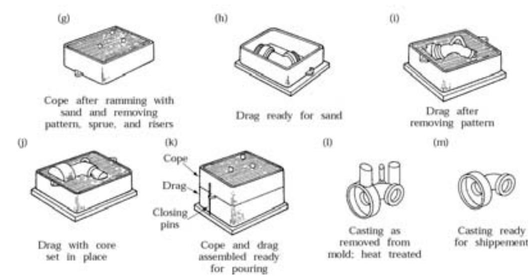


Figure 11.11 (g) The flask is rammed with sand and the plate and inserts are removed. (g) The drag half is produced in a similar manner, with the pattern inserted. A bottom board is placed below the drag and aligned with pins. (i) The pattern, flask, and bottom board are inverted, and the pattern is 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 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).

Squeeze Heads

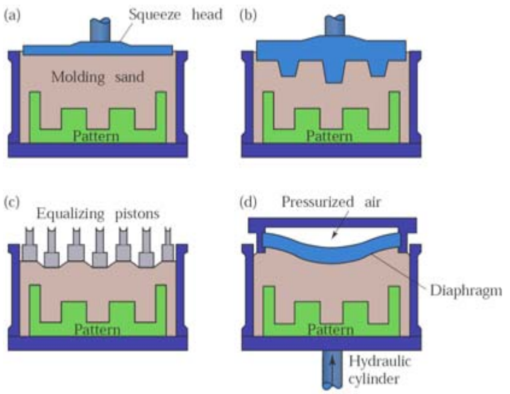


Figure 11.9 Various designs of squeeze heads for mold making: (a) conventional flat head; (b) profile head; (c) equalizing squeeze pistons; and (d) flexible diaphragm. *Source*: © Institute of British Foundrymen. Used with permission.

The squeeze head: Don't bury your head in the sand ...

... use DYNAMATIC® instead. The multi rods of the compaction head penetrate into the sand exactly where a more intense compaction is required by the pattern. You simply have to push the buttons on the control panel to select the individual rods squeezing the mould. Once compaction profile for a specific pattern has been established, it can be repeated over and over again. This guarantees true-to-pattern castings from uniform high-quality moulds. Pattern plates can be packed tightly up to their edges.
The squeeze pressure is up to 100 N/cm^2. It may be possible that fewer cores will be necessary.

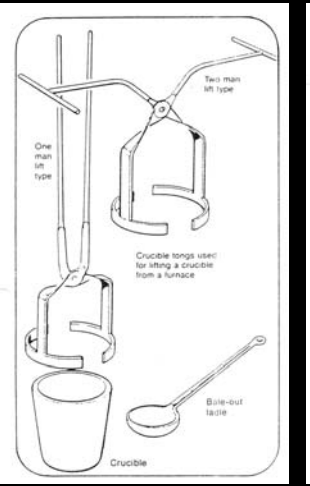
Making the Sand Mold

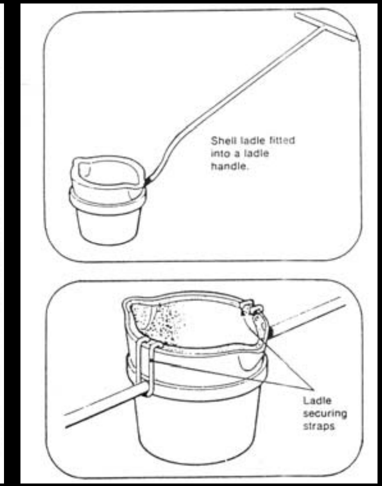
- The *cavity* in the sand mold is formed by packing sand around a pattern, then separating the mold into two halves and removing the pattern
- The mold must also contain gating and riser system
- If casting is to have internal surfaces, a *core* must be included in mold
- A new sand mold must be made for each part produced

Desirable Mold Properties and Characteristics

- *Strength* - to maintain shape and resist erosion
- *Permeability* - to allow hot air and gases to pass through voids in sand
- *Thermal stability* - to resist cracking on contact with molten metal
- *Collapsibility* - ability to give way and allow casting to shrink without cracking the casting
- *Reusability* - can sand from broken mold be reused to make other molds?

5. Melting & pouring

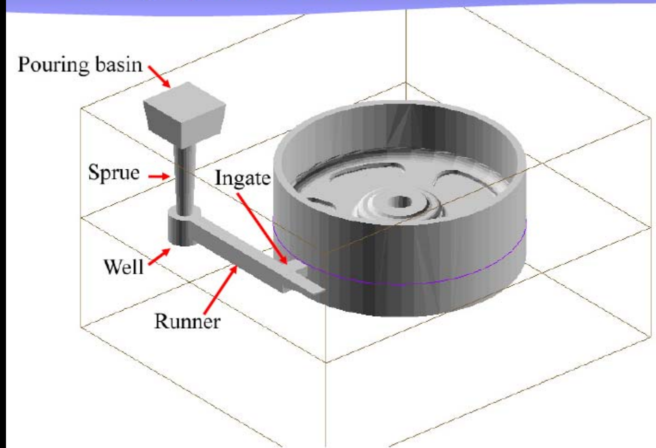




Casting Filling Requirement

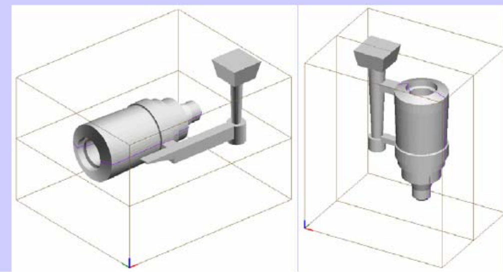
- Proper filling of mould cavity to ensure good quality casting.
- **Clean Metal**: Free of sand, slag and other impurities.
  - Ensure clean metal enters cavity, and remains clean.
- **Smooth Filling**: Prevent erosion and oxidation.
  - Minimise turbulence (velocity and obstructions)
- **Uniform Filling**: All sections filled at the same time.
  - Multiple entry points, and simultaneous flow of metal.
- **Complete Filling**: Thin and end sections must be filled.
  - Sufficient temperature, velocity; minimum resistance.

Gating System – Elements



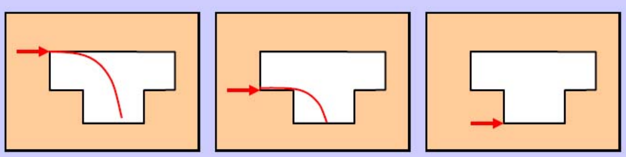
Gating Types

- Horizontal or vertical, depending on parting plane
- Parting plane contains runner and ingates in both types
- Sprue: vertical in gravity casting, can be horizontal in PDC
- Horizontal gating: mainly for flat casting, and gravity filling
- Vertical gating: mainly for tall castings, or pressure filling.

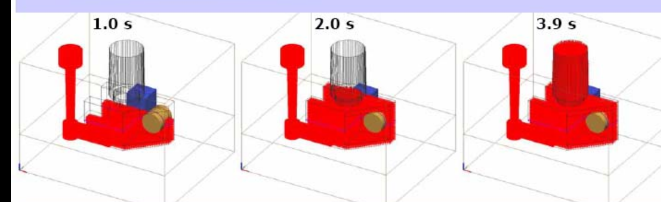


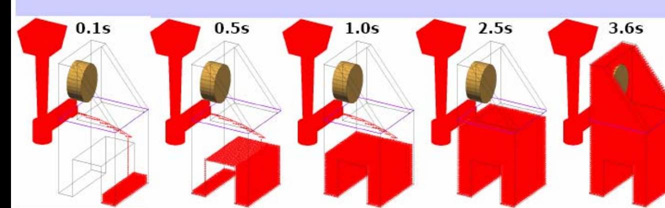
Horizontal Gating: Location

- **Top**: Bad for free fall of melt: turbulence, erosion, oxidation
  Good for directional solidification (hot metal at top)
  Useful for only flat castings (low height).
- **Bottom**: Good for turbulence-free filling
  Bad for directional solidification
  Useful for tall castings, if feeding is not a problem.
- **Parting**: Compromise between the above; easy to fettle.

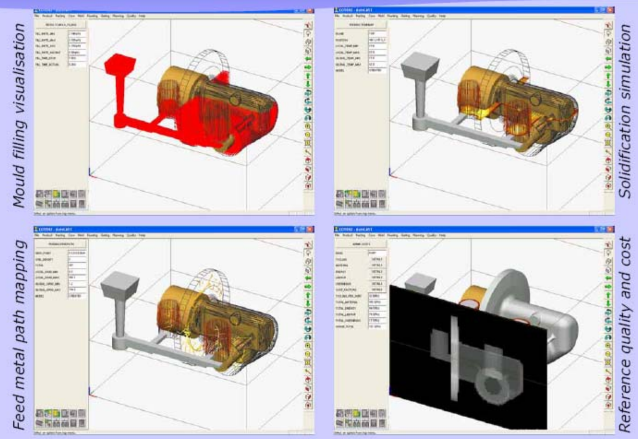


Mould filling time estimation





Intelligent Simulation



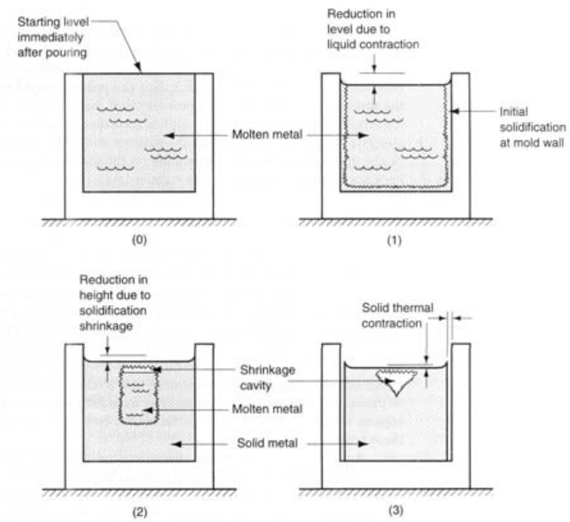
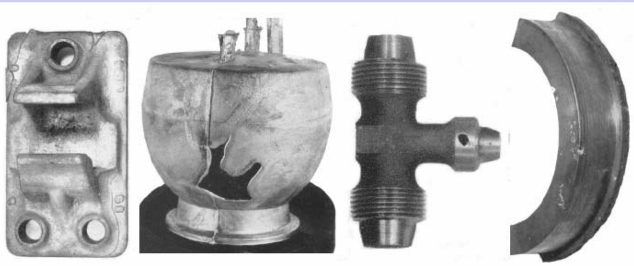


FIGURE 10.8 Shrinkage of a cylindrical casting during solidification and cooling: (0) starting level of molten metal immediately after pouring; (1) reduction in level caused by liquid contraction during cooling; (2) reduction in height and formation of shrinkage cavity caused by solidification shrinkage; and (3) further reduction in height and diameter due to thermal contraction during cooling of the solid metal. For clarity, dimensional reductions are exaggerated in our sketches.

Filling-related Defects

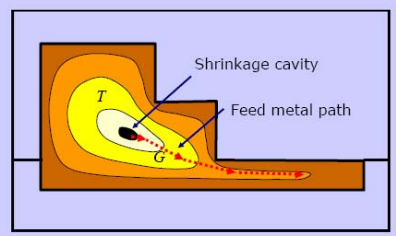
- **Incomplete Filling**: cold shut and misrun
- **Solid Inclusions**: sand inclusion, slag inclusion
- **Gaseous Entrapments**: blow hole, gas porosity.

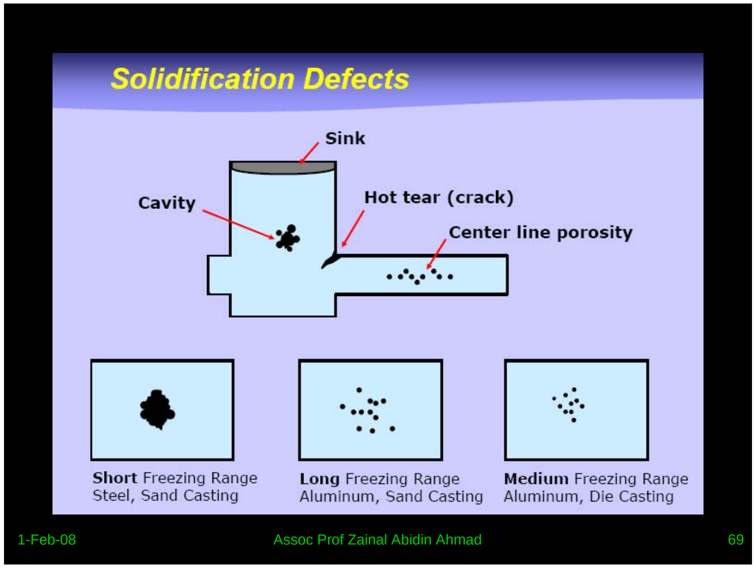


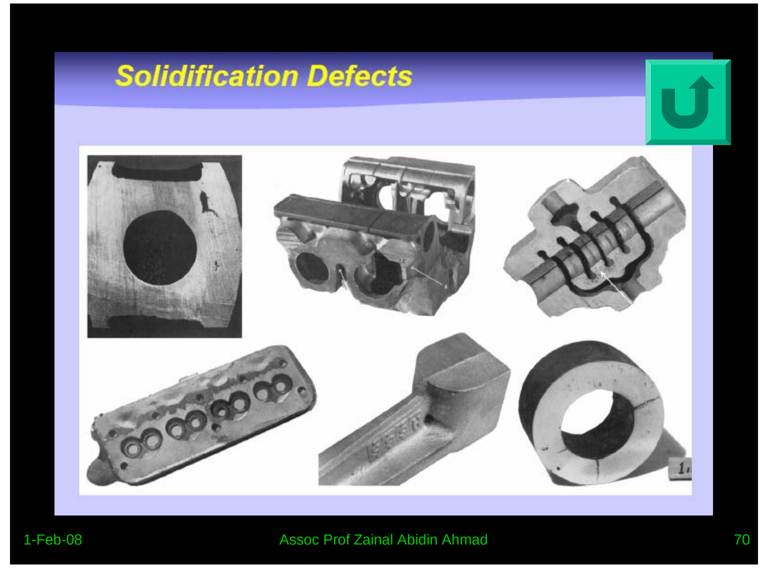
COLD SHUT MISRUN BLOW HOLE GAS POROSITY

Casting Solidification

- **Solidification type:**
  - Progressive: in a cross-section, mould wall to interior
  - Directional: thin to thicker to thickest regions: feed path
- Solidification contraction compensated by inner (hotter) regions
- **Hot spot** (high temperature, low gradient): shrinkage defect
- **Shrinkage defect type** depends on freezing range:
  - Short FR: concentrated *cavity*
  - Long FR: distributed *porosity*





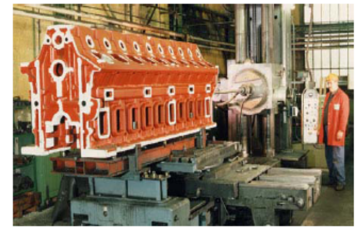


6. Cleaning & inspection

7. Heat treatment & other processes

machining

deep-hole drilling



Other Expendable Mold Casting Processes

- Shell Molding
- Vacuum Molding
- Expanded Polystyrene Process
- Investment Casting
- Plaster Mold and Ceramic Mold Casting

Shell Molding

- Casting process in which the mold is a thin shell of sand held together by thermosetting resin binder
- Developed in Germany during early 1940s

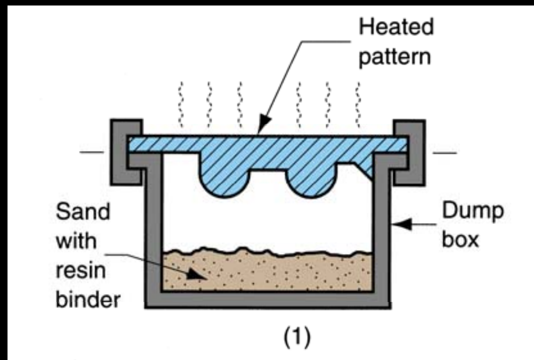


Figure 11.5 - Steps in shell-molding: (1) a match-plate or cope-and-drag metal pattern is heated and placed over a box containing sand mixed with thermosetting resin

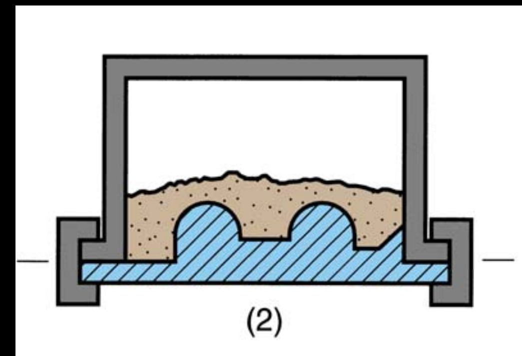


Figure 11.5 - Steps in shell-molding: (2) box is inverted so that sand and resin fall onto the hot pattern, causing a layer of the mixture to partially cure on the surface to form a hard shell

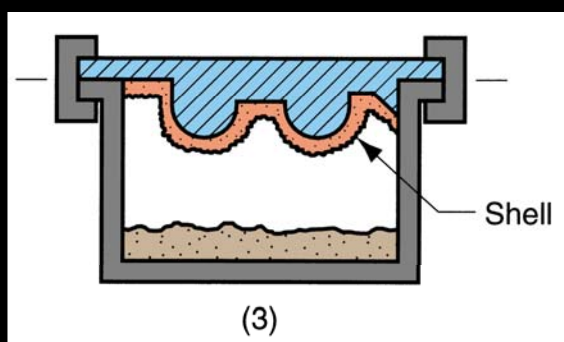


Figure 11.5 - Steps in shell-molding: (3) box is repositioned so that loose uncured particles drop away

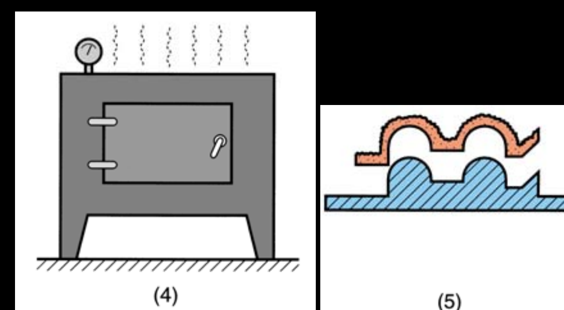


Figure 11.5 - Steps in shell-molding:
(4) sand shell is heated in oven for several minutes to complete curing
(5) shell mold is stripped from the pattern

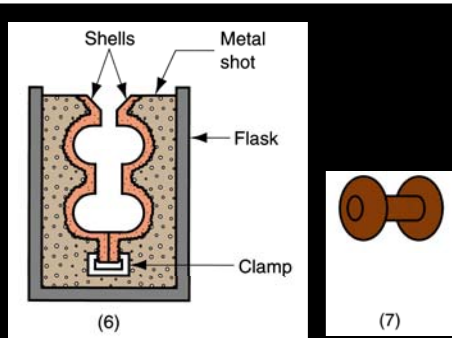


Figure 11.5 - Steps in shell-molding:

(6) two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is accomplished

(7) the finished casting with sprue removed

Advantages and Disadvantages of Shell Molding

- Advantages:
  - Smoother cavity surface permits easier flow of molten metal and better surface finish on casting
  - Good dimensional accuracy
  - Machining often not required
  - Mold collapsibility usually avoids cracks in casting
  - Can be mechanized for mass production
- Disadvantages:
  - More expensive metal pattern
  - Difficult to justify for small quantities

Expanded Polystyrene Process

- Uses a mold of sand packed around a polystyrene foam pattern which vaporizes when molten metal is poured into mold
- Other names: *lost-foam process*, *lost pattern process*, *evaporative-foam process*, and *full-mold process*
- Polystyrene foam pattern includes sprue, risers, gating system, and internal cores (if needed)
- Mold does not have to be opened into cope and drag sections

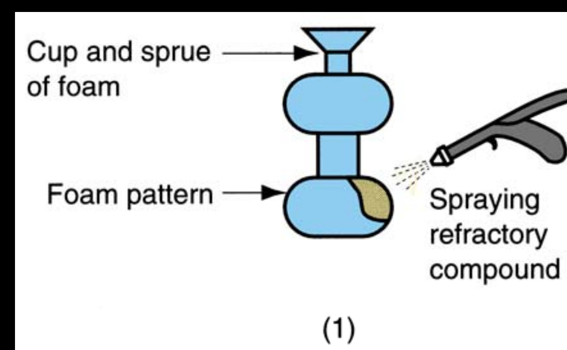


Figure 11.7 - Expanded polystyrene casting process: (1) pattern of polystyrene is coated with refractory compound

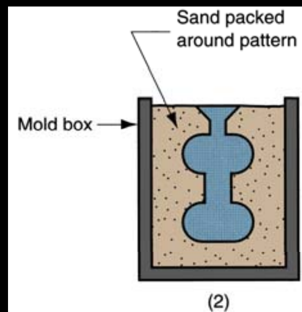


Figure 11.7 - Expanded polystyrene casting process:
(2) foam pattern is placed in mold box, and sand is compacted around the pattern

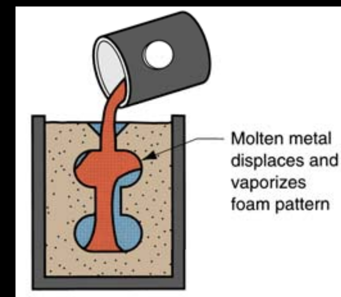


Figure 11.7 - Expanded polystyrene casting process:
(3) molten metal is poured into the portion of the pattern that forms the pouring cup and sprue. As the metal enters the mold, the polystyrene foam is vaporized ahead of the advancing liquid, thus allowing the resulting mold cavity to be filled.

Advantages and Disadvantages of Expanded Polystyrene Process

- Advantages:
  - Pattern need not be removed from the mold
  - Simplifies and expedites mold-making, since two mold halves (cope and drag) are not required as in a conventional green-sand mold
- Disadvantages:
  - A new pattern is needed for every casting
  - Economic justification of the process is highly dependent on cost of producing patterns

Applications of Expanded Polystyrene Process

- Mass production of castings for automobile engines
- Automated and integrated manufacturing systems are used to
  - Mold the polystyrene foam patterns and then
  - Feed them to the downstream casting operation

Investment Casting (Lost Wax Process)

- A pattern made of wax is coated with a refractory material to make mold, after which wax is melted away prior to pouring molten metal
- "Investment" comes from one of the less familiar definitions of "invest" - "to cover completely," which refers to coating of refractory material around wax pattern
- It is a precision casting process - capable of castings of high accuracy and intricate detail

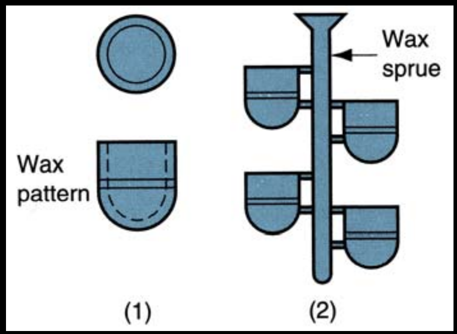


Figure 11.8 - Steps in investment casting:
(1) wax patterns are produced
(2) several patterns are attached to a sprue to form a pattern tree

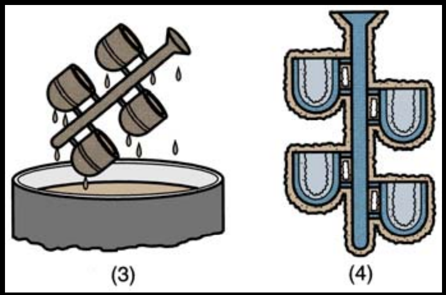


Figure 11.8 - Steps in investment casting:
(3) the pattern tree is coated with a thin layer of refractory material
(4) the full mold is formed by covering the coated tree with sufficient refractory material to make it rigid

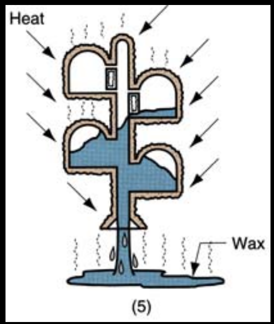


Figure 11.8 - Steps in investment casting:
(5) the mold is held in an inverted position and heated to melt the wax and permit it to drip out of the cavity

Figure 11.8 - Steps in investment casting:

(6) the mold is preheated to a high temperature, which ensures that all contaminants are eliminated from the mold; it also permits the liquid metal to flow more easily into the detailed cavity; the molten metal is poured; it solidifies

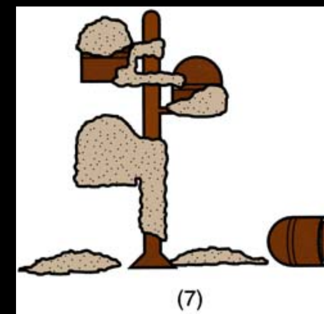


Figure 11.8 - Steps in investment casting:

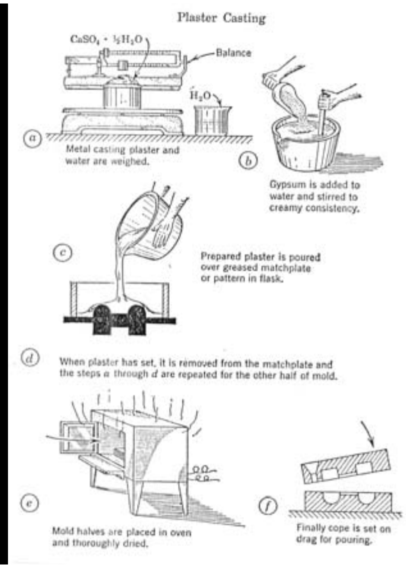
(7) the mold is broken away from the finished casting - parts are separated from the sprue

Advantages and Disadvantages of Investment Casting

- Advantages:
  - Parts of great complexity and intricacy can be cast
  - Close dimensional control and good surface finish
  - Wax can usually be recovered for reuse
  - Additional machining is not normally required - this is a net shape process
- Disadvantages
  - Many processing steps are required
  - Relatively expensive process

Plaster Mold Casting

- Similar to sand casting except mold is made of plaster of Paris (gypsum - $CaSO_4$-$2H_2O$)
- In mold-making, plaster and water mixture is poured over plastic or metal pattern and allowed to set
  - Wood patterns not generally used due to extended contact with water
- Plaster mixture readily flows around pattern, capturing its fine details and good surface finish



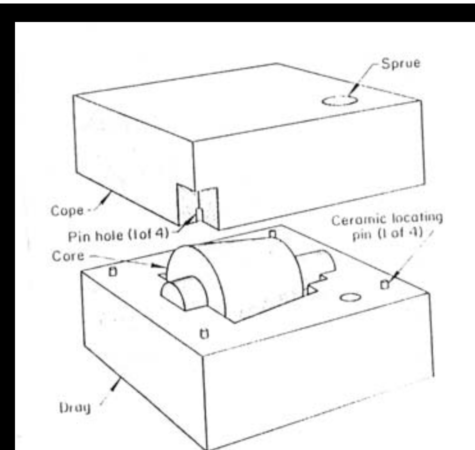


Fig. 3. Plaster mold and core, showing locating pins for matching the cope and drag sections

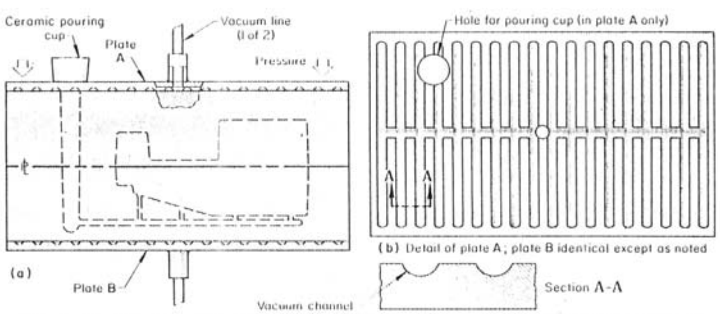


Fig. 4. (a) Side view of a conventional plaster mold positioned between upper and lower plates for pouring with vacuum assist. (b) Details of a top plate, showing vacuum channels.

Advantages and Disadvantages of Plaster Mold Casting

- Advantages:
  - Good dimensional accuracy and surface finish
  - Capability to make thin cross-sections in casting
- Disadvantages:
  - Moisture in plaster mold causes problems:
    - *Mold must be baked to remove moisture*
    - *Mold strength is lost when is over-baked, yet moisture content can cause defects in product*
  - Plaster molds cannot stand high temperatures, so limited to lower melting point alloys

Ceramic Mold Casting

- Similar to plaster mold casting except that mold is made of refractory ceramic materials that can withstand higher temperatures than plaster
- Ceramic molding can be used to cast steels, cast irons, and other high-temperature alloys
- Applications similar to those of plaster mold casting except for the metals cast
- Advantages (good accuracy and finish) also similar

Ceramic Molds

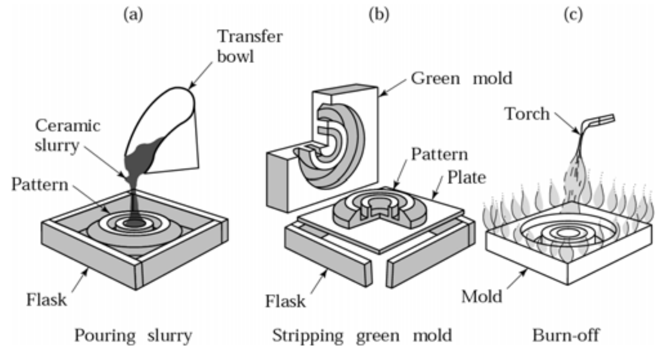


Figure 11.16 Sequence of operations in making a ceramic mold. *Source*: *Metals Handbook*, vol. 5, 8th ed.

Ceramic Molds

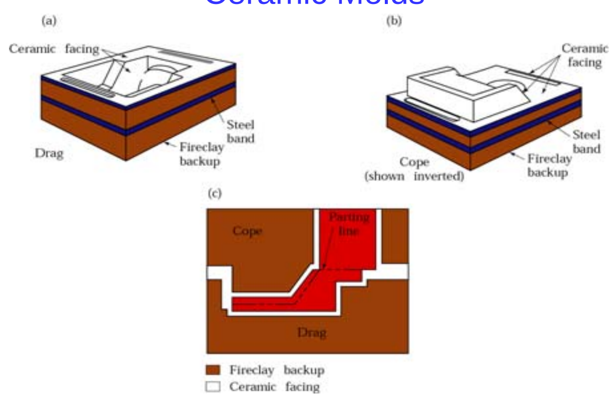


Figure 11.17 A typical ceramic mold (Shaw process) for casting steel dies used in hot forging. *Source: Metals Handbook*, vol. 5, 8th ed.