ME 350 – Lecture 9 – Chapter 11

METAL CASTING PROCESSES

1. Sand Casting
2. Other Expendable Mold Casting Processes
3. Permanent Mold Casting Processes
4. Casting Quality
5. Product Design Considerations

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

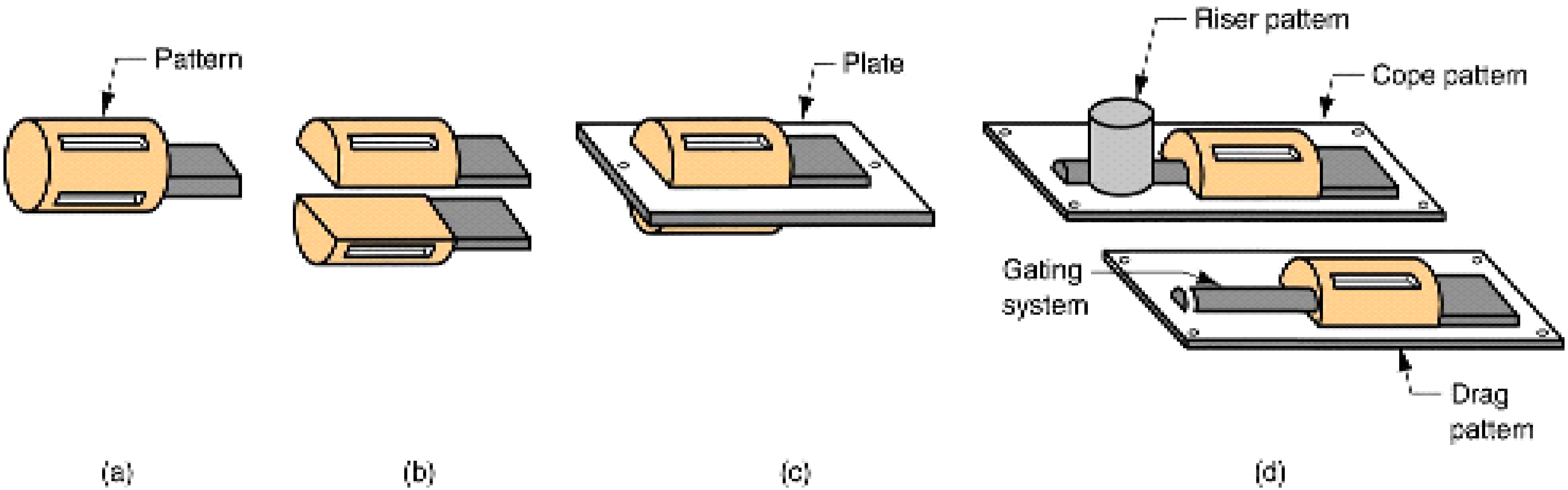
Patterns

Pattern – a model of the part, slightly ***enlarged to account for shrinkage and machining allowances***

Types of patterns used in sand casting:

(a) solid pattern, (b) split pattern, (c) match-plate pattern

(d) cope and drag pattern



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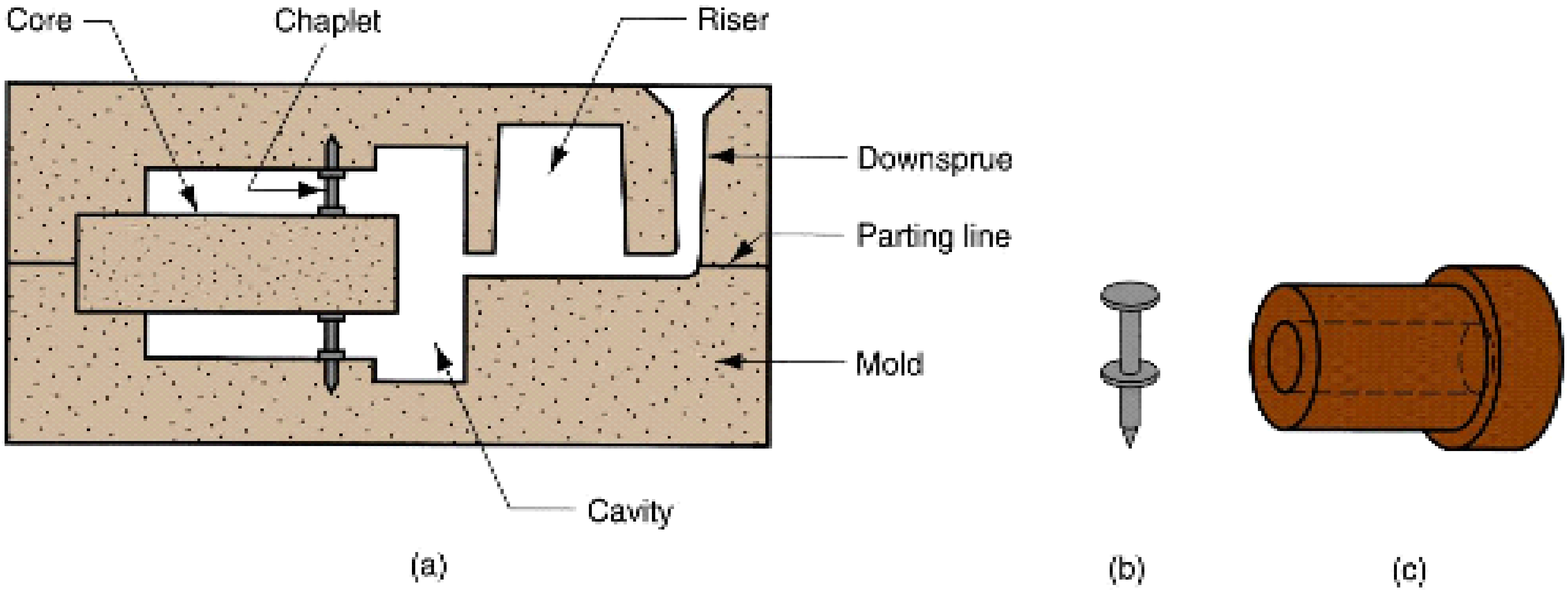
Core

Full-scale model of ***interior*** surfaces of part

- May require supports to hold it in position in the mold cavity during pouring, called ***chaplets***



(a) Core held in place in the mold cavity by chaplets, (b) possible chaplet design, (c) casting with internal cavity.

Buoyancy in Sand Casting Operation

- During pouring, buoyancy of the molten metal tends to displace the core, which can cause casting to be defective
- Force tending to lift core = weight of displaced liquid less the weight of core itself

$$F_b = W_m - W_c$$

where F_b = buoyancy force; W_m = weight of molten metal displaced; and W_c = weight of core

Desirable Mold Properties

- 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?

Foundry Sands

Silica (SiO_2) or silica mixed with other minerals

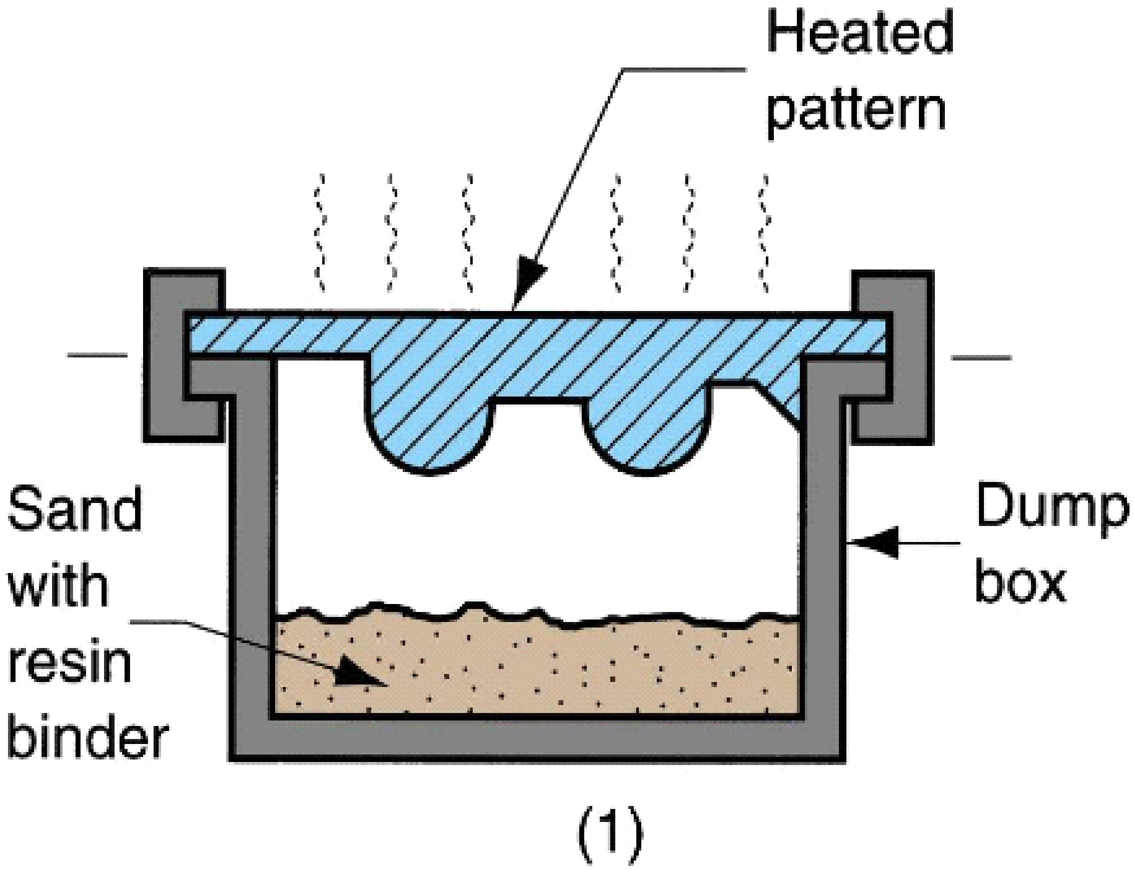
- Good refractory properties - capacity to endure high ***temperatures***
- Small grain size yields better ***surface finish***
- During pouring, large grain size is more ***permeable, allowing gases to escape***
- Irregular grain shapes strengthen molds due to interlocking, compared to round grains
  – Disadvantage: interlocking tends to reduce ***permeability***

Types of Sand Mold

- Green-sand molds - mixture of sand, clay, and water or oil;
  - “Green" means mold contains moisture at time of pouring
- Dry-sand mold – instead of clay it uses organic binders such as phenolic resins
  - For strength, mold usually must be: ***baked***
- Skin-dried mold - drying mold cavity surface of a green-sand mold
  - Typical depth of 10 to 25 mm, using torches or heating lamps

1. Shell Molding

Casting process in which the mold is a thin shell of sand held together by thermosetting resin binder



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.

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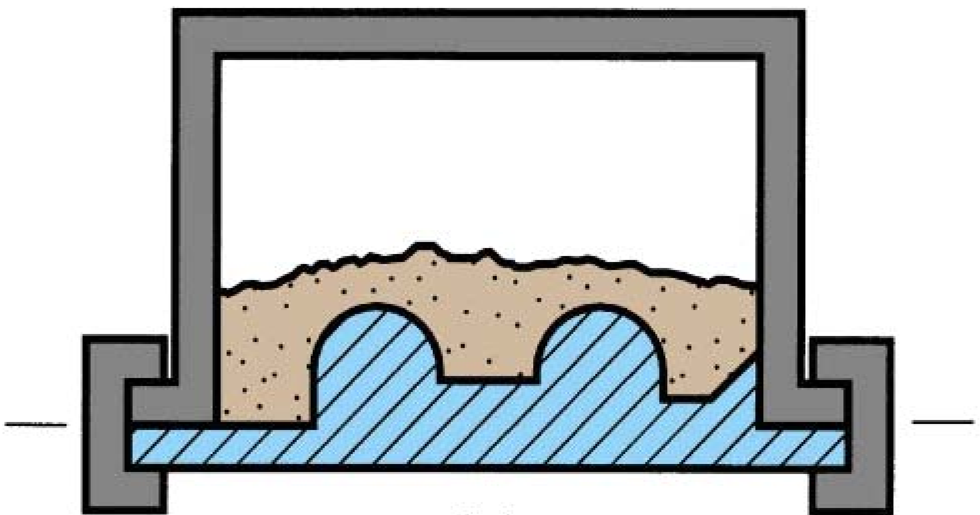
1. Shell Molding

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; (3) box is repositioned so that loose uncured particles drop away;



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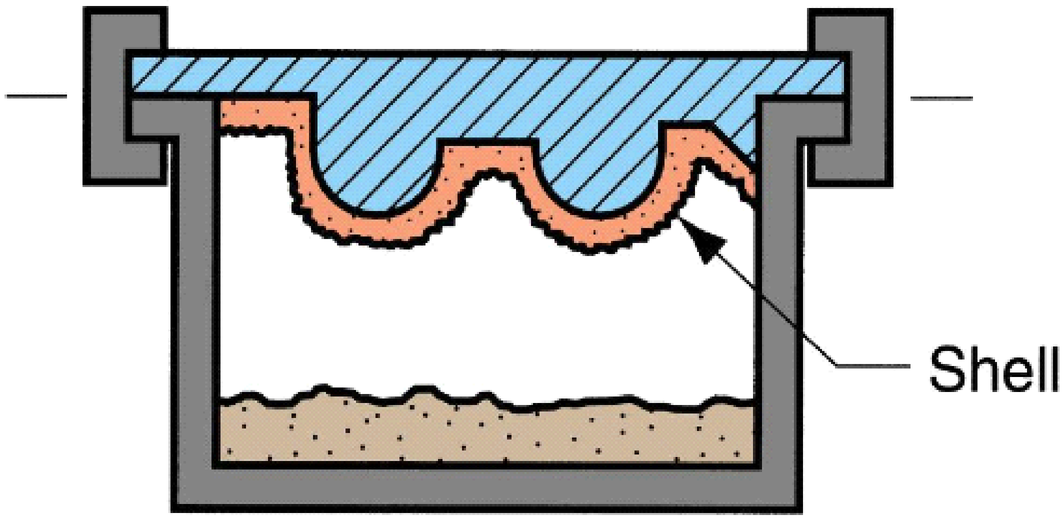

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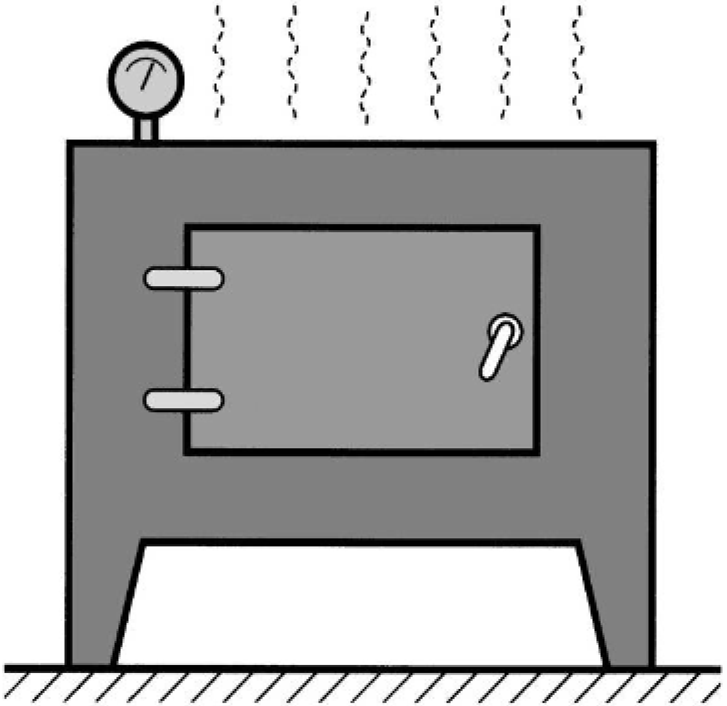
1. Shell Molding

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;



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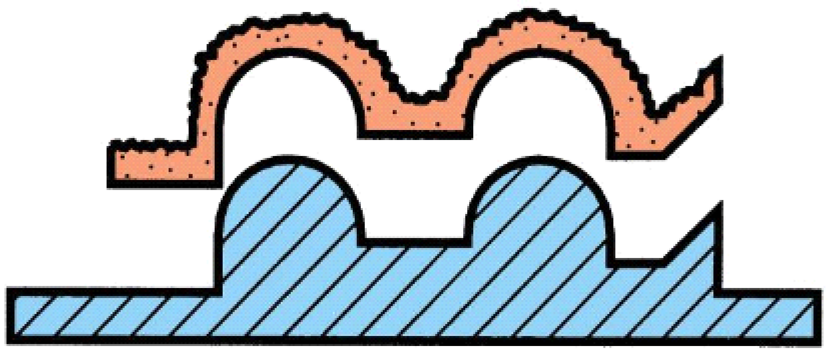

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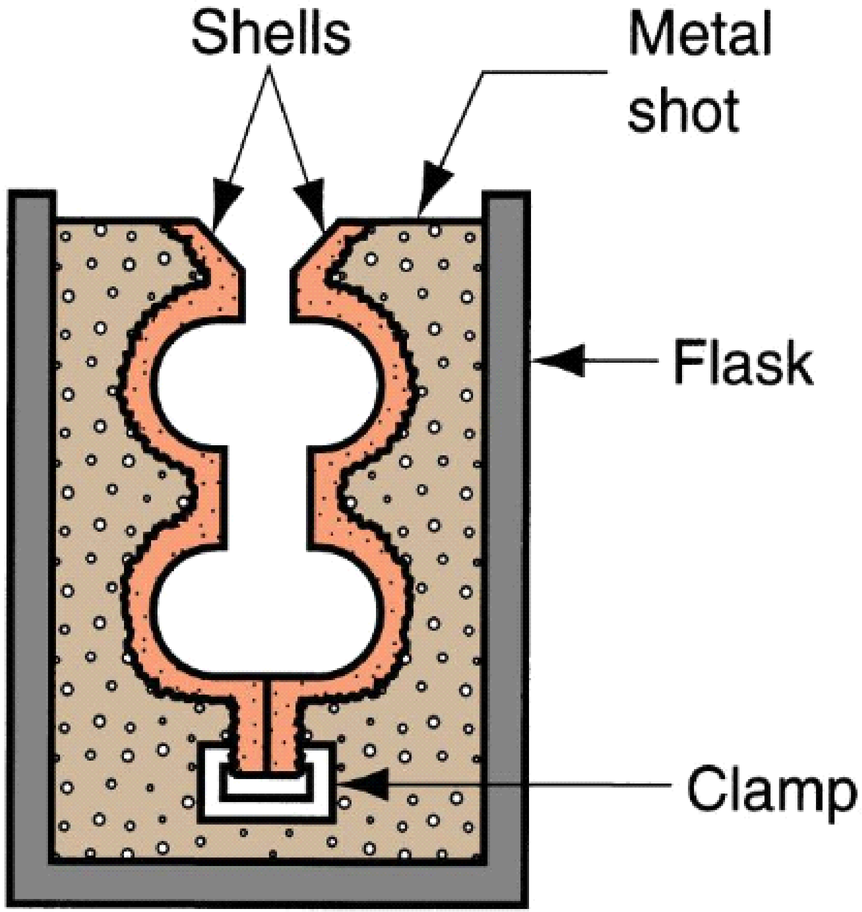
1. Shell Molding



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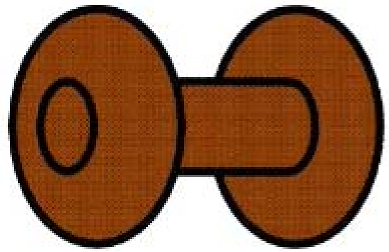

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Steps in shell-molding: (6) two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is accomplished; (7) the finished casting with sprue removed.

Advantages and Disadvantages

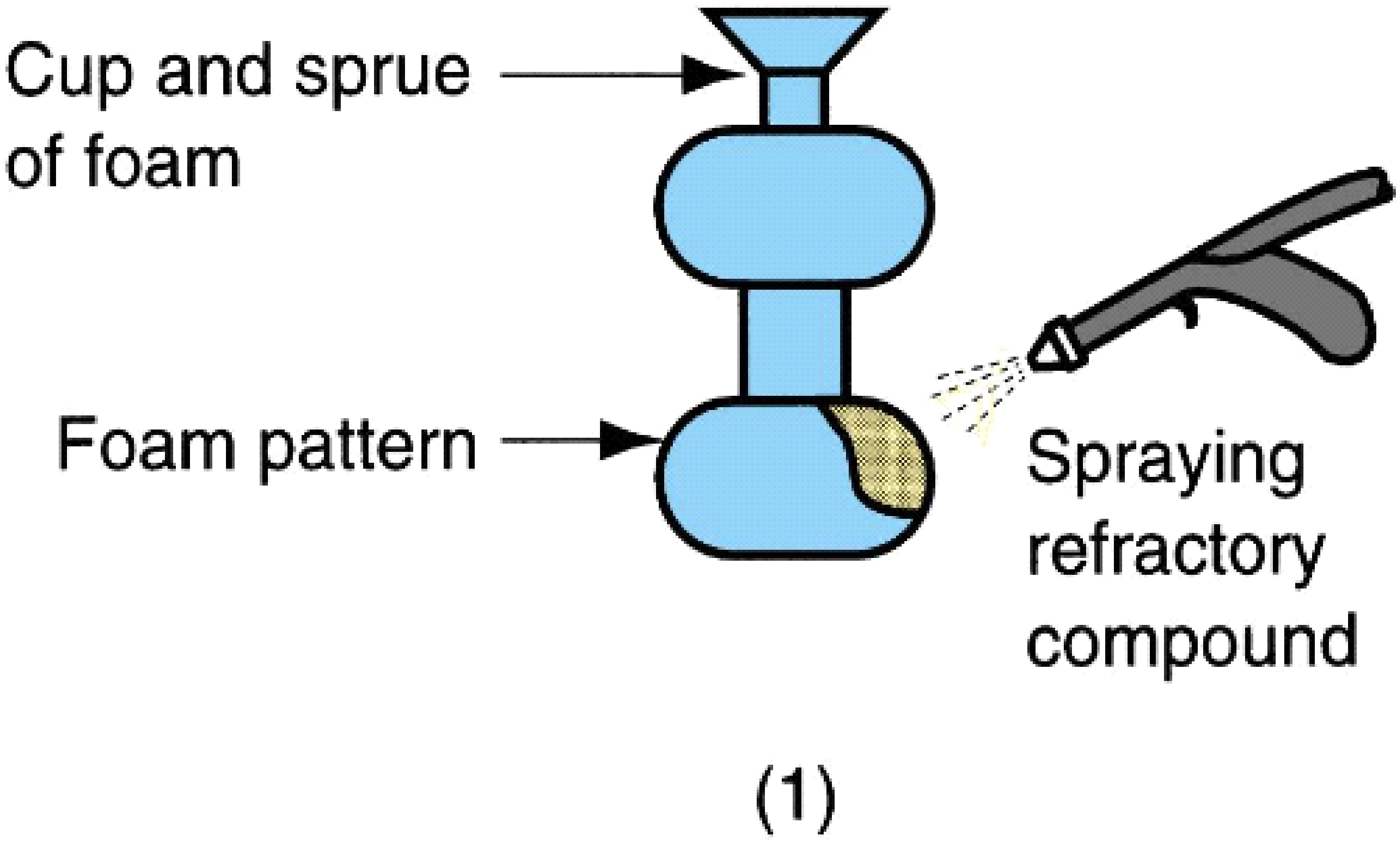
- Advantages of shell molding:
  - Smoother cavity surface permits easier flow of molten metal and better surface finish
  - Good dimensional accuracy - machining often not required
  - Less cracks in casting
- Disadvantages:
  - Takes ***more time***
  - Because of resin, more ***expensive***
  - Shell not ***reusable***

2. Expanded Polystyrene Process

Uses a mold of sand packed around a polystyrene foam pattern which vaporizes when molten metal is poured into mold

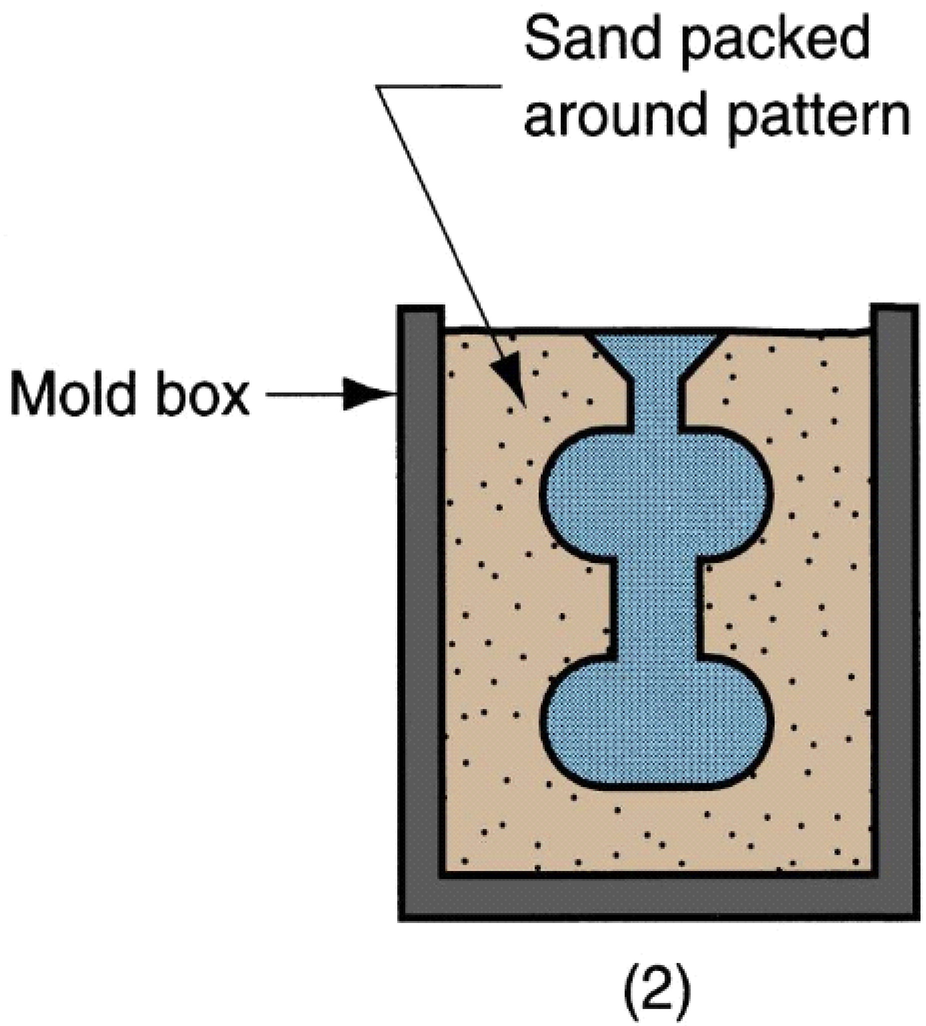
- Other names: lost-foam process, lost pattern process, evaporative-foam process, and full-mold process
- Polystyrene foam pattern includes sprue, risers, gating system, and internal cores (if needed)
- ***Mold does not have to be opened into cope and drag sections***

2. Expanded Polystyrene Process



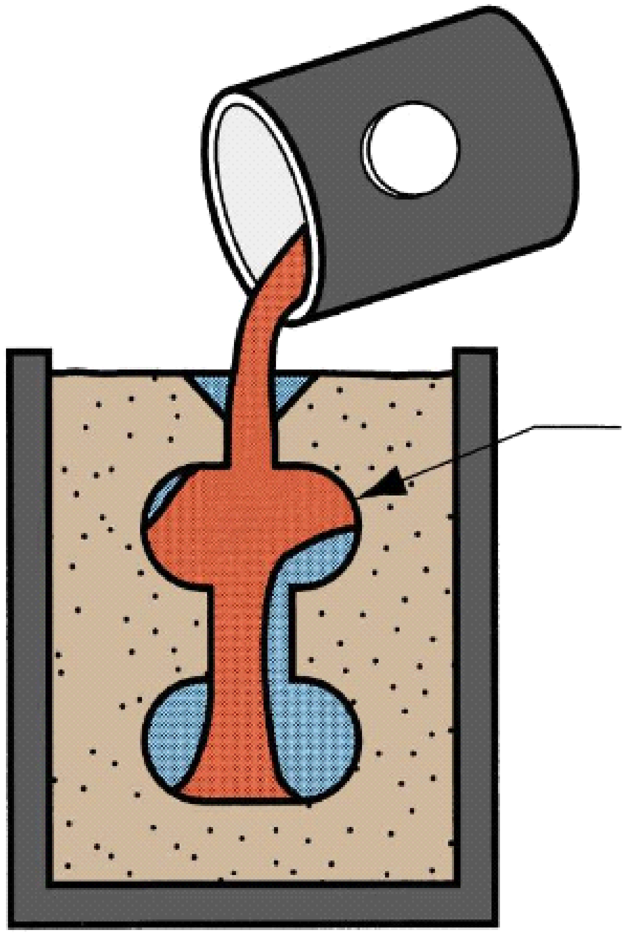
Expanded polystyrene casting process: (1) pattern of polystyrene is coated with refractory compound;

2. Expanded Polystyrene Process



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

2. Expanded Polystyrene Process



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 the resulting mold cavity is filled.

Advantages and Disadvantages

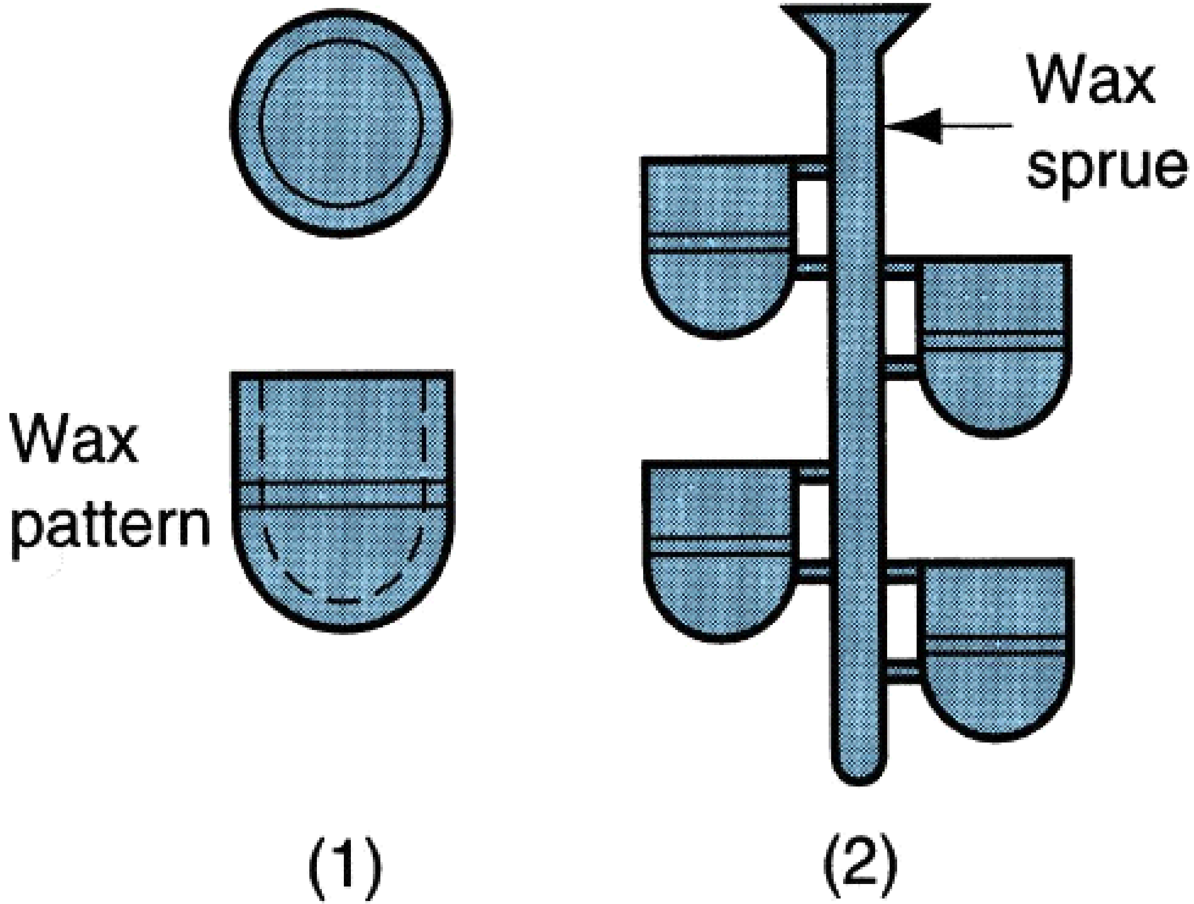
- Advantages of expanded polystyrene process:
  - Pattern need not be removed from the mold
  - Faster: two mold halves are not required
- Disadvantages:
  - A new pattern is needed for every casting
  - Cost is highly dependent on cost of producing patterns

3. 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

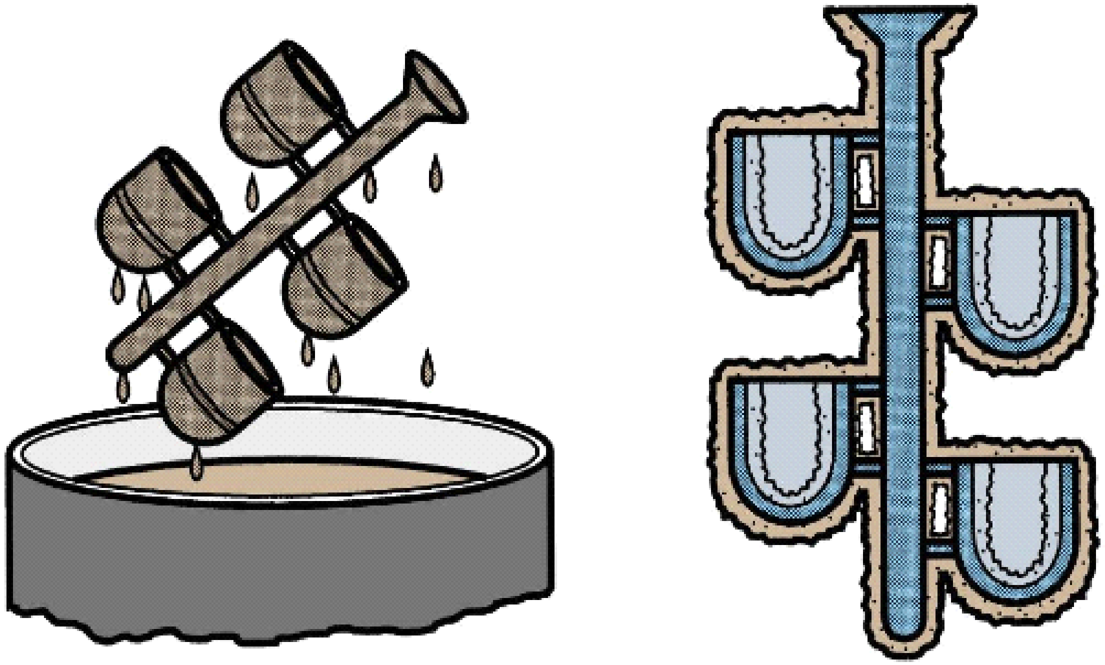
- "Investment" comes from a less familiar definition of "invest" - "to cover completely," which refers to coating of refractory material around wax pattern
- It is a precision casting process - capable of producing castings of high accuracy and intricate detail

3. Investment Casting



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

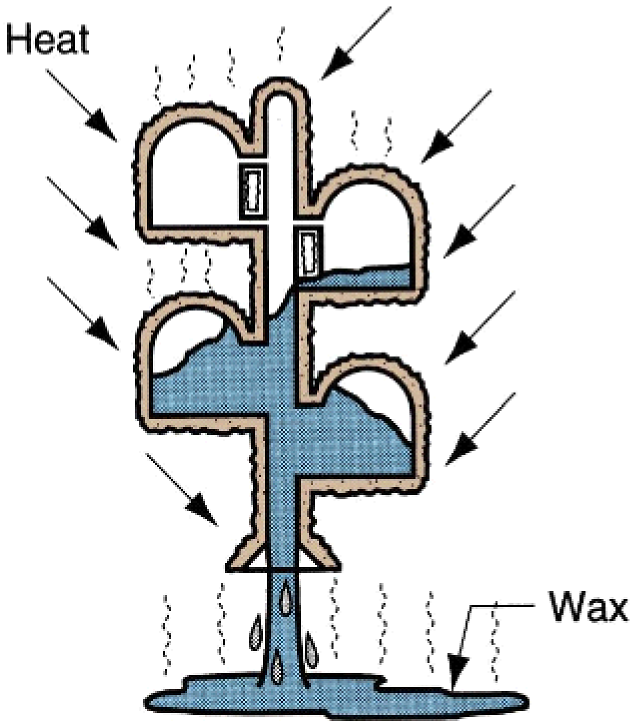
3. Investment Casting



(3) (4)

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

3. Investment Casting



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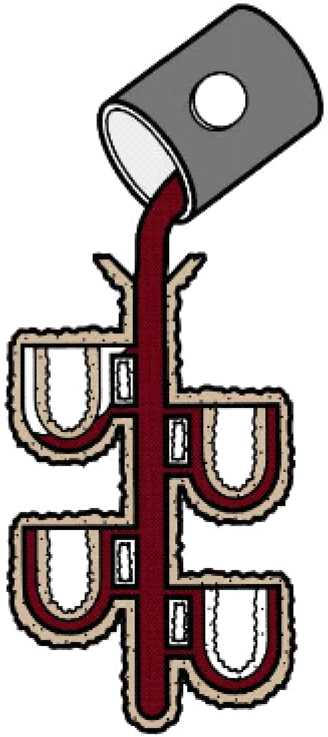
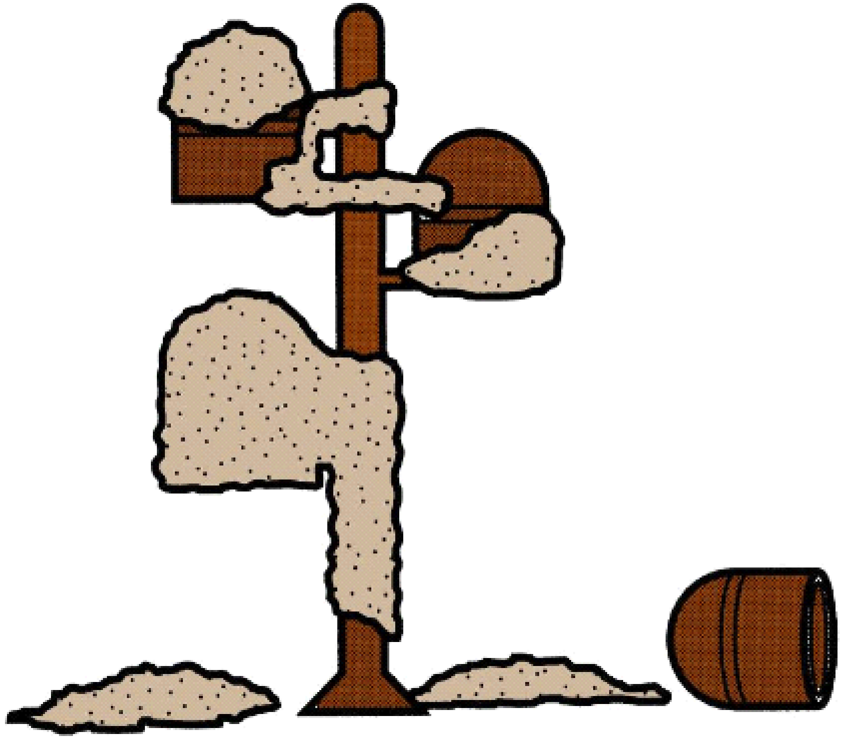


(6)

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, (6) the mold is preheated to a high temperature, the molten metal is poured, and it solidifies

3. Investment Casting



(7)

Steps in investment casting: (7) the mold is broken away from the finished casting and the parts are separated from the sprue

3. Investment Casting

A one-piece compressor stator with 108 separate airfoils made by investment casting (photo courtesy of Howmet Corp.).

Advantages and Disadvantages

- Advantages of investment casting:
  - 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

Permanent Mold Casting Processes

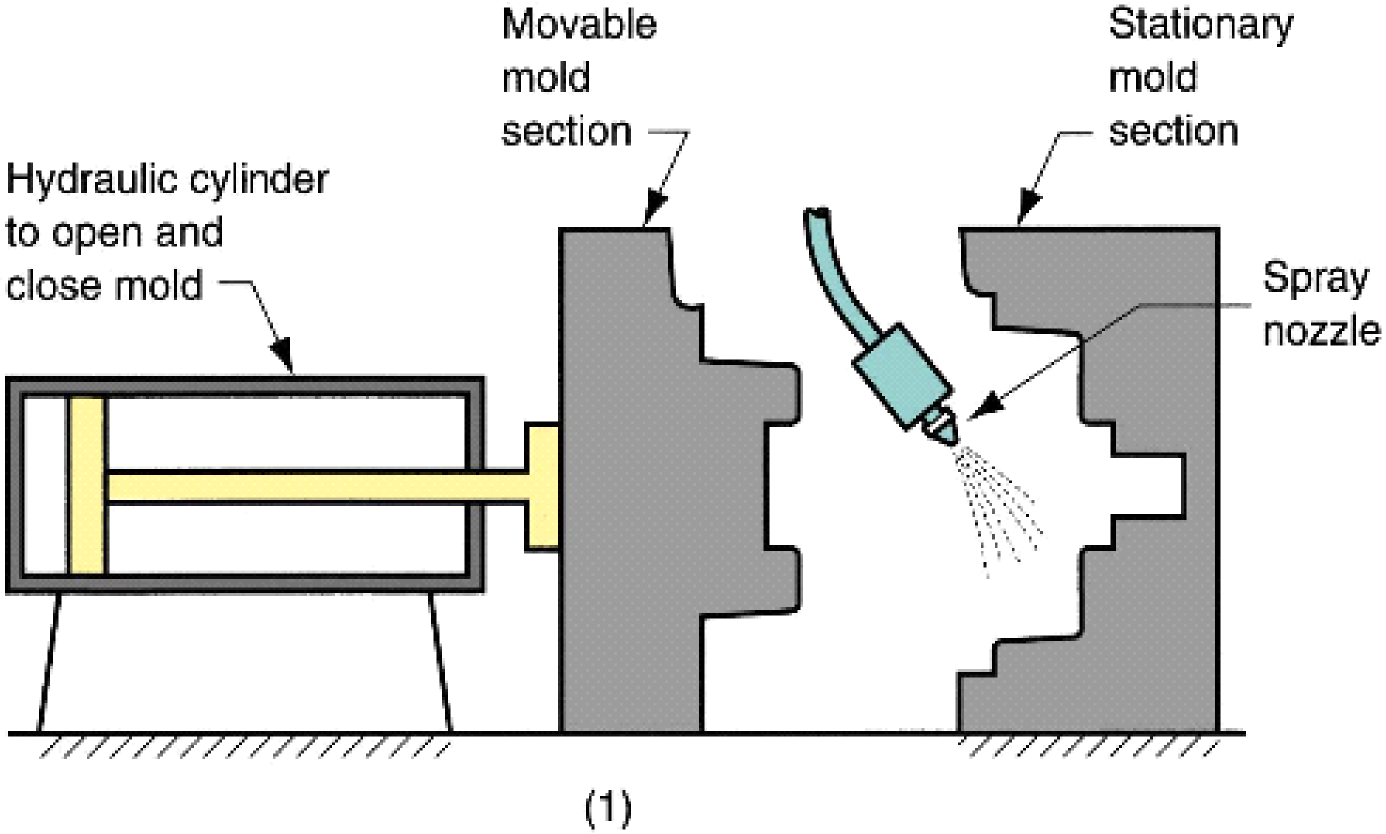
- Economic disadvantage of expendable mold casting: a new mold is required for every casting
- In permanent mold casting, the mold is reused many times
- The processes include:
  - Basic permanent mold casting
  - Die casting
  - Centrifugal casting

The Basic Permanent Mold Process

- Uses a metal mold constructed of two sections designed for easy, precise opening and closing
- Molds used for casting lower melting point alloys are commonly made of steel or cast iron
- Molds used for casting steel must be made of refractory material, due to the very high pouring temperatures

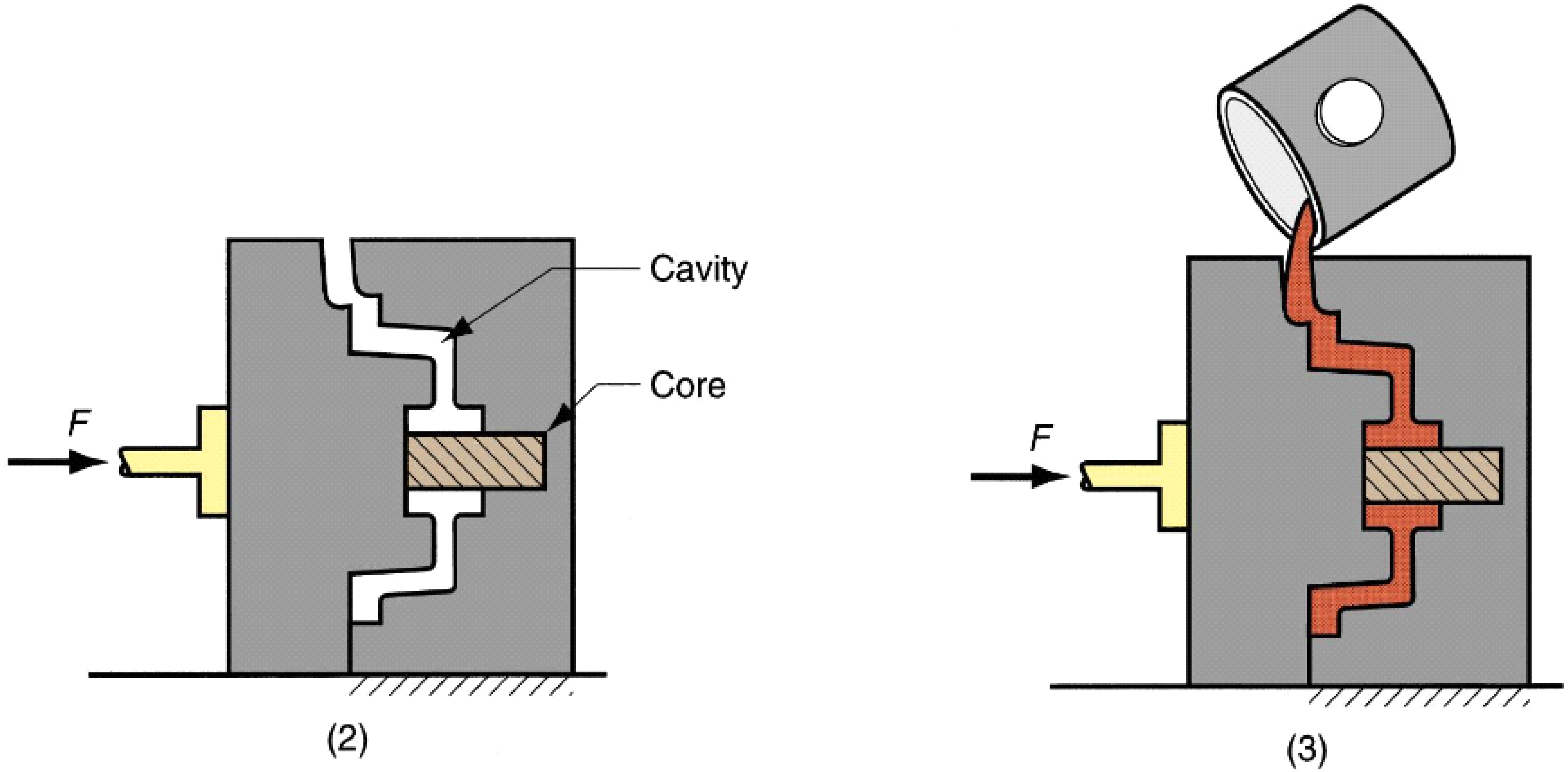
Mold metal must have higher melt temperature than casting metal

Permanent Mold Casting



Steps in permanent mold casting: (1) mold is preheated and coated

Permanent Mold Casting



Steps in permanent mold casting: (2) cores (if used) are inserted and mold is closed, (3) molten metal is poured into the mold, where it solidifies.

Advantages and Limitations

- Advantages of permanent mold casting:
  - Good dimensional control and surface finish
  - More rapid solidification caused by the cold metal mold results in a ***finer*** grain structure, so castings are stronger
- Limitations:
  - Generally limited to metals of ***lower melting point***
  - Simpler part geometries compared to sand casting because of need to open the mold
  - High cost of mold

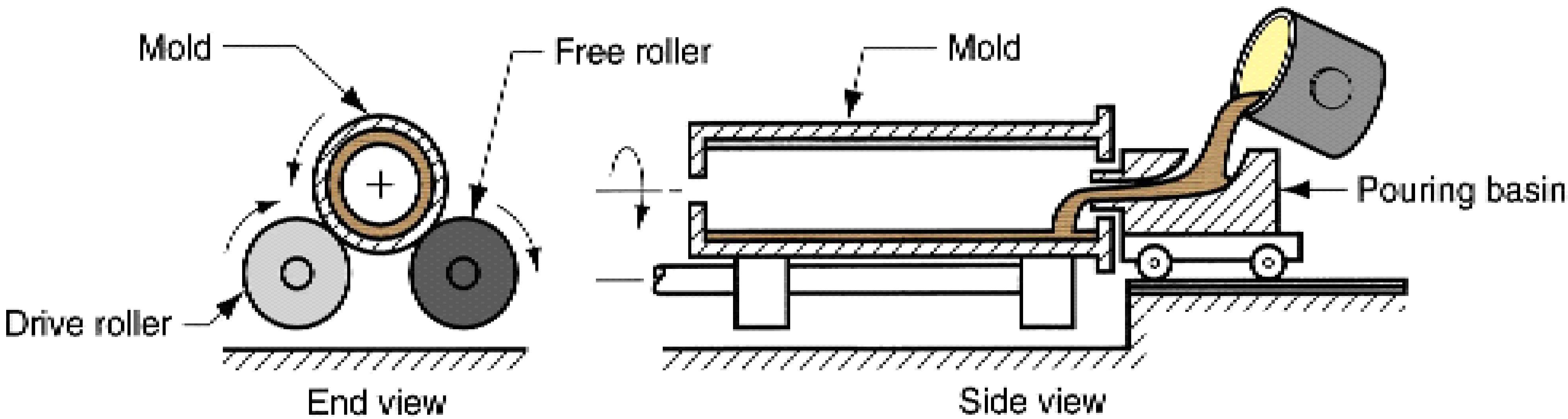
Die Casting

A permanent mold casting process in which molten metal is injected into mold cavity under high pressure

- Pressure is maintained during solidification, then mold is opened and part is removed
- Molds in this casting operation are called dies;
- Use of high pressure to force metal into die cavity is what distinguishes this from other permanent mold processes
- Tungsten and molybdenum dies used to die cast steel and cast iron

Centrifugal Casting

A family of casting processes in which the mold is rotated at high speed so centrifugal force distributes molten metal to outer regions of die cavity. Example:

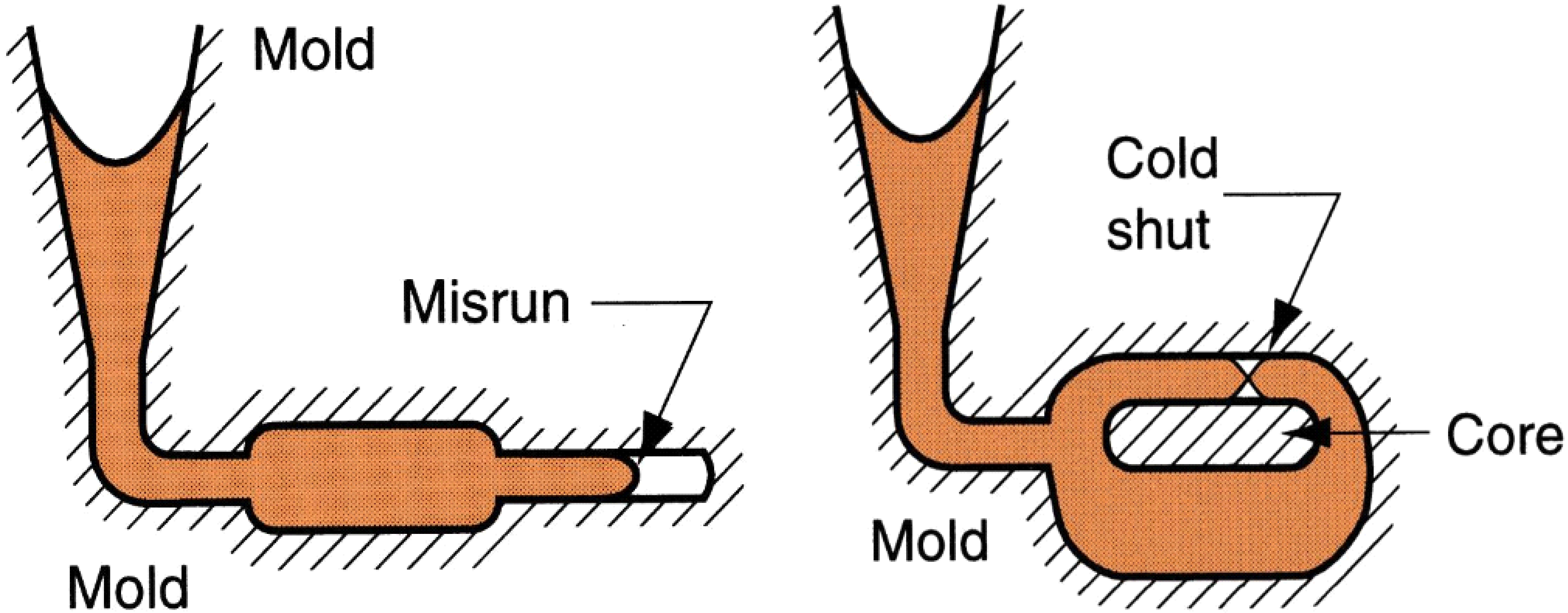


Additional Steps After Solidification

- Trimming
  – Removal of sprues, runners, risers, parting-line flash, fins, chaplets, and any other excess metal
- Removing the core
  – Most cores fall out, some by shaking, in rare cases, removed by chemically dissolving bonding agent
- Surface cleaning – primarily removal of sand
- Inspection
- Repair, if required
- Heat treatment

Casting Quality - Misrun & Cold Shut

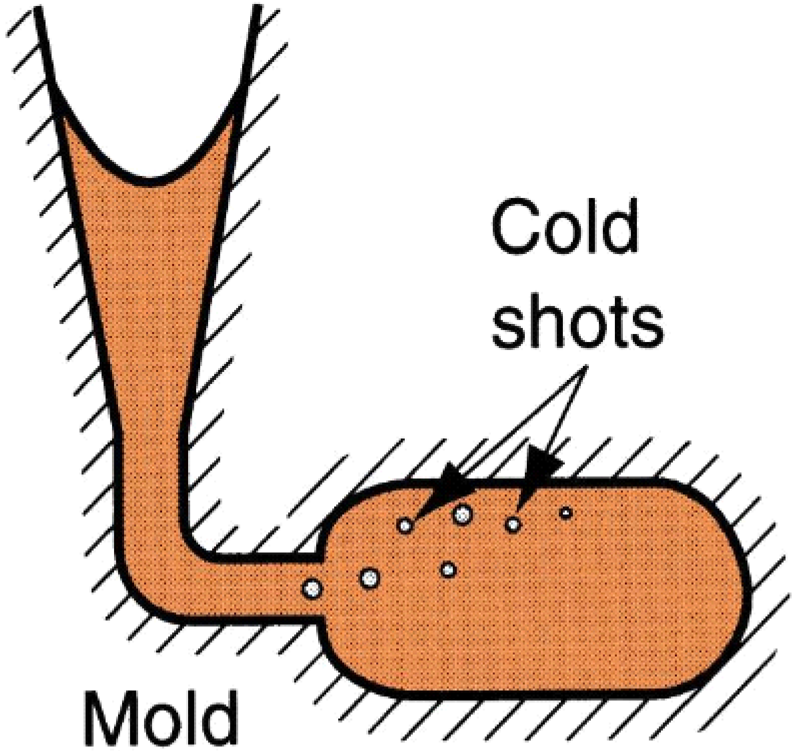
Misrun – metal solidified before completely filling cavity. Cold shut – metal has flowed together but failed to fuse or blend into a solid mass.



Increase pour temperature, increase sand permittivity, or increase height of downsprue

Casting Quality - Cold Shot

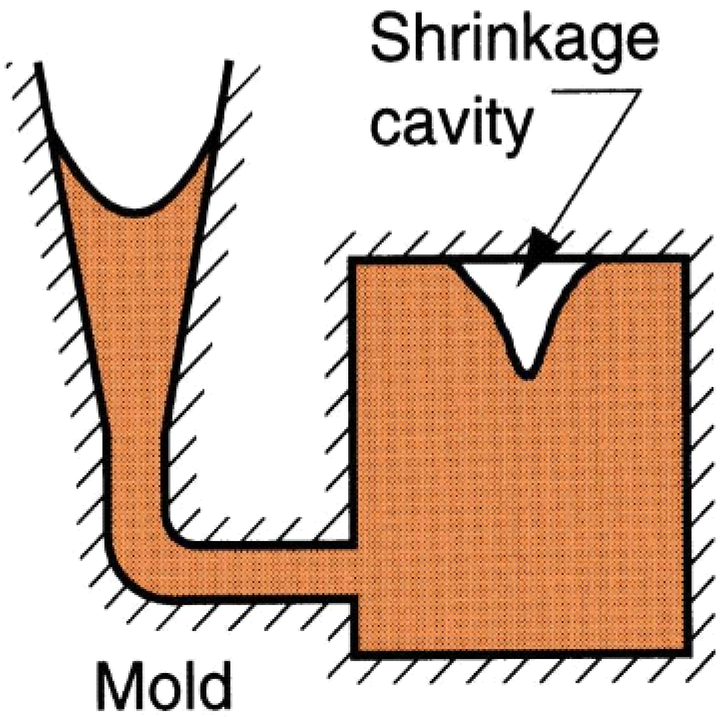
Metal splatters during pouring and solid globules form and become entrapped in casting



Increase diameter of pouring cup or slow down pour

Casting Quality - Shrinkage Cavity

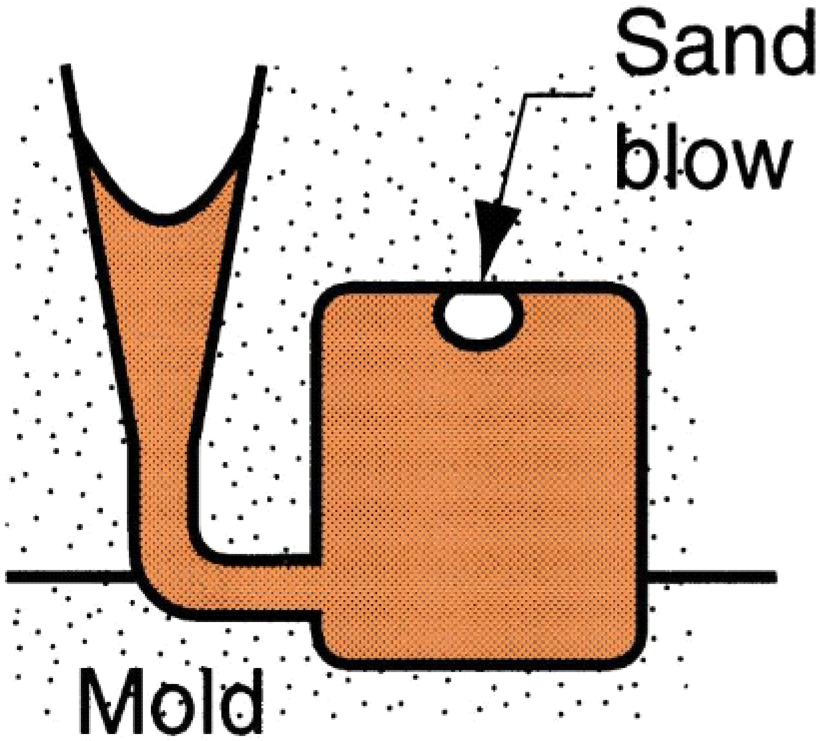
Depression in surface or internal void caused by solidification shrinkage that restricts amount of molten metal available in last region to freeze

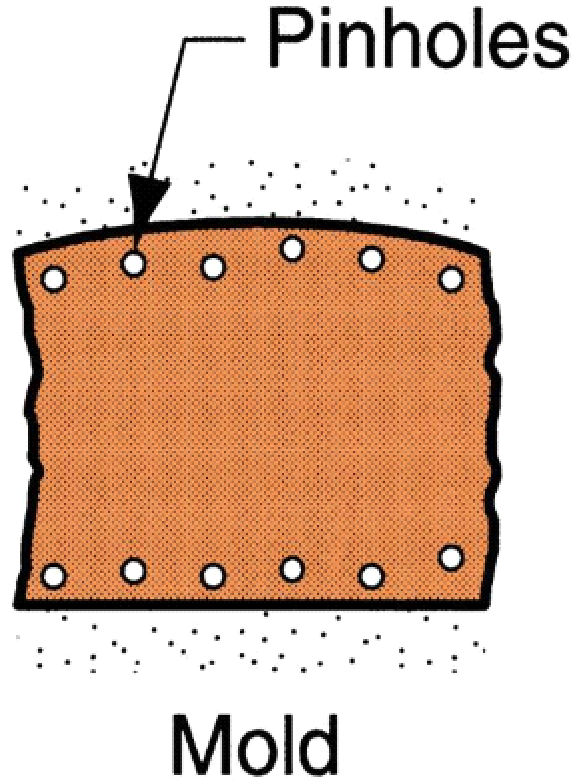


Increase riser volume to surface area ratio

Casting Quality - Sand Blow & Pin Holes

Balloon-shaped gas cavity or many small gas cavities just below the surface





Decrease pour temperature or increase sand permittivity

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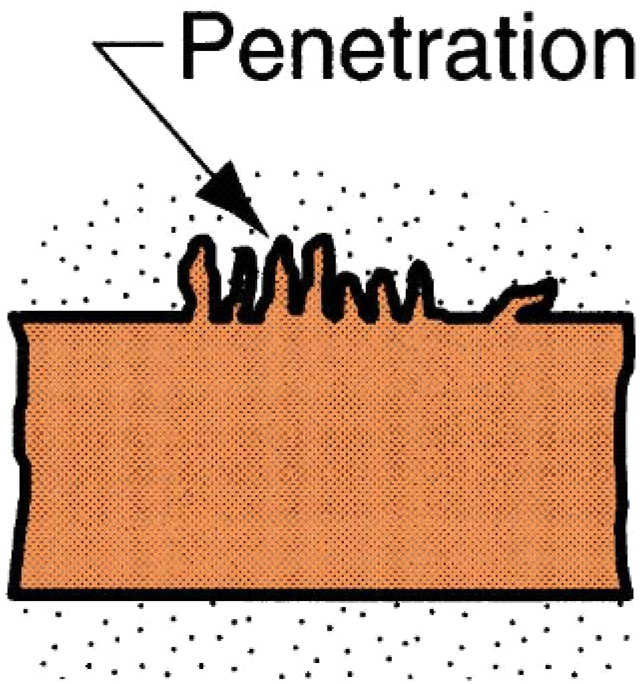
Casting Quality - Penetration

When fluidity of liquid metal is high, it may penetrate into sand mold or core, causing casting surface to consist of a mixture of sand grains and metal



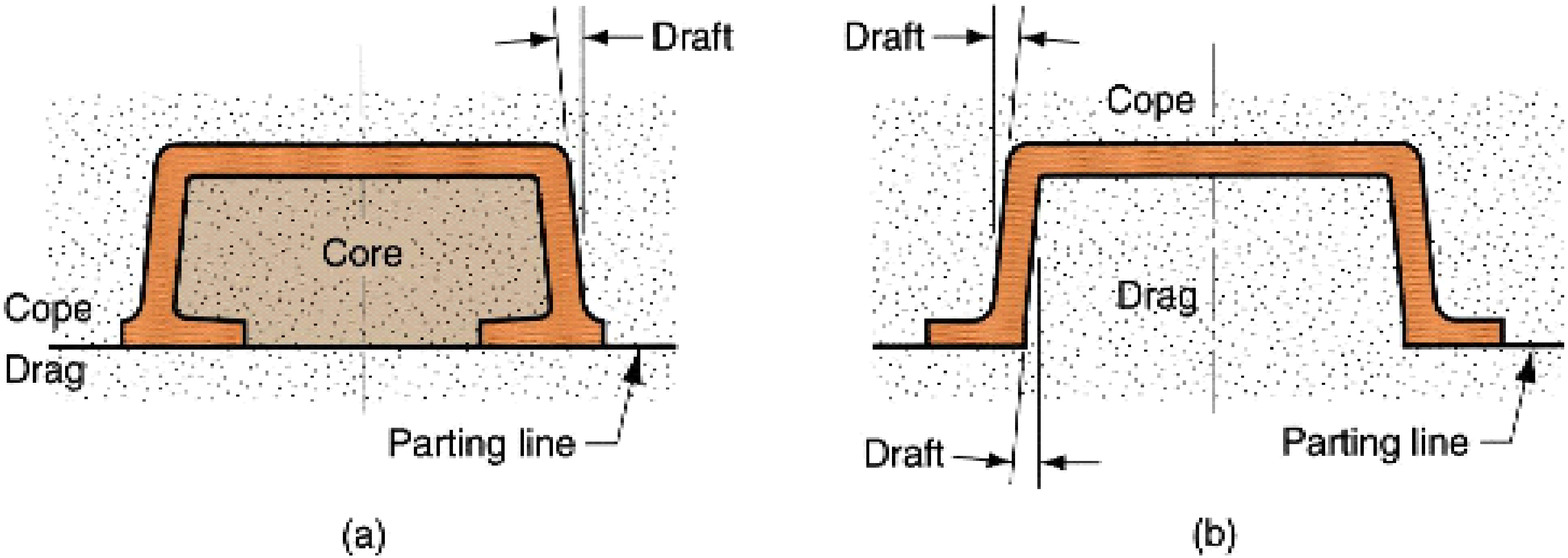
Lower pour temperature or decrease sand permittivity

Product Design Considerations

1. Geometric simplicity that allows for shrinkage and reduces the need for cores.
2. Reduce sharp angles by rounding corners and reducing stress concentrations areas that may cause hot tearing and cracks.
3. Increase draft angles (interior and exterior). Minimums:
   - Draft = 1° for sand casting
   - Draft = 2° to 3° for permanent mold processes

Draft

- Minor changes in part design can reduce need for coring



Design change to eliminate the need for using a core: (a) original design, and (b) redesign.

Product Design Considerations - Cont

4. Dimensional Tolerances and Surface Finish:
   – Sand casting: poor dimensional accuracies and finish
   – Die casting and investment casting: better dimensional accuracies and finish
5. Machining Allowances:
   – Additional material, called the *machining allowance*, is left on the casting in those surfaces where machining is necessary

Example Problem

- **Problem 11.16:** A part is made by aluminum sand castings, but it is plagued by misruns and cold shuts defects. The foreman complains that the parts are too thin, and that is the reason for the defects. However, it is known that the same components are cast successfully in other foundries. What explanation can be given for the defects?
- ***Solution**: Misruns and cold shuts result from low fluidity. The foreman could be correct that the thickness of the casting cross sections is too small. However, given that the casting of these parts is successfully accomplished at other foundries, three other possible explanations are (1) the pouring temperature is too low, (2) the sand permittivity is too low, or (3) the downsprue height is too small*

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