CASTING PROCESSES

by

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Mechanical Engineering

Mechanical engineering is a discipline of engineering that applies the principles of physics and materials science for analysis, design, manufacturing, and maintenance of mechanical systems.

Manufacturing

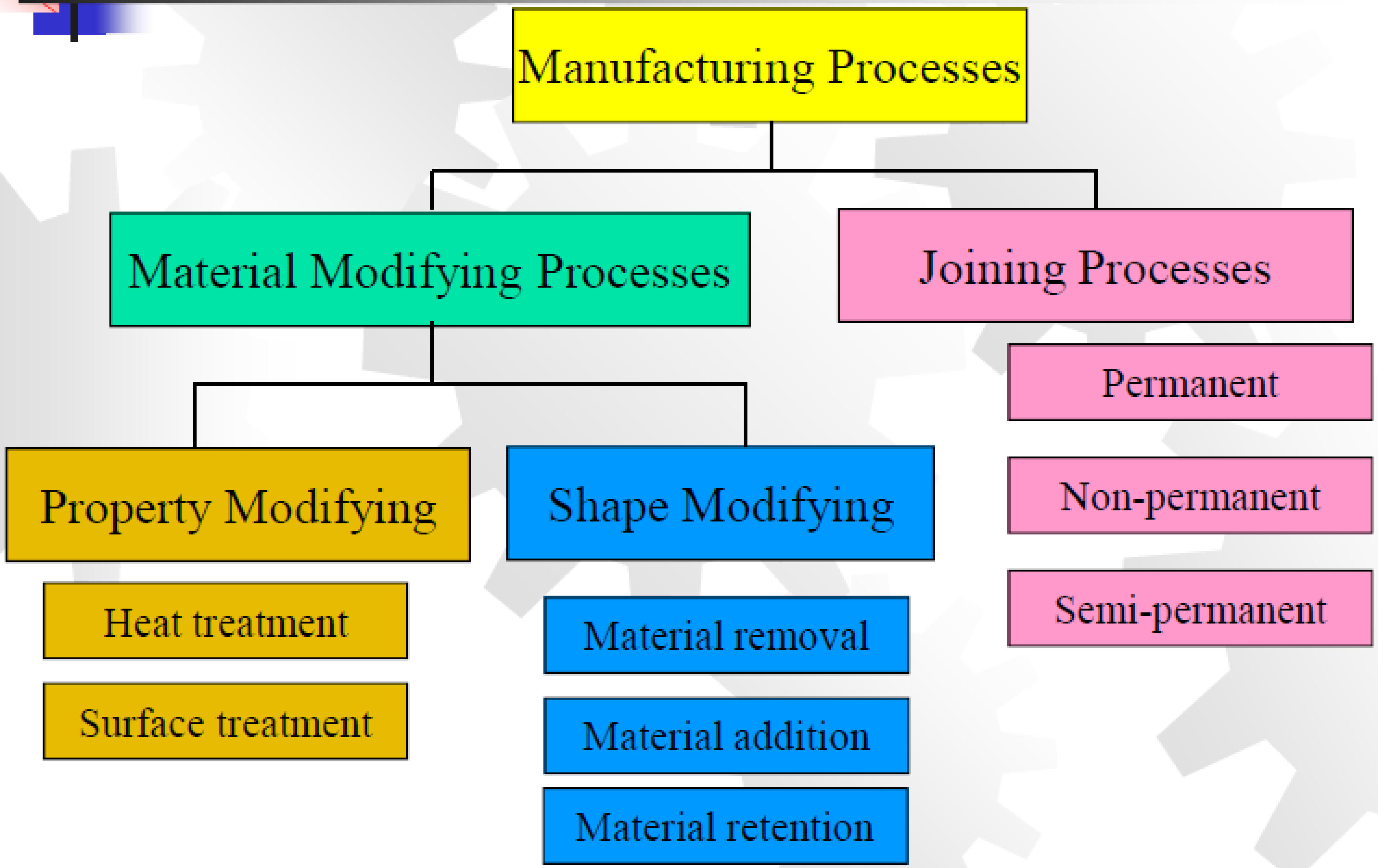
Manufacturing basically implies making of goods or articles and providing services to meet the needs of mankind.

Manufacturing process is that part of the production process which is directly concerned with the change of form or dimensions of the part being produced.

Evolution of Manufacturing

- Began about 5000 to 4000 B.C with the production of various articles of wood, ceramic, stone and metal
- Derived from Latin word *manu factus* – meaning “made by hand”
- The word *manufacture* first appeared in 1567
- The word *manufacturing* appeared in 1683
- Production is also used interchangeably .

Manufacturing process



Traditional Manufacturing Processes

- Casting
- Forming
- Sheet metal processing
- Plastics processing
- Joining
- Lathe

Bronze statue of Zeus from Artemision,
ca. 460 BC

CASTING

Casting since about 4000 BC…

Ancient Greece; bronze statue casting circa 450BC

Iron works in early Europe, e.g. cast iron cannons from England circa 1543

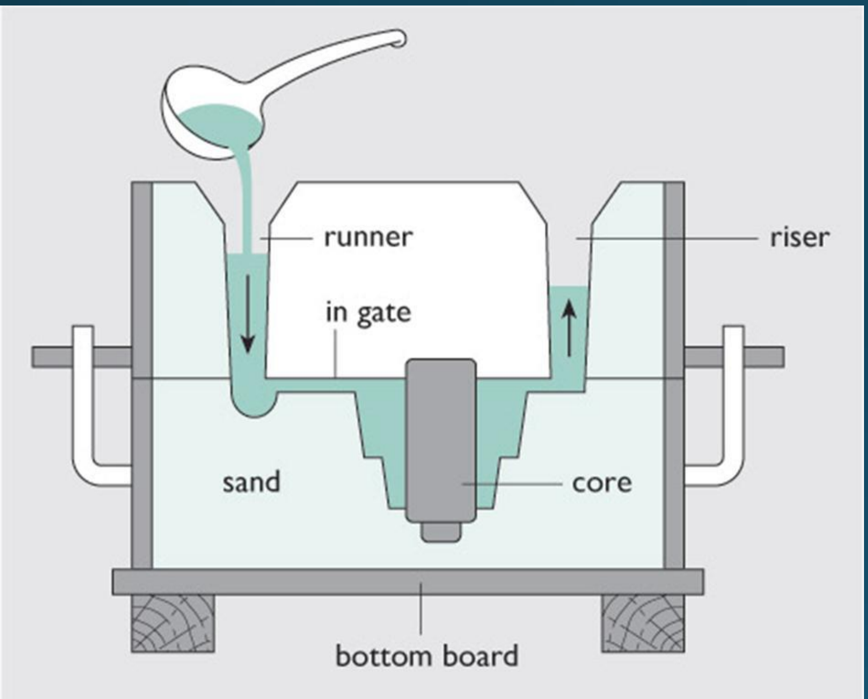
Casting Process

- Casting process is one of the **earliest metal shaping techniques** known to human being.
- It means **pouring molten metal into a refractory mold cavity and allows it to solidify.**
- The solidified object is taken out from the mold either by breaking or taking the mold apart.
- The **solidified object is called casting** and the technique followed in method is known as casting process.

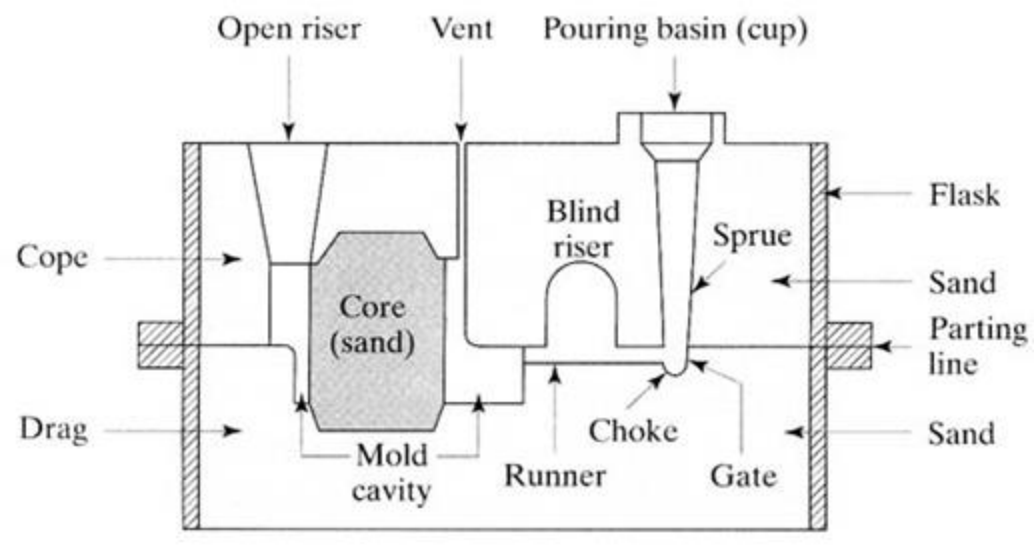
Six basic steps in this process:

- Place a pattern in sand to create a mold.
- Incorporate the pattern and sand in a gating system.
- Remove the pattern.
- Fill the mold cavity with molten metal.
- Allow the metal to cool.
- Break away the sand mold and remove the casting.

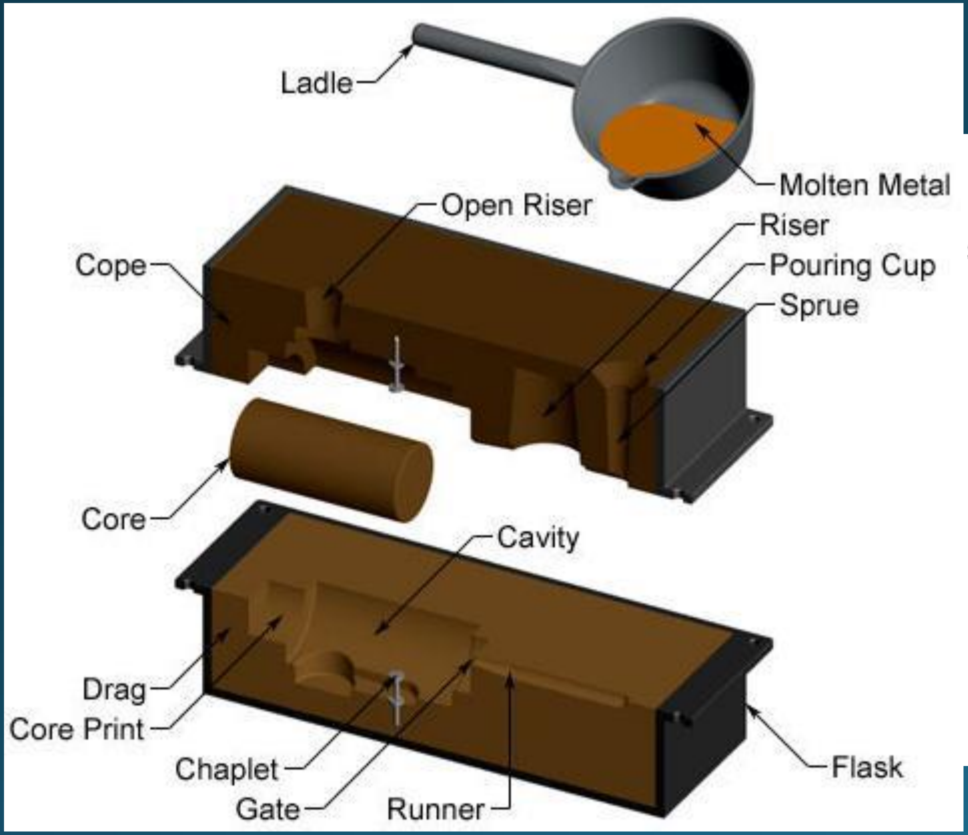
Mold Box

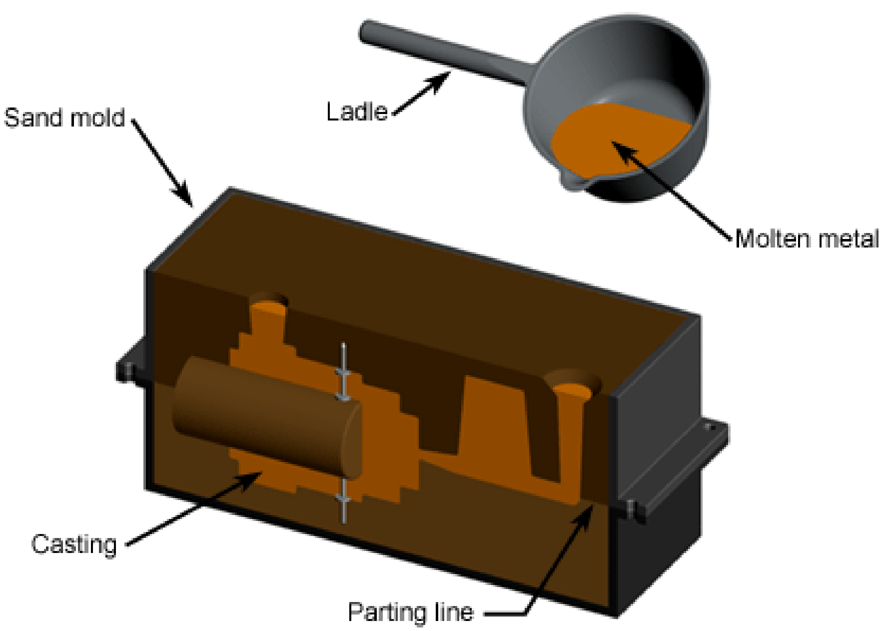


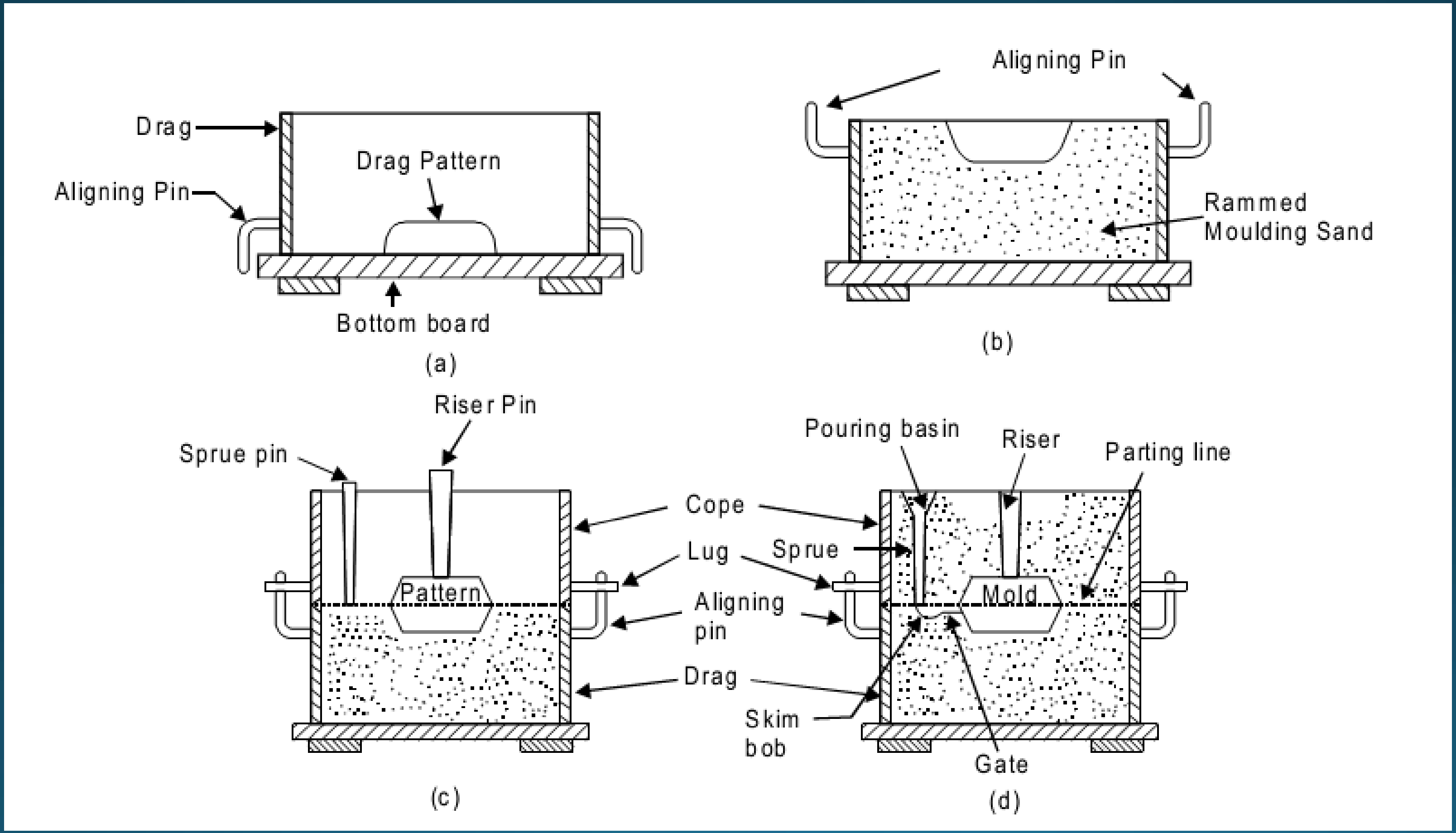
runner
riser
in gate
sand
core
bottom board



Open riser
Vent
Pouring basin (cup)
Flask
Cope
Blind riser
Sprue
Sand
Core (sand)
Parting line
Drag
Choke
Sand
Mold cavity
Runner
Gate


Ladle
Molten Metal
Open Riser
Riser
Pouring Cup
Sprue
Cope
Core
Cavity
Drag
Core Print
Chaplet
Gate
Runner
Flask


Sand mold
Ladle
Molten metal
Casting
Parting line


Drag
Drag Pattern
Aligning Pin
Bottom board
(a)
Aligning Pin
Rammed
Moulding Sand
(b)
Riser Pin
Sprue pin
Pattern
(c)
Pouring basin
Riser
Parting line
Cope
Lug
Sprue
Aligning
pin
Mold
Drag
Skim
bob
Gate
(d)

Casting Terminology

- Pattern: An approximate duplicate or true replica of required product of casting
- Flask/Box: The rigid metal or a wooden frame that holds the moulding material
- Cope: Top half of the moulding box
- Drag: Bottom half of the moulding box
- Core: As and shape that is inserted into a mould to produce internal features of a casting such as holes.

Continue.....

- Riser: A vertical opening in the mould
- Act as a vent for gases
- Helps to confirm that the mould is completely filled
- Act as a **reservoir** of molten metal to feed and compensate for shrinkage during solidification of a casting

Continue….

- Gating System: Channels used to deliver the molten metal to the mould cavity
- Sprue: The vertical passage in the gating system
- Runner: The horizontal channel of the gating system
- Gate: Channel which connects runner and mould

Advantages

- Product can be cast as one piece.
- Very heavy and bulky parts can be manufactured
- Metals difficult to be shaped by other manufacturing processes may be cast (eg: Cast Iron)
- Best for mass production
- Complex shapes can be manufactured

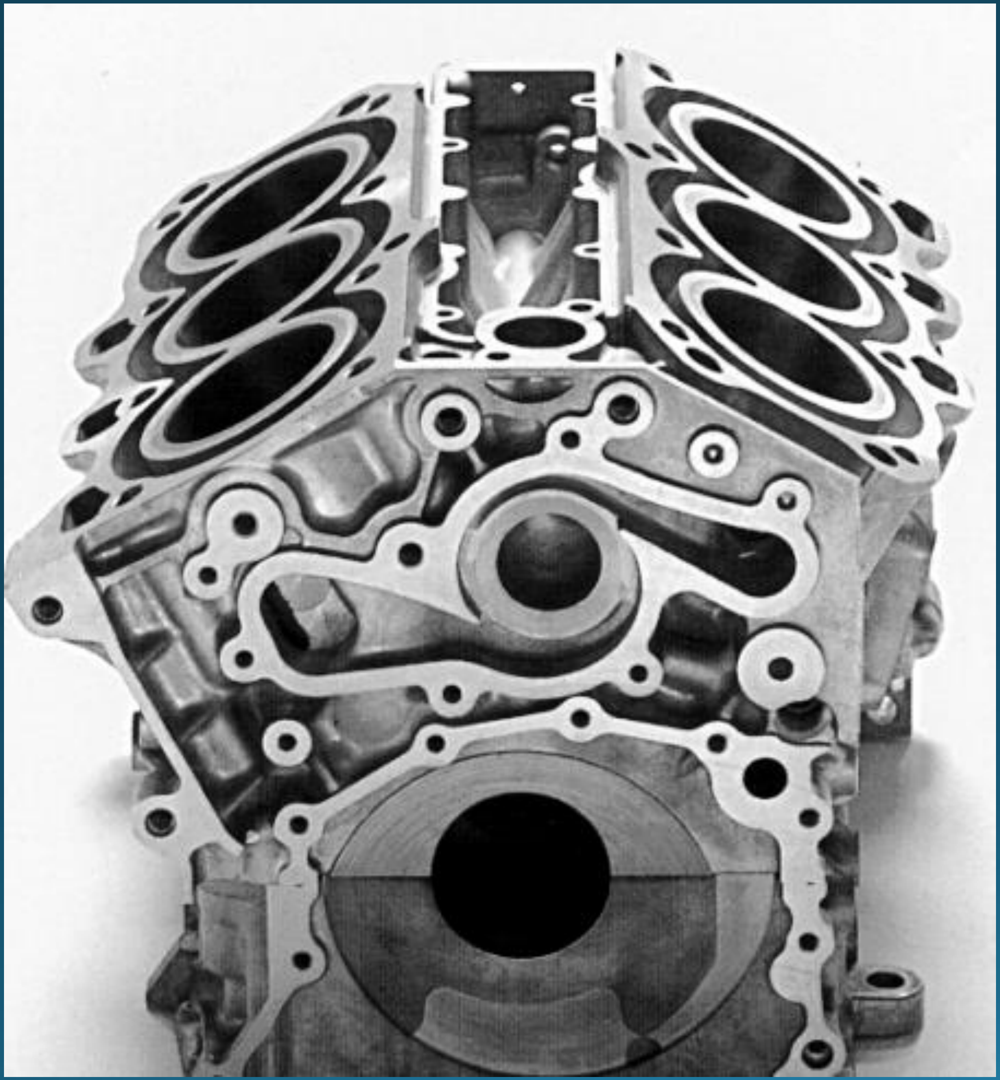
- VERSATILE: complex geometry, internal cavities, hollow sections
- VERSATILE: small (~10 grams) → very large parts (~1000 Kg)
- ECONOMICAL: little wastage (extra metal is re-used)
- ISOTROPIC: cast parts have same properties along all directions

Disadvantages of Casting

- Casting process is a labour intensive process
- Not possible for high melting point metals
- Dimensional accuracy, surface finish and the amount of defects depends on the casting process
- Allowances required.

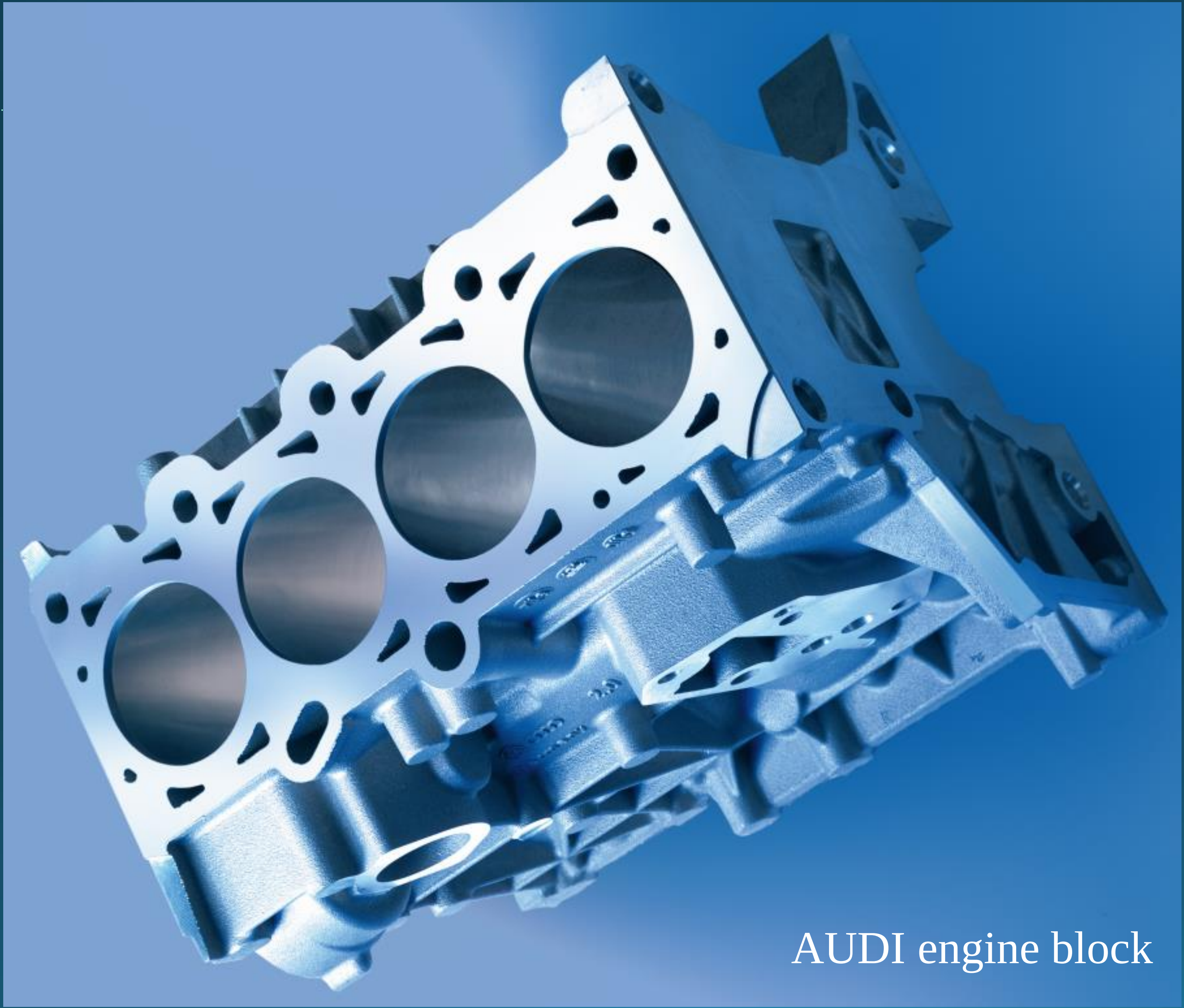
Applications

- Transportation vehicles(eg.:engines)
- Machine tool structures.
- Turbine vanes
- Mill housing
- Valves
- Sanitary fittings
- Agricultural parts
- Construction &atomic energy applications.

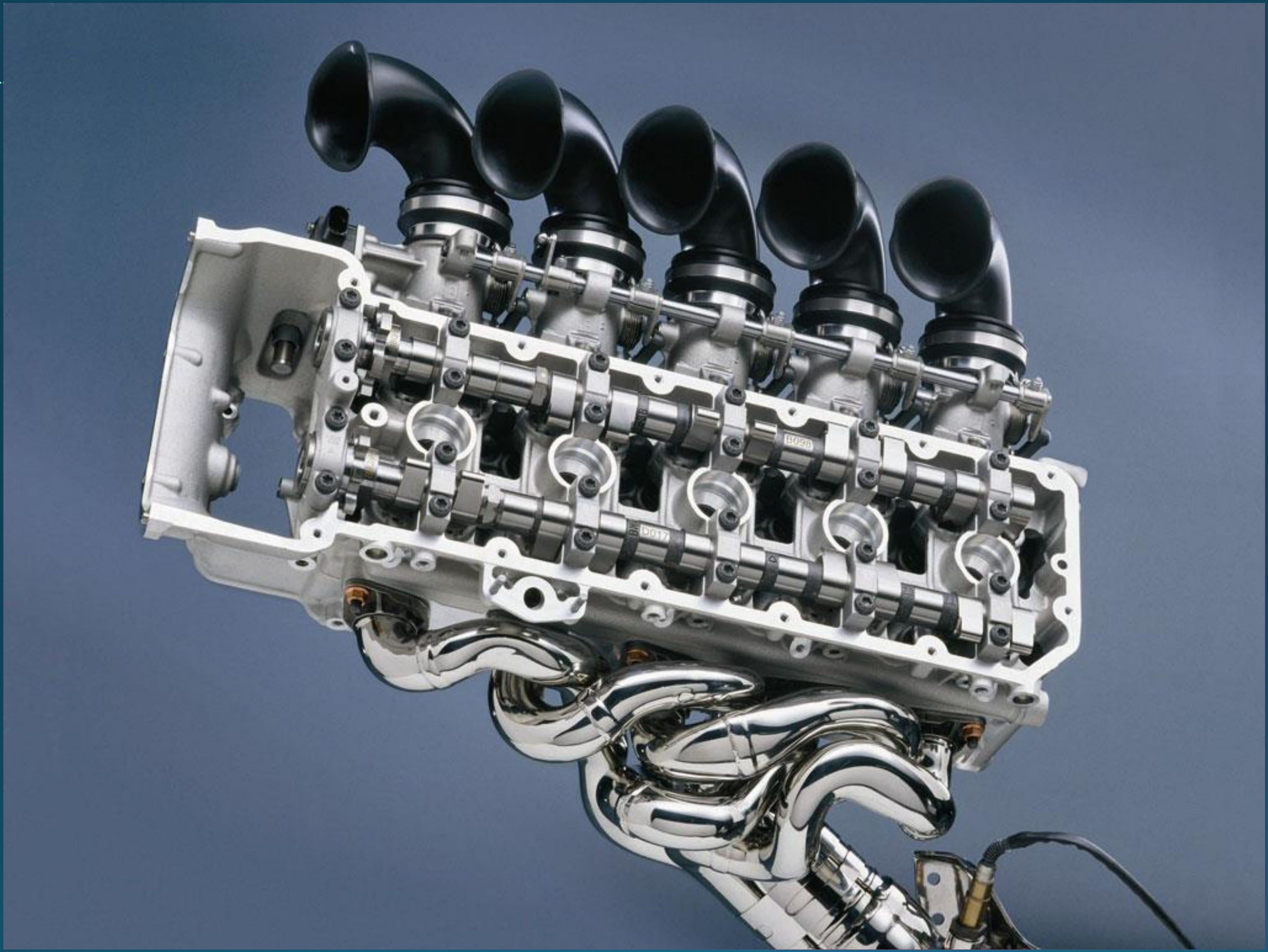


V6 engine block

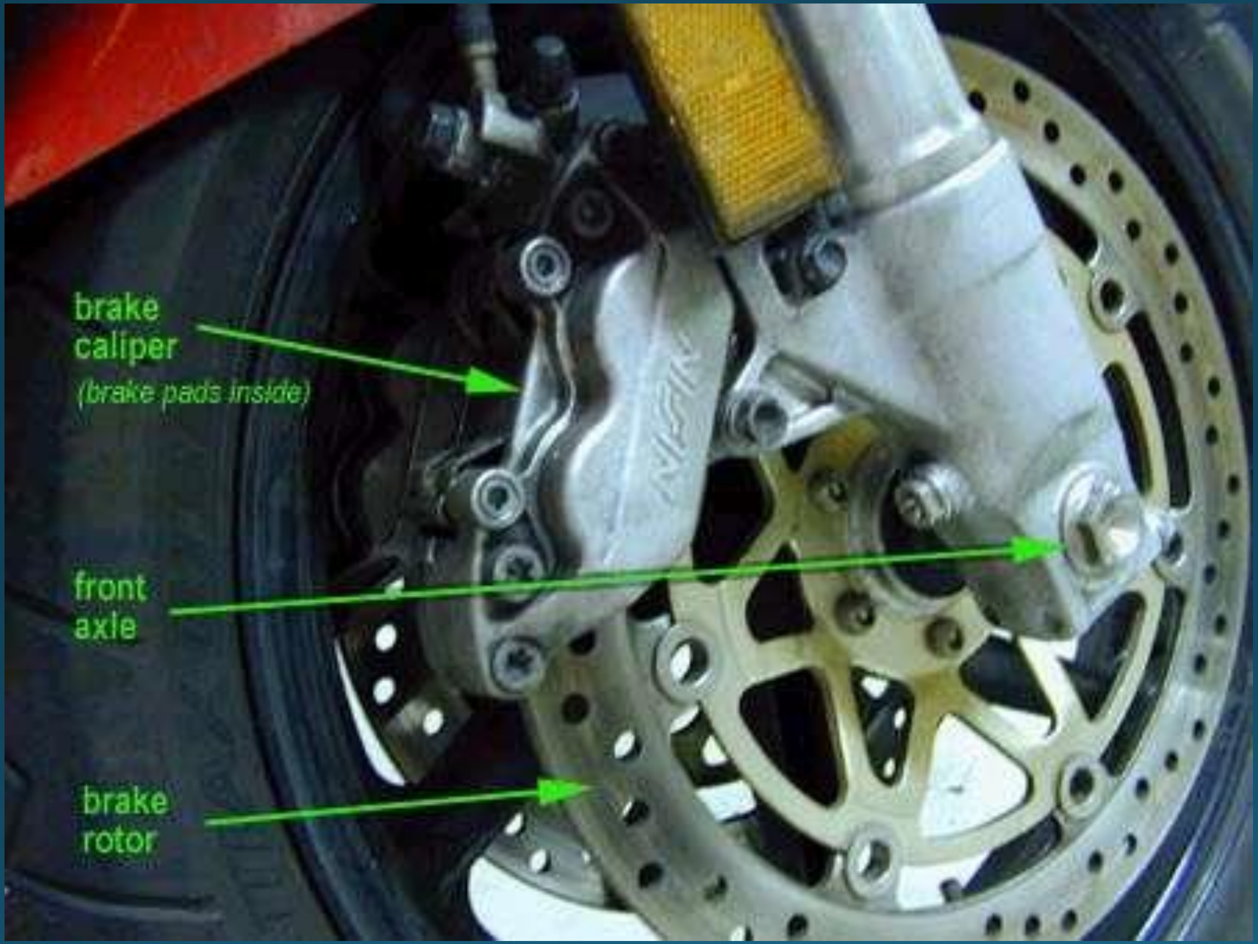
Crank Shaft



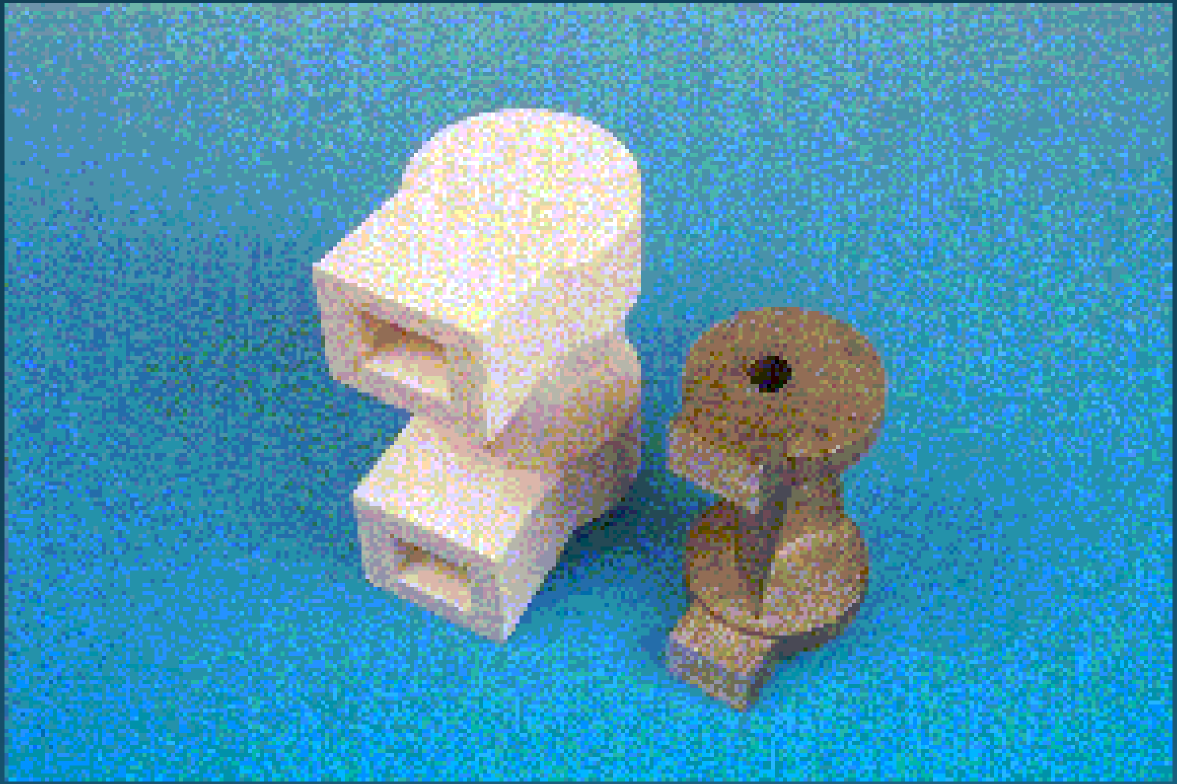
AUDI engine block

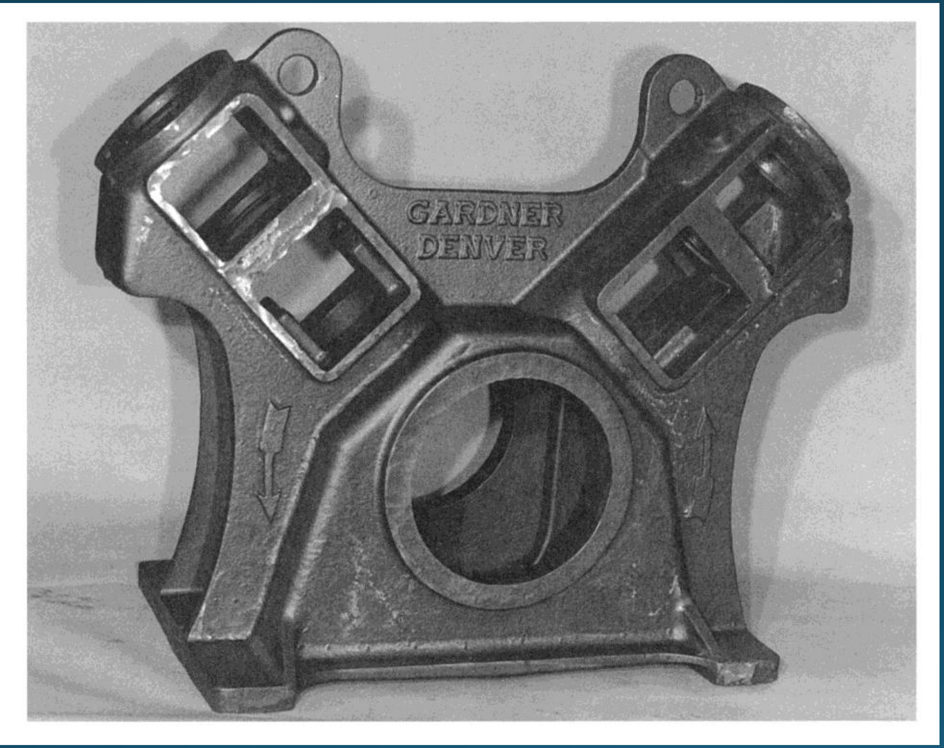


BMW cylinder head



Brake assembly




GARDNER
DENVER

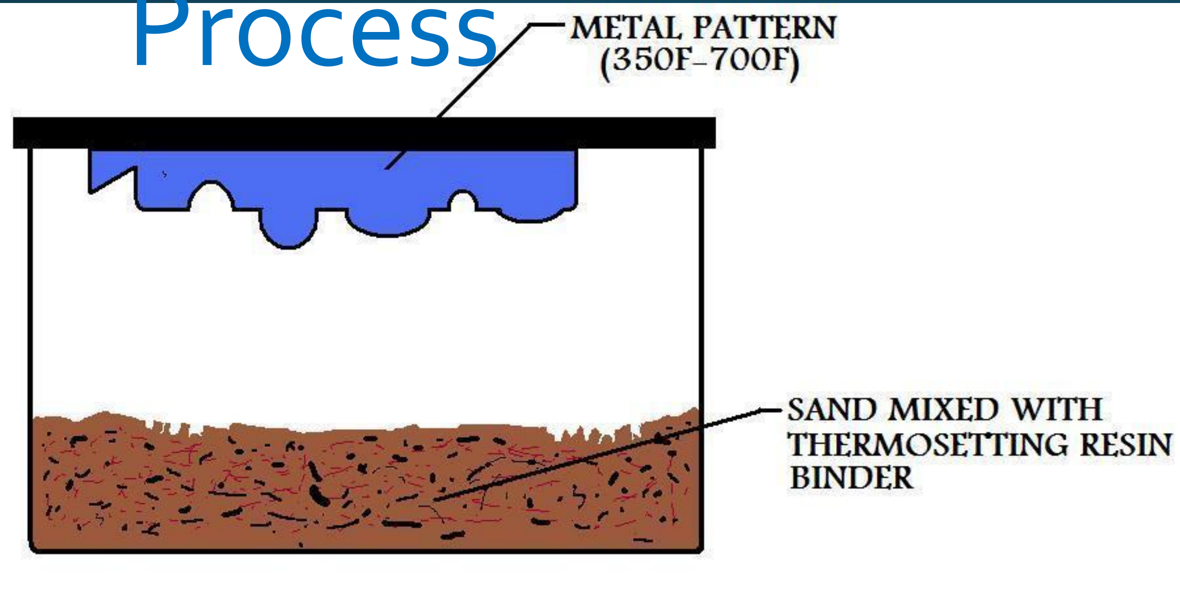
- Special Casting Processes

Shell Mold Casting

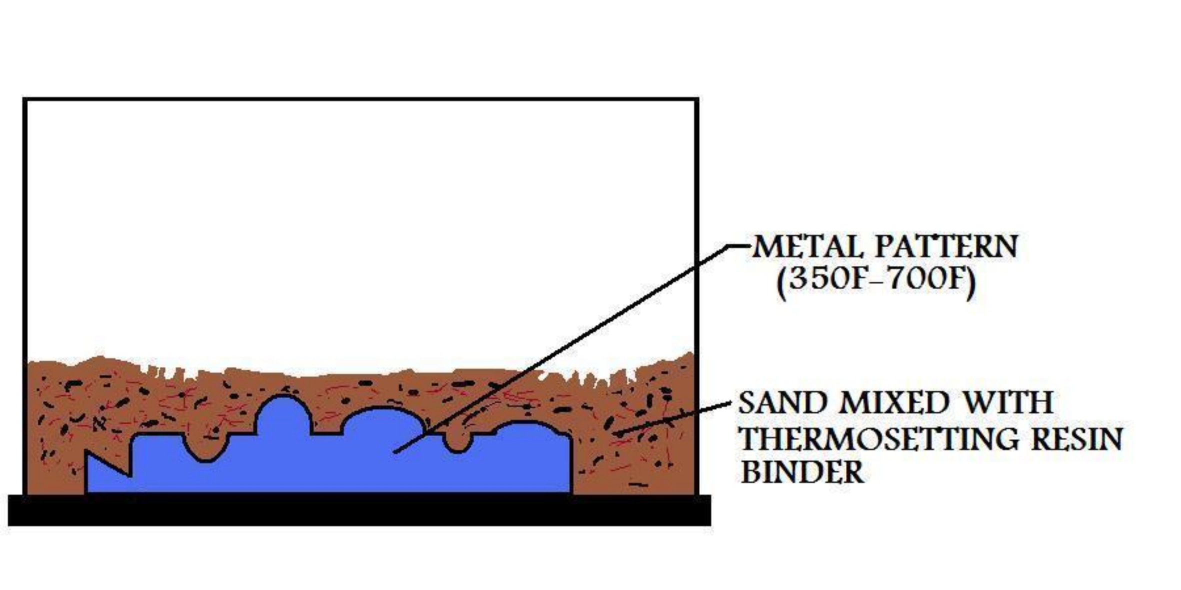
- Shell mold casting or shell molding is a metal casting process in manufacturing industry in which the mold is a thin hardened shell of sand and thermosetting resin binder, backed up by some other material.

- Typical parts manufactured in industry using the shell mold casting process include cylinder heads, gears, bushings, connecting rods, camshafts and valve bodies.

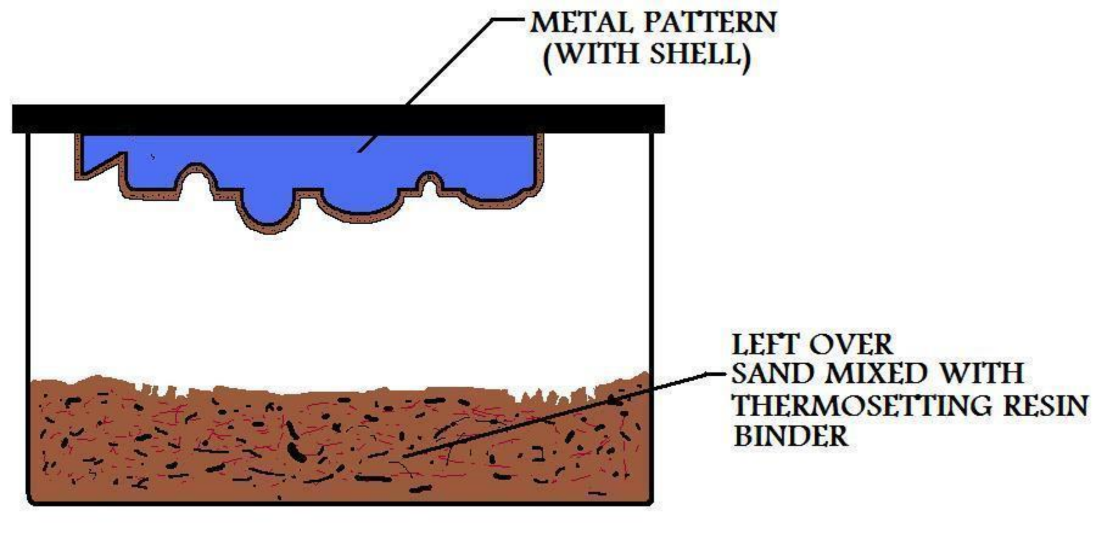
Process

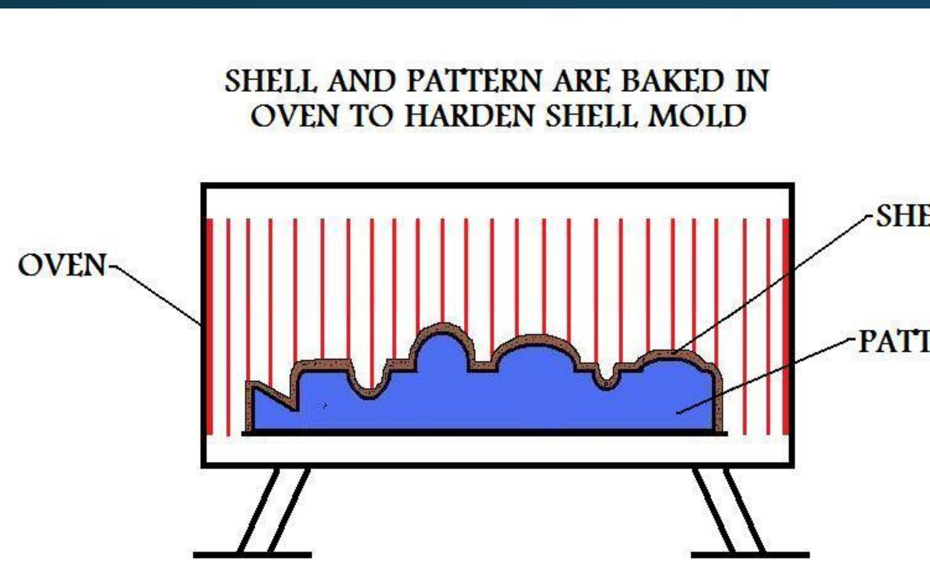


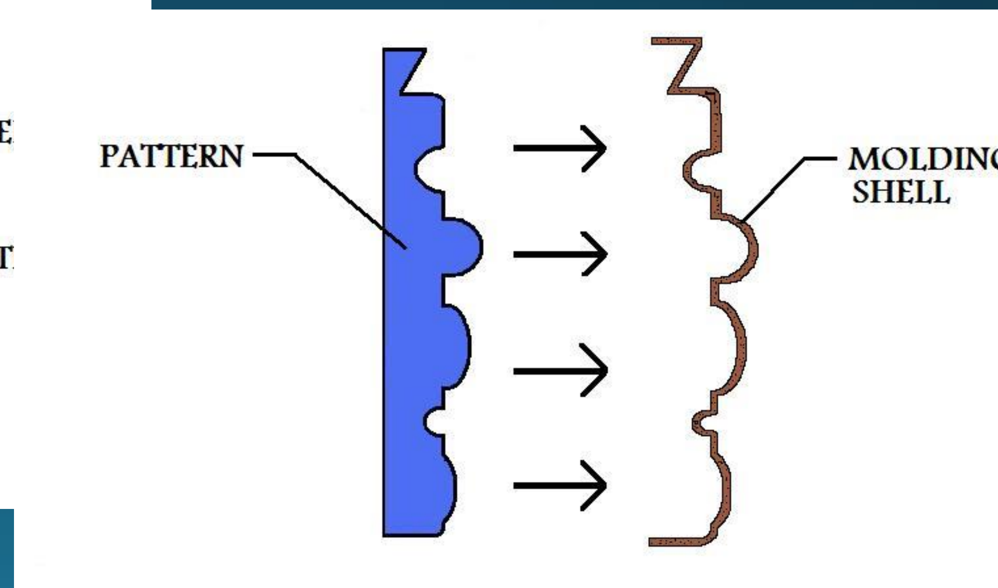
METAL PATTERN
(350F-700F)
SAND MIXED WITH
THERMOSETTING RESIN
BINDER

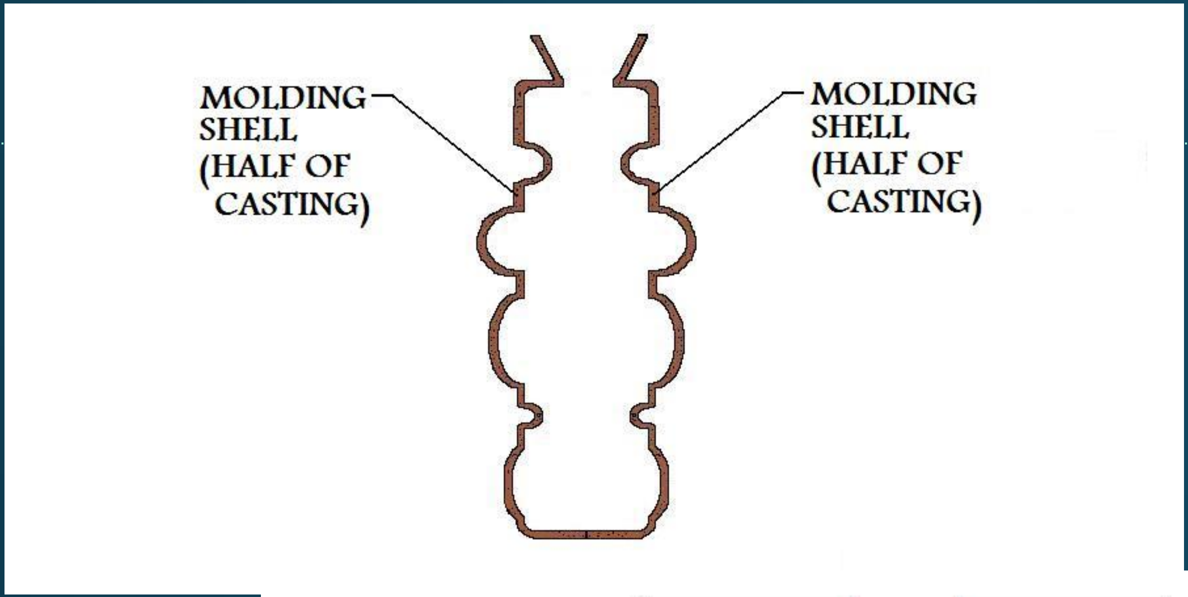


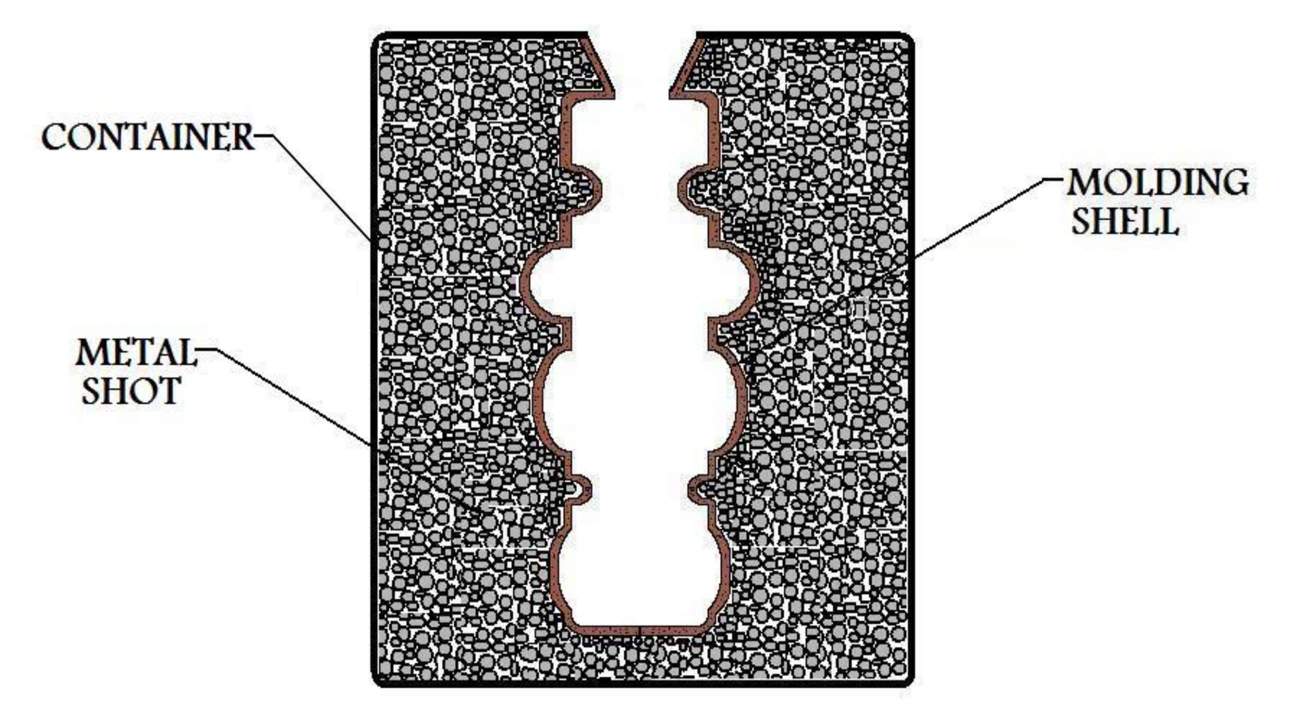
METAL PATTERN
(350F-700F)
SAND MIXED WITH
THERMOSETTING RESIN
BINDER


METAL PATTERN
(WITH SHELL)
LEFT OVER
SAND MIXED WITH
THERMOSETTING RESIN
BINDER


SHELL AND PATTERN ARE BAKED IN
OVEN TO HARDEN SHELL MOLD
OVEN


PATTERN
SHELL


MOLDING SHELL (HALF OF CASTING)
MOLDING SHELL (HALF OF CASTING)


CONTAINER
METAL SHOT
MOLDING SHELL

Properties and Considerations of Manufacturing by Shell Mold Casting

- The internal surface of the shell mold is very smooth and rigid.
- Shell mold casting enables the manufacture of complex parts with thin sections and smaller projections than green sand mold casting.
- Manufacturing with the shell mold process also imparts high dimensional accuracy. Tolerances of .010 inches (.25mm) are possible. Further machining is usually unnecessary when casting by this process.
- Shell sand molds are less permeable than green sand molds and binder may produce a large volume of gas as it contacts the molten metal being poured for the casting. For these reasons, shell molds should be well ventilated.
- The expense of shell mold casting is increased by the cost of the thermosetting resin binder, but decreased by the fact that only a small percentage of sand is used compared to other sand casting processes.
- Shell mold casting processes are easily automated.
- manufacturing by shell casting may be economical for large batch production.

Investment Casting

- Investment casting is one of the oldest manufacturing processes, dating back thousands of years, in which molten metal is poured into an expendable ceramic mold.
- The mold is formed by using a wax pattern - a disposable piece in the shape of the desired part. The pattern is surrounded, or "invested", into ceramic slurry that hardens into the mold.
- Investment casting is often referred to as "lost-wax casting" because the wax pattern is melted out of the mold after it has been formed.
- However, since the mold is destroyed during the process, parts with complex geometries and intricate details can be created.
-

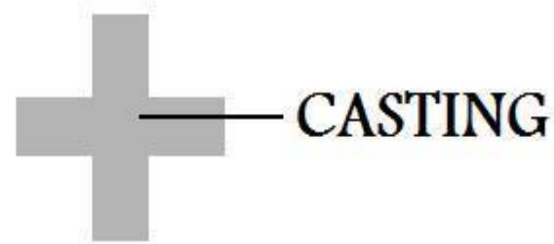
- Investment casting can make use of most metals, most commonly using **aluminum alloys, bronze alloys, magnesium alloys, cast iron, stainless steel, and tool steel**
- This process is beneficial for casting metals with high melting temperatures that can not be molded in plaster or metal.
- Parts that are typically made by investment casting include those with **complex geometry such as turbine blades or firearm components.**

- Investment casting requires the use of a metal die, wax, ceramic slurry, furnace, molten metal, and any machines needed for sandblasting, cutting, or grinding. The process steps include the following:

Process

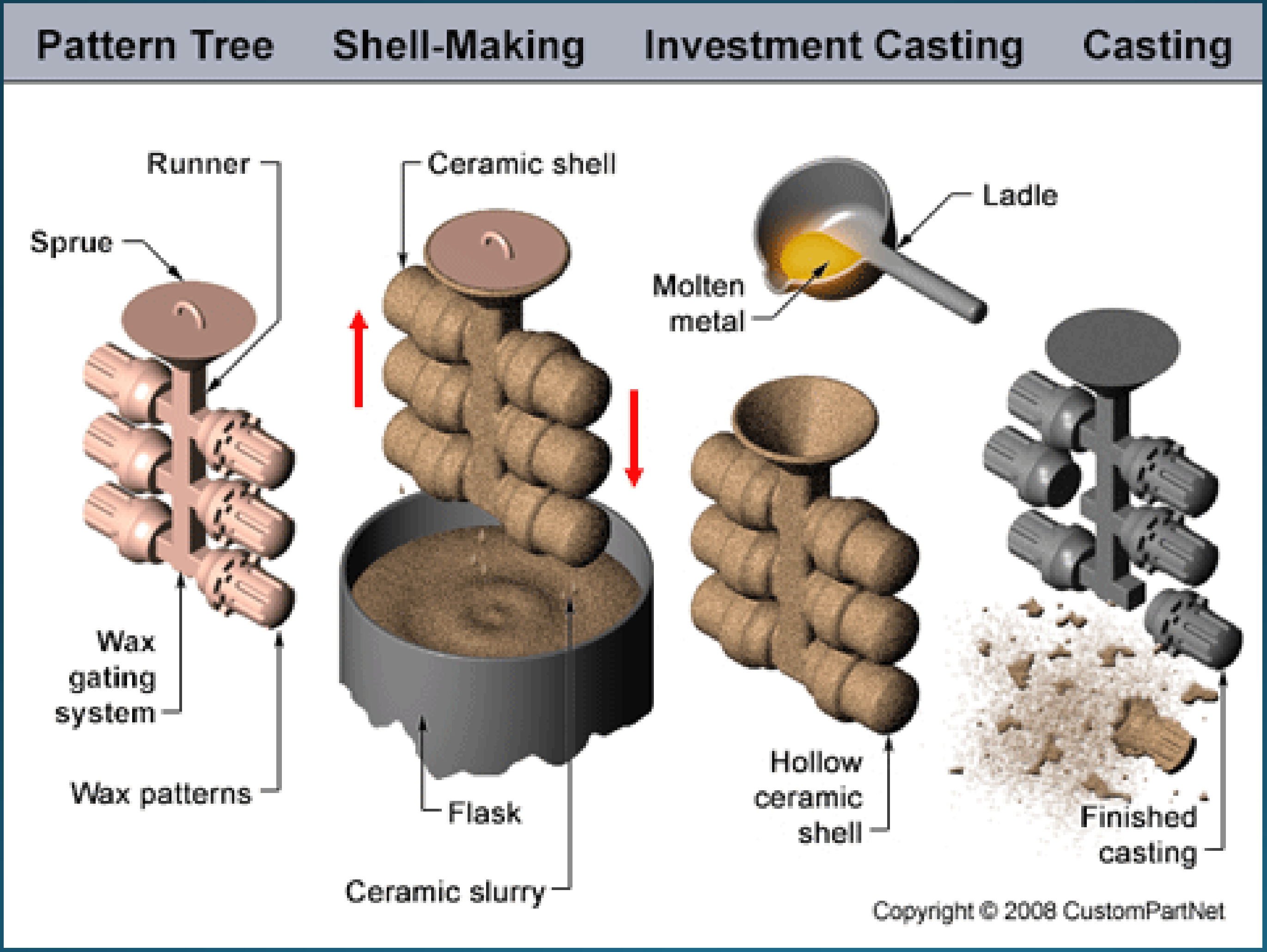
- ***Pattern creation*** **- The wax patterns are typically injection molded into a metal die and are formed as one piece. Cores may be used to form any internal features on the pattern.**
- ***Mold creation*** **- This "pattern tree" is dipped into a slurry of fine ceramic particles, coated with more coarse particles, and then dried to form a ceramic shell around the patterns and gating system. This process is repeated until the shell is thick enough to withstand the molten metal it will encounter.**

INVESTMENT CASTING
FINAL PRODUCT



- The shell is then placed into an oven and the wax is melted out leaving a hollow ceramic shell that acts as a one-piece mold, hence the name "lost wax" casting.
- *Pouring* - The mold is preheated in a furnace to approximately 1000°C (1832°F) and the molten metal is poured from a ladle into the gating system of the mold, filling the mold cavity..
- *Cooling* - After the mold has been filled, the molten metal is allowed to cool and solidify into the shape of the final casting. Cooling time depends on the thickness of the part, thickness of the mold, and the material used.

- *Casting removal* - After the molten metal has cooled, the mold can be broken and the casting removed. The ceramic mold is typically broken using water jets, but several other methods exist. Once removed, the parts are separated from the gating system by either sawing or cold breaking (using liquid nitrogen).
- *Finishing* - Often times, finishing operations such as grinding or sandblasting are used to smooth the part at the gates. Heat treatment is also sometimes used to harden the final part.


Pattern Tree
Shell-Making
Investment Casting
Casting
Runner
Sprue
Wax
gating
system
Wax patterns
Ceramic shell
Flask
Ceramic slurry
Ladle
Molten
metal
Hollow
ceramic
shell
Finished
casting
Copyright © 2008 CustomPartNet

Typical	Feasible	
Shapes:	Thin-walled: Complex Solid: Cylindrical Solid: Cubic Solid: Complex	Flat Thin-walled: Cylindrical Thin-walled: Cubic
Part size:	Weight: 0.02 oz - 500 lb	
Materials:	Metals Alloy Steel Carbon Steel Stainless Steel Aluminum Copper Nickel	Cast Iron Lead Magnesium Tin Titanium Zinc
Surface finish - Ra:	50 - 125 μin	16 - 300 μin
Tolerance:	± 0.005 in.	± 0.002 in.
Max wall thickness:	0.06 - 0.80 in.	0.025 - 5.0 in.
Quantity:	10 - 1000	1 - 1000000
Lead time:	Weeks	Days
Advantages:	Can form complex shapes and fine details Many material options High strength parts Very good surface finish and accuracy Little need for secondary machining	
Disadvantages:	Time-consuming process High labor cost High tooling cost Long lead time possible	
Applications:	Turbine blades, armament parts, pipe fittings, lock parts, handtools, jewelry	

Part to manufctured

Properties And Considerations

- casting of extremely complex parts, with good surface finish.
- Very thin sections can be produced by this process , narrow as .015in (.4mm) have been manufactured using investment casting.
- Investment casting also allows for high dimensional accuracy. Tolerances as low as .003in (.076mm) have been claimed.
- Practically any metal can be investment cast. Parts manufactured by this process are generally small, but parts weighing up to 75lbs have been found suitable for this technique.
- Parts of the investment process may be automated.
- Investment casting is a complicated process and is relatively expensive.

Applications

- Investment casting is used in the **aerospace and power generation industries** to produce turbine blades with complex shapes or cooling systems.
- Blades produced by investment casting can include single-crystal (SX), directionally solidified (DS), or conventional equi-axed blades.
- Investment casting is also widely used by firearms manufacturers to **fabricate firearm receivers, triggers, hammers, and other precision parts at low cost.**
- Other industries that use standard investment-cast parts include **military, medical, commercial and automotive.**

- **Centrifugal casting** or **rotocasting** is a casting technique that is typically used to cast thin-walled cylinders.
- It is noted for the high quality of the results attainable, particularly for precise control of their metallurgy and crystal structure.
- Unlike most other casting techniques, centrifugal casting is chiefly used to manufacture stock materials in standard sizes for further machining, rather than shaped parts tailored to a particular end-use.

Process

- In centrifugal casting, a permanent mold is rotated continuously about its axis at high speeds (300 to 3000 rpm) as the molten metal is poured.
- The molten metal is centrifugally thrown towards the inside mold wall, where it solidifies after cooling.
- The casting is usually a fine-grained casting with a very fine-grained outer diameter, owing to chilling against the mould surface.
- Impurities and inclusions are thrown to the surface of the inside diameter, which can be machined away.
- Casting machines may be either horizontal or vertical-axis. Horizontal axis machines are preferred for long, thin cylinders, vertical machines for rings.
- Most castings are solidified from the outside first. This may be used to encourage directional solidification of the casting, and thus give useful metallurgical properties to it. Often the inner and outer layers are discarded and only the intermediary *columnar zone* is used.
- Centrifugal casting was the invention of Alfred Krupp, who used it to manufacture cast steel tyres for railway wheels in 1852.

•Features of centrifugal casting

- Castings can be made in almost any length, thickness and diameter.
- Different wall thicknesses can be produced from the same size mold.
- Eliminates the need for cores.
- Resistant to atmospheric corrosion, a typical situation with pipes.
- Mechanical properties of centrifugal castings are excellent.
- Only cylindrical shapes can be produced with this process.
- Size limits are up to 3 m (10 feet) diameter and 15 m (50 feet) length.
- Wall thickness range from 2.5 mm to 125 mm (0.1 - 5.0 in).
- Tolerance limit: on the OD can be 2.5 mm (0.1 in) on the ID can be 3.8 mm (0.15 in).
- Surface finish ranges from 2.5 mm to 12.5 mm (0.1 - 0.5 in) rms.

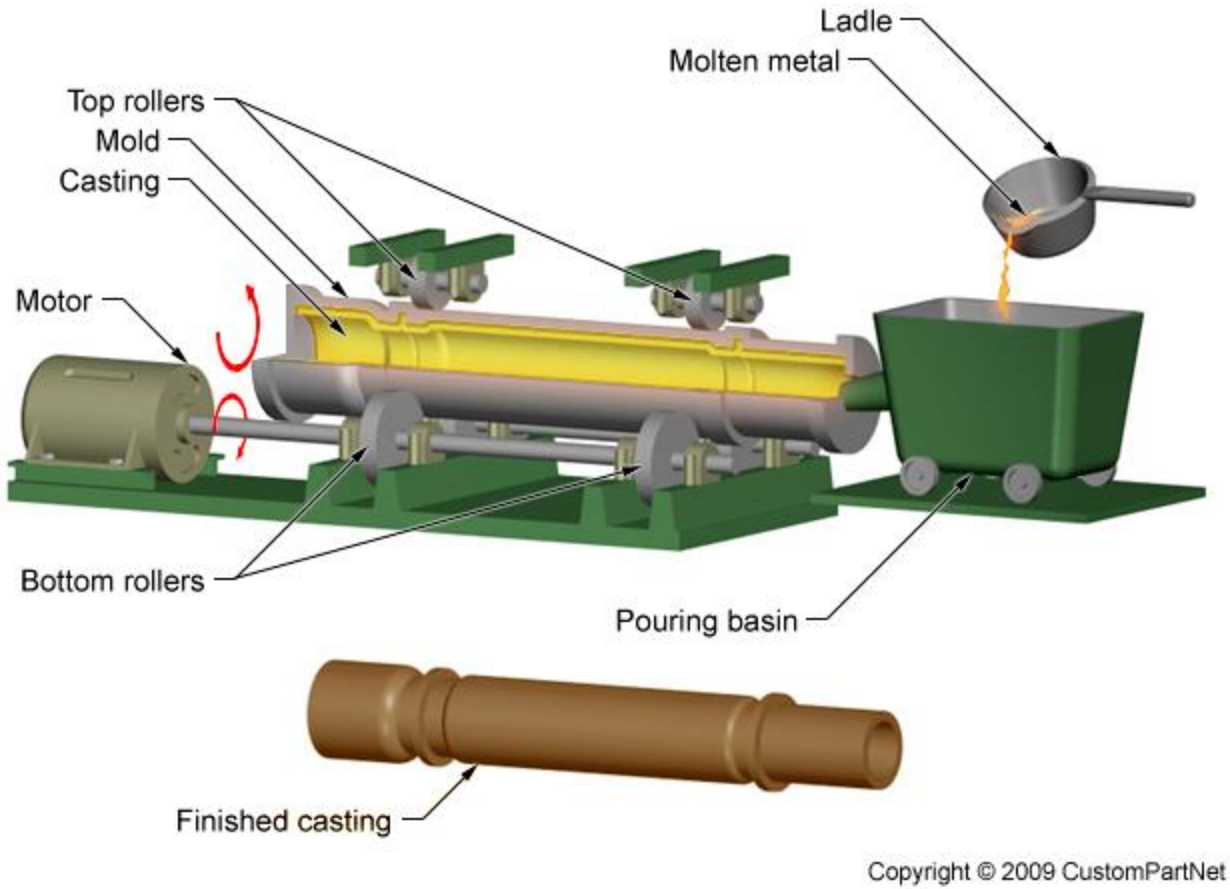
Benefits

- Cylinders and shapes with rotational symmetry are most commonly cast by this technique. "Tall" castings are always more difficult than short castings. In the centrifugal casting technique the radius of the rotation, along which the centrifugal force acts, replaces the vertical axis.
- The casting machine may be rotated to place this in any convenient orientation, relative to gravity's vertical. Horizontal and vertical axis machines are both used, simply to place the casting's longest dimension conveniently horizontal.
- Thin-walled cylinders are difficult to cast by other means, but centrifugal casting is particularly suited to them.
- Centrifugal casting is also applied to the casting of disk and cylindrical shaped objects such as railway carriage wheels or machine fittings where the grain, flow, and balance are important to the durability and utility of the finished product.
- Providing that the shape is relatively constant in radius.
- noncircular shapes may also be cast.

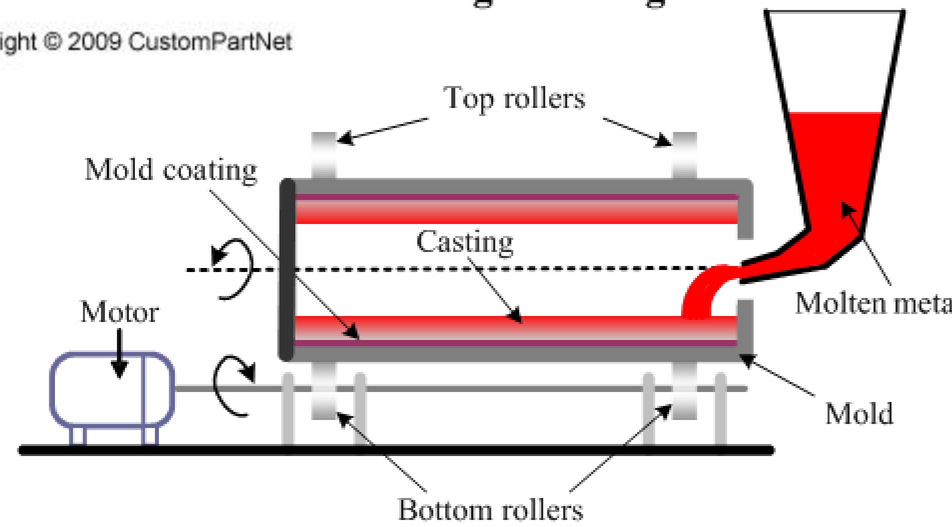
Materials

- Typical materials that can be cast with this process are iron,
- steel,
- stainless steels,
- glass, and
- alloys of aluminum,
- copper and nickel.

- Typical parts made by this process are
- **pipes,**
- **boilers,**
- **pressure vessels ,**
- **flywheels,**
- **cylinder liners and**
- **other parts that are axi-symmetric.**
- It is notably used to cast cylinder liners and sleeve valves for piston engines, parts which could not be reliably manufactured otherwise.



Centrifugal casting



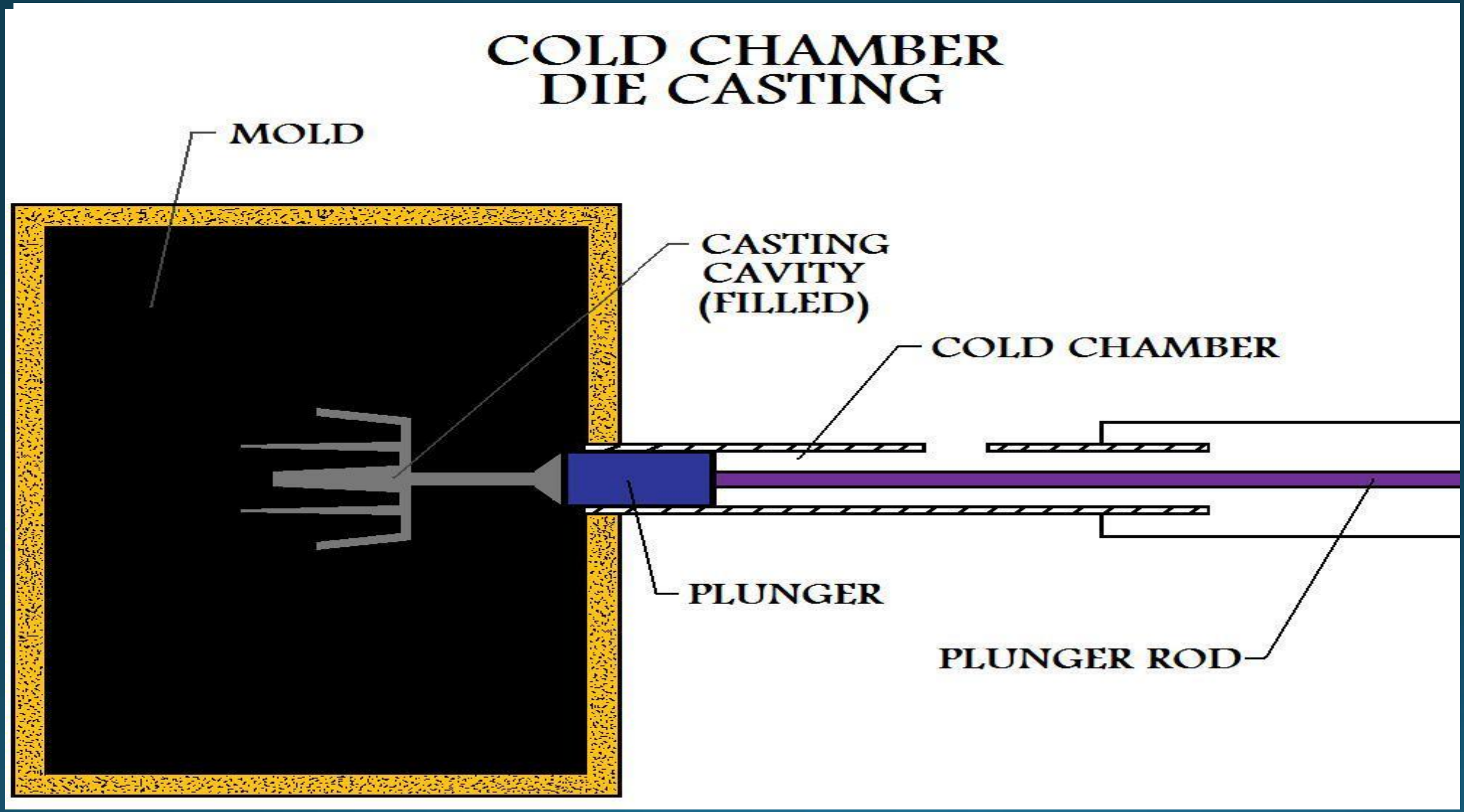

CLI

CENTRIFUGAL CASTING

Cold chamber die casting

- Cold chamber die casting is the second of the two major branches of the die casting manufacturing process.

Cold chamber die casting



- Pressures of 3000psi to 50000psi (20MPa to 350MPa) may be used in manufacturing industry to fill the mold cavities with molten material during cold chamber die casting manufacture.
- Castings manufactured by cold chamber die casting have all the advantages characteristic of the die casting process, such as intricate detail, thin walls, and superior mechanical properties.
- The significant initial investment into this manufacturing process makes it suitable for high production applications.

Advantages

- Excellent dimensional accuracy (dependent on casting material, but typically 0.1 mm for the first 2.5 cm (0.005 inch for the first inch) and 0.02 mm for each additional centimeter (0.002 inch for each additional inch).
- Smooth cast surfaces (Ra 1–2.5 micrometres or 0.04–0.10 thou rms).
- Thinner walls can be cast as compared to sand and permanent mold casting (approximately 0.75 mm or 0.030 in).
- Inserts can be cast-in (such as threaded inserts, heating elements, and high strength bearing surfaces).
- Reduces or eliminates secondary machining operations.
- Rapid production rates.
- Casting tensile strength as high as 415 megapascals (60 ksi).
- Casting of low fluidity metals.

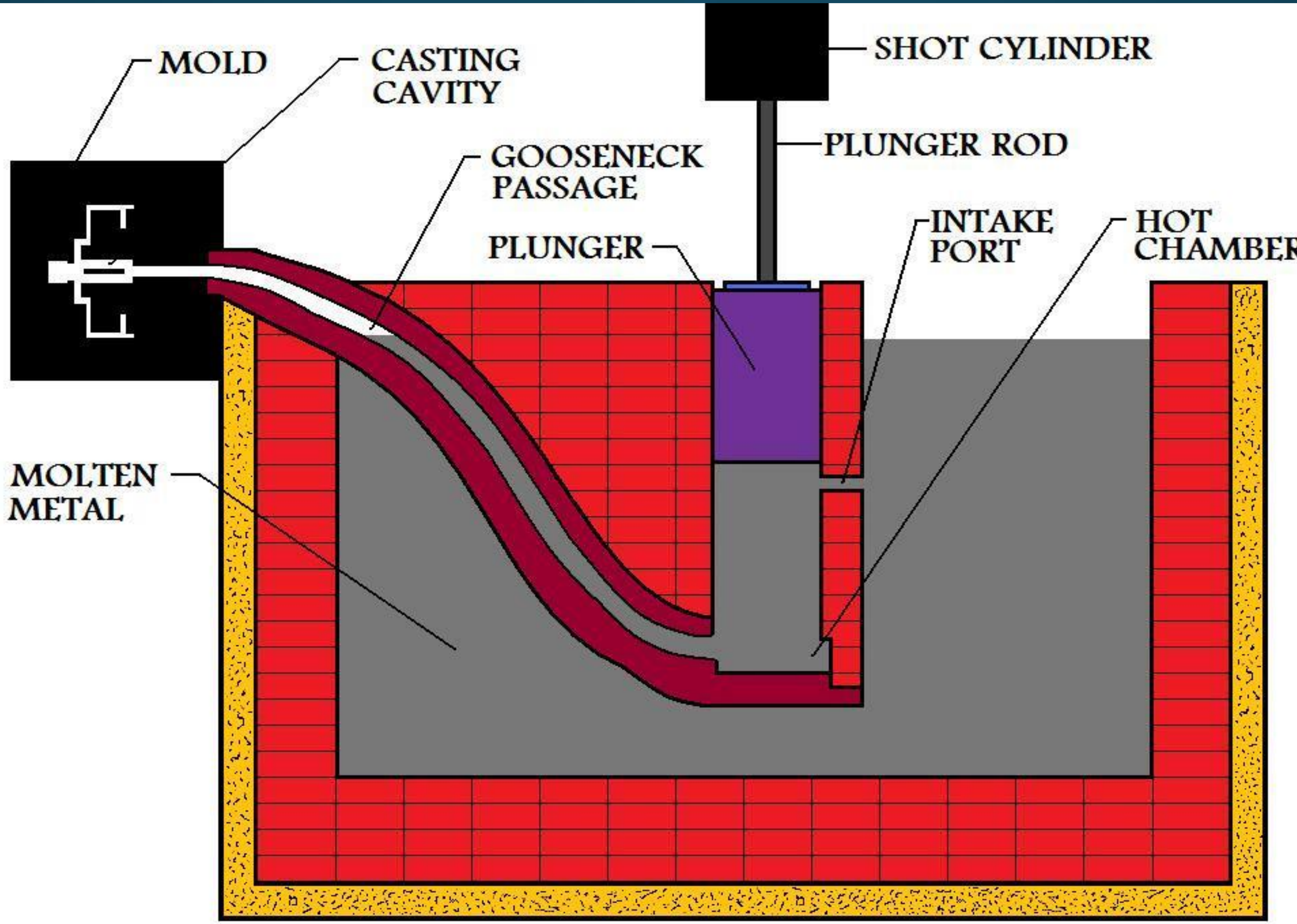
Diadvantages

- The main disadvantage to die casting is the very high capital cost.

- Therefore to make die casting an economic process a large production volume is needed.
- Other disadvantages include: the process is limited to high-fluidity metals and casting weights must be between 30 grams and 10 kg
- In the standard die casting process the final casting will have a small amount of porosity.
- This prevents any heat treating or welding, because the heat causes the gas in the pores to expand, which causes micro-cracks inside the part and exfoliation of the surface.

Hot chamber die casting

- Die casting process is the use of high pressure to force molten metal through a mold called a die.
- Many of the superior qualities of castings manufactured by die casting, can be attributed to the use of pressure to ensure the flow of metal through the die.
- In hot chamber die casting manufacture, the supply of molten metal is attached to the die casting machine and is an integral part of the casting apparatus for this manufacturing operation
- The pressure exerted on the liquid metal to fill the die in hot chamber die casting manufacture usually varies from about 700psi to 5000psi (5MPa to 35 MPa).
- The pressure is held long enough for the casting to solidify.



HOT CHAMBER DIE CASTING

- Hot chamber die casting has the advantage of a very high rate of productivity.
- During industrial manufacture by this process one of the disadvantages is that the setup requires that critical parts of the mechanical apparatus, (such as the plunger), must be continuously submersed in molten material.
- Continuous submersion in a high enough temperature material will cause thermal related damage to these components rendering them inoperative.
- For this reason, usually only lower melting point alloys of lead, tin, and zinc are used to manufacture metal castings with the hot chamber die casting process.

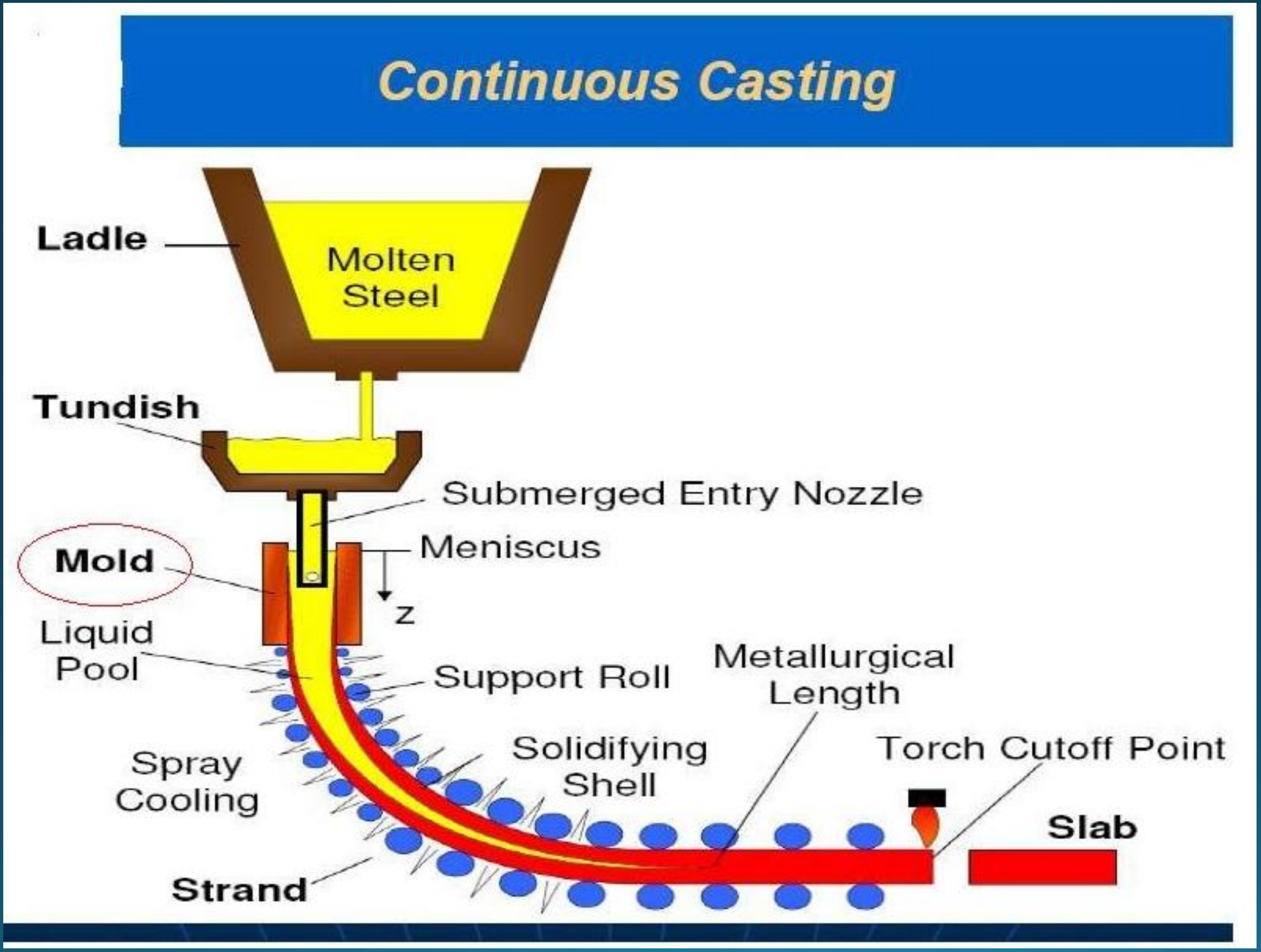
Hot chamber die casting

- It is very possible to manufacture castings from lower melting point alloys using the cold-chamber method.

Continuous casting

- **Continuous casting**, also referred to as strand casting, is a process used in manufacturing industry to cast a continuous length of metal.

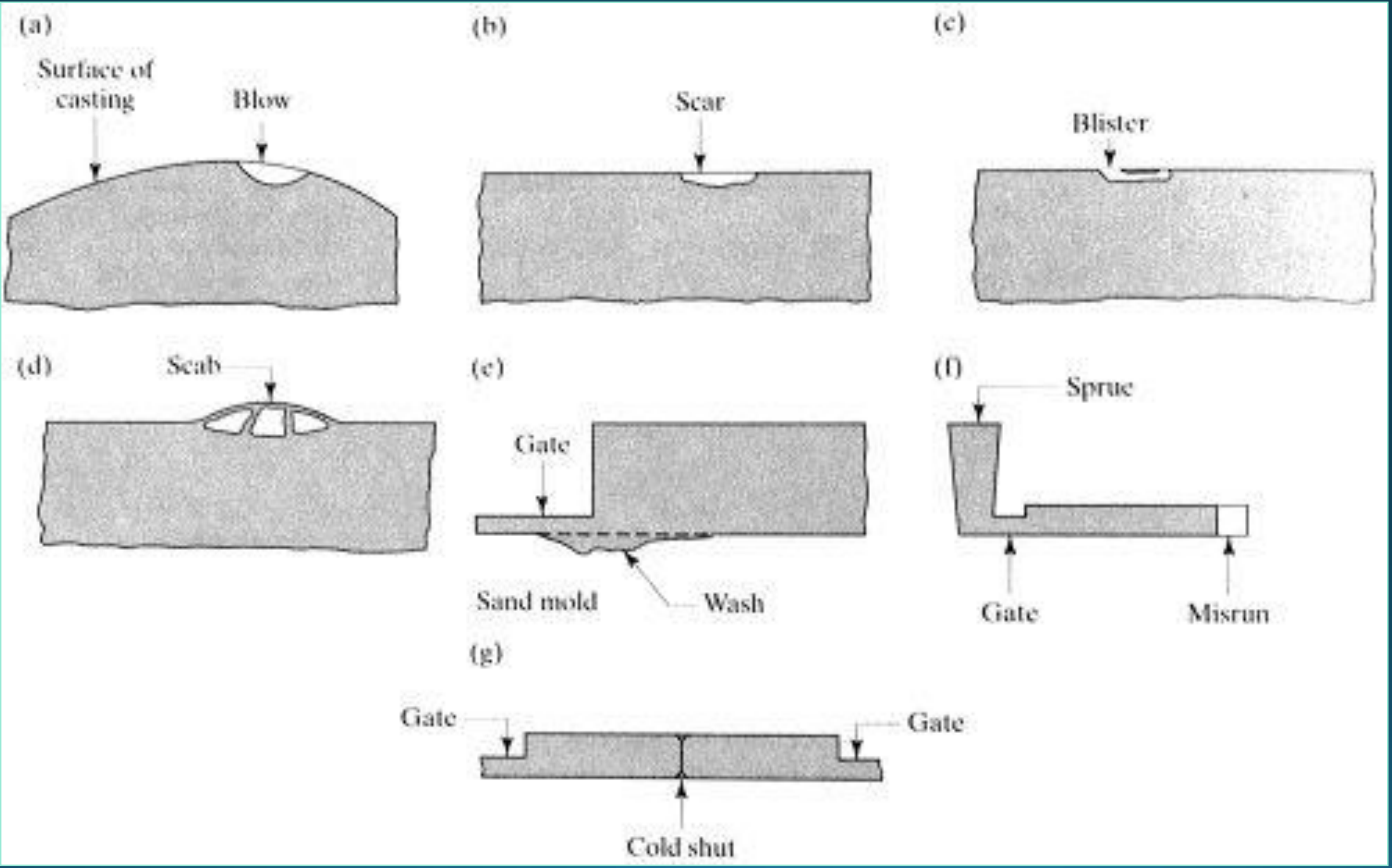
- Continuous casting can produce long strands from aluminum and copper, also the process has been developed for the production of steel.

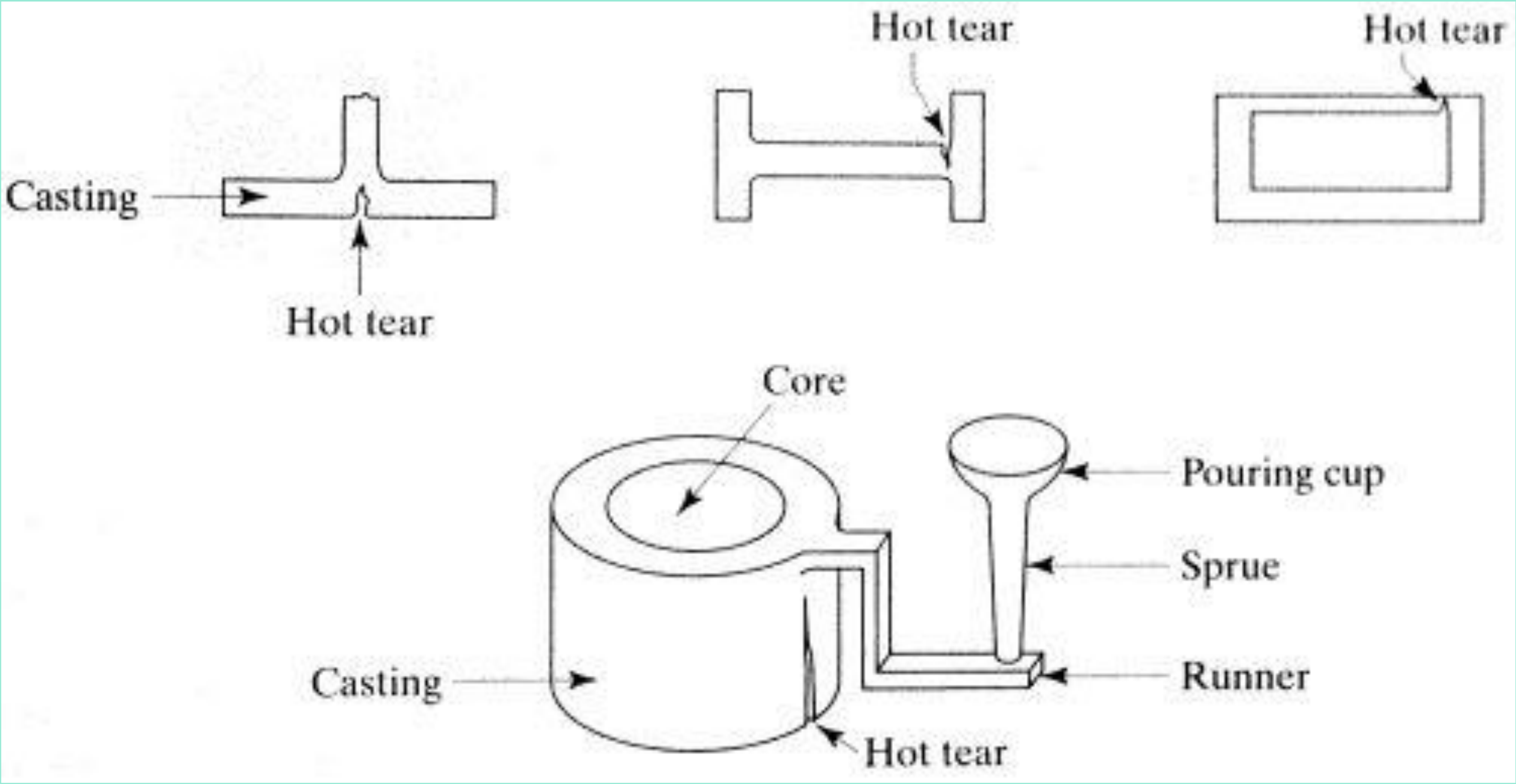

Continuous Casting
Ladle
Molten Steel
Tundish
Submerged Entry Nozzle
Mold
Meniscus
z
Liquid Pool
Support Roll
Metallurgical Length
Spray Cooling
Solidifying Shell
Torch Cutoff Point
Slab
Strand

Different Casting Processes

Process	**Advantages**	**Disadvantages**	**Examples**
Sand	many metals, sizes, shapes, cheap	poor finish & tolerance	engine blocks, cylinder heads
Shell mold	better accuracy, finish, higher production rate	limited part size	connecting rods, gear housings
Expendable pattern	Wide range of metals, sizes, shapes	patterns have low strength	cylinder heads, brake components
Plaster mold	complex shapes, good surface finish	non-ferrous metals, low production rate	prototypes of mechanical parts
Ceramic mold	complex shapes, high accuracy, good finish	small sizes	impellers, injection mold tooling
Investment	complex shapes, excellent finish	small parts, expensive	jewellery
Permanent mold	good finish, low porosity, high production rate	Costly mold, simpler shapes only	gears, gear housings
Die	Excellent dimensional accuracy, high production rate	costly dies, small parts, non-ferrous metals	gears, camera bodies, car wheels
Centrifugal	Large cylindrical parts, good quality	Expensive, few shapes	pipes, boilers, flywheels

Casting Design: Typical casting defects



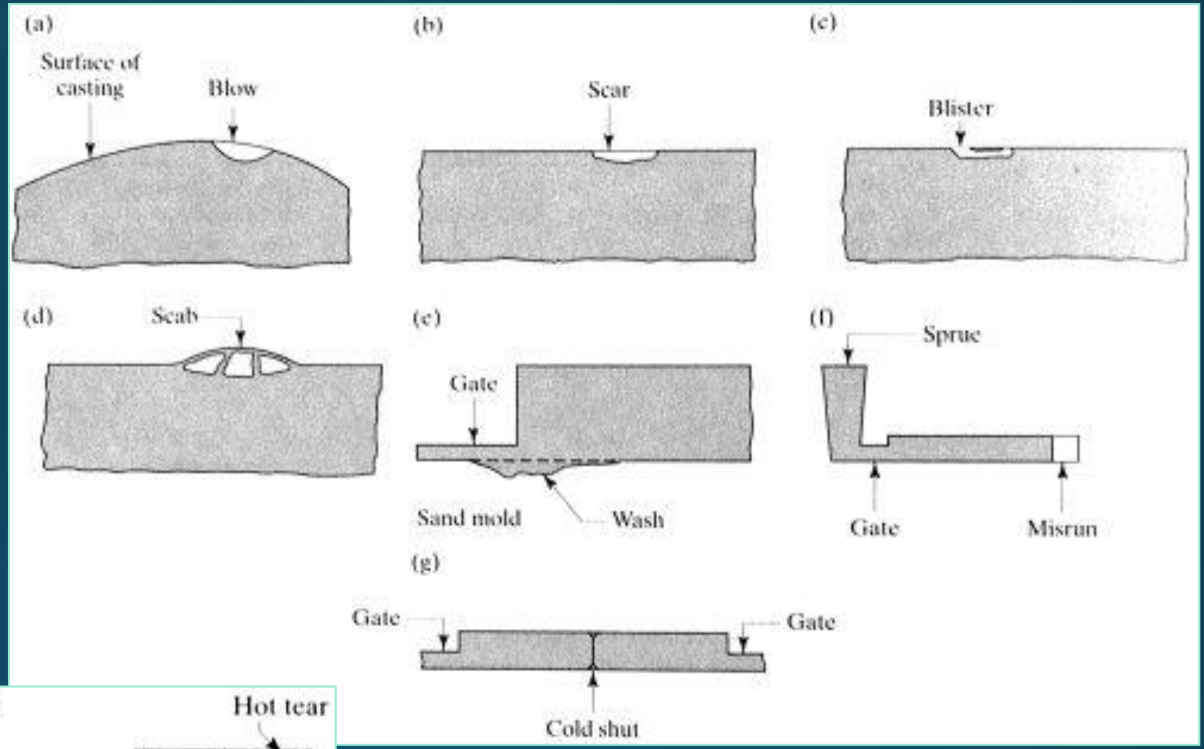

Casting
Hot tear
Hot tear
Hot tear
Core
Pouring cup
Sprue
Runner
Casting
Hot tear

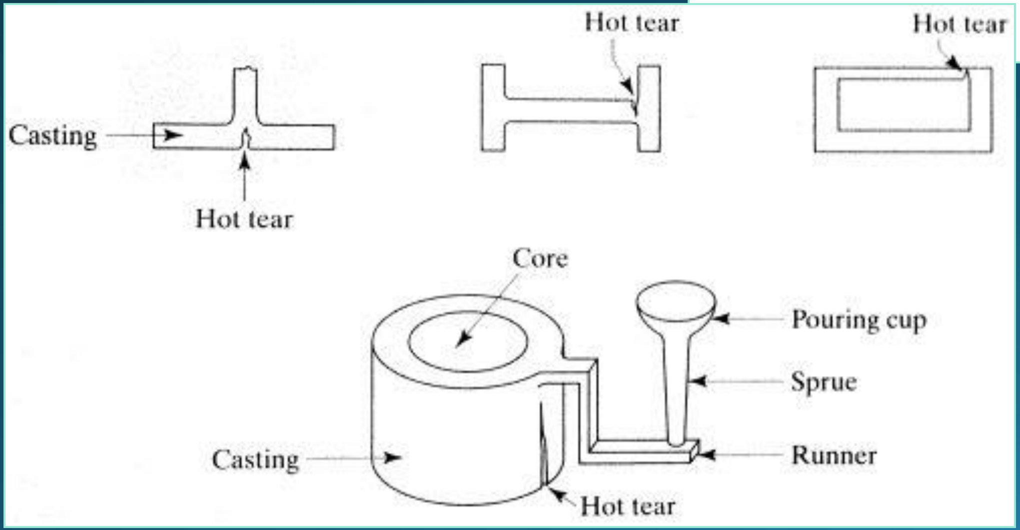
Inclusions	1. Faulty gating.	1. Modify gating system
	2. Faulty pouring.	2. Improve pouring to minimize turbulence.
	3. Inferior molding or core sand.	3. Use of superior sand of good strength.
	4. Soft ramming of mold.	4. Provide hard, ramming.
	5. Rough handling of mold and core.	
Fusion	1. Low refractoriness in molding sand	1. Improve refractoriness of sand.
	2. Faulty gating.	2. Modify gating system.
	3. Too high pouring temperature of metal.	3. Use lower pouring temperature.
	4. Poor facing sand.	4. Improve quality of facing sand.

Inspection of Casting

- Visual Inspection
- Dimensional inspection
- Sound test
- Impact test
- Pressure test
- Magnetic particle testing
- Penetrant test
- Ultrasonic test

Casting Design: Typical casting defects

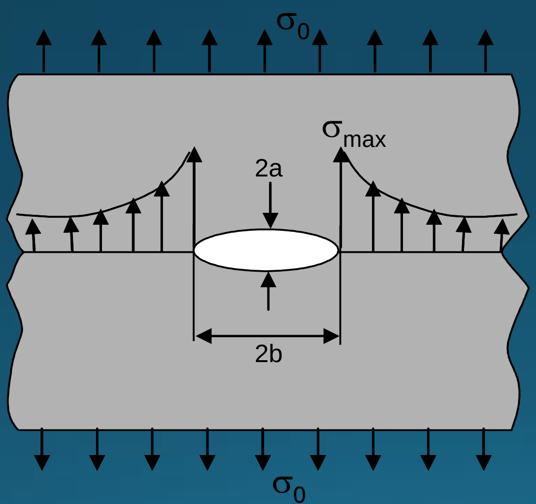




Casting Design: Defects and Associated Problems

- Surface defects: finish, stress concentration

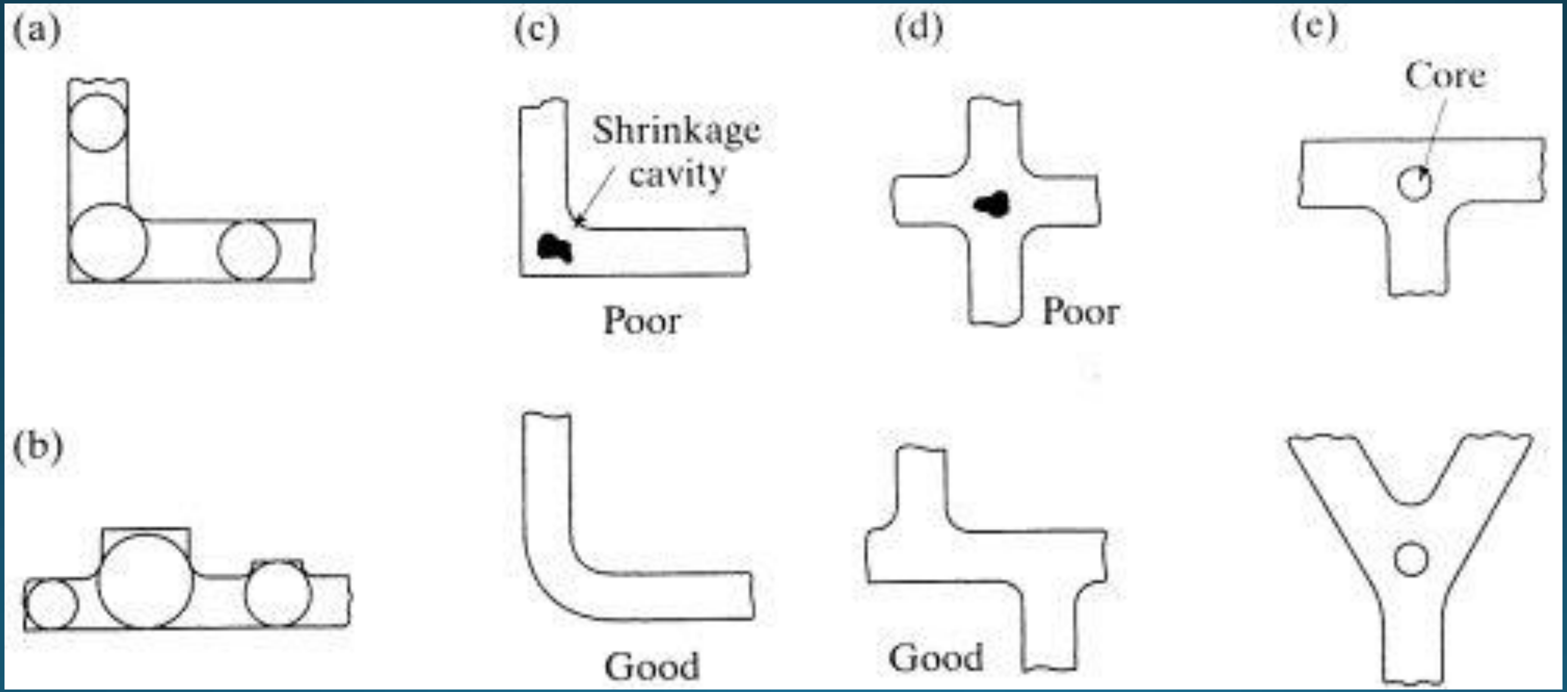
- Interior holes, inclusions: stress concentrations



$\sigma_{max} = \sigma_0(1 + 2b/a)$

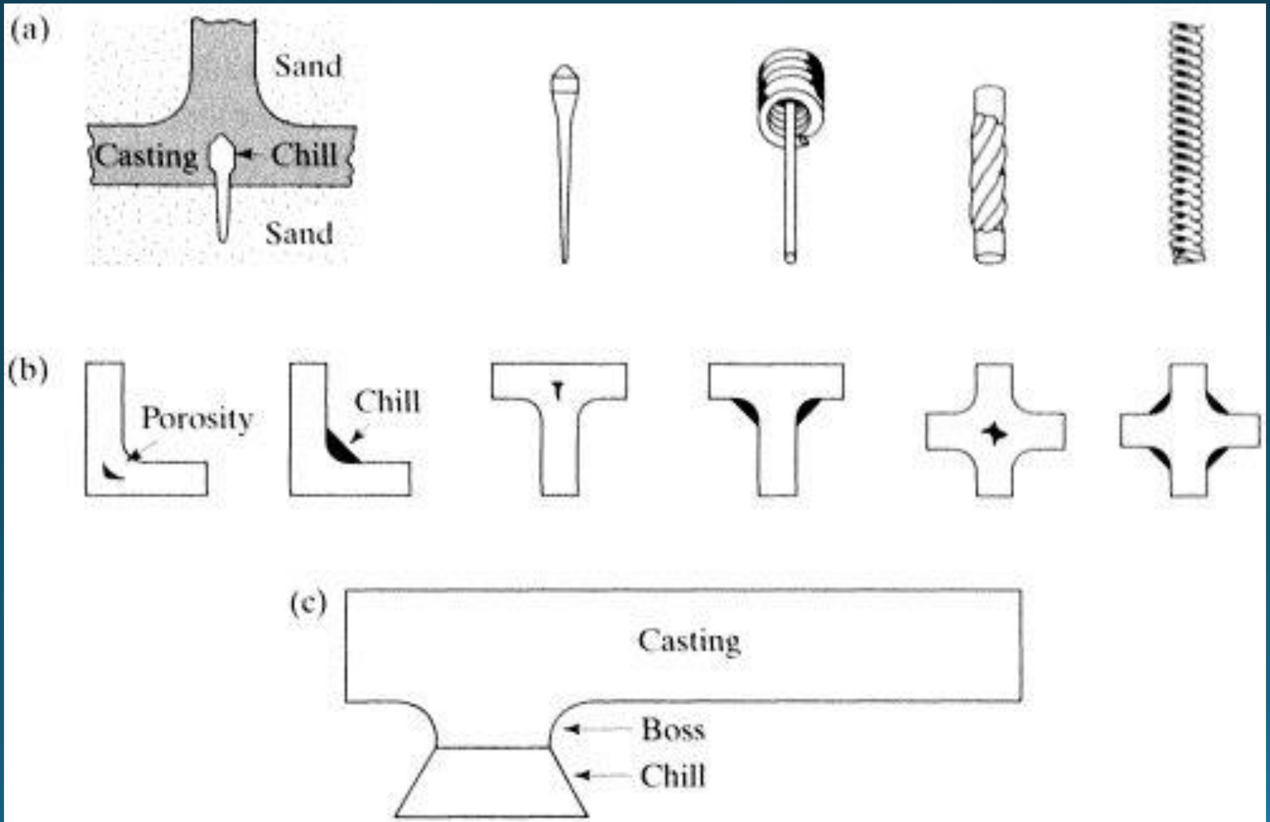
Casting Design: guidelines

(a) avoid sharp corners
(b) use fillets to blend section changes smoothly
(c1) avoid rapid changes in cross-section areas



Casting Design: guidelines

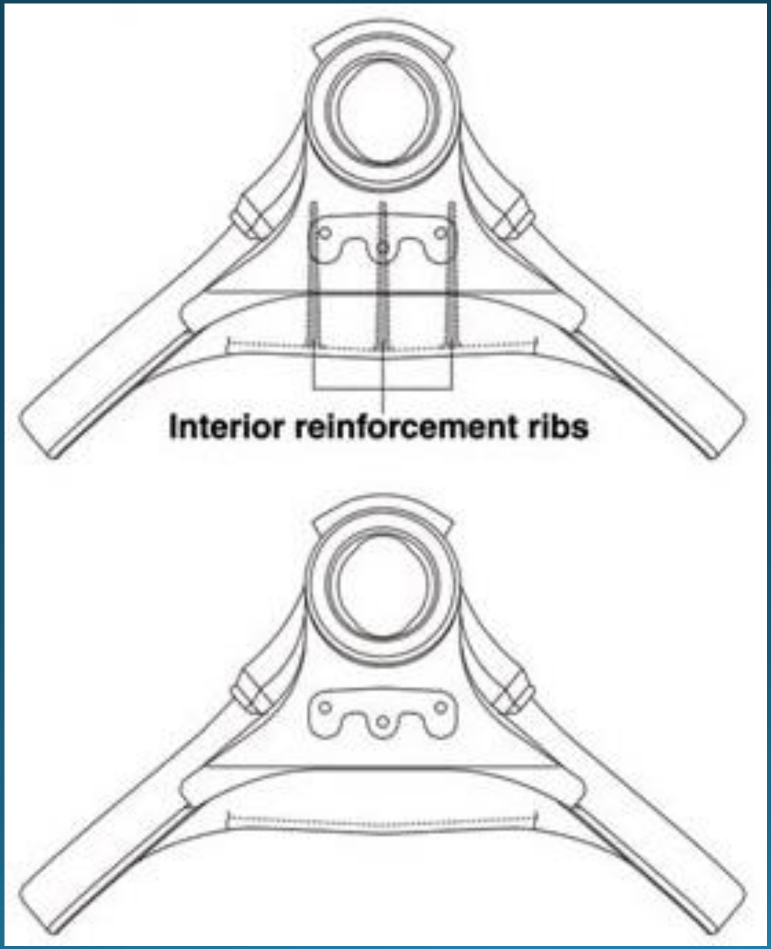
(c1) avoid rapid changes in cross-section areas
(c2) if unavoidable, design mold to ensure
- easy metal flow
- uniform, rapid cooling (use chills, fluid-cooled tubes)



Casting Design: guidelines

(d) avoid large, flat areas

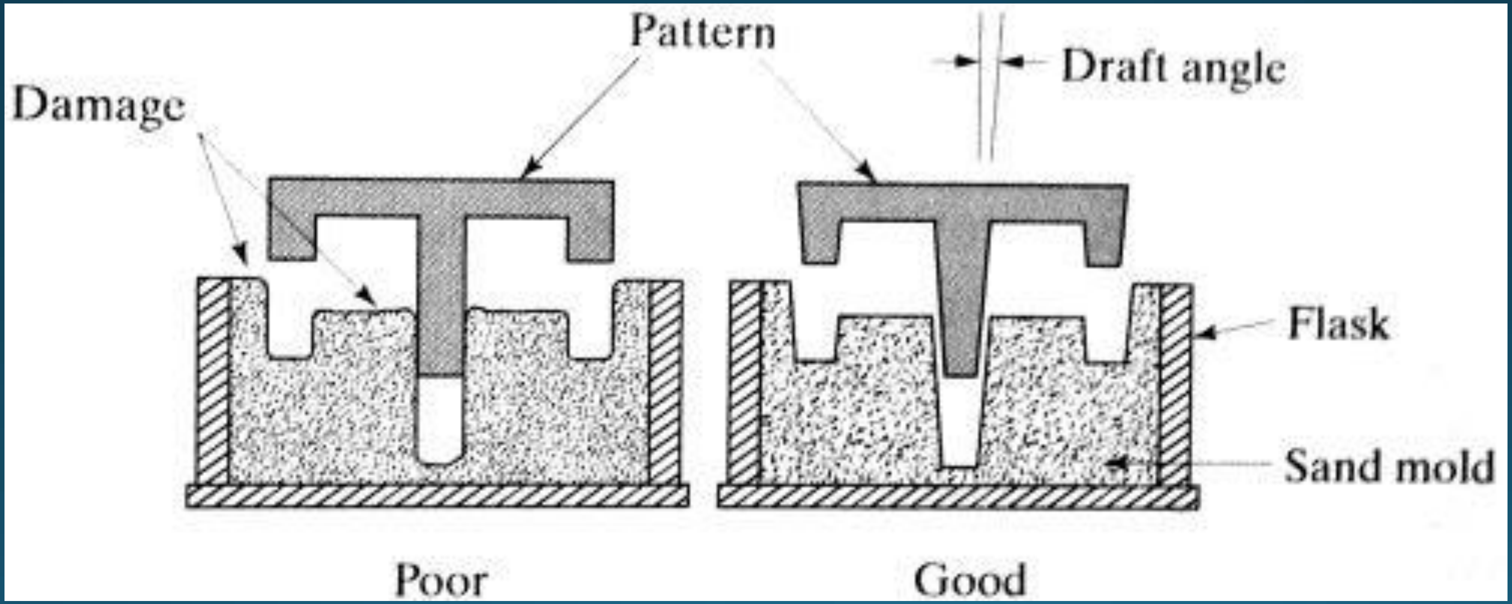
- warpage due to residual stresses (why?)



Casting Design: guidelines

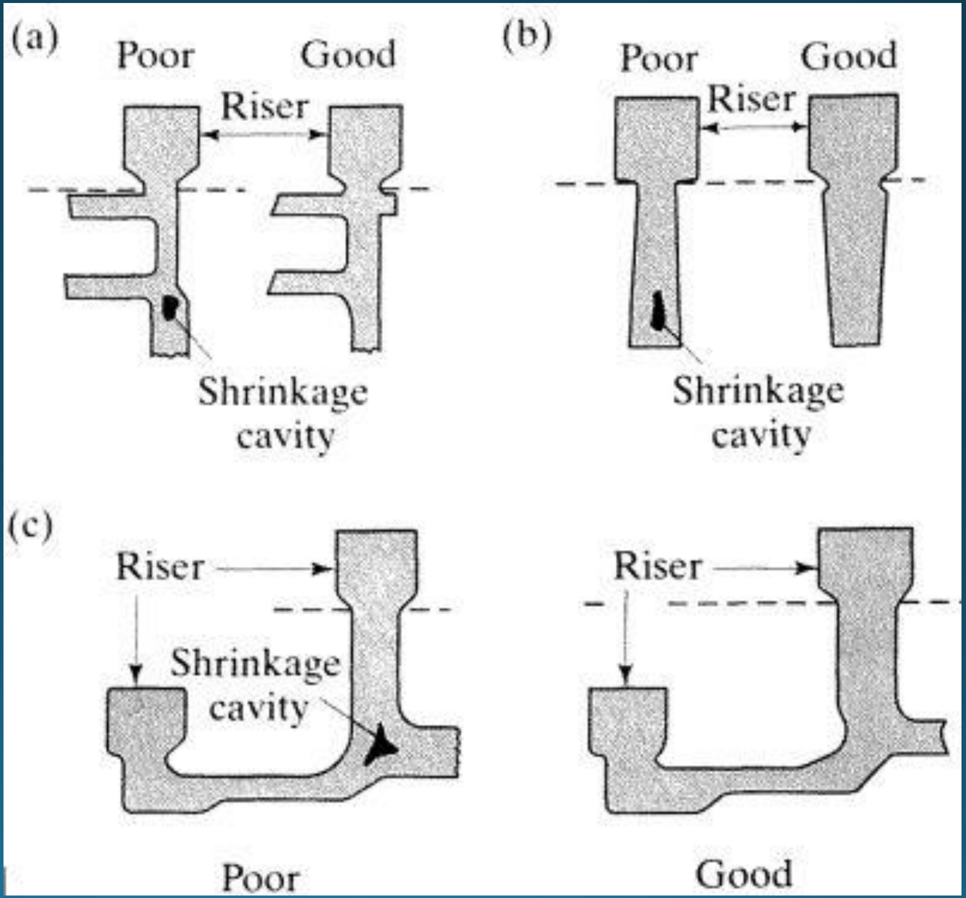
(e) provide drafts and tapers

- easy removal, avoid damage
- along what direction should we taper ?



Casting Design: guidelines

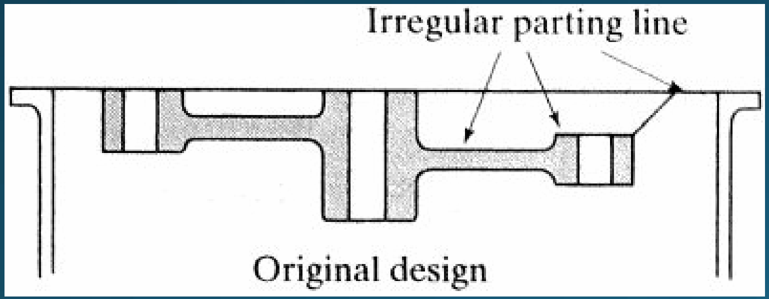
(f) account for shrinkage
- geometry
- shrinkage cavities

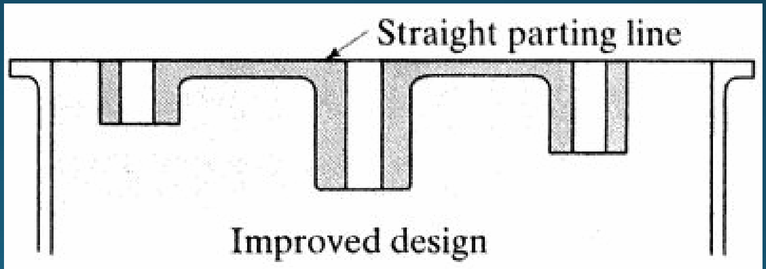


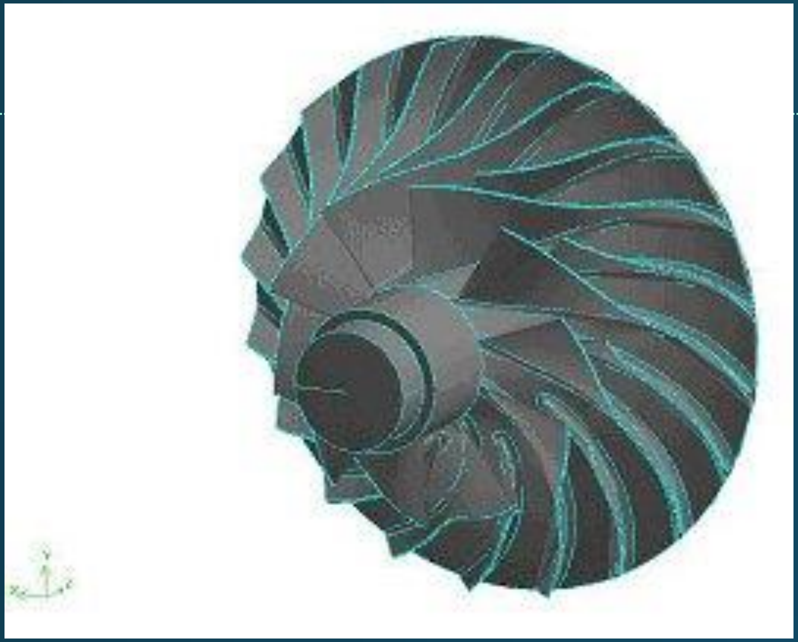
Casting Design: guidelines

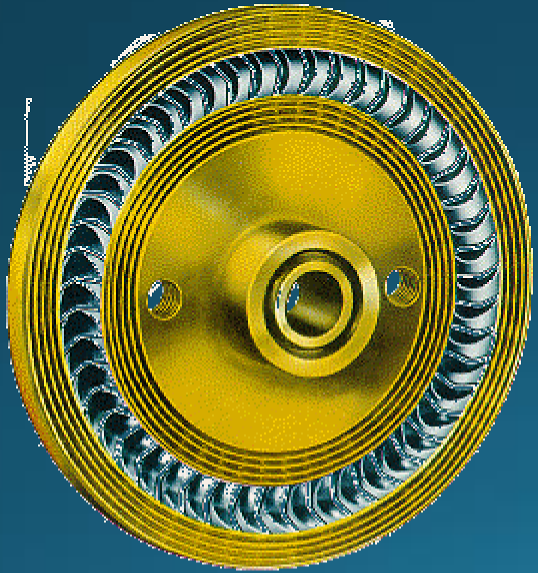
(g) proper design of parting line

- "flattest" parting line is best









Impellers

THANK YOU