Department of Materials Science and Engineering

Casting, Powder Metallurgy

Balázs Varbai, PhD, EWE/IWE

Materials Engineering
BMEGEMTBGF1
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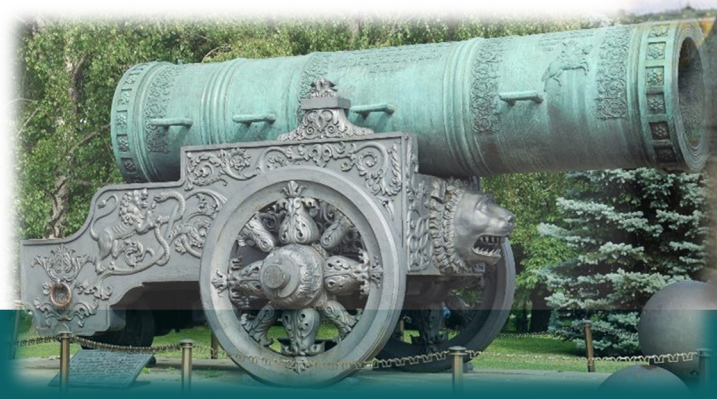
Outline

- Solidification of metals
- Fluid flow, effect of cooling rate
- Cast defects
- Metal casting processes
  - Sand mold casting
  - Shell-mold casting
  - Investment casting
  - Evaporative-pattern casting
  - Permanent mold casting
  - Pressure die casting
  - Centrifugal casting

History

- B.C. 3000-1500 Bronze age (tin-bronze)
- B.C. 224 Colossus of Rhodes (32 m high, bronze)
- 1252 Great Buddha, Japan(120 t (9% Sn, 20% Pb))
- 1400 Yongle Great Bell (China, Beijing) 46 t, 120 dB-20 km)
- 1586 Tsar cannon
- 1709 Cast iron bridge (USA Coalbrookdale)
- 1735 Tsar Bell (193 t)



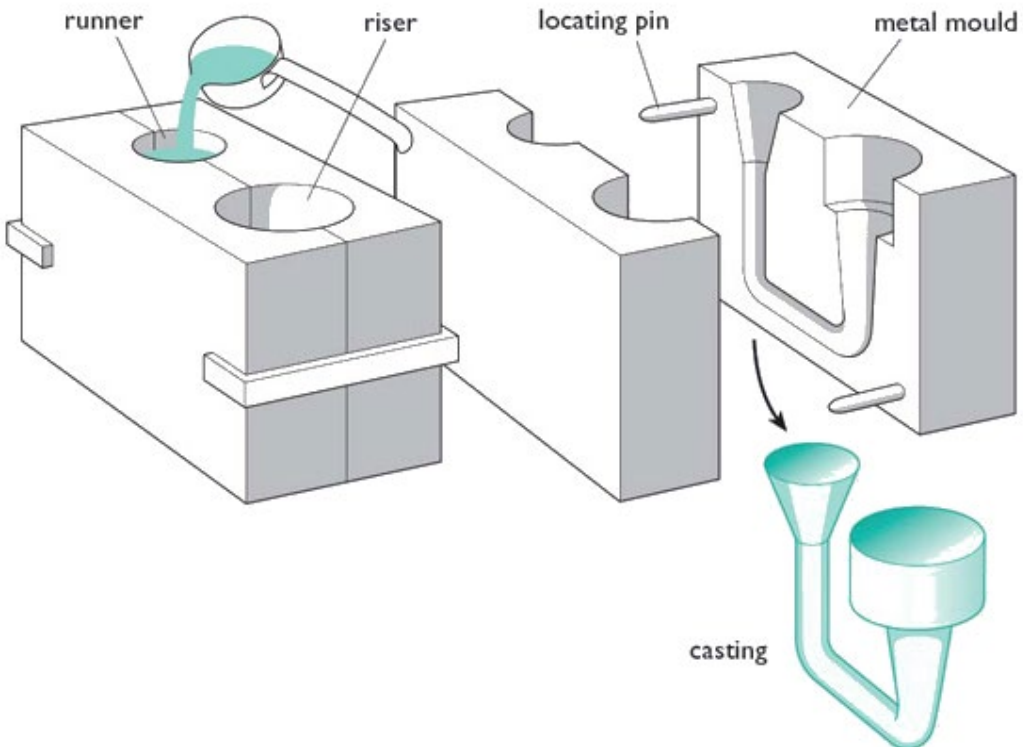
Casting process

The casting process basically involves:

(a) pouring molten molten metal into the mold cavity

(b) solidification and cooling of the metal in the mold

(c) removing the part from the mold



Efficiency and energy consumption

Utilization of the mat.	Process	Energy consumption
90	Casting	0-38
95	Powder metallurgy	29
85	Cold and warm forming	41
75-80	Closed die forging	41-49
45-40	Machining	66-82
100% ⇐ 0%		0 MJ ⇒ 100 MJ

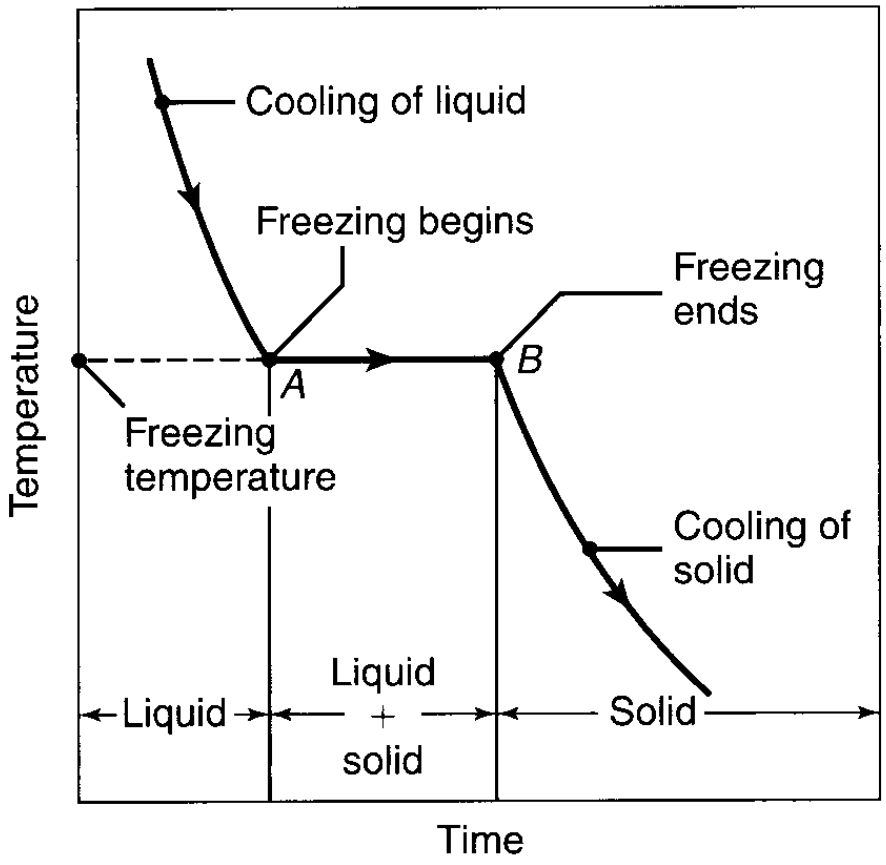
(1kg product)

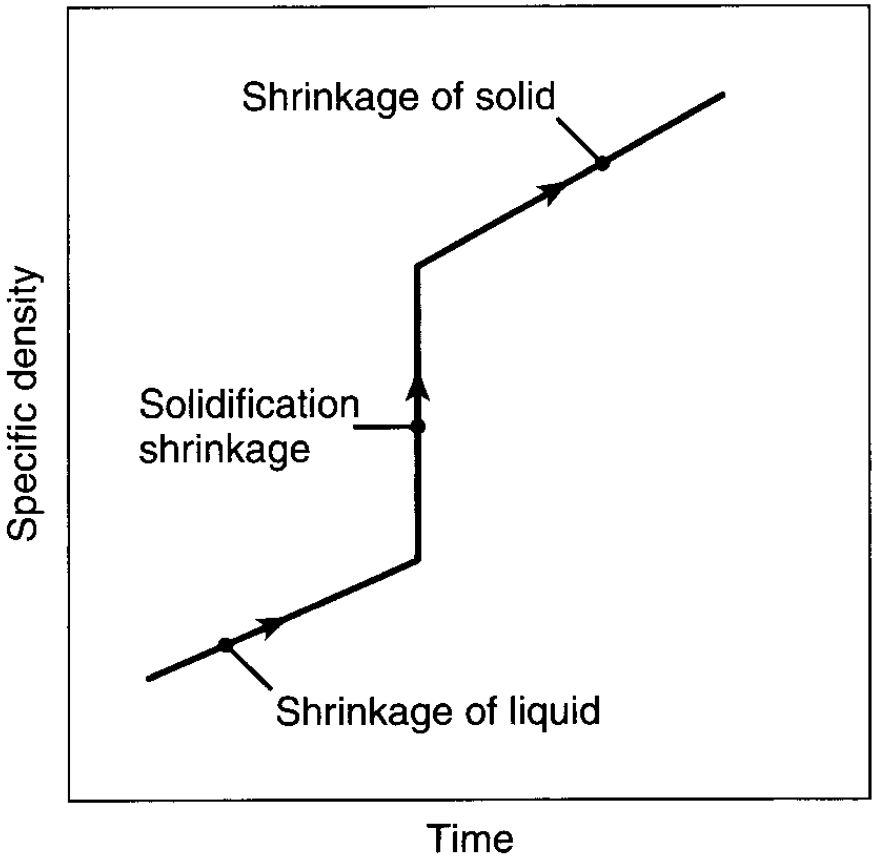
https://www.machinedesign.com/materials/metals/article/21834820/reap-the-benefits-of-modernday-powder-metallurgy

Solidification of pure metals and eutectic alloys

Latent heat

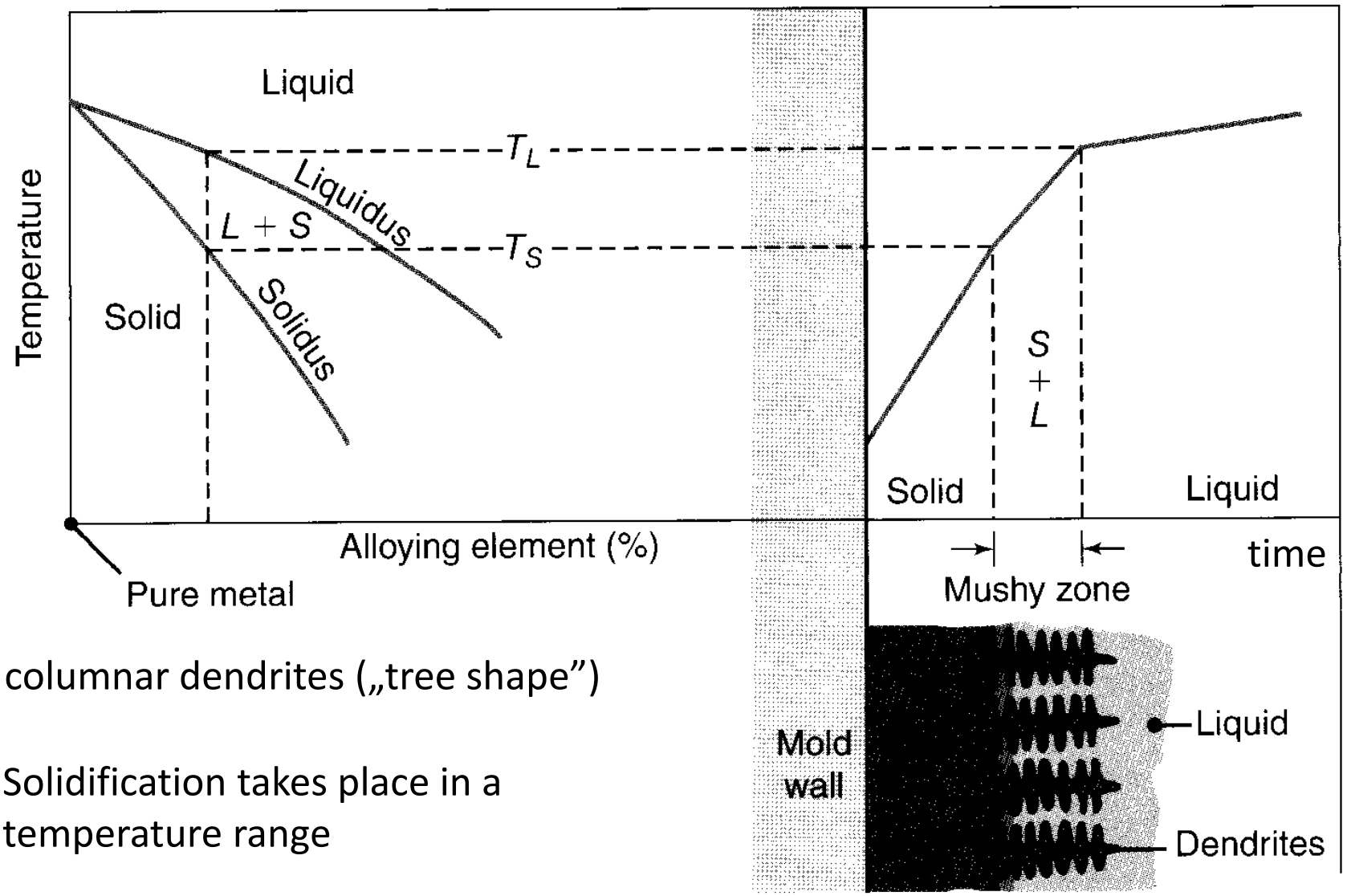
Solidification takes place at a constant temperature





Pure metals and eutectic alloys - good castability

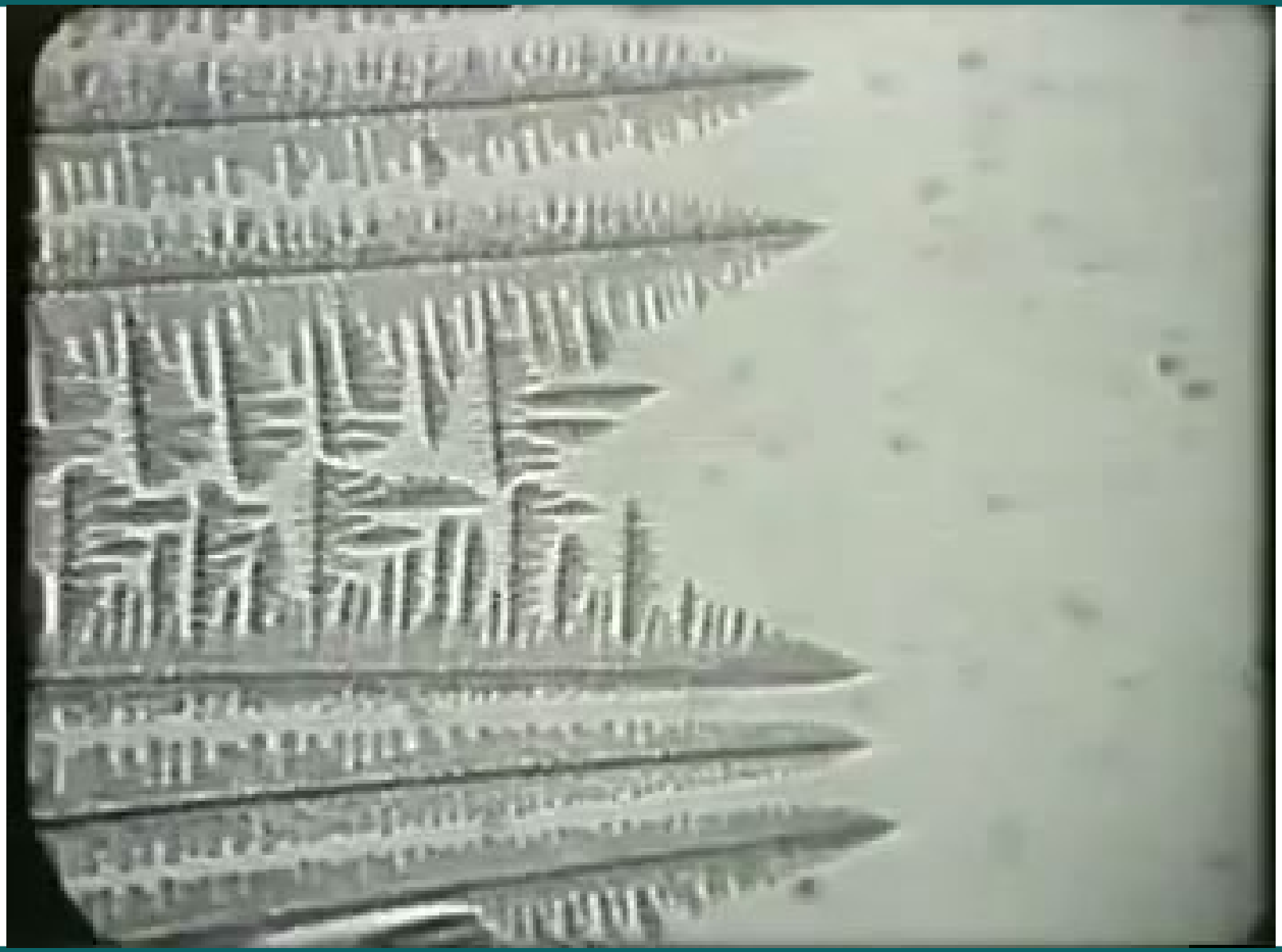
Solidification of alloys



columnar dendrites („tree shape”)

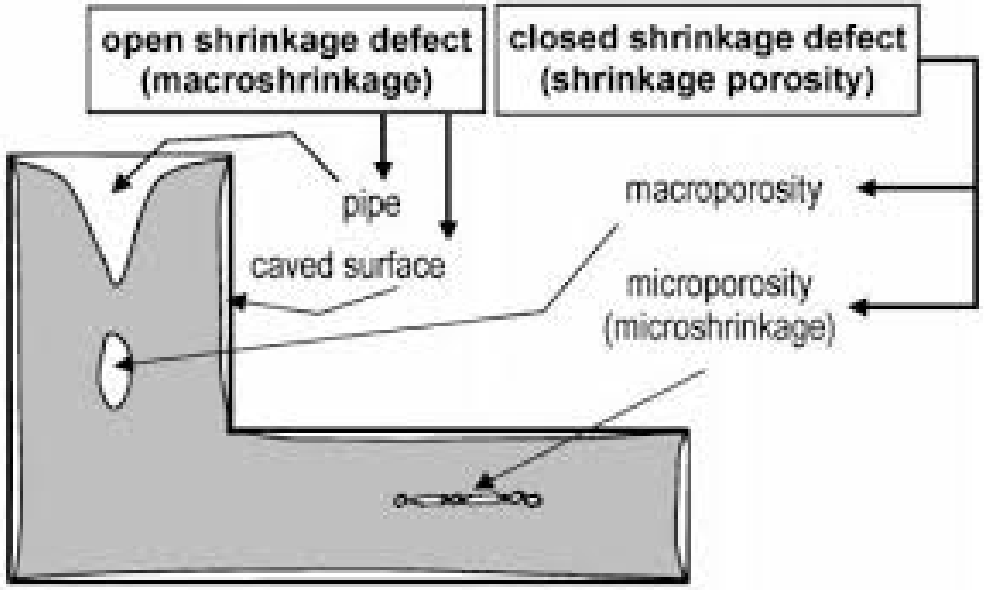
Solidification takes place in a temperature range

Dendritic solidification



Volumetric Solidification Contraction or Expansion for Various Cast Metals

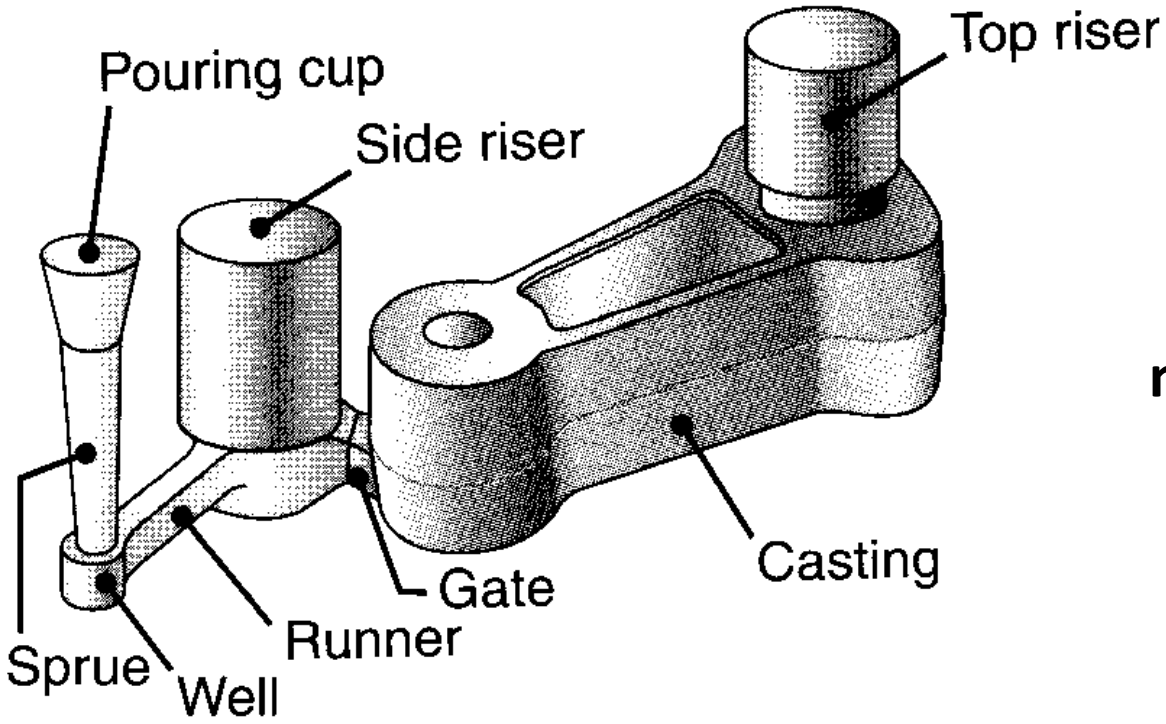
Contraction (%)		Expansion (%)	
Aluminum	7.1	Bismuth	3.3
Zinc	6.5	Silicon	2.9
Al–4.5% Cu	6.3	Gray iron	2.5
Gold	5.5		
White iron	4–5.5		
Copper	4.9		
Brass (70–30)	4.5		
Magnesium	4.2		
90% Cu–10% Al	4		
Carbon steels	2.5–4		
Al–12% Si	3.8		
Lead	3.2		



https://www.researchgate.net/publication/45917826_On_the_prediction_of_shrinkage_defects_by_thermal_criterion_functions

Risers (feeders):

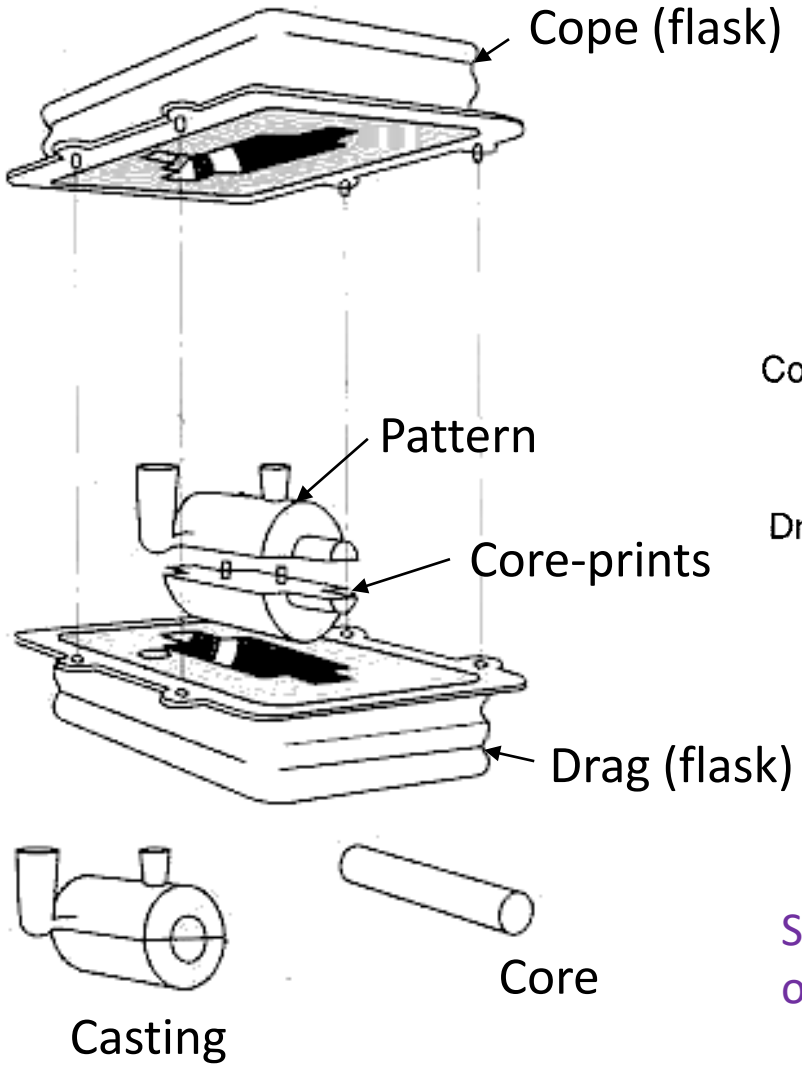
reservoirs of molten metal prevent porosity due to shrinkage



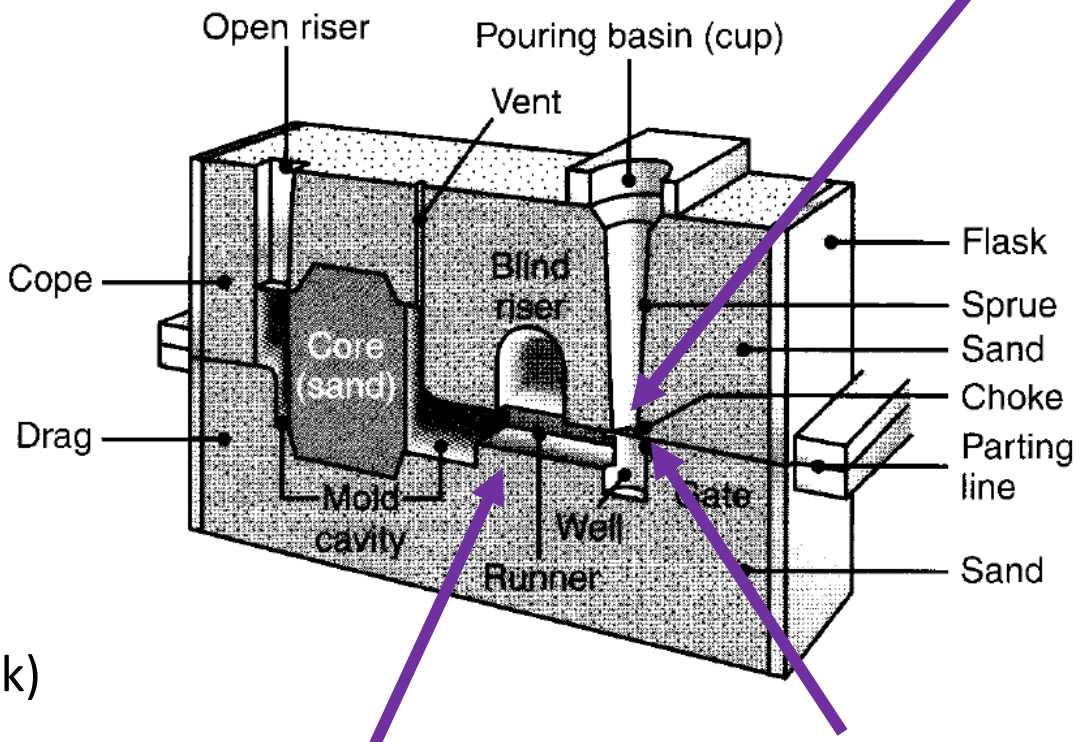
mold cavity

Gating system (sprue, runners, gates) sand casting: traps contaminants

Sand casting



Minimize turbulence and formation of air bubbles.

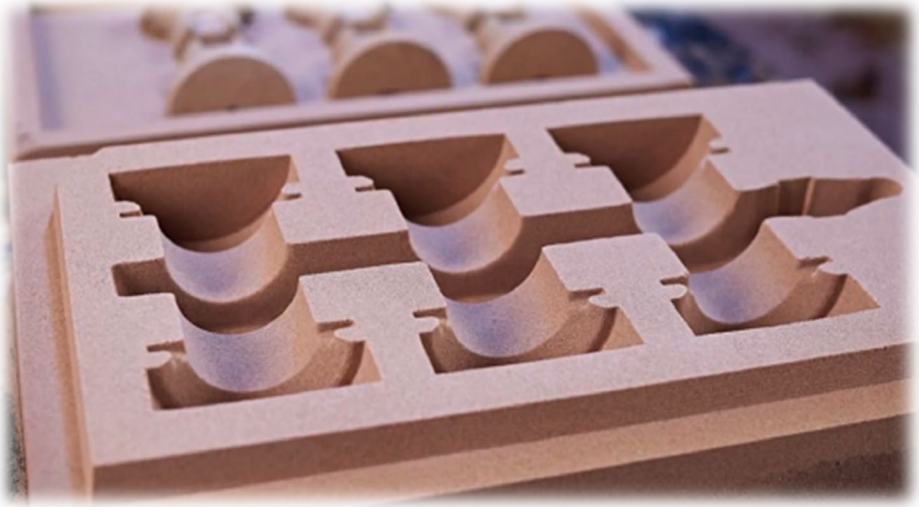


Slow down and smooth out the flow (uniform).

The controlled entrances from the runners into the mold cavities.

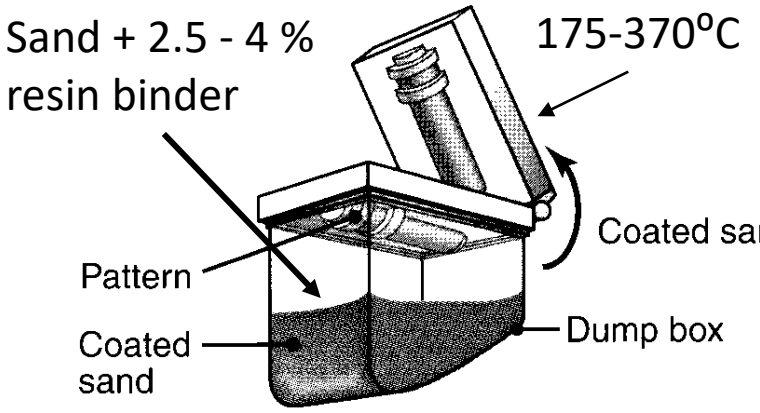
Sand casting

- Molding sands + Binders
  - Refractoriness
  - Chemical inertness
  - Permeability (to exhaust gases)
  - Surface finish
  - Cohesiveness
  - Flowability
  - Collapsibility
  - Availability/cost

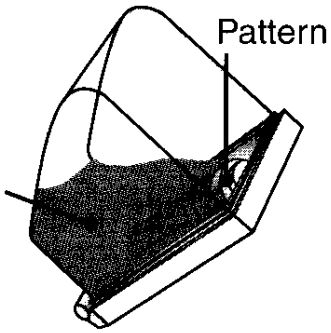


Sand casting

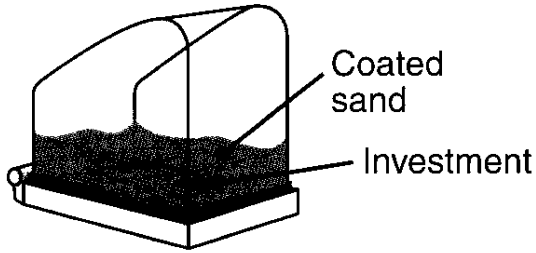
Shell molding



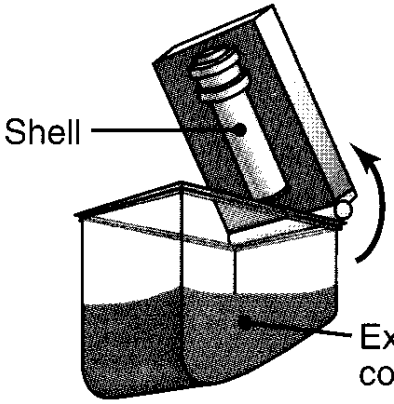
1. Pattern rotated and clamped to dump box



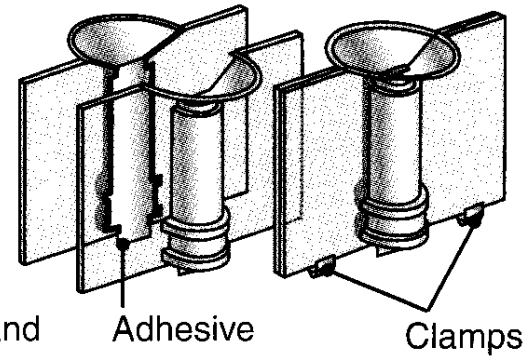
2. Pattern and dump box rotated



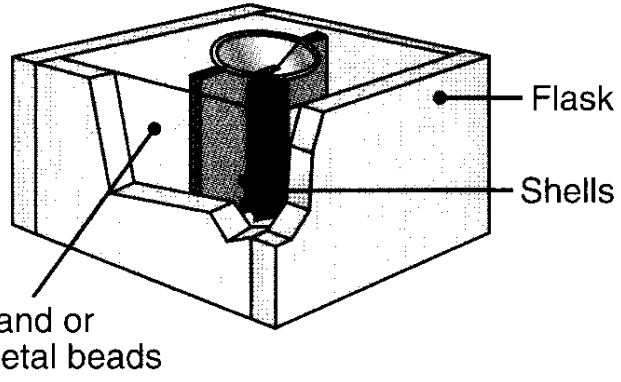
3. Pattern and dump box in position for the investment



4. Pattern and shell removed from dump box



5. Mold halves joined together

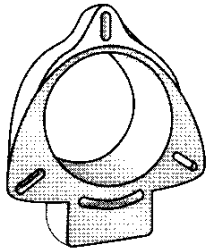


6. Mold placed in flask and metal poured

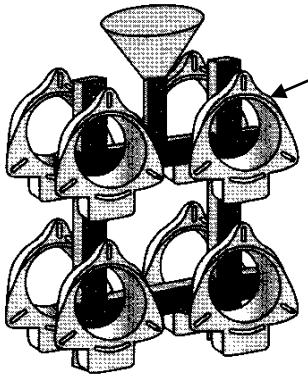
Shell molding

Evaporative-pattern casting (Lost-foam Process)

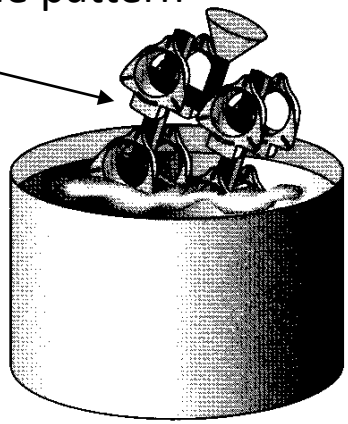
polystyrene pattern



1. Pattern molding



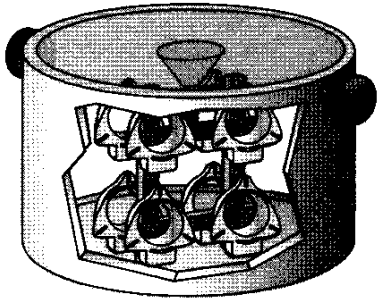
2. Cluster assembly



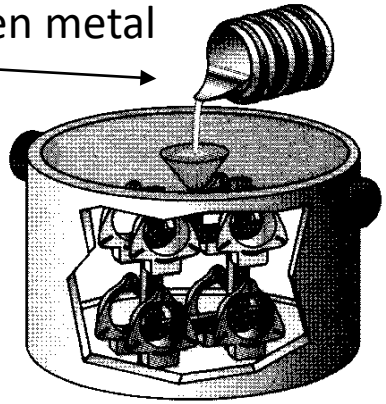
3. Coating

Coating with water-based refractory slurry & drying

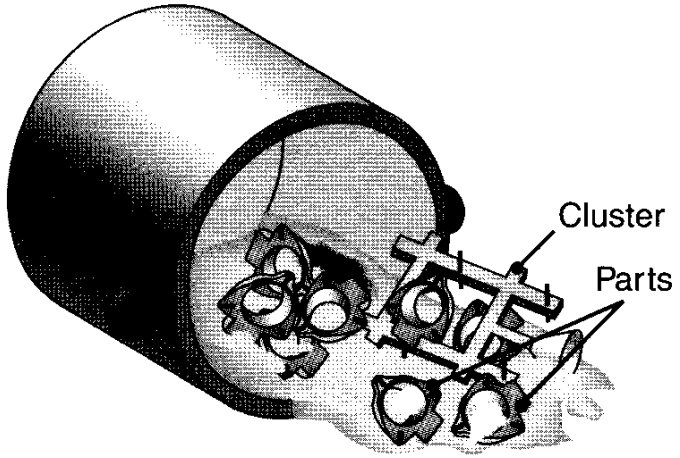
polystyrene pattern evaporates upon contact with molten metal



4. Compacted in sand



5. Casting

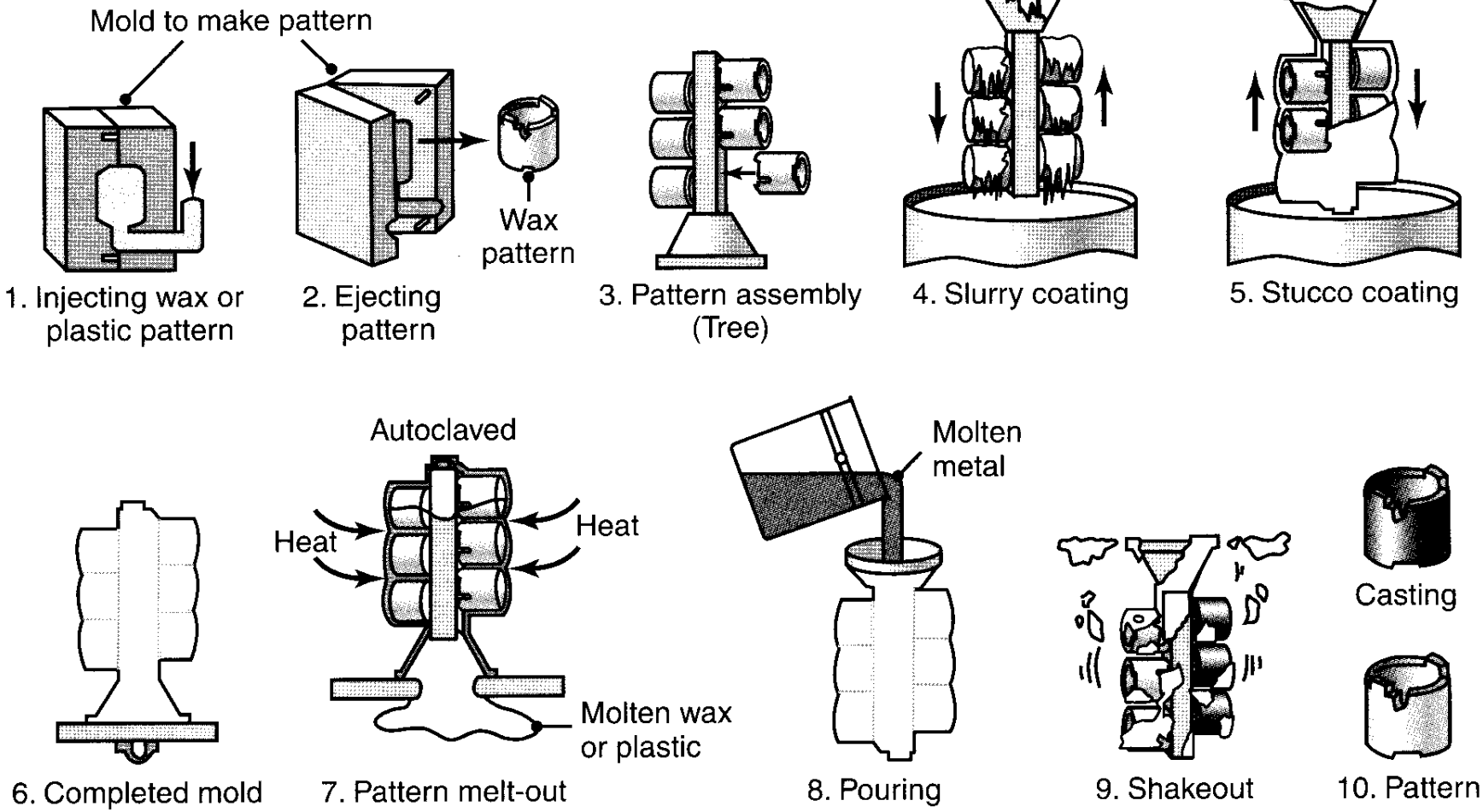


6. Shakeout

The degradation products from the polystyrene are vented into the surrounding sand.

Investment (precision) casting

wax can be recovered and reused



Investment (precision) casting

Advantages

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

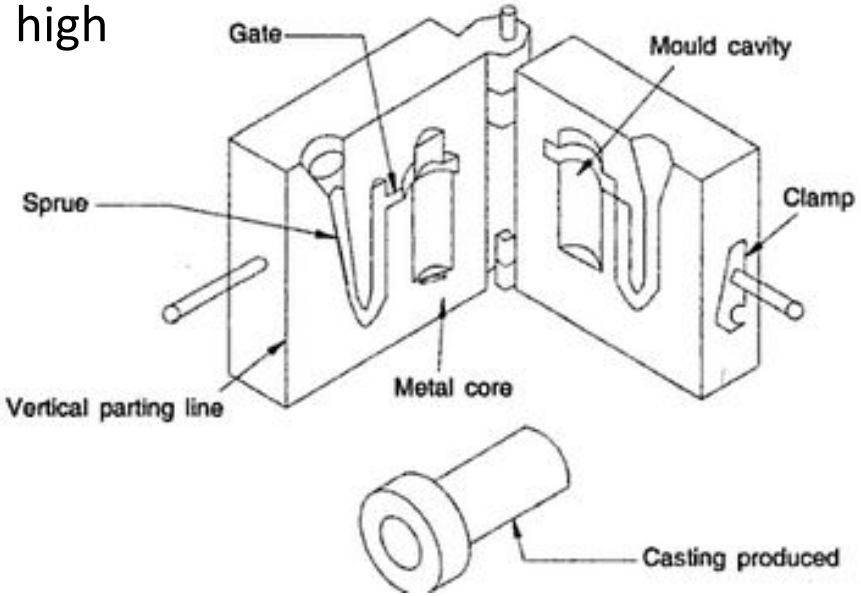
Disadvantages

- It can be difficult to cast objects requiring cores.
- This process is expensive, is usually limited to small casting, and presents some difficulties where cores are involved.
- Holes cannot be smaller than 1/16 in. (1.6 mm) and should be no deeper than about 1.5 times the diameter.
- Investment castings require longer production cycles compared to other casting processes.

Investment (precision) casting

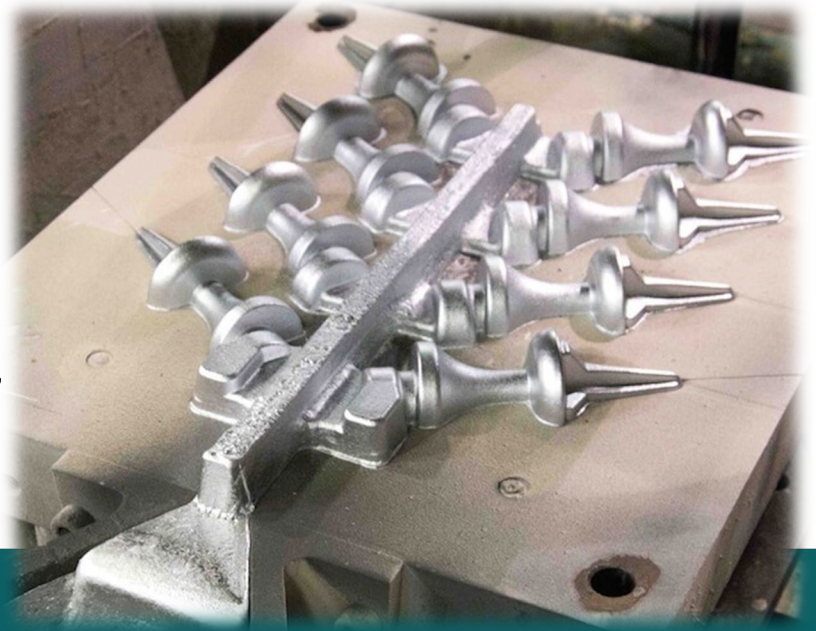
Permanent mold casting

2 halves of a mold: made from materials with high resistance to erosion and thermal fatigue, (cast iron, steel, bronze, graphite, or refractory metal alloys)
Mold cavity and gating system are machined into the mold
+ **cores** made of metal or sand aggregate
The molds are clamped together
heated to 150° - 200°C



The process is used mostly for **aluminum**, **magnesium**, and **copper** alloys, **gray iron**, *lower melting points*
Steels: graphite or heat-resistant metal molds.

Good surface finish, close dimensional tolerances, uniform and good mechanical properties, and at high production rates.



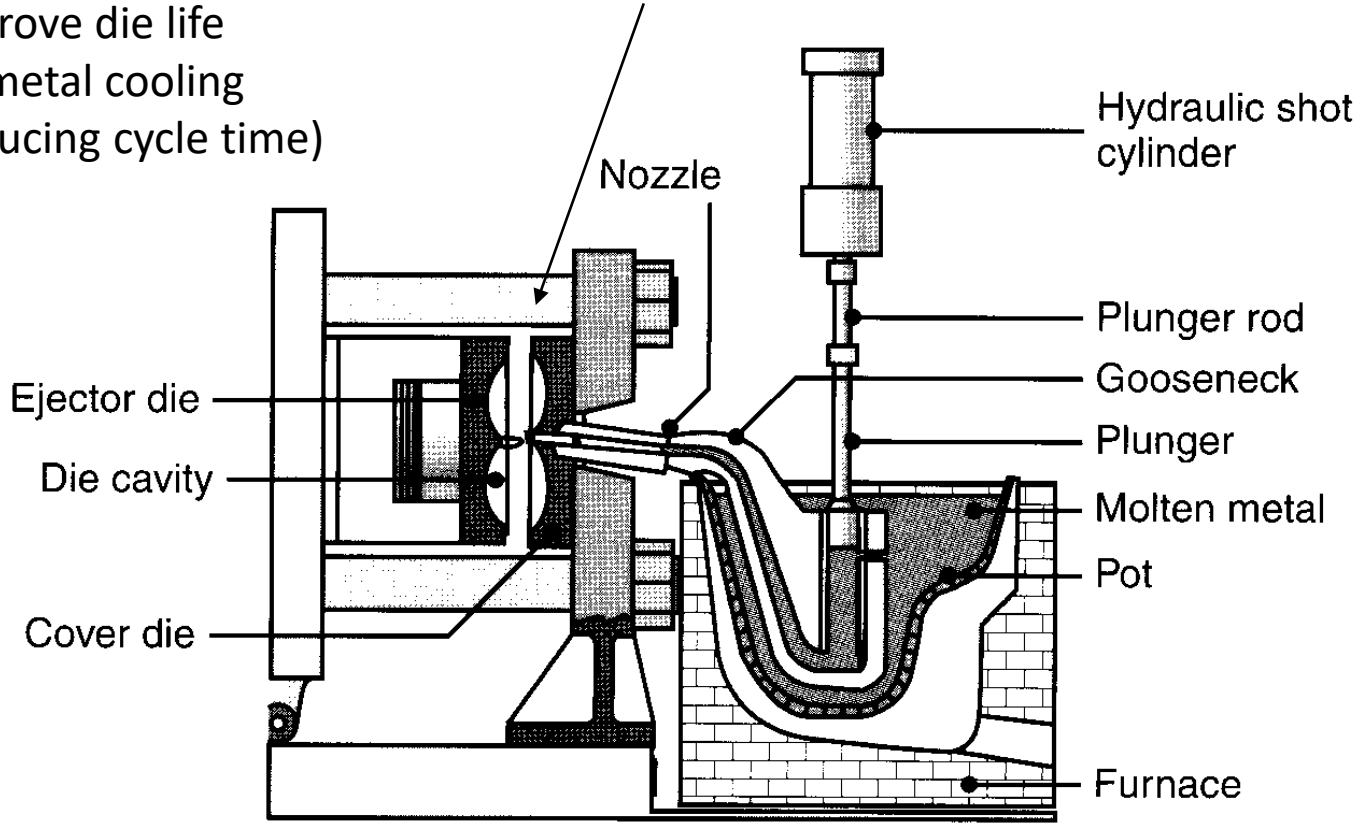
https://batesvilleproducts.com/process/

Hot-chamber process

Dies are cooled by circulating water or oil:

- to improve die life
- rapid metal cooling
  (reducing cycle time)

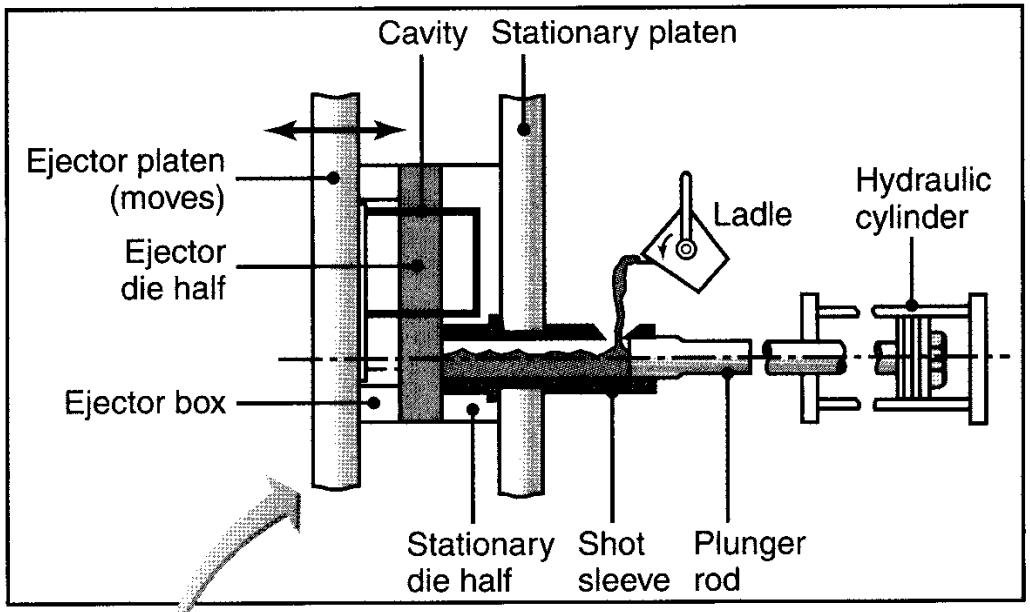
Pressure: up to 35 MPa

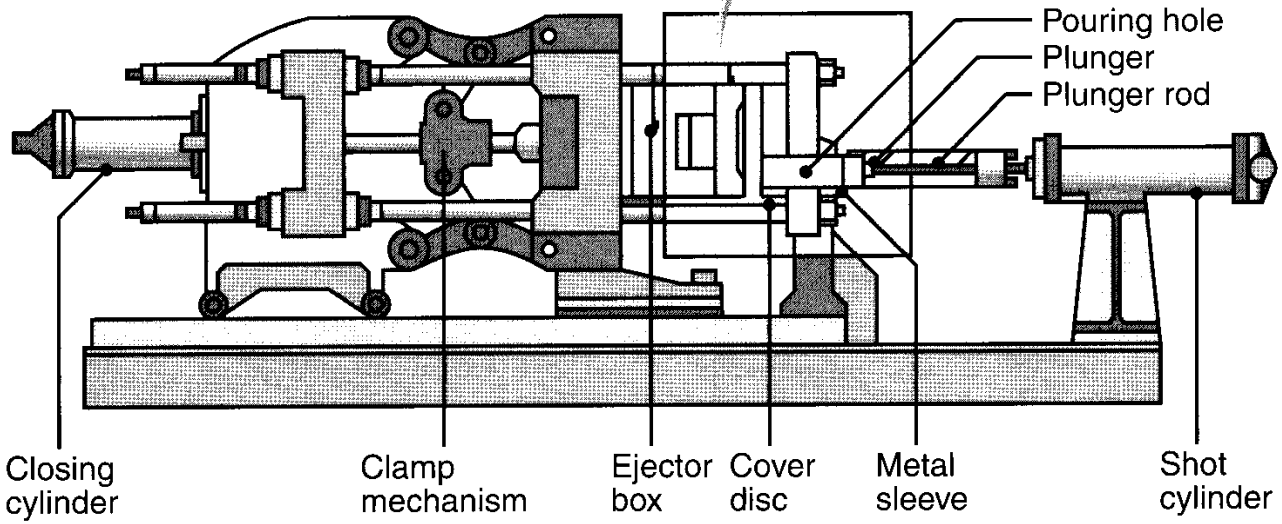


Cycle times: 200 - 300 shots per hour for zinc

Cold-chamber process

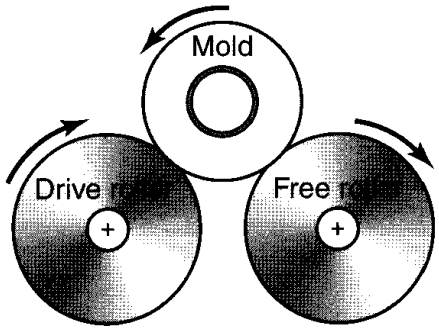
Pressure: 20-70 MPa

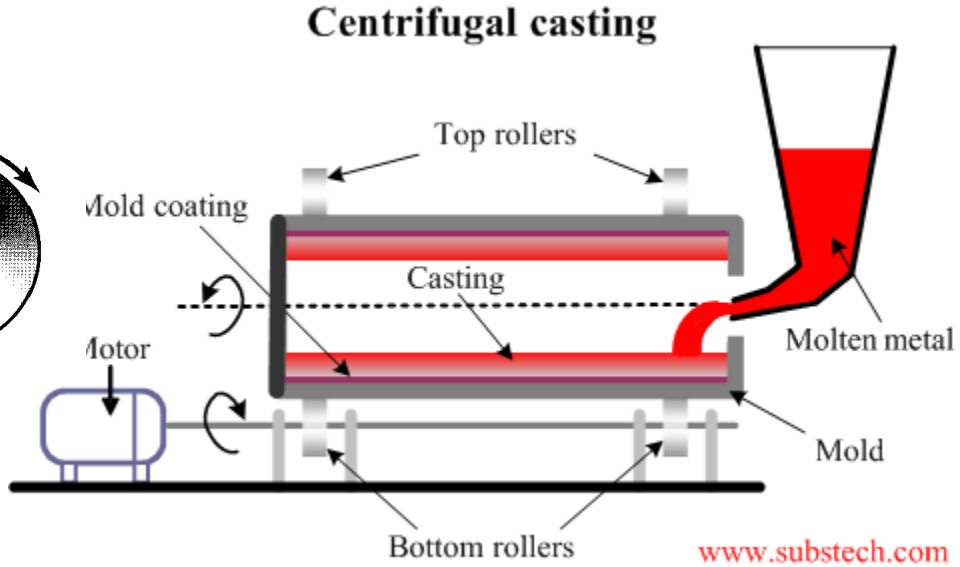




(Pressure) Die casting

Centrifugal casting





http://essenaluminium.com/services/centrifugal-casting-products-manufacturers-in-india/

Centrifugal casting

Metal casting processes overview

	Sand	Shell	Evaporative pattern	Plaster	Invest-ment	Permanent mold	Die	Centri-fugal
material	All			Non-ferrous	All		Non-ferrous	All
Weight Min	0.01	0.01	0.01	0.01	0.001	0.1	<0.01	0.01
Max	No limit	100+	100+	50+	100+	300	50	5000+
Surface	accep-table	good	acceptable	good	Very good	good	good	good
Shape complexity	good	good	good	good	Very good	good	Very good	good
Dim. tolerance	1.6-4 mm	+0.003		+0.005 - 0.01	+0.005	±0.015	+0.001 - 0.005	0.015
Min. thickness	3	2	2	1	1	2	0.5	2
Min. quantity	1	100	500	10	10	1000	10 000	10-10 000

Metal casting processes

Process / mass (kg)	0.01	0.1	1	10	100	1000	10 000	100 000
Sand		Ra =100 µm						
Shell			Ra =10-25 µm					
Investment	Ra < 10 µm							
Permanent mold		Ra = 10-50 µm						
Die	Ra =1.6 - 10 µm							

Powder metallurgy

- Components are made of metal powders
- Reduce the need of metal removal
- Materials that cannot be melted or formed in other ways (WC)
- Very high alloying content (HSS)

https://www.pm-review.com/introduction-to-powder-metallurgy/why-powder-metallurgy/

Powder metallurgy

Steps

1. Powder blending
2. Die compaction
3. Sintering
    1. Coining
    2. Heat treatment

Processes

- Powder forging

Press and sinter + hot forging

- Hot isostatic pressing

Powder in sealed can, 0.7 T_{hom},
100 MPa

- Metal injection moulding

Powder + binder injection moulded (green), heated (brown) and sintered

- Electric current assisted sintering

Electric current to densify powders

- Additive manufacturing

SLS, SLM, EBM

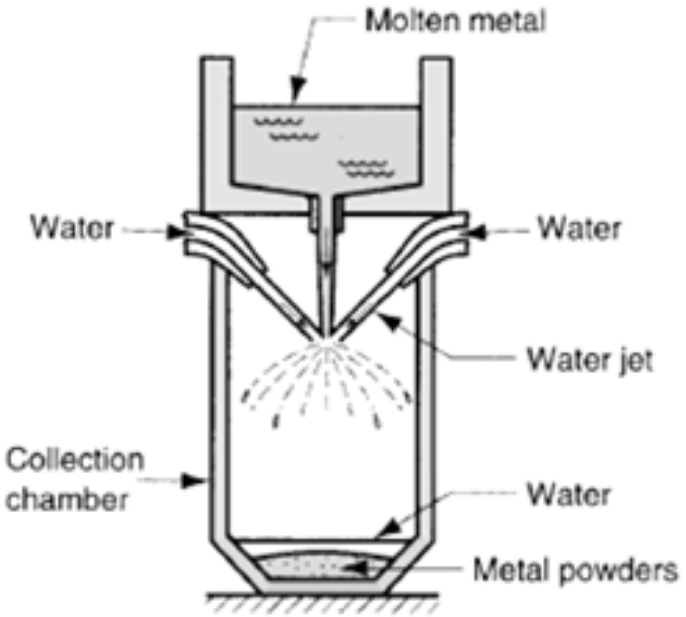
Powder manufacturing

- Sponge iron process

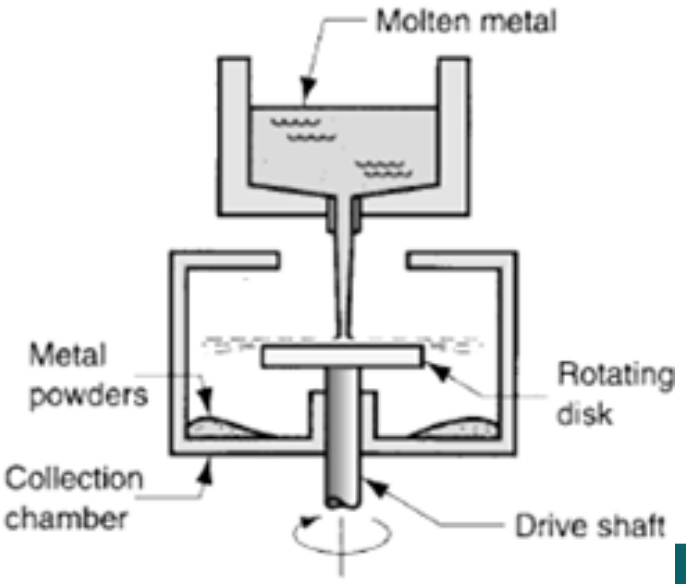
Fe_3O_4 ore is mixed with coke and lime and placed in a silicon carbide retort. The filled retort is then heated in a kiln, where the reduction process leaves an iron “cake” and a slag.

- Atomization

Forcing a molten metal stream through an orifice at moderate pressures. Gas, liquid is introduced or centrifugal process.



(c)



(d)

Powder compaction + Sintering

- Die pressing

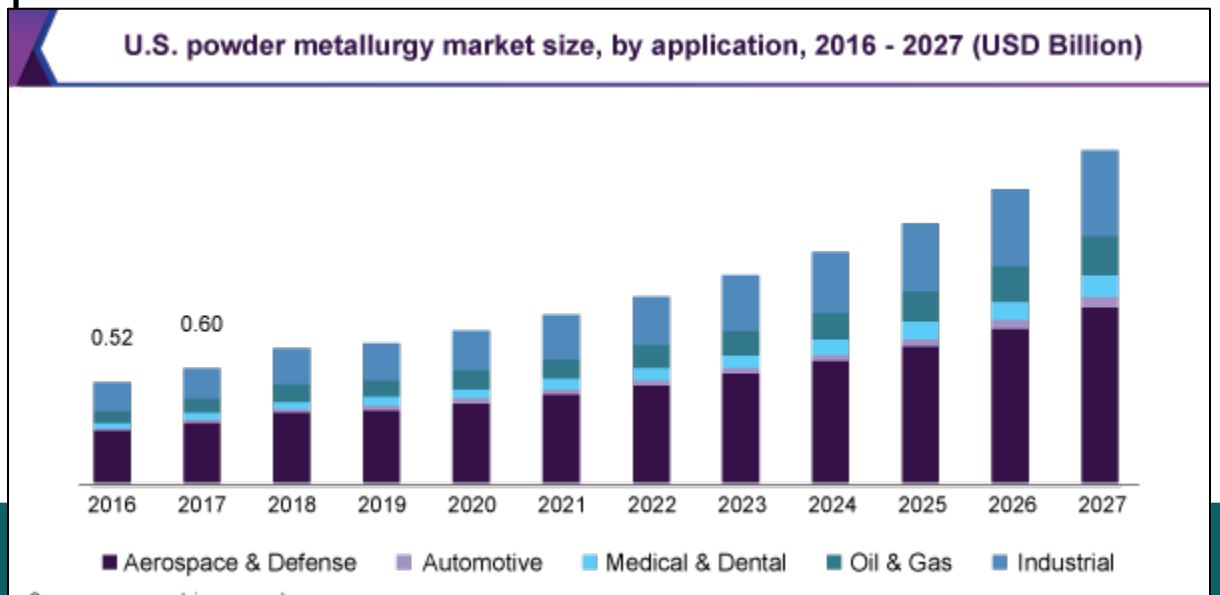
Presses are used (hydraulic, mechanical, servo-electrical)

- Isostatic pressing

In hot isostatic pressing (HIP) compact formation and sintering occur simultaneously.

- Sintering

During this process, the surfaces of the particles are bonded and desirable properties are achieved.



https://www.grandviewresearch.com/industry-analysis/powder-metallurgy-market

Powder Metallurgy

Thank you for your attention!

References

- https://youtu.be/S07fPo45BvM
- https://youtu.be/UBeUp-oP7Lk
- https://youtu.be/WhS1ziBDxag
- https://youtu.be/TVsJlWEzZY8
- https://youtu.be/3G2sBqXkRT8
- https://youtu.be/N4-kfSD6XJI