TA201A
Manufacturing Processes

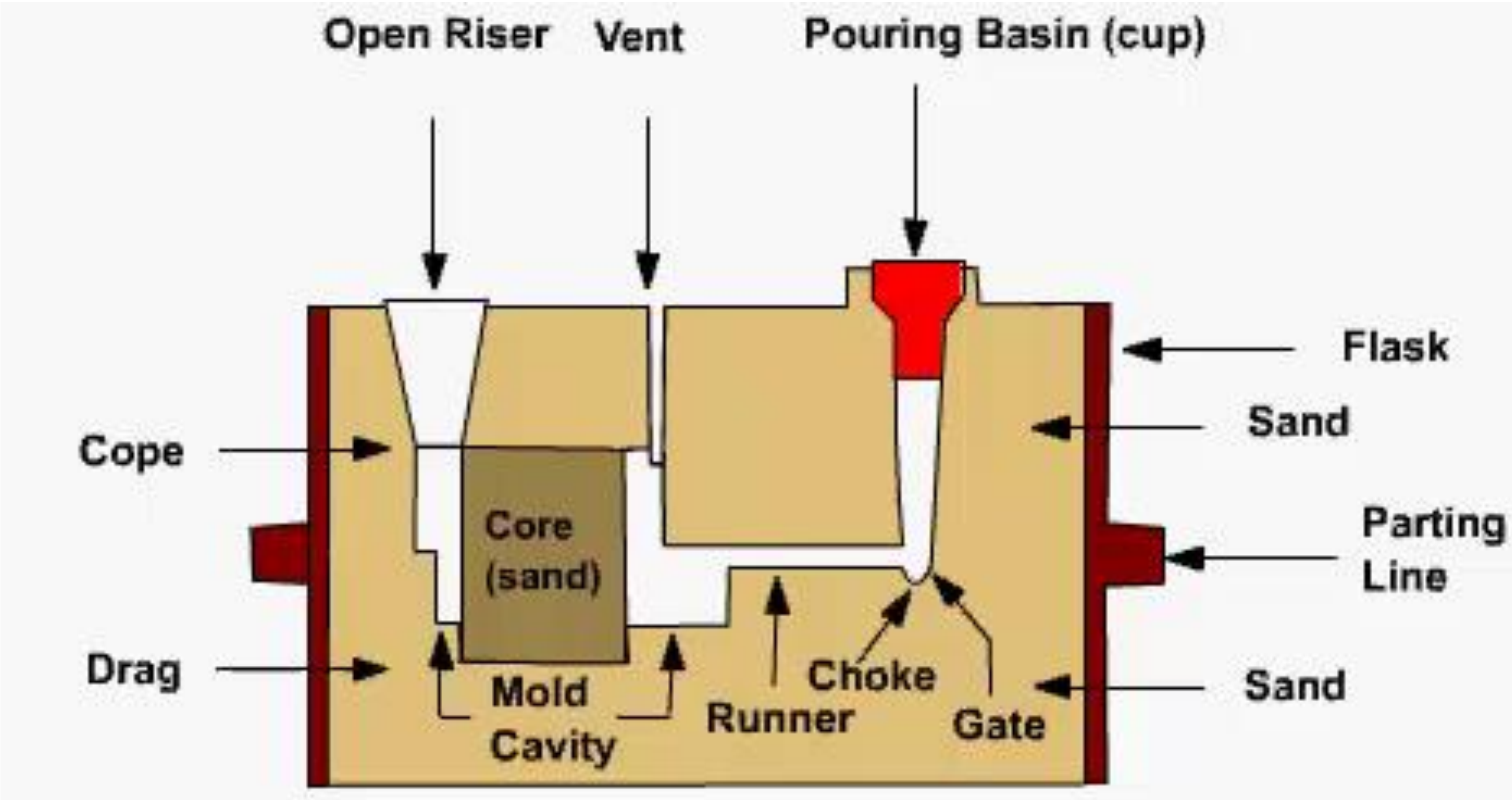
Week-6

13 Sept, 2022

2022-2023 Semester-I

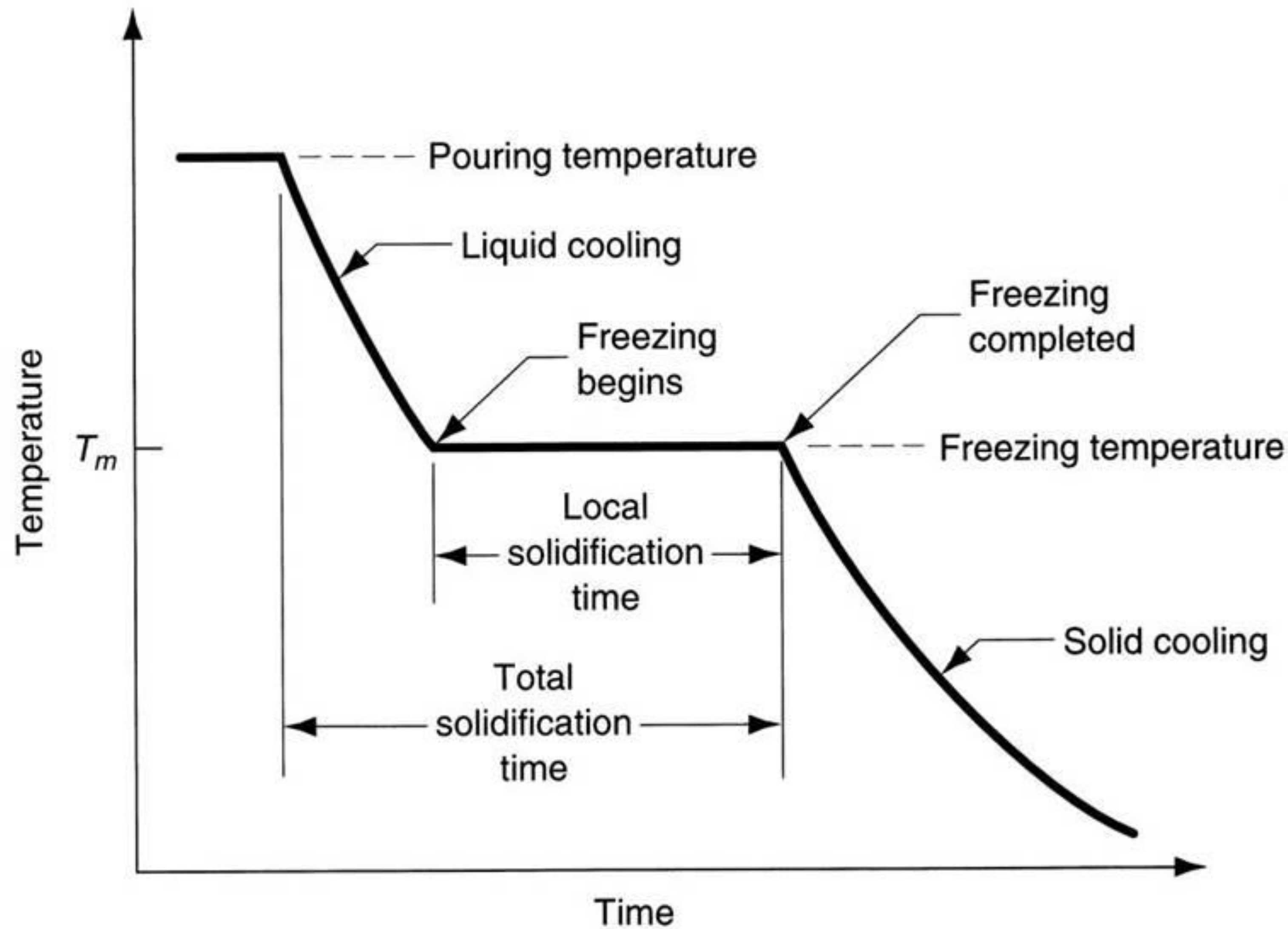
Lecture 6

Casting: Recap



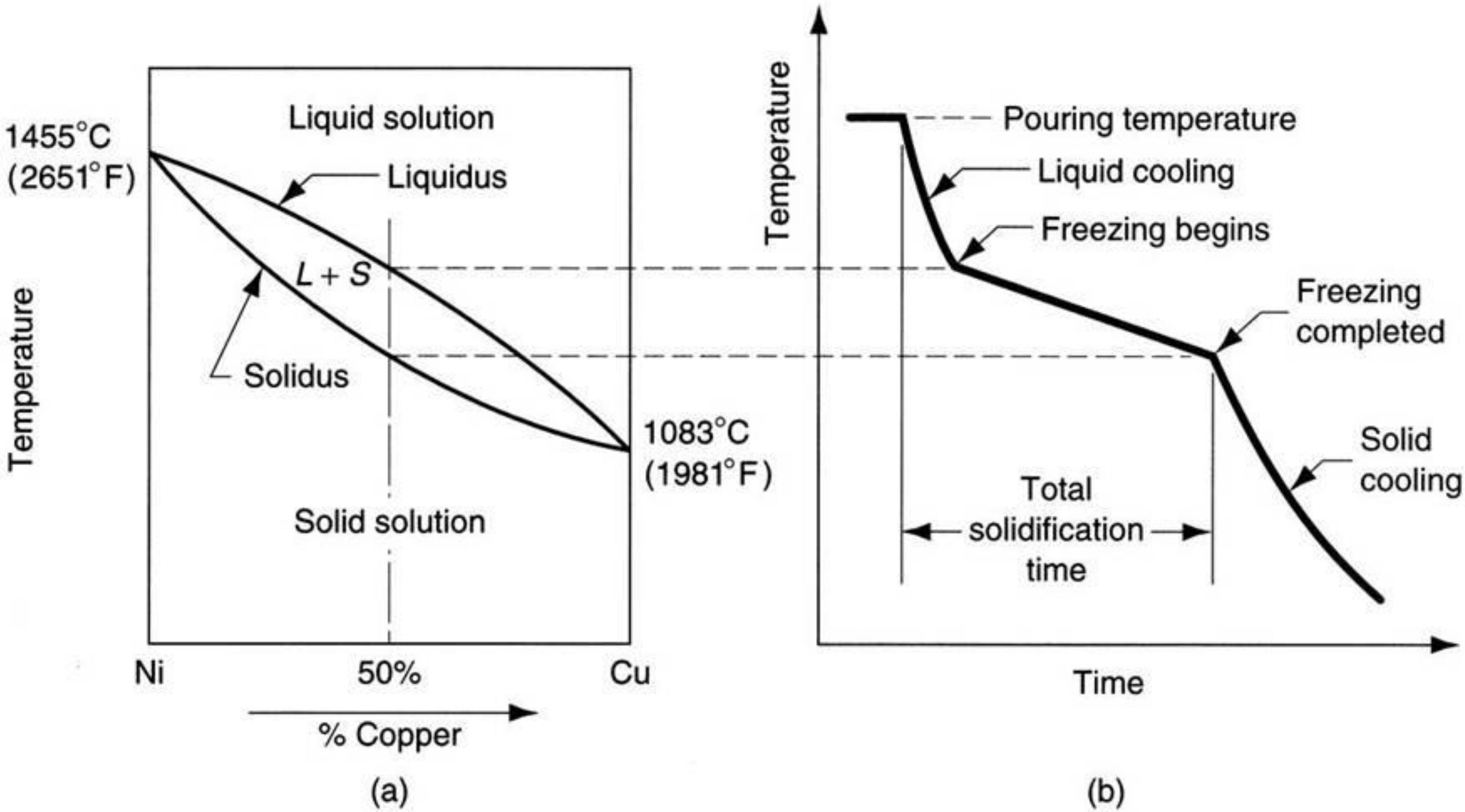
http://msvs-dei.vlabs.ac.in/mem103/MEM103/Unit3/Simulations/Casting.mp4

Solidification time: Pure Metal



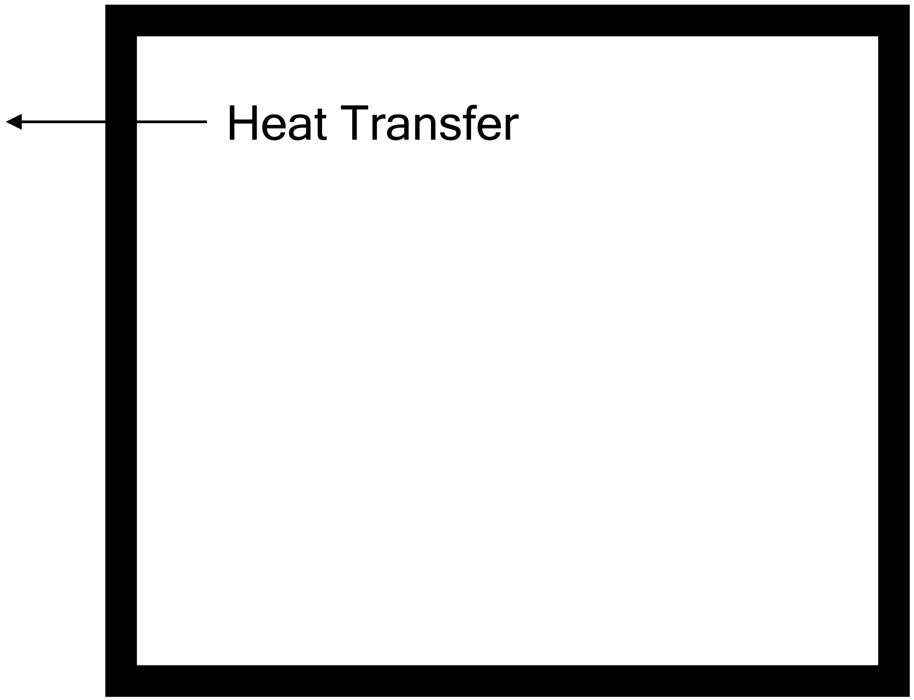
Solidification time: Alloys

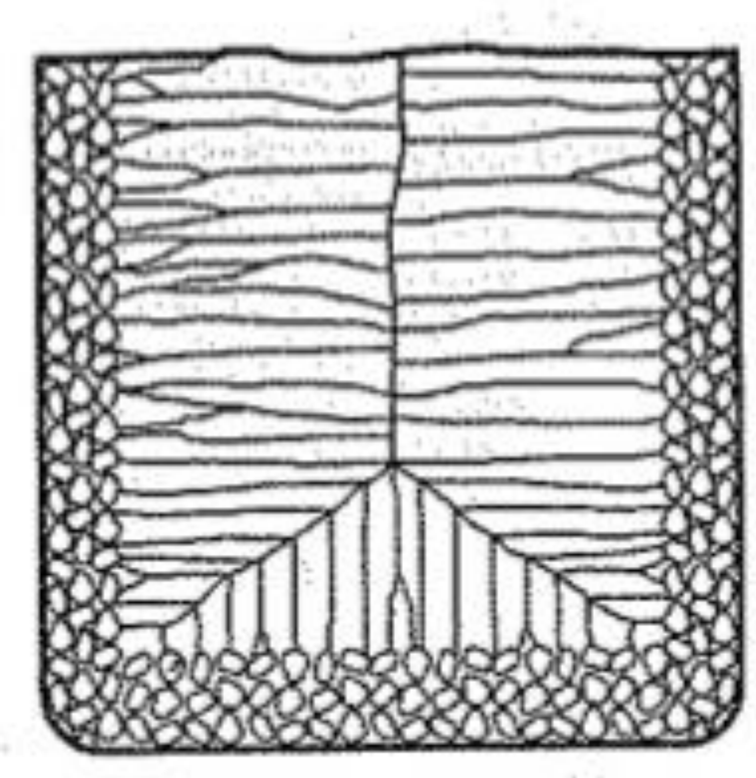
- Most alloys



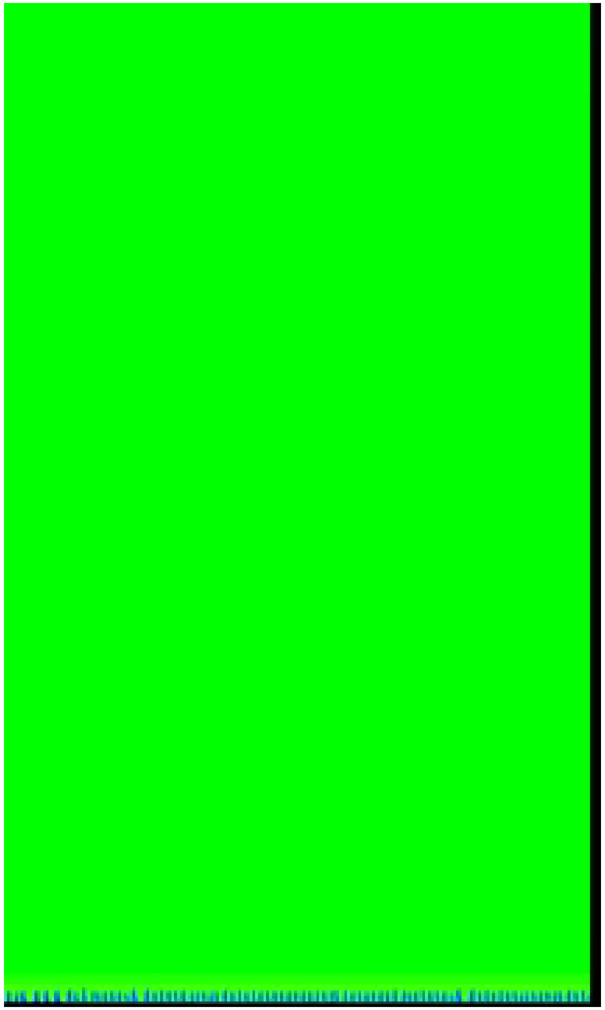
Chilling effect of mold

- Chilling action of mold
  - Thin layer of metal initially forms at the interface immediately after pouring
  - Fine, equiaxed grains that are randomly oriented
- Further grain formation in direction away from heat transfer (long columnar grains)





Dendritic and directional solidification

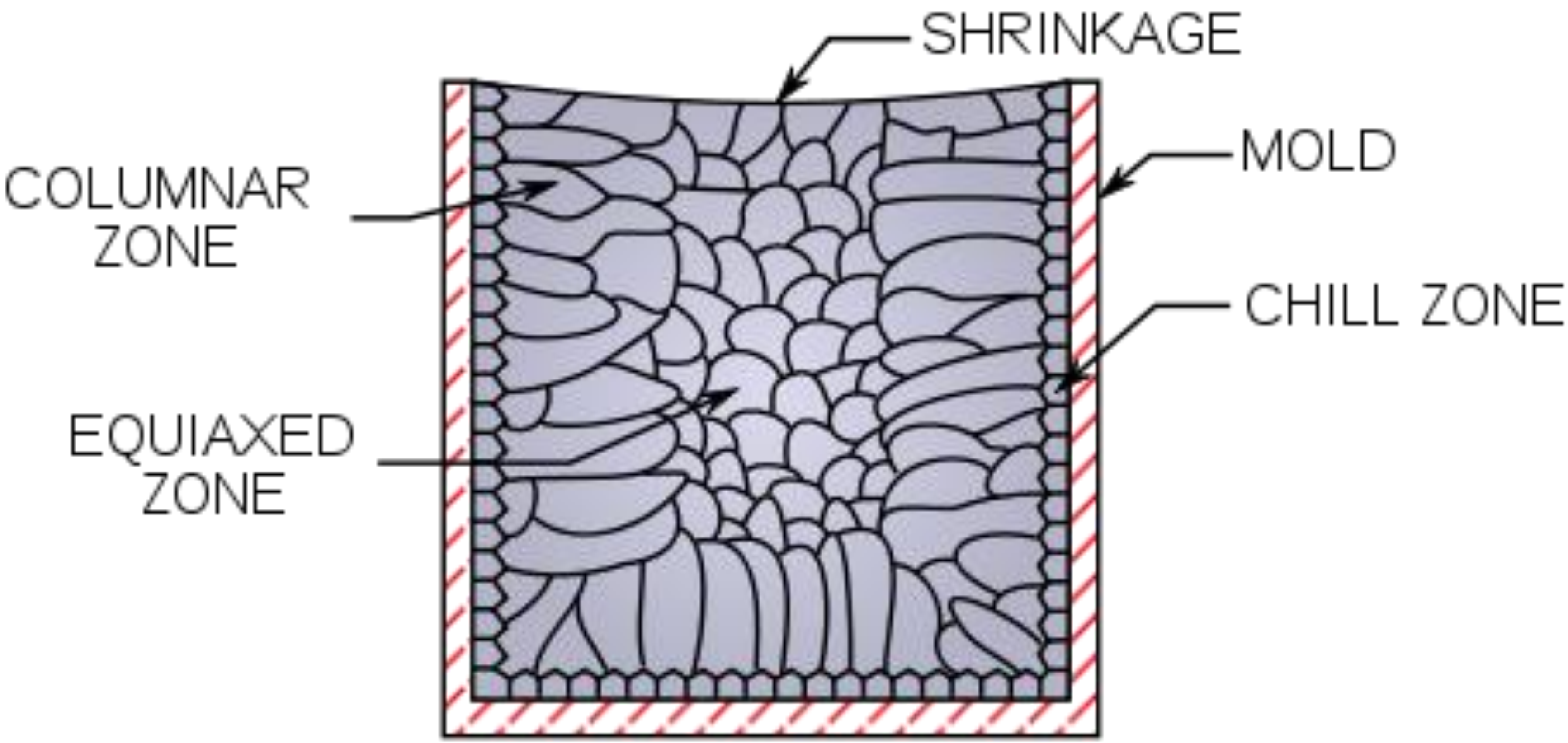


https://www.youtube.com/watch?v=IR8lkSupcMo

https://www.youtube.com/watch?v=1Dboh3A8V78

Cast Ingot: Microstructure

- Most alloys



Time for solidification?

Where do you expect tea will take more time to cool down?
In a Cup or a Saucer?

Why?

Volume to Surface area ration

Metal Casting: Solidification Time

Total solidification time = time required for the casting to solidify after pouring.

Solidification time:
- Size of the casting
- Shape of the casting

Chvorinov's rule (empirical relation):

TST(*Total solidification time*) $= C_m(V/A)^n$

V = Volume of the casting (cm^3)

A = Surface area of the casting (cm^2)

n = Exponent ($\approx$ 2)

C_m = Mold constant (min/cm^2)

C_m depends on

1. Mold material (specific heat, thermal conductivity)
2. Thermal properties of cast metal (specific heat, thermal conductivity, heat of fusion)
3. Pouring temperature

$$(\mathrm{TST})_{\mathrm{riser}} > (\mathrm{TST})_{\mathrm{casting}}$$

Chvorinov's rule: Design of Riser

$$\left(\frac{V}{A}\right)_1 \rangle \left(\frac{V}{A}\right)_2$$

$$\Rightarrow \mathrm{TST}_1 \rangle \mathrm{TST}_2$$

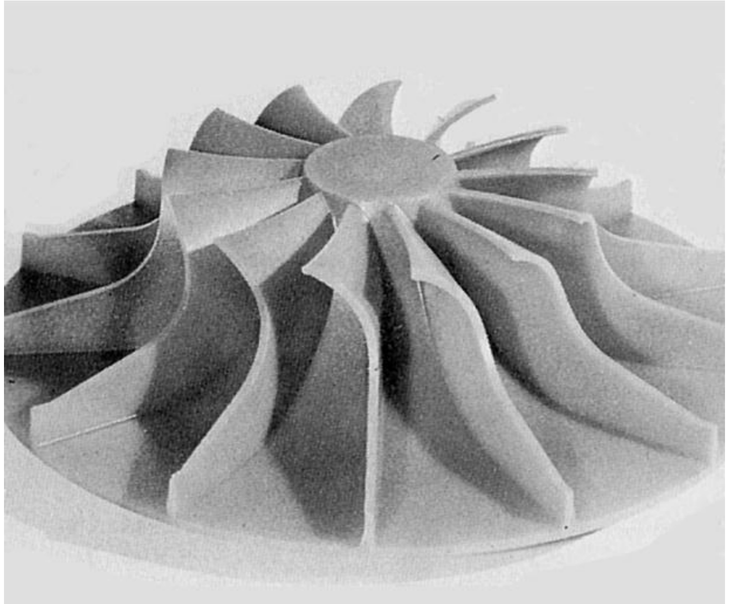
Cooling will be slower for a casting with higher volume to area ratio. *(or equivalently weight to surface area ratio)*

Casting Design Thumb rule (Riser size):

TST of Riser > TST of actual casting

Since Riser is a reservoir that provides liquid metal to cast cavity, Riser should solidify last.

Liquid metal characteristics



What characteristics of liquid metal will allow the formation of thin-veins or intricate thin walled structures without resulting in defects (e.g., mis-runs)

Fluidity

Fluidity

- Scientific Definition
  - Inverse of viscosity: Exact quantity
- Foundry Definition
  - Distance that a liquid metal will flow into a mould cavity and is thus a relative term
- As molten metal is introduced into a mould cavity it loses thermal energy to the walls of the mould as it flows. Eventually it begins to freeze and at some point the metal will cease to flow.

Fluidity

- Initial metal temperature
- Heat extracting power of the mould material including the effect of any insulating die coating that are applied
- Kinetic energy of the metal (will be different for different kinds of moulds, e.g., sand mould casting vs pressure die casting)
- Purity of the metal/ alloy
- Composition of alloy (e.g. Al-Si alloy)

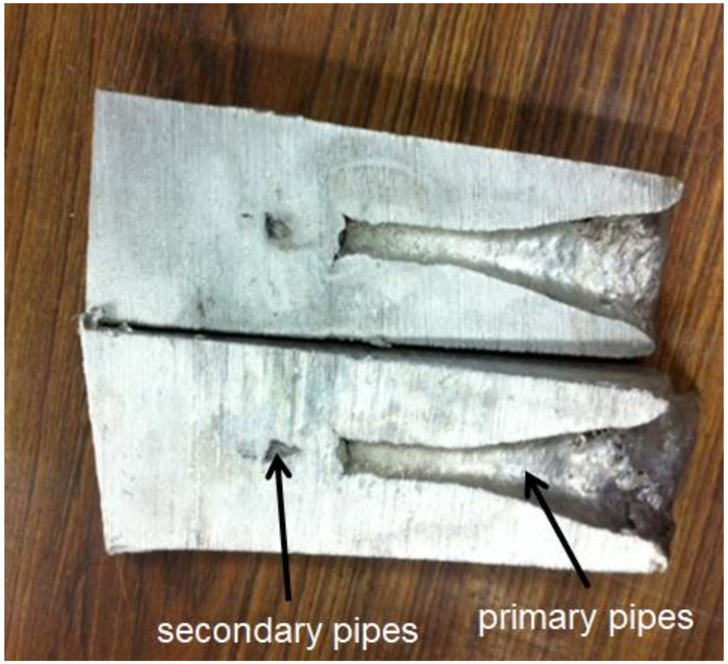
Metal Casting: Defects

The solid phase has a smaller molar volume than the liquid phase , typically 4%.

Three Steps

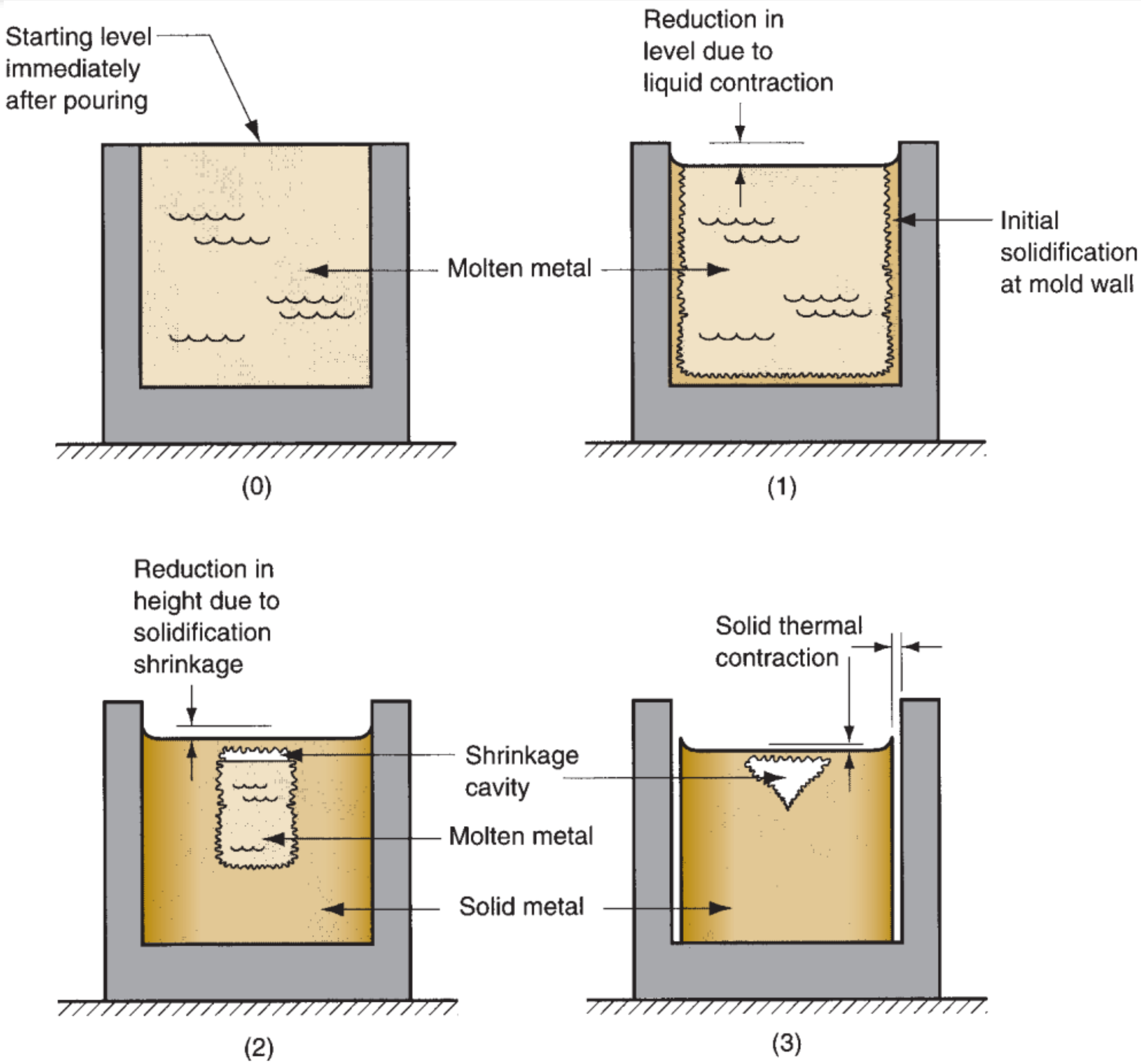
- Liquid contraction during cooling
- Solidification shrinkage
- Thermal contraction of solidified cast during cooling to room temperature

Why do these pipe defects occur during casting?



Shrinkage

Shrinkage: Three steps



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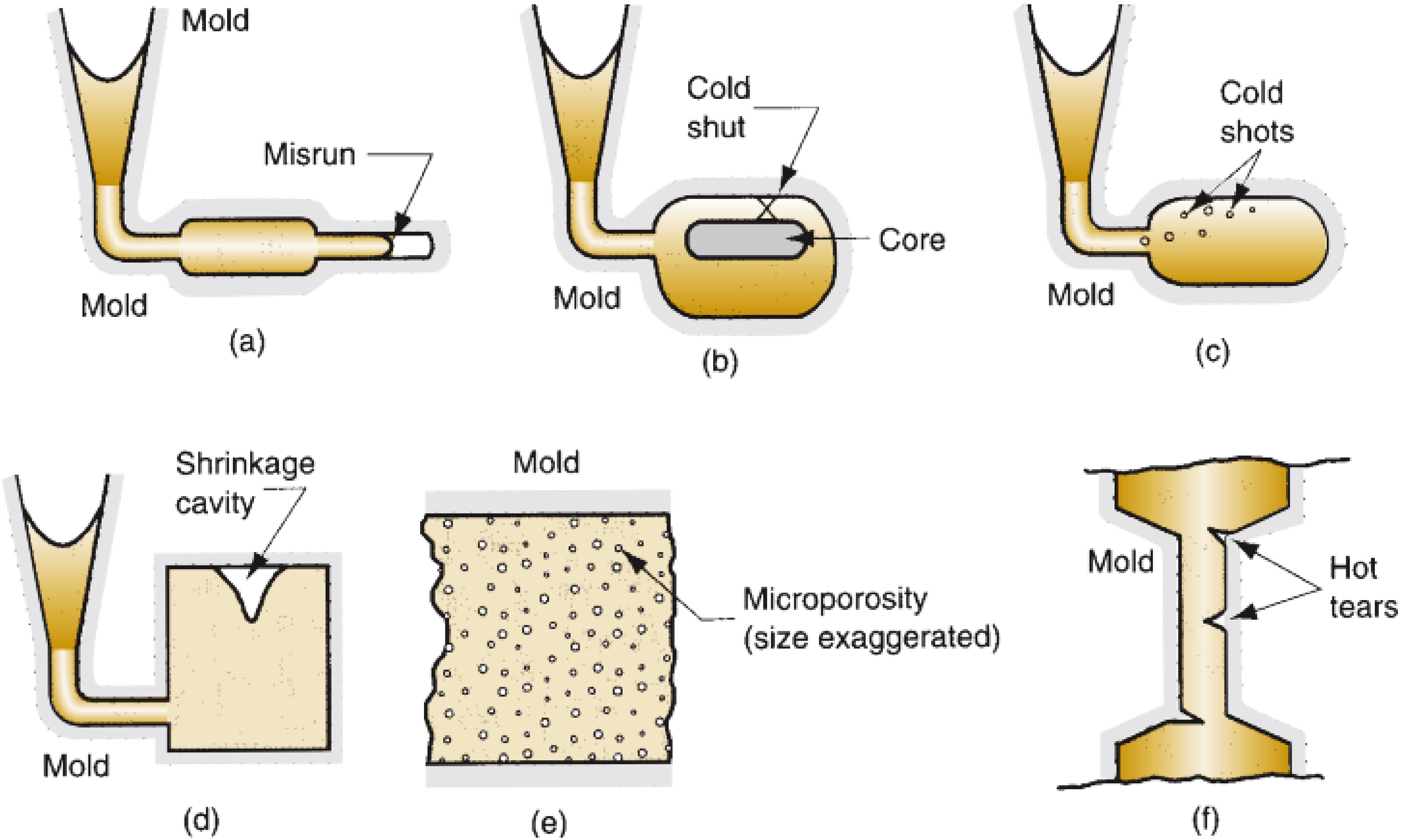
Casting Defects



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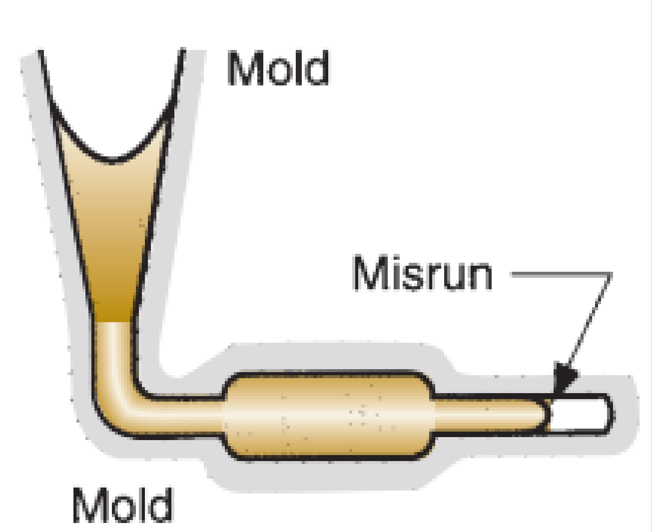
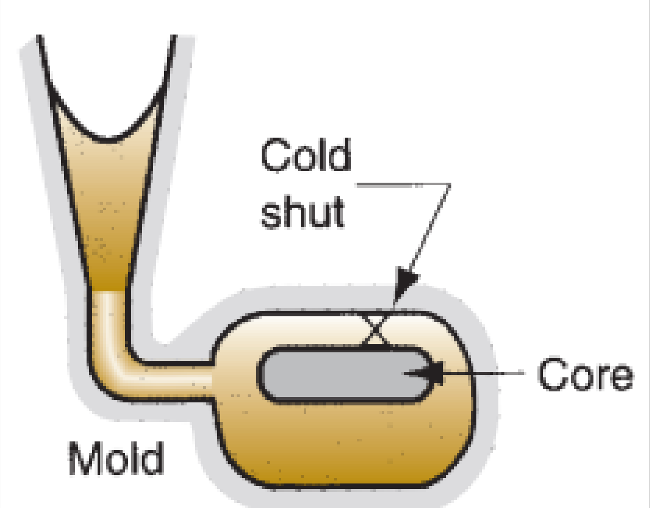
Casting Defects

Misruns- A misrun is a casting that has solidified before completely filling the mold cavity. Typical causes include

(1) Fluidity of the molten metal is insufficient,
(2) Pouring temperature is too low,
(3) Pouring is done too slowly, and or
(4) Cross section of the mold cavity is too thin.



Cold shut- occurs when two portions of the metal flow together but there is lack of fusion between them due to premature freezing. Its causes are similar to those of a misrun.



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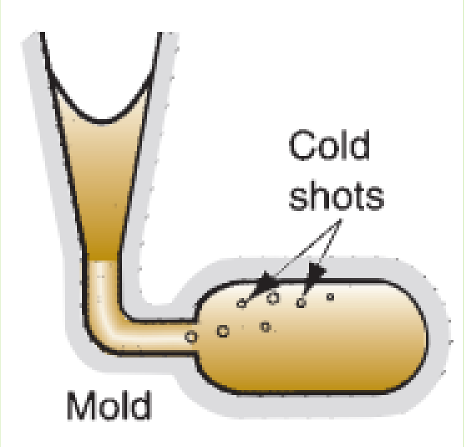
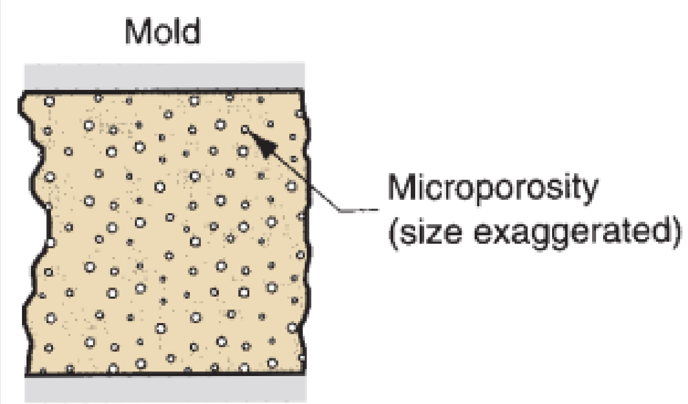
Casting Defects

Cold shots- When splattering occurs during pouring, solid globules of metal are formed and that become entrapped in the casting. Pouring procedures and gating system designs that avoid splattering can prevent this defect.

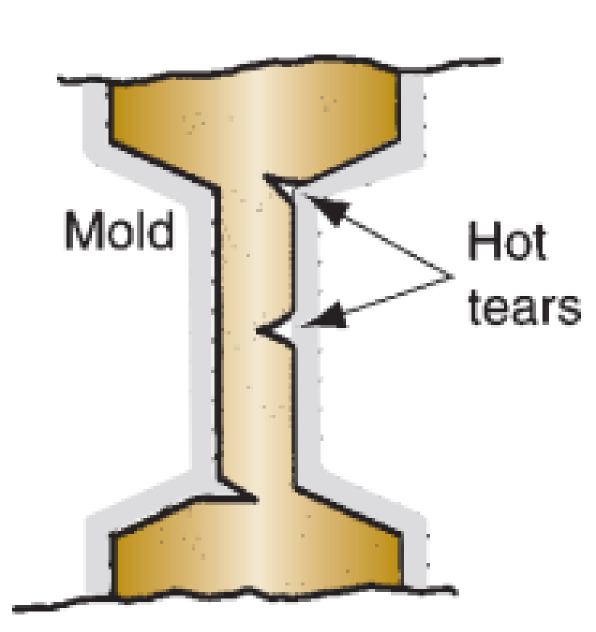


Microporosity- This refers to a network of small voids distributed through the casting caused by localized solidification shrinkage of the final molten metal in the dendrites structure. The defect is usually associated with alloys.



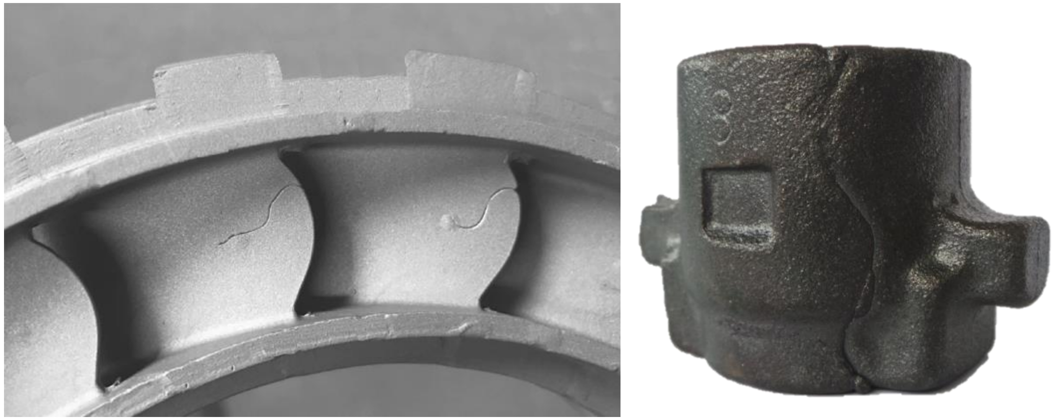
Casting Defects

Hot tearing- this defect also called Hot cracking, occurs when the casting is restrained from contraction by an unyielding mold during the final stages of solidification or early stages of cooling after solidification. The defect is manifested as a separation of metal (hence, the terms tearing or cracking) at a point of high tensile stress caused by the metal's inability to shrink naturally. In sand casting and other expendable mold processes, hot tearing is reduced by removing the part from the mold immediately after freezing.



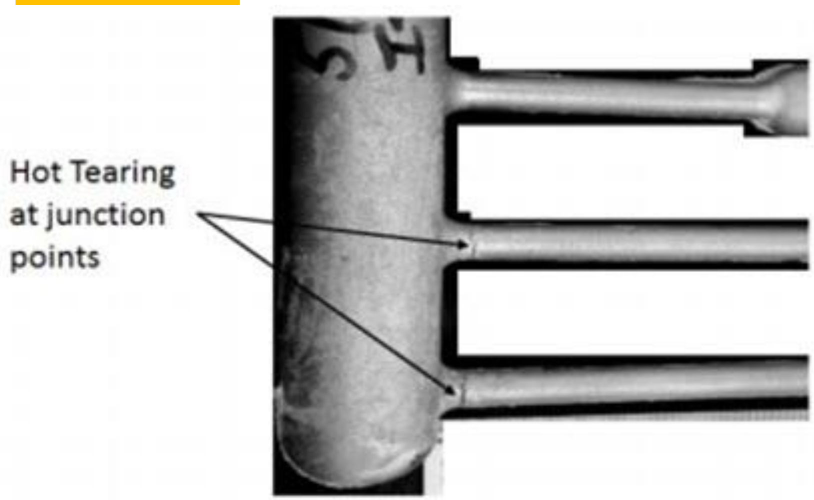
Casting Defects

Cold-shut

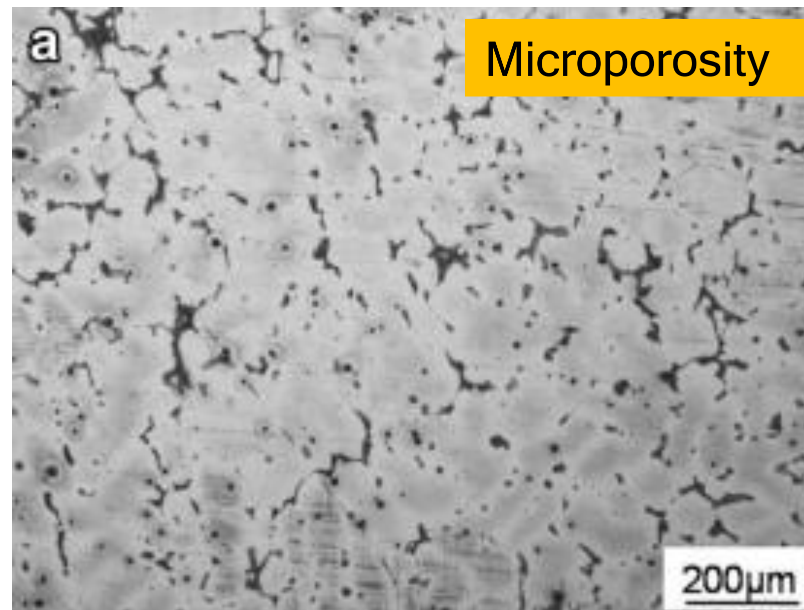


Misrun

Hot-tear

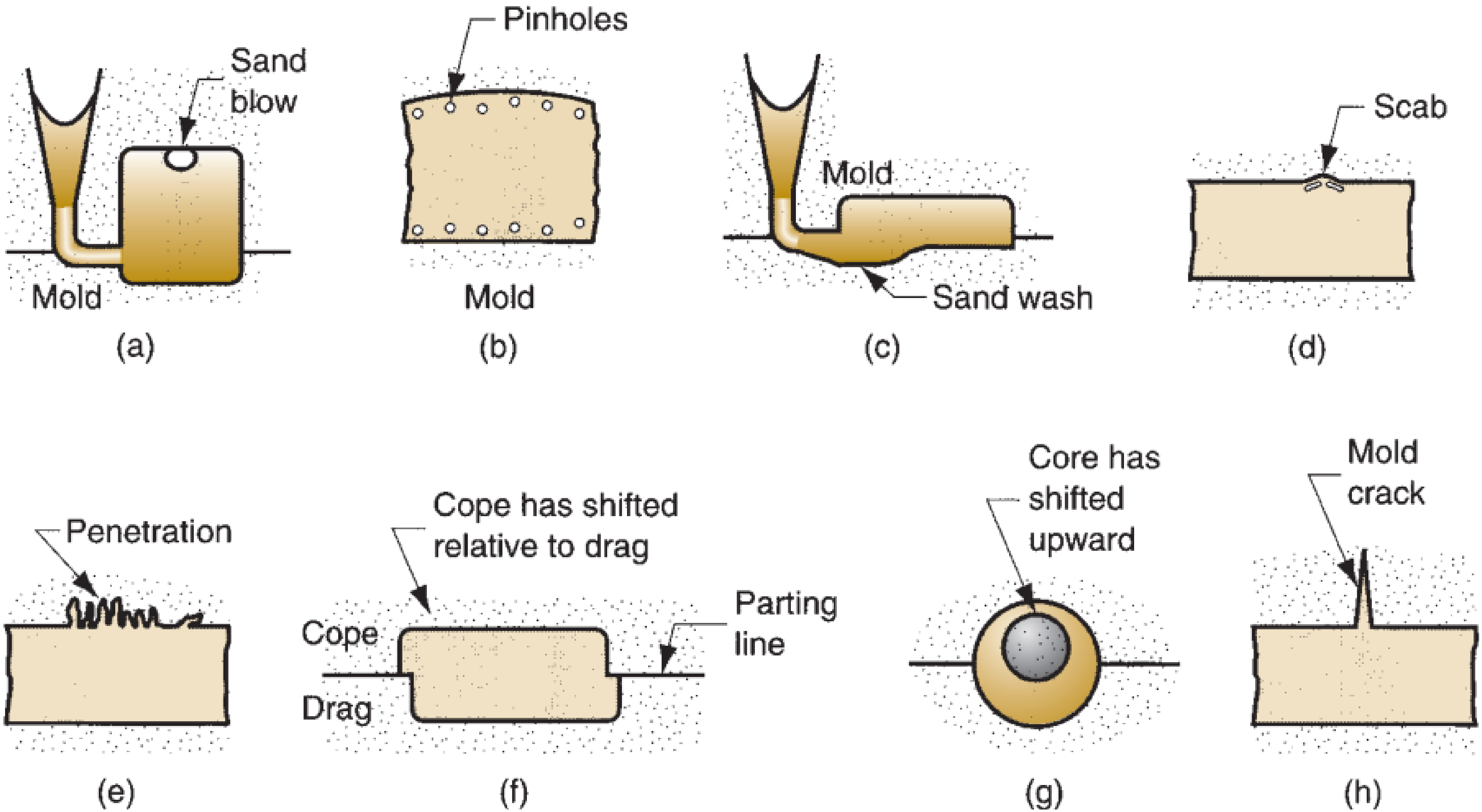


Microporosity



Ref: (1) http://61746c6173.investmentcasting.org/; (2) http://efoundry.iitb.ac.in/; (3) https://www.totalmateria.com/; (4) Dr. M. Di Sabatino

Casting Defects (sand mold related)



Some defects are related to the use of sand molds, and therefore they occur only in sand castings.

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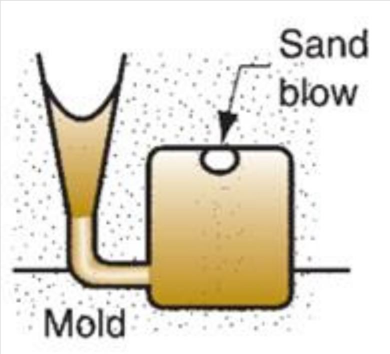
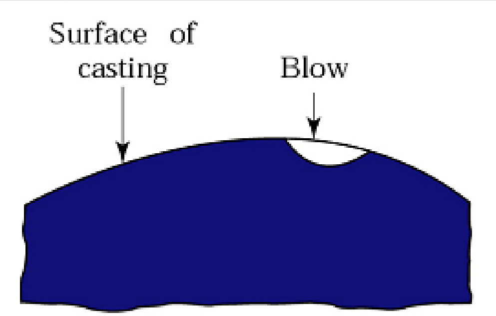
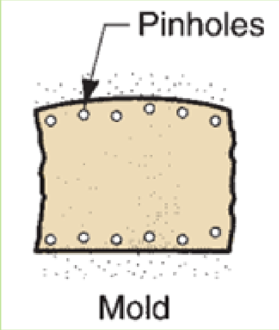
Casting Defects (sand mold related)

Sand blow- This defect consist of a balloon shaped gas cavity caused by release of mold gases during pouring. It occurs at or below the casting surface near the top of the casting. Low permeability, poor venting , and high moisture content of the sand mold are the usual causes.



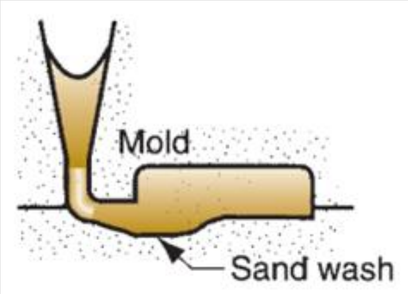


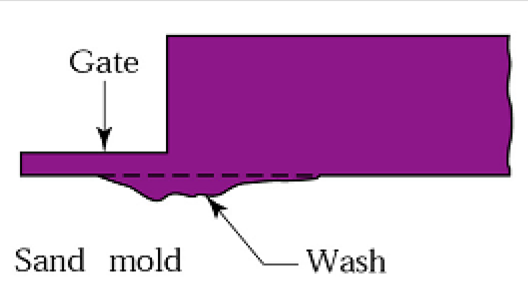


Pinhole- A defect similar to sand blow involves the formation of many small gas cavities at or slightly below the surface of the casting.

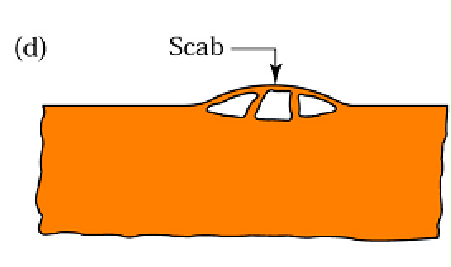
Ref: (1) Groover; (2) http://mechanicalinventions.blogspot.com/; (3)https://www.giessereilexikon.com/

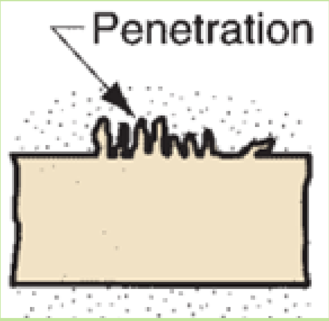
Sand wash- A wash is an irregularity in the surface of the casting that results from erosion of the sand mold during pouring. The contour of the erosion is imprinted into the surface of the final cast part.





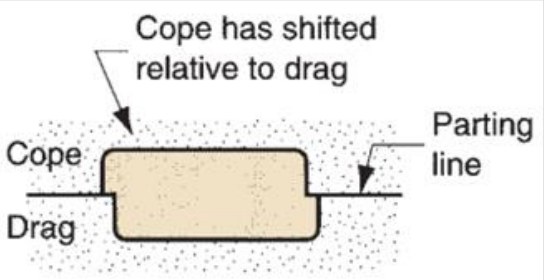
Scab- This is a rough area on the surface of the casting due to encrustations of sand and metal. It is caused by portions of the mold surface flaking off during solidification and becoming imbedded in the casting surface.





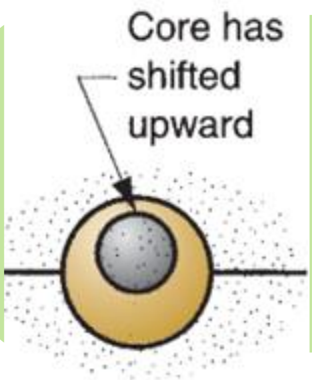
Penetration- When the fluidity of the liquid metal is high, it may penetrate into the sand mold or sand core. After freezing, the surface of the casting consists of a mixture of sand grains and metal. Harder packing of the sand mold helps to alleviate this condition.

Mold shift- This is manifested as a step in the cast product at the parting line caused by sidewise displacement of the cope with respect to the drag.

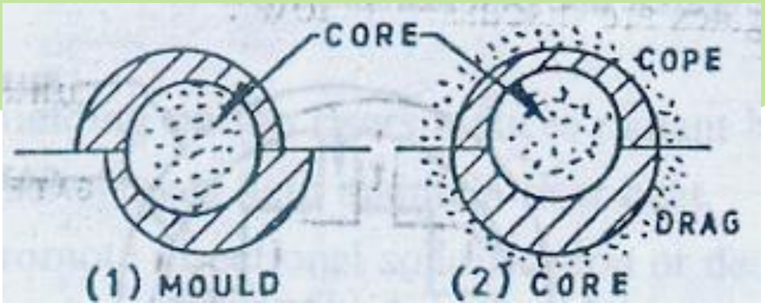


Ref: (1) Groover; (2) https://www.intouch-quality.com/

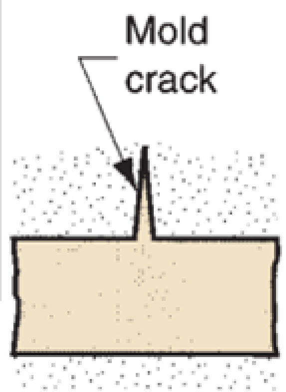
Casting Defects (sand mold related)



Core shift- A similar movement can happen with the core, but the displacement is usually vertical. Core shift and mold shift are caused by buoyancy of the molten metal.

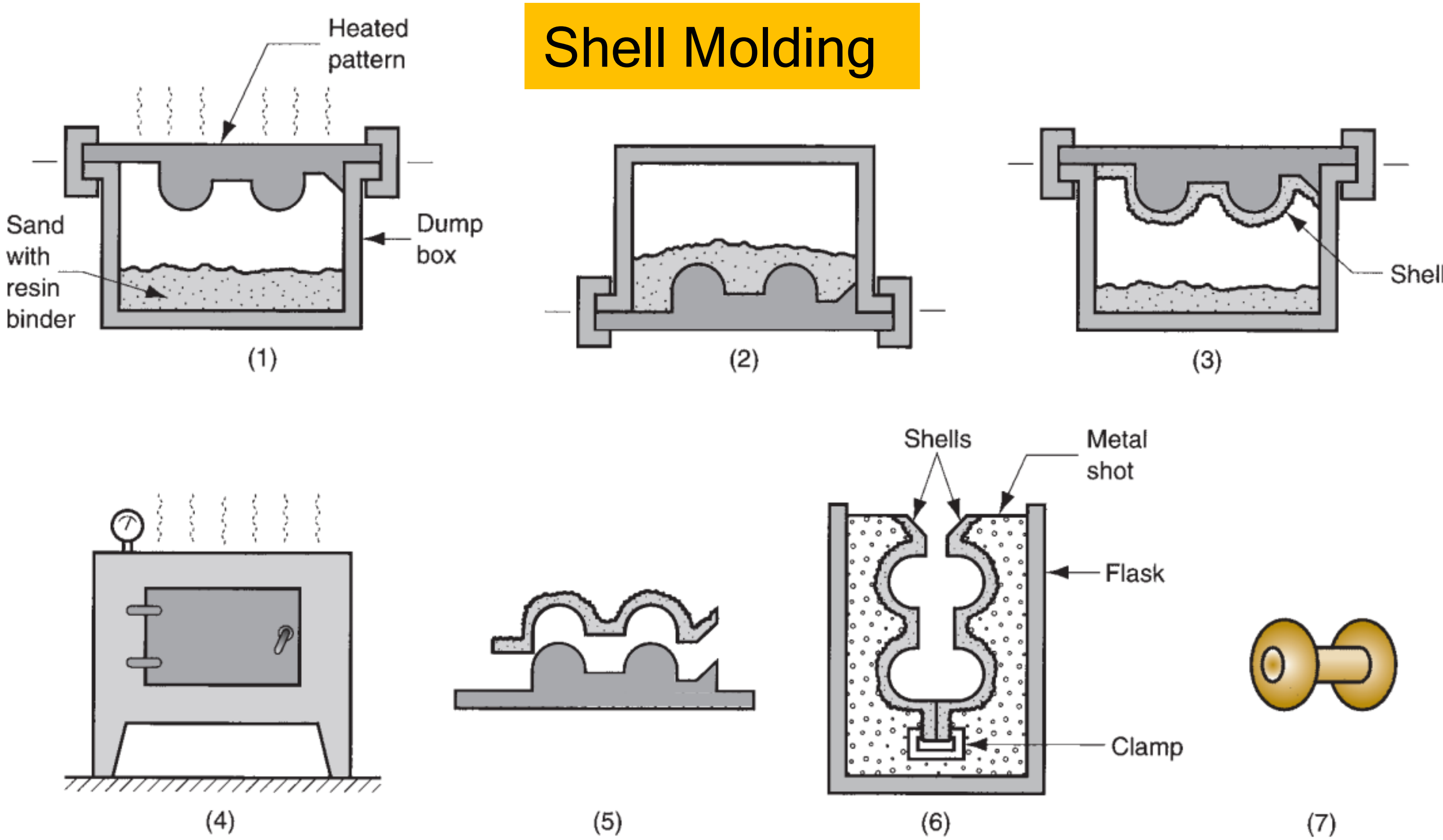


Molds crack- If mold strength is insufficient, a crack may develop, into which liquid metal can seep to form a "fin" on the final casting.



Other expendable mold casting processes

Shell Molding



Advantages:
- Smoother cavity surface permit easier flow of metal
- Good dimensional accuracy
- e.g., gears, bushings

Disadvantage
- Pattern expensive
- Small quantities are not justified

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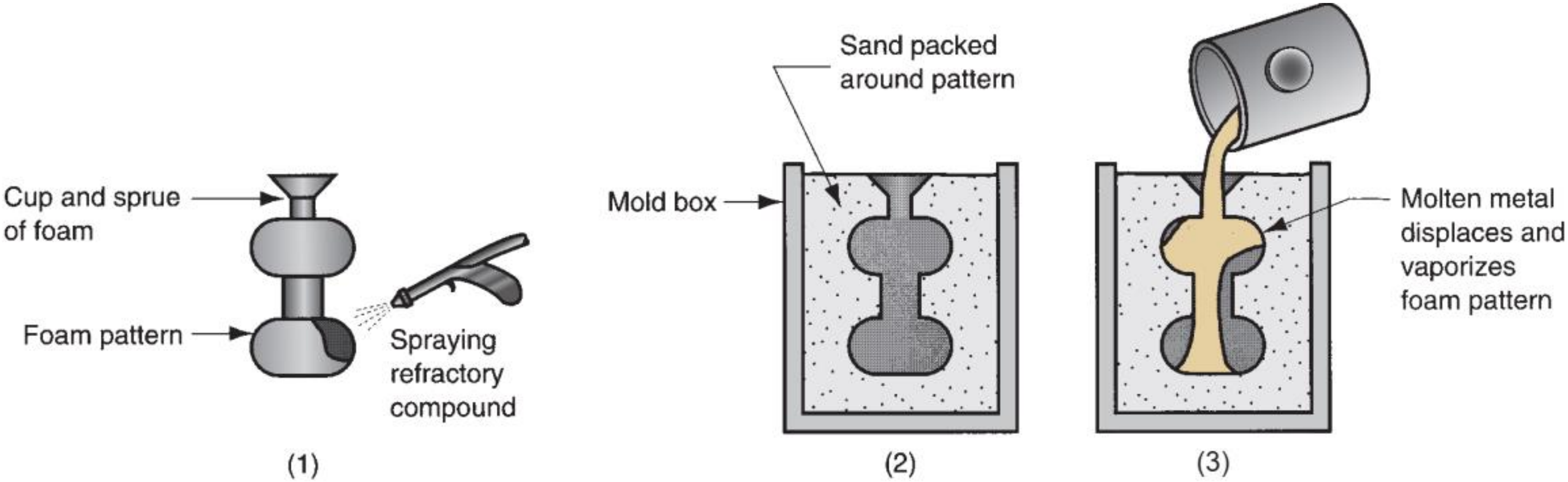
Expanded polystyrene process

Also known as lost-foam, lost pattern, evaporative foam, full-mold process



Advantages:
- Considerations of draft and parting lines can be ignored
- Does not have to be opened into cope and drag portions
- Pattern need not be removed

Disadvantage:
- New pattern needed every time

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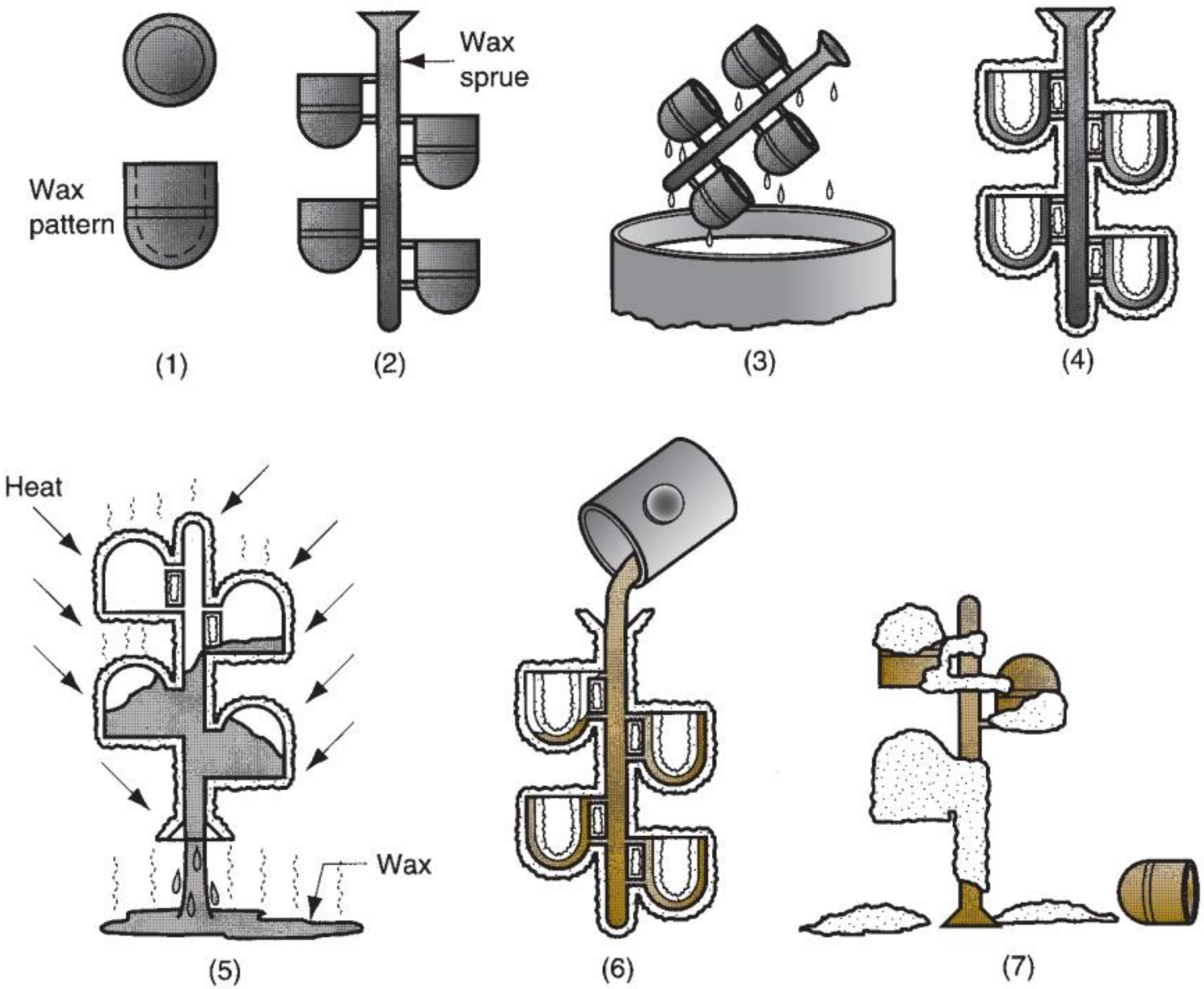
Investment casting



Steps in investment casting:

(1) wax patterns are produced;
(2) Several patterns are attached to a sprue to form a pattern tree;
(3) 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;
(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, 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; and
(7) The mold is broken away from the finished casting. Parts are separated from the sprue.

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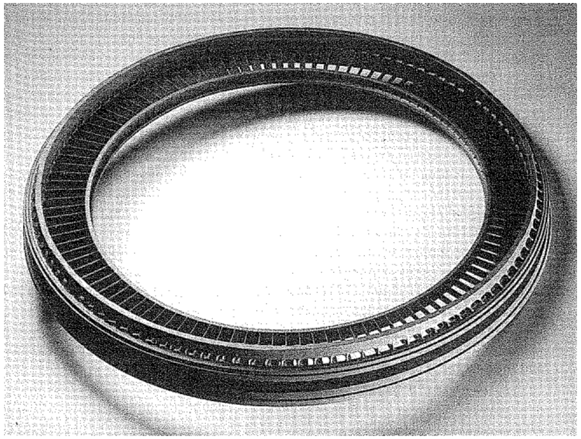
Investment casting



A one piece compressor stator with 108 separate airfoils made by investment casting

The investment shell for casting a turbocharger rotor

The completed workpiece

Investment casting is used with almost any castable metal, however aluminium alloys, copper alloys, and steel are the most common.

The advantages of investment casting are:

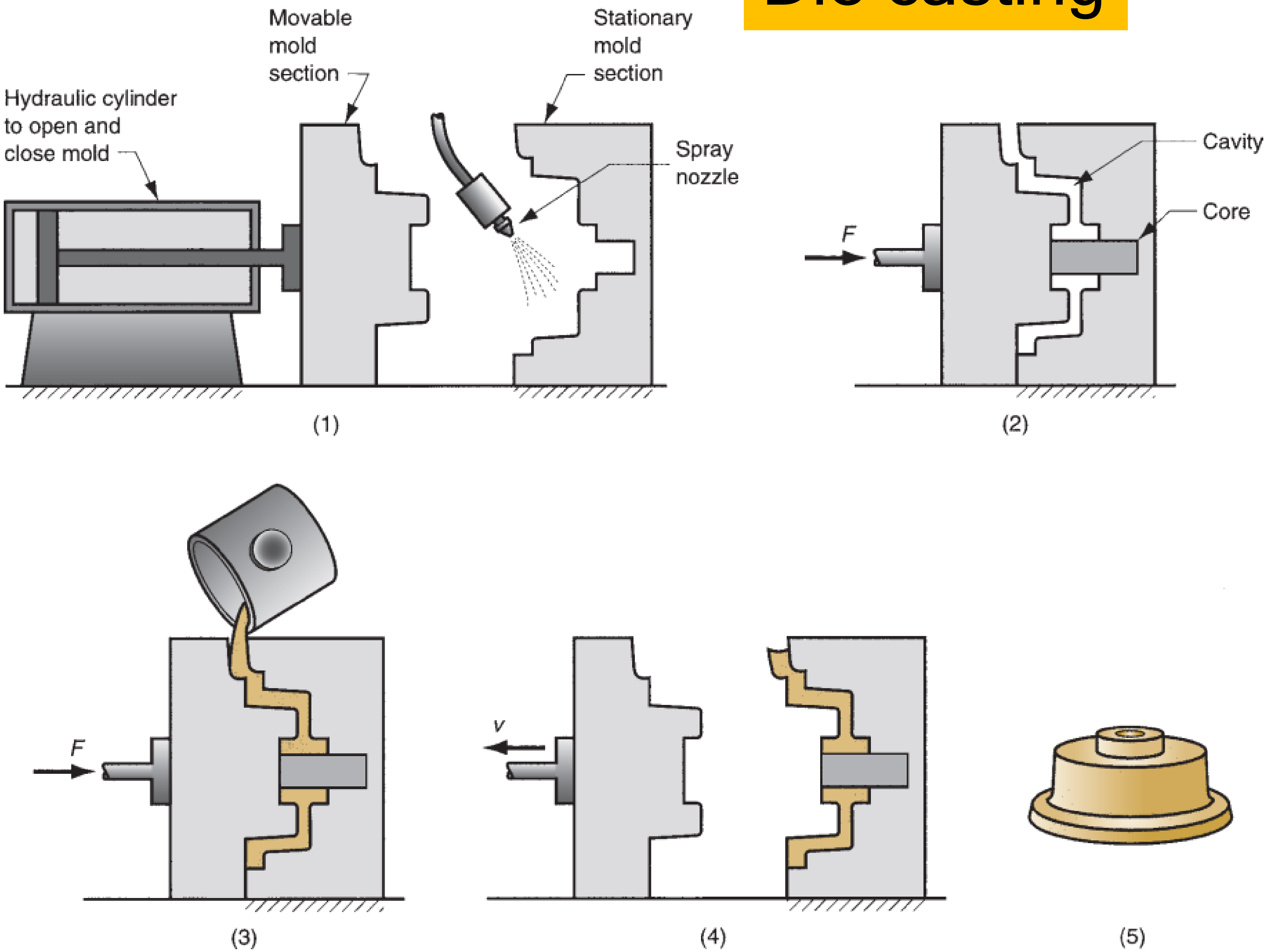
- Excellent surface finish
- High dimensional accuracy
- Extremely intricate parts are castable
- Almost any metal can be cast
- No flash or parting lines

Disadvantages:

- Large processing steps
- Cost intensive setup

Permanent Mold Casting

Die casting



Advantages:
- Good surface finish
- Fine grains (because of faster cooling) give better strength
- Good dimensional control

Disadvantage
- Single geometries
- Used only for low-melting metals/alloys
- Suitable only for high volume production

e.g., Automotive pistons and pump bodies

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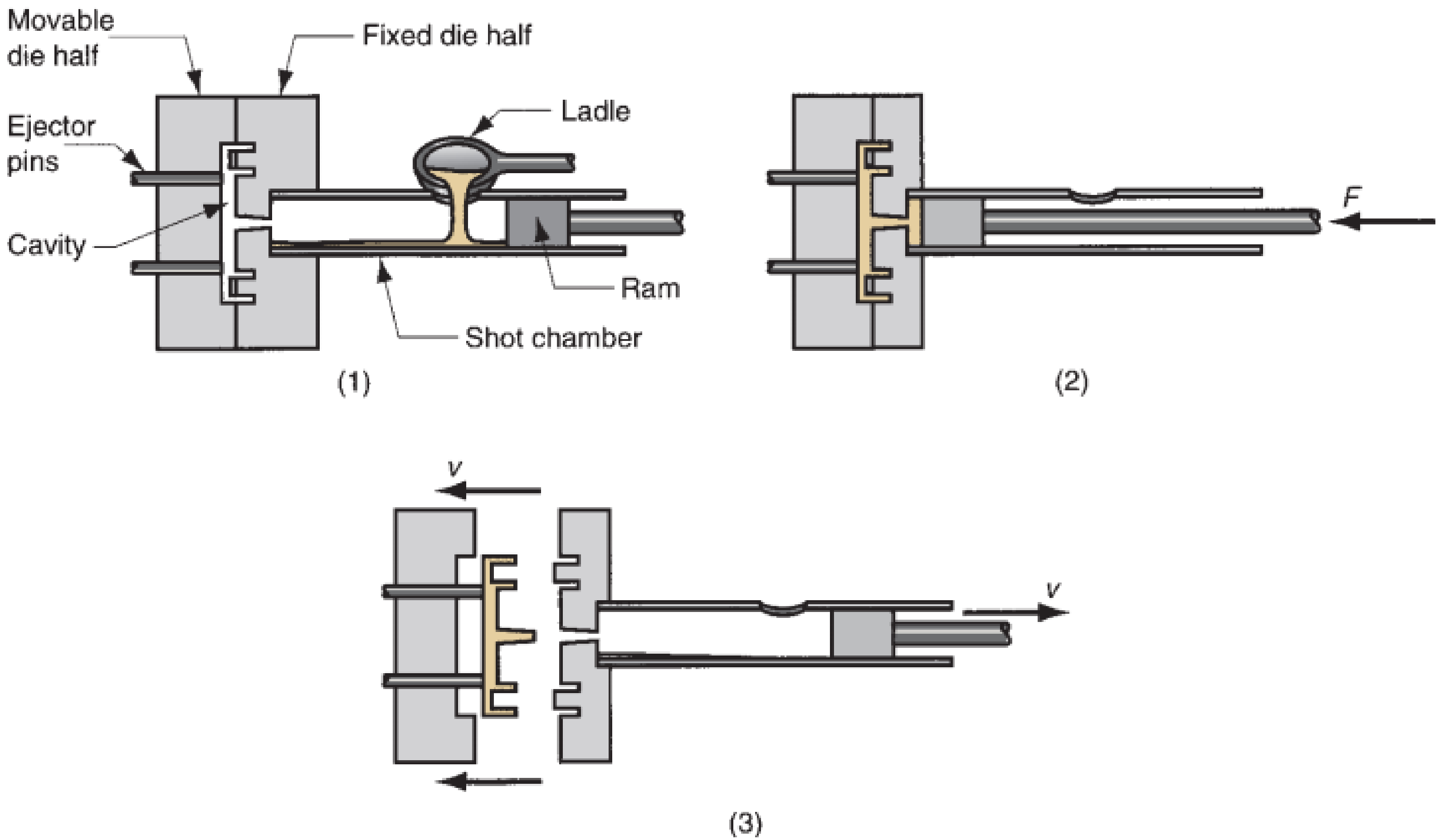
Cold chamber Pressure Die casting



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Pressure Die casting

Advantages

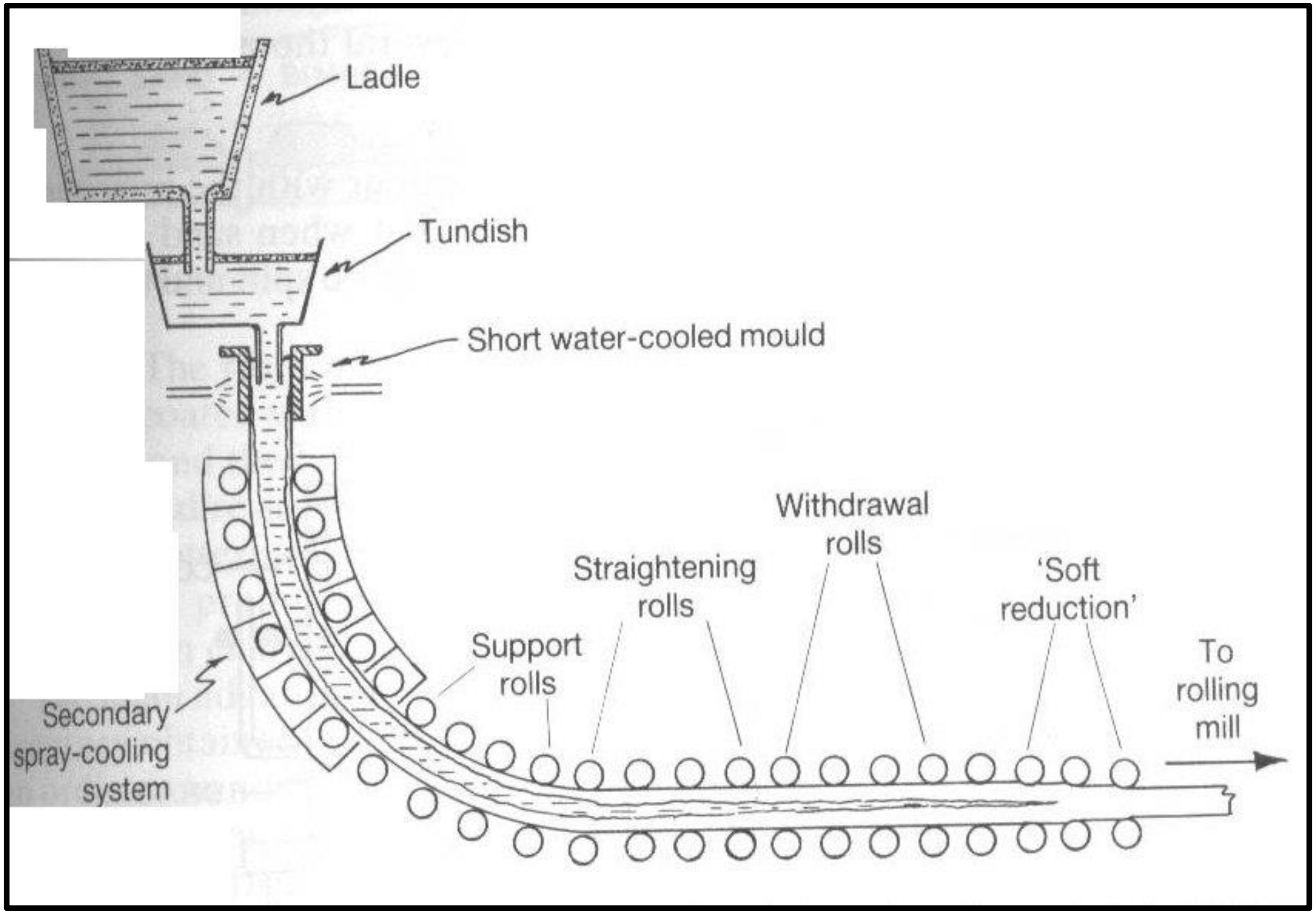
- Low porosity
- Near net shape process
- Rapid production rates
- Excellent dimensional accuracy (± 0.076mm)
- Smooth cast surfaces
- Thinner walls can be cast as compared to sand and permanent mold casting (0.5mm)
- Castings have very high tensile strength
- Casting of low fluidity metals

Disadvantages

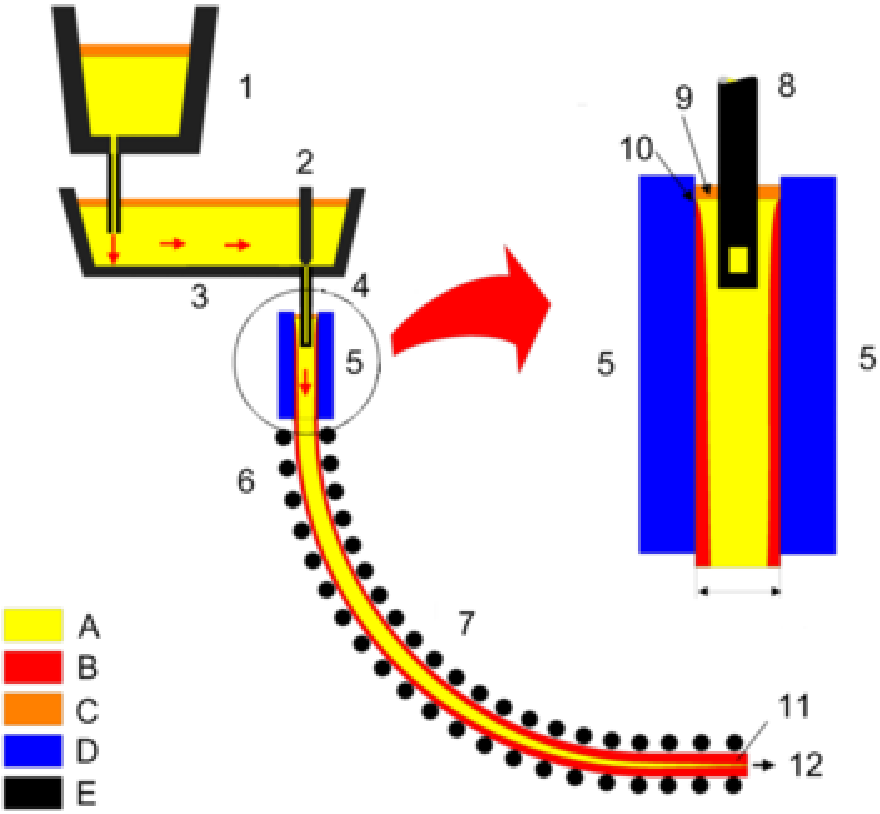
- Very high capital cost
- Single geometries
- Formation of flash is common due to high pressure

An engine block with aluminium and magnesium die castings.

Continuous Casting



Difference between continuous casting and what we do in lab !!



Continuous Casting

- **Continuous casting**, also called **strand casting**, is the process whereby molten metal is solidified into a "semifinished" billet, bloom, or slab for subsequent rolling in the finishing mills.

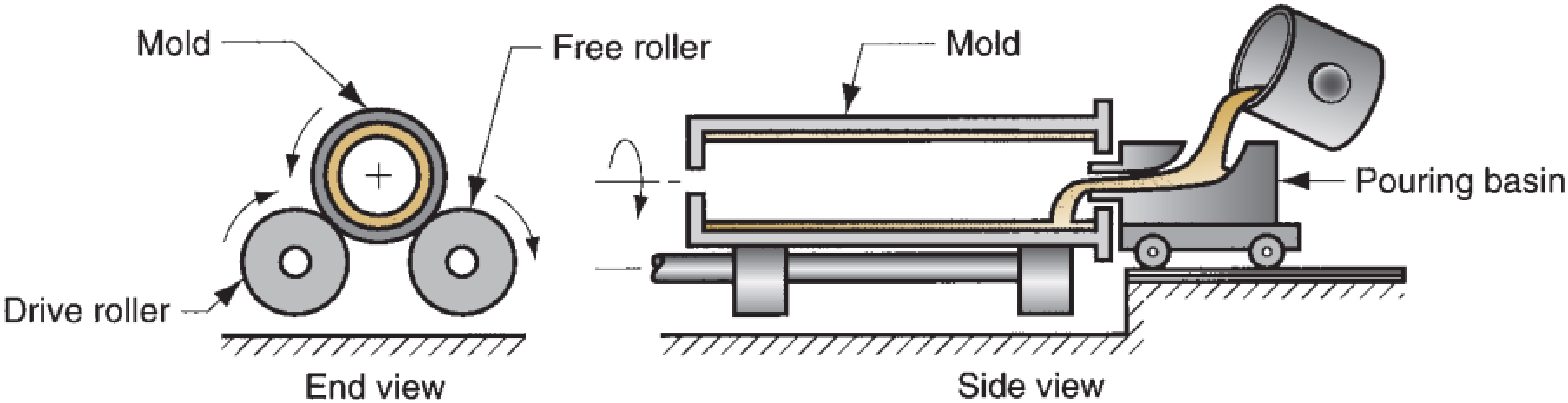
- Prior to the introduction of continuous casting, steel was poured into stationary molds to form ingots. Since then, "continuous casting" has evolved to achieve improved yield, quality, productivity and cost efficiency.

- It allows lower-cost production of metal sections with better quality, due to the inherently lower costs of continuous, standardized production of a product, as well as providing increased control over the process through automation.

- This process is used most frequently to cast steel. Aluminium and copper are also continuously cast.

- A major problem that may occur in continuous casting is that of *breakout*

Centrifugal Casting



The outside shape of the casting can be round, octagonal, hexagonal, and so on. However, the inside shape of the casting is (theoretically) perfectly round, due to the radially symmetric forces at work.

Find the required rotational speed (N) to achieve casting?

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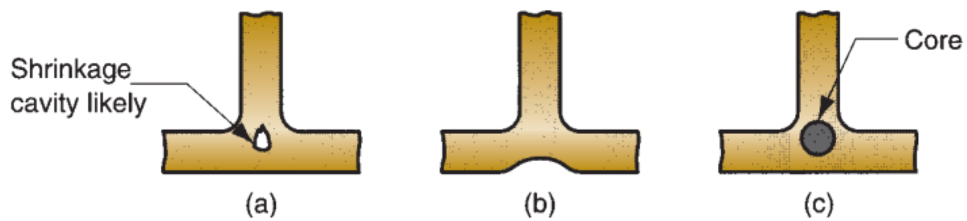
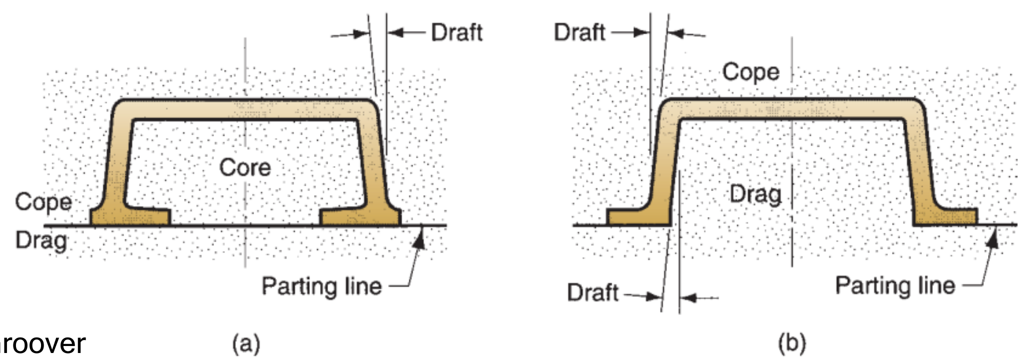
Product Design Considerations

- ✓ Geometric simplicity - avoid unnecessary complexities
- ✓ Corners- no sharp corner and angles - hot tearing
- ✓ Section thickness - uniform in order to avoid shrinkage cavities (hot spots); Gradual thickness transitions
- ✓ Proper use of cores
- ✓ Draft for removal - tapers: 0.5 to 2 degrees
- ✓ Dimensional tolerances
- ✓ Machining allowance





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Further reading

- What is DISAMATIC sand mould method?
- What is Semicentrifugal Casting?
- What is Centrifuge casting?