Shakeout, Cleaning and Finishing

- Final operation in casting is to separate casting from mould.
- Shakeout is designed to do
  - Separate the moulds and remove casting from mould
  - Remove sand from flask and cores from cast
- Punch out or vibratory machines are available for this task
- Blast cleaning is done to remove adhering sand from casting, or remove oxide scale and parting line burs.
- Final finishing operations include Grinding, Turning or any forms of machining

Types of Pattern

Table 5–2. Types of molds/dies, mold materials, patterns, and pouring principles classified in four basic process groups

Grouping	Type of mold	Mold material	Pouring principle	Pattern material	Process name
Sand casting	Nonpermanent (single-purpose)	Sand (green)	Gravity	Wood, metal, plastics	Green sand, dry sand, core sand casting
Permanent (metallic) mold casting	Permanent	Alloy steels	High pressure	—	Die casting
		Graphite, steel, cast iron	Low pressure	—	Low pressure (permanent mold casting)
		Cast iron, steel	Gravity		Nonpressure gravity permanent mold casting
Precision casting	Nonpermanent (single-purpose)	Nonmetallic (sand, plaster, ceramics, etc.)	Gravity (low pressure)	Metal	Shell mold casting
Investment or precision casting				Wax, plastic, (rubber, metal)	Plaster mold casting
Investment or precision casting				Wax, plastic, (rubber, metal)	Ceramic shell mold casting
Investment or precision casting				Wax, plastic, (rubber, metal)	"Lost wax" casting (investment casting)
Centrifugal casting	Nonpermanent/ permanent	Nonmetallic/ metallic	Centrifugal forces	—	Centrifugal casting

MECH 423 Casting, Welding, Heat Treating and NDT

Time: _ _ W _ F 14:45 - 16:00

Credits: 3.5 Session: Fall

Multiple Mould Casting

Lecture 4

Multiple Use Mould Casting

- Use the same mould many times rather than make a new one for each casting.
  - high production rates,
  - more consistent castings (not necessarily better!)
  - different problems
  - limited to lower melting point metals
  - small to medium size castings
  - dies/moulds expensive to make

Permanent Mould Casting

Also known as Gravity Die Casting

- Machine (milling, EDM - spark erosion etc) a cavity in metal die. Gray cast iron, steel, bronze, graphite etc.
- Hinged or pinned to co-locate rapidly.
- Pre-heat die the first time (molten metal must get all the way through the mould before solidifying). Heat from previous casting is usually sufficient for subsequent castings.
- Directional solidification promoted by heating/cooling specific parts of the mould.
- Sound, relatively defect-free castings
- Multiple cavities in one die.

Permanent Mould Casting

- Expendable sand core or retractable metal cores can be used.
- Faster cooling rates than sand casting mean smaller grain size

  - better mechanical properties and surface finish, usually.

Process:	Mold cavities are machined into mating metal die blocks, which are then preheated and clamped together. Molten metal is then poured into the mold and enters the cavity by gravity flow. After solidification, the mold is opened and the casting is removed.
Advantages:	Good surface finish and dimensional accuracy; metal mold gives rapid cooling and fine-grain structure; multiple-use molds (up to 25,000 uses).
Limitations:	High initial mold cost; shape, size, and complexity are limited; yield rate rarely exceeds 60%, but runners and risers can be directly recycled; mold life is very limited with high-melting-point metals such as steel.
Common metals:	Alloys of aluminum, magnesium, and copper are most frequently cast; irons and steels can be cast into graphite molds; alloys of lead, tin, and zinc are also cast.
Size limits:	Several ounces to about 150 lb
Thickness limits:	Minimum depends on material but generally greater than $\frac{1}{8}$ in.; maximum thickness about 2.0 in.
Typical tolerances:	0.015 in. for the first inch and 0.002 in. for each additional inch; 0.01 in. added if the dimension crosses a parting line
Draft allowance:	2–3°
Surface finish:	100 to 250 μin. rms

Permanent Mould Casting

Limitations

- Limited to lower melting point metals usually but life still limited from 10,000 to 120,000 cycles. Mould life depends on:
  - Alloy being cast - higher the T_m (mp), the shorter the life.
  - Mould material - Gray cast iron best thermal fatigue resistance, easily machined.
  - Pouring temperature - higher temps mean reduced life, higher shrinkages and longer cycle times.
  - Mould temperature - too low, get misruns; too high long cycle times and erosion.
  - Mould configuration - difference in section sizes produce temperature variations through mould - reduce life.

Permanent Mould Casting

- No collapsibility so die opened as soon as solidification occurs.
- Refractory washes or graphite coatings used to prevent sticking & extend mould life.
- When casting iron, carbon deposited on walls with acetylene torch
- Moulds are non permeable. Special provision for venting. Cracks between die halves or special vent holes.
- Under gravity feed only so risers/feeders still necessary to compensate for solidification shrinkage. (yields < 60%)
- Sand and retractable metal cores used to increase complexity
- High volume production can justify die cost. Process mostly automated

Permanent Mould Casting

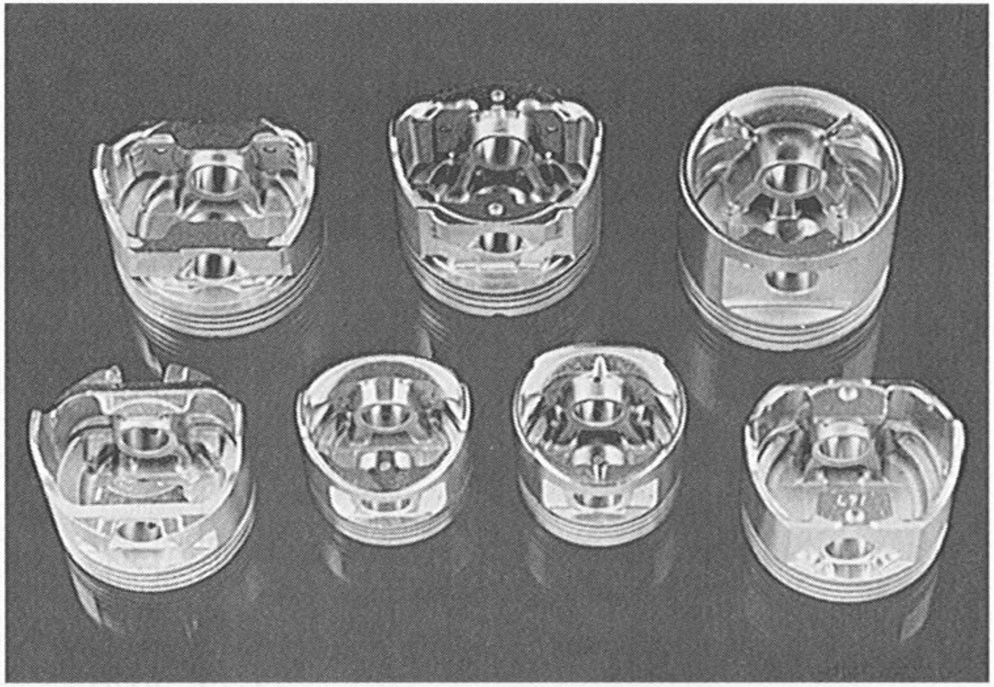


FIGURE 15-1 Truck and car pistons, mass-produced by the millions using permanent mold casting. *(Courtesy of Central Foundry Division of General Motors Corporation.)*

- Casting ornamental objects, candlesticks, lamp bases from low MP metals

- Slush casting - permanent mould for hollow castings.
- Metal poured into die and allowed to cool
- Once shell of metal solidifies against die, mould is inverted excess metal poured out.
- Variable wall thickness, good outer surface - poor inner surface.

Low Pressure Permanent Mould Casting

- Low pressures (5-15 psi) used to force molten metal up tube into mould. (common for Al or Mg)
- Clean metal from centre of bath fed directly into mould.
  - Dross floats up or sinks down, clean in the middle.
  - No sprues, gates runners, risers etc
  - Minimal oxidation
  - minimal turbulence

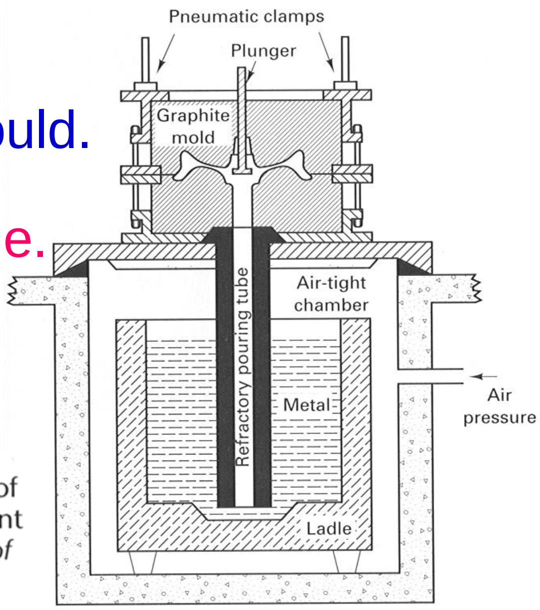


FIGURE 15-2 Schematic of the low-pressure permanent mold process. *(Courtesy of Amsted Industries.)*

- Mould solidifies directionally - tube can keep feeding liquid during solidification.
- Unused liquid drops back tube. Yields > 85%.
- Better mechanical properties than gravity die casting but slightly longer cycle times.

Vacuum Permanent Mould Casting

- Another variation of permanent mould casting
- Use vacuum to suck metal up into die.,
- Vacuum helps reduce surface oxidation and removes dissolved gases.
- Advantages of LPM are retained including clean metal from center
- Cleaner than LPM process
- Properties 10 to 15% better than conventional processes

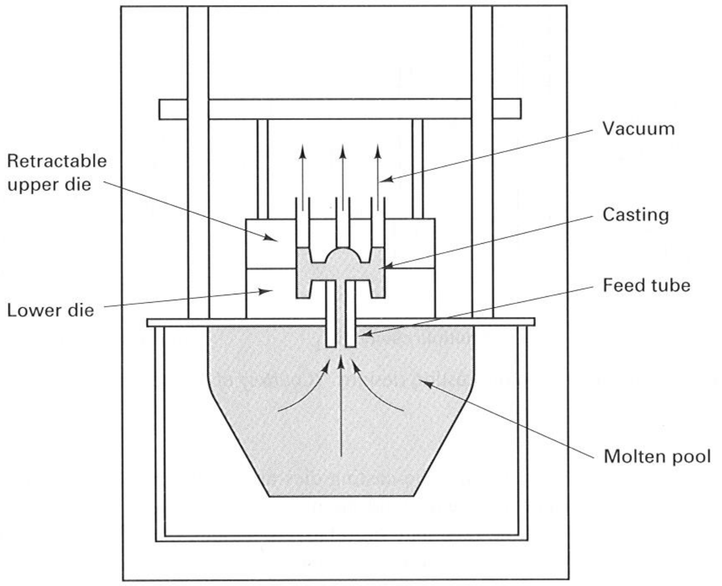
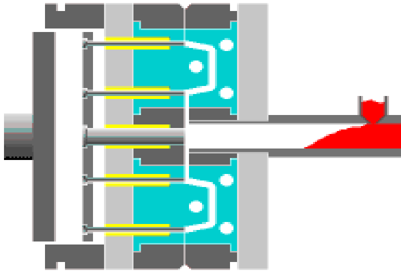


FIGURE 15-3 Schematic illustration of vacuum permanent mold casting.

Die Casting – High Pressure

- Metal forced into mould at high pressures (1,500 - 25,000 psi)
- Usually non-ferrous metals.
- Fine sections and excellent surface detail
- Need hardened hot-worked tool steels to withstand heat pressure - expensive. ($7500 - 15000)
- Complex parts - complex moulds. At least in 2 sections for removal
- Often water cooling passages, retractable cores, knock-out pins.



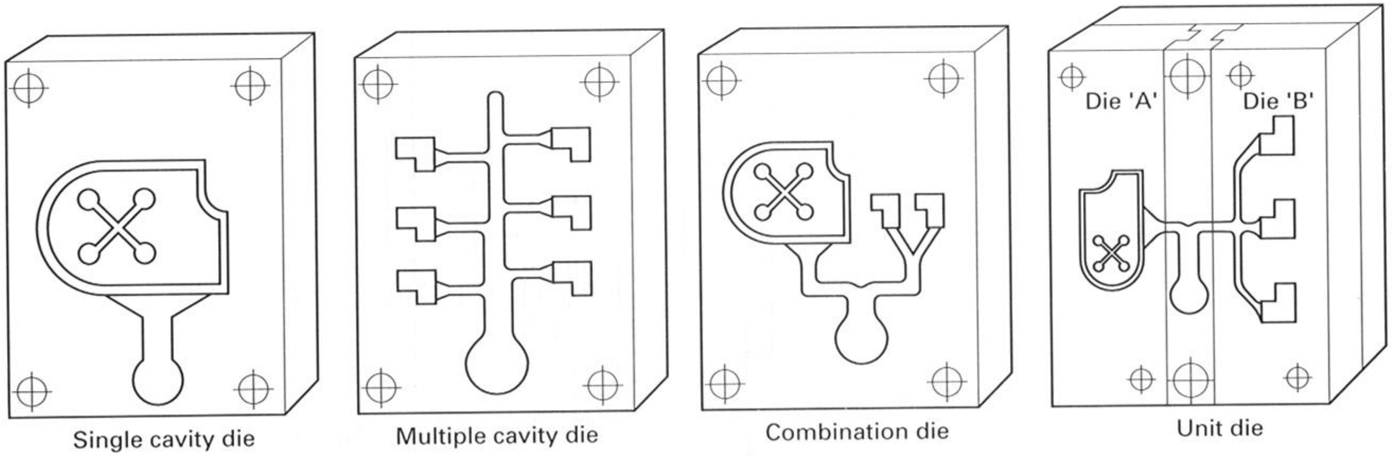


FIGURE 15-4 Some common die-casting designs. *(Courtesy of American Die Casting Institute, Inc., Des Plaines, Illinois.)*

Die Casting – High Pressure

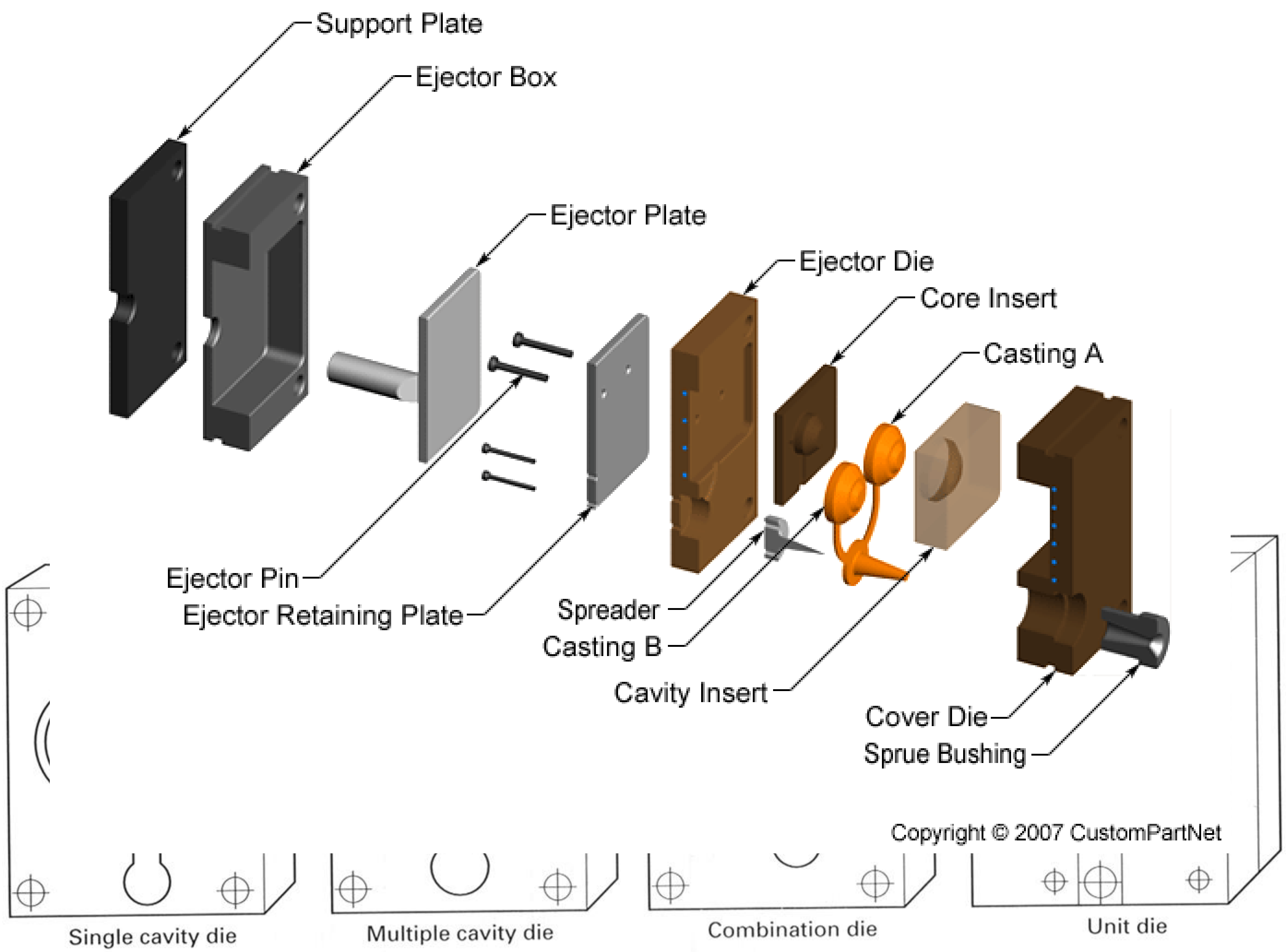


FIGURE 15-4 Some common die-casting designs. *(Courtesy of American Die Casting Institute, Inc., Des Plaines, Illinois.)*

Die Casting – High Pressure

- Die life limited by wear & erosion, and thermal fatigue.
- Die lubricated before closing.
- High injection pressures/ velocities cause turbulence - move to using larger gates and controlled filling - reduce porosity and entrained oxide. There are 2 types of Die Casting
- **Hot-chamber machines (gooseneck design)**
  - fast cycle times (up to 15 per minute)
  - same melting & holding chamber (no transfer required) (Al picks up iron from chamber, hence not good for Al)
  - lower mpt metals (zinc, tin, lead-based alloys)

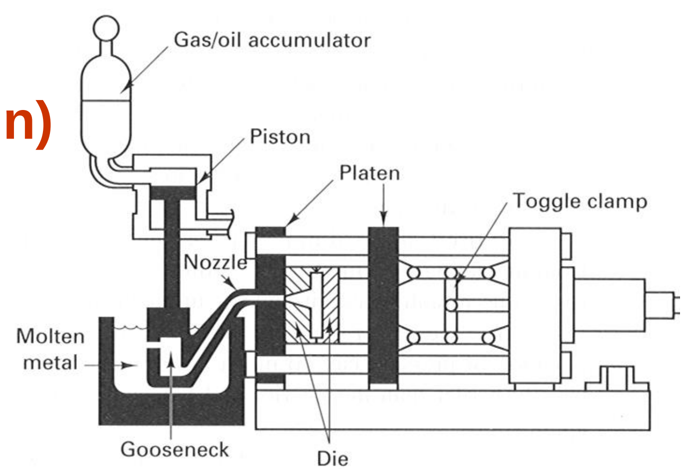
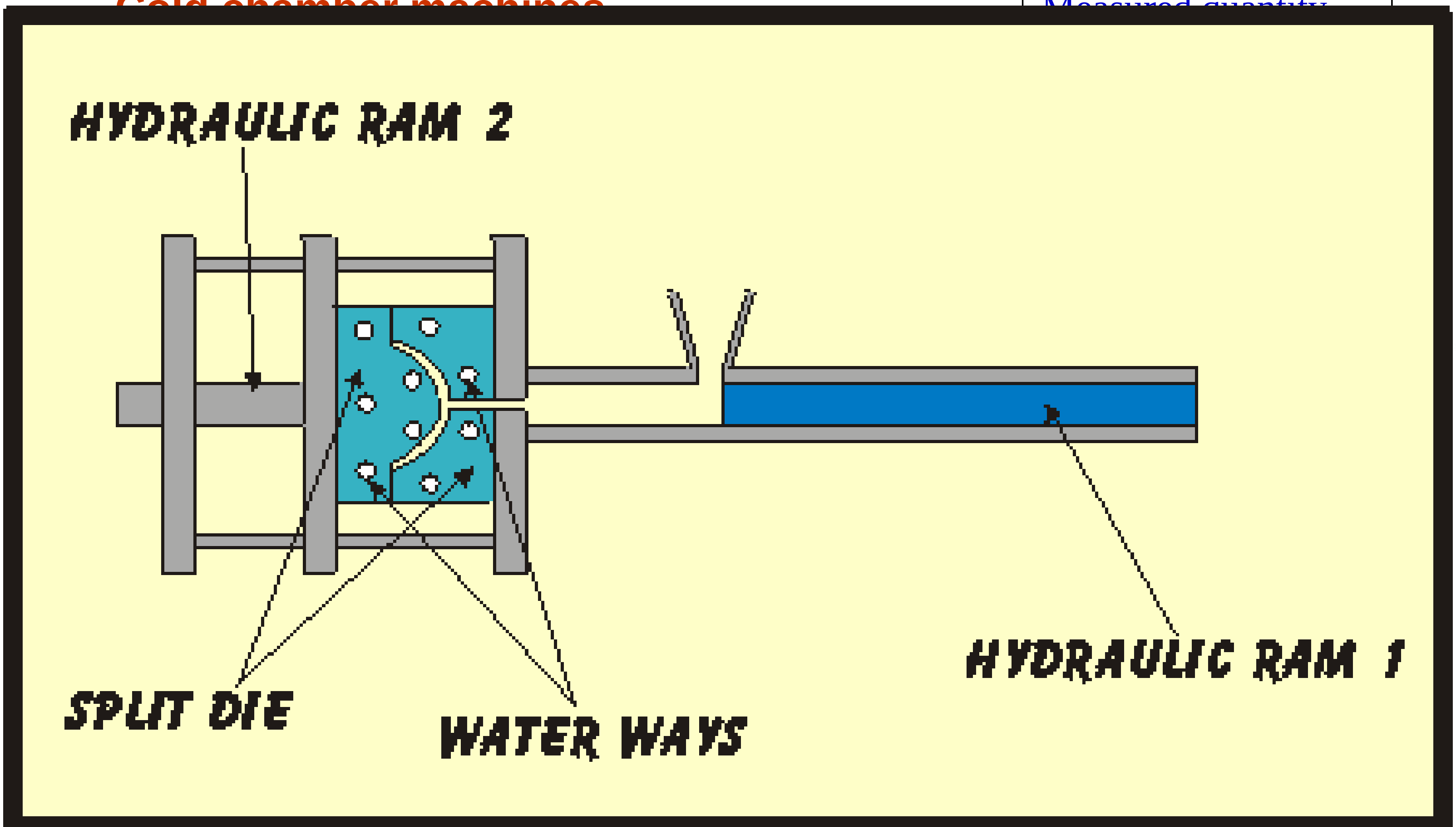


FIGURE 15-5 Principal components of a hot-chamber die-casting machine. *(Courtesy of Noranda Sales Corp. Ltd.)*

Die Casting – High Pressure

Cold chamber machines

Measured quantity



Die Casting – High Pressure

- No risers, pressure can fill for shrinkage. But trapped air can cause porosity in the center
- Pore-free casting
  - oxygen introduced into cavity to react with metal to form **small** oxide particles (eliminates gas porosity). Increase mechanical properties. Applied commonly in Al, Zn, Pb.
- Sand cores cannot be used (due to high pressure used). Retractable metal cores needed.
- Inserts may be placed in cavity for inclusion into casting; threaded bosses, heating elements, bearing surfaces can be placed in die before casting low MP metals/alloys.

Die Casting – High Pressure

Metal	Minimum Section	Minimum Draft
Aluminum alloys	0.035 in. (0.89 mm)	1:100 (0.010 in./in.)
Brass and bronze	0.050 in. (1.27 mm)	1:80 (0.015 in./in.)
Magnesium alloys	0.050 in. (1.27 mm)	1:100 (0.010 in./in.)
Zinc alloys	0.025 in. (0.63 mm)	1:200 (0.005 in./in.)

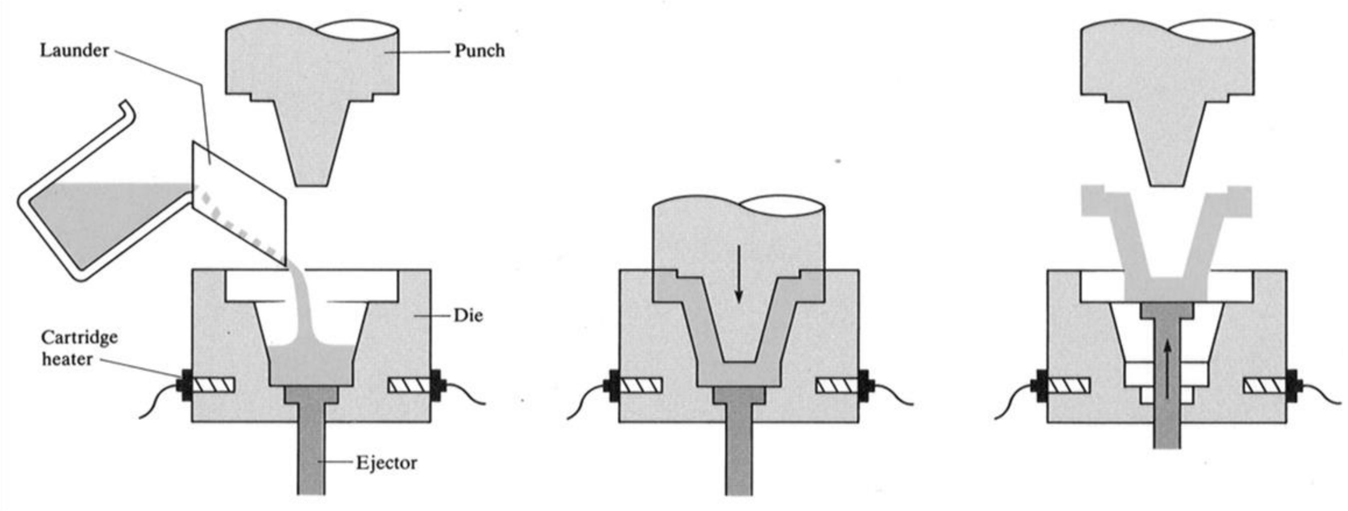
- No machining required due high tolerances and lesser draft

TABLE 15-2. Die Casting

Process:	Molten metal is injected into closed metal dies under pressures ranging from 1500 to 25,000 psi. Pressure is maintained during solidification, after which the dies separate and the casting is ejected along with its attached sprues and runners. Cores must be simple and retractable and take the form of moving metal segments
Advantages:	Extremely smooth surfaces and excellent dimensional accuracy; rapid production rate.
Limitations:	High initial die cost; limited to high-fluidity nonferrous metals; part size is limited; porosity may be a problem; some scrap in sprues, runners, and flash, but this can be directly recycled
Common metals:	Alloys of aluminum, zinc, magnesium, and lead; also possible with alloys of copper and tin
Size limits:	Less than 1 oz up through about 15 lb most common
Thickness limits:	As thin as 0.03 in., but generally less than $\frac{1}{2}$ in.
Typical tolerances:	Varies with metal being cast; typically 0.005 in. for the first inch and 0.002 in. for each additional inch
Draft allowances:	2°
Surface finish:	40–100 µin. rms.

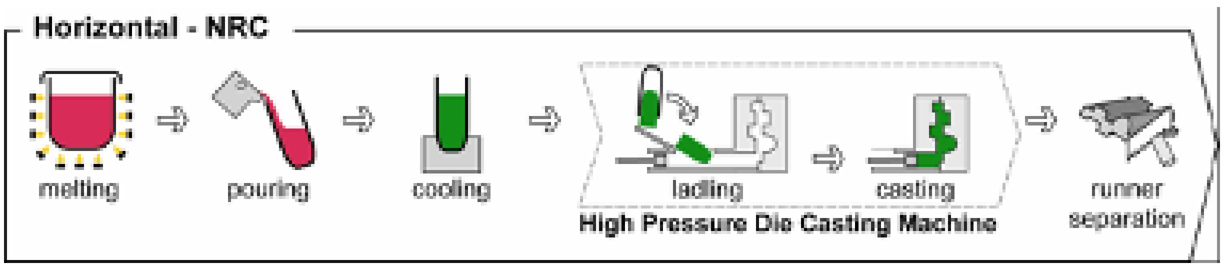
Squeeze Casting & Semi-Solid Casting

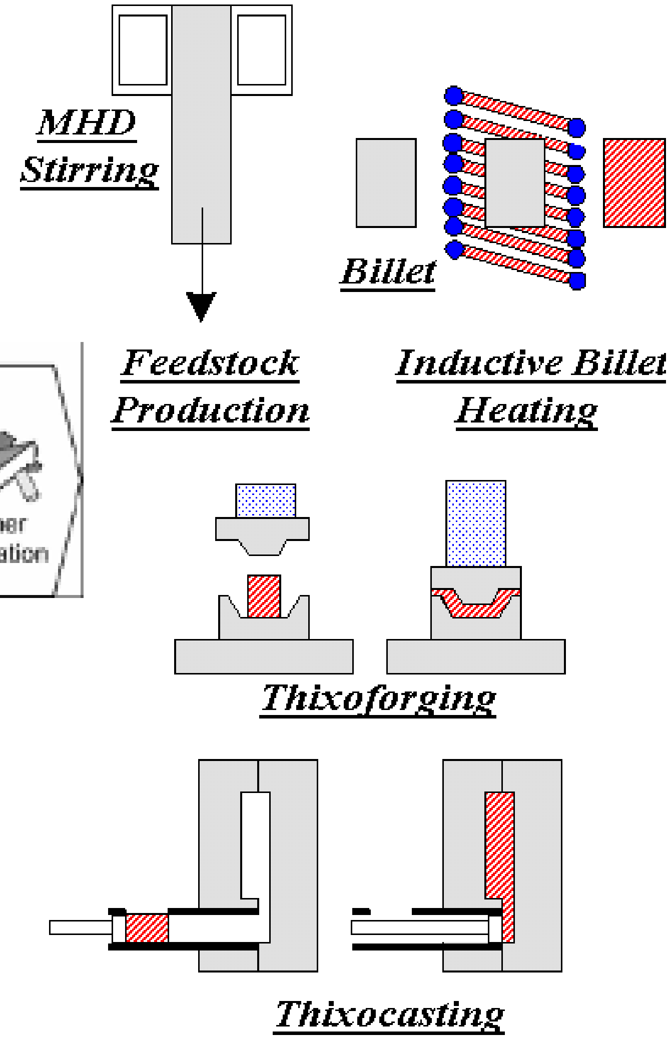
- Cast metal into die bottom, allow partial solidification then squeeze with die top.
- Use of large gates reduce velocity and turbulence
- Core can be used. Gas and shrinkage porosity are minimal.
- Reinforcement inserts can be used (Metal Matrix Composites)



Squeeze Casting & Semi-Solid Casting

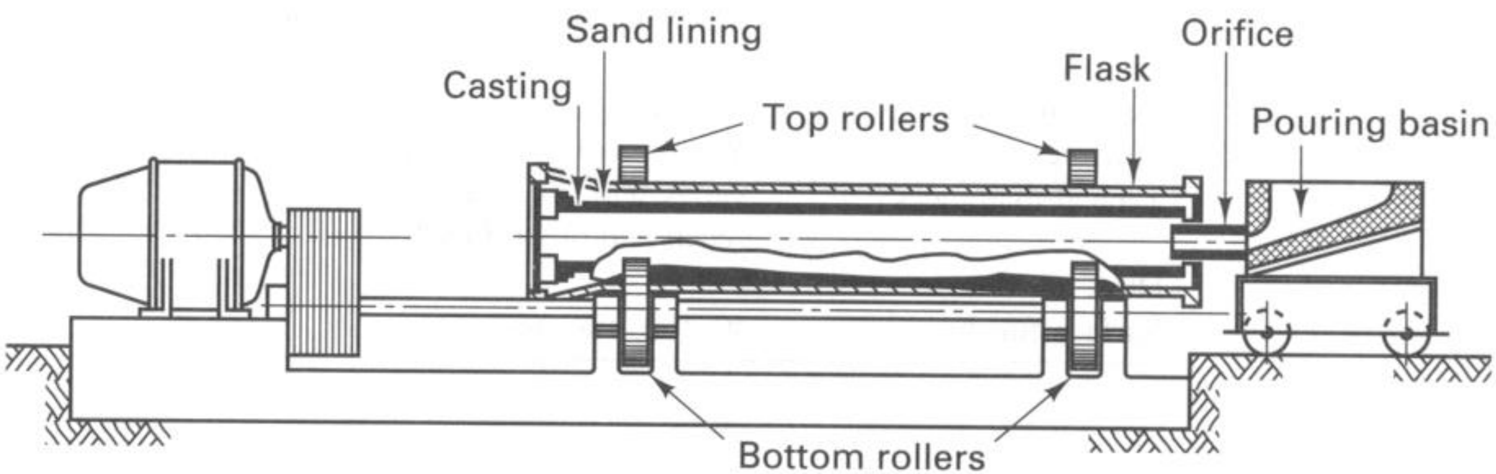
- Material in the form of semi solid (thixo tropic material) can be cast with this
- Less gas entrapment, high quality finish





Centrifugal Casting

- Inertial forces of rotation distribute molten metal in cavity (300-3000rpm) against mould walls to form hollow product; pipes, gun barrels etc



Horizontal centrifugal casting

Centrifugal Casting

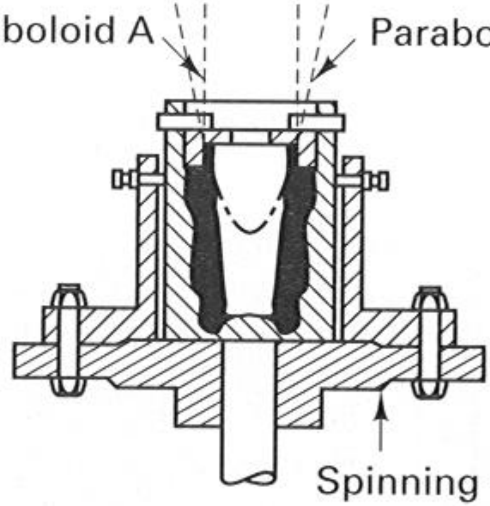


FIGURE 15-9 Vertical centrifugal casting, showing the effect of rotational speed on the shape of the inner surface. Paraboloid A results from fast spinning, paraboloid B from slow spinning.

TABLE 15-3. Centrifugal Casting

Process:	Molten metal is introduced into a rotating sand, metal, or graphite mold, and held against the mold wall by centrifugal force until it is solidified
Advantages:	Can produce a wide range of cylindrical parts, including ones of large size; good dimensional accuracy, soundness, and cleanliness
Limitations:	Shape is limited; spinning equipment can be expensive
Common metals:	Iron, steel, stainless steel, and alloys of aluminum, copper, and nickel
Size limits:	Up to 10 ft in diameter and 50 ft in length
Thickness limits:	Wall thickness 0.1–5 in.
Typical tolerances:	O.D. to within 0.1 in.; I.D. to about 0.15 in.
Draft allowance:	$\frac{1}{8}$ in./ft.
Surface finish:	100–500 μin. rms.

Centrifugal Casting

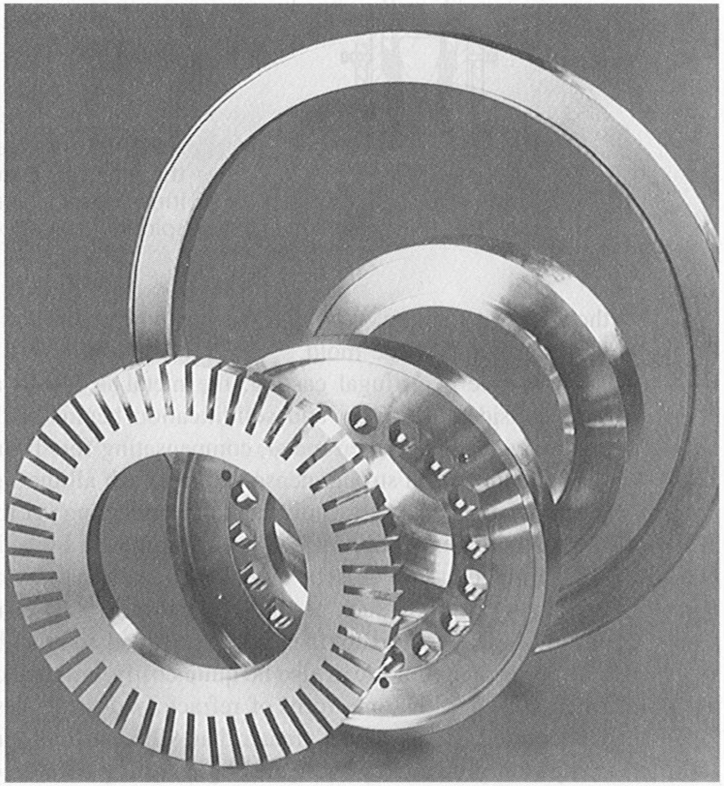


FIGURE 15-10 Electrical products (collector rings, slip rings, and rotor end rings) that have been centrifugally cast from aluminum and copper. *(Courtesy of The Electric Materials Company.)*

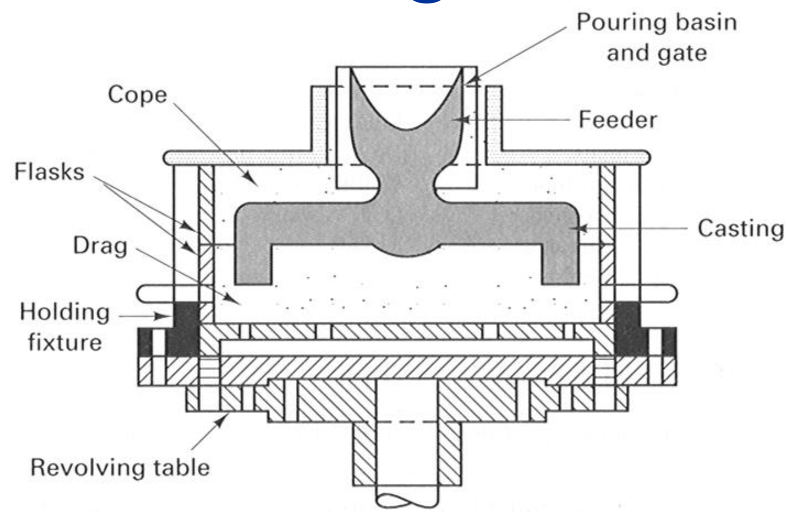


FIGURE 15-11 Semicentrifugal casting process.

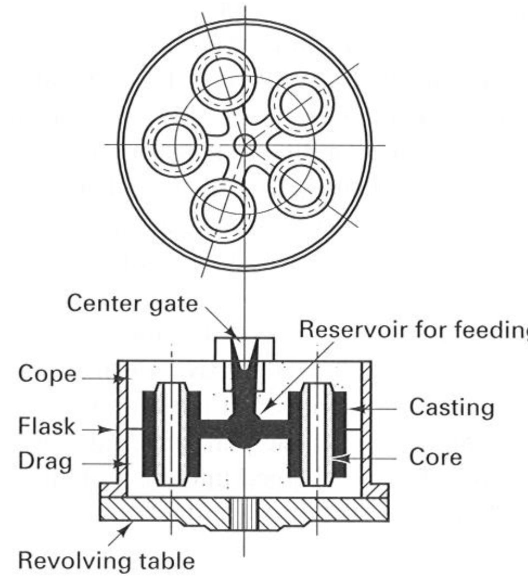


FIGURE 15-12 Method of casting by the centrifuging process. Metal is poured into the central pouring sprue and spun into the various mold cavities. *(Courtesy of American Cast Iron Pipe Company.)*

Continous Casting

- Used to produce:
  - basic shapes for subsequent hot/cold working.
  - Long lengths of uniform cross section product.
- Direct chill - long ingots (semi-continuous casting)

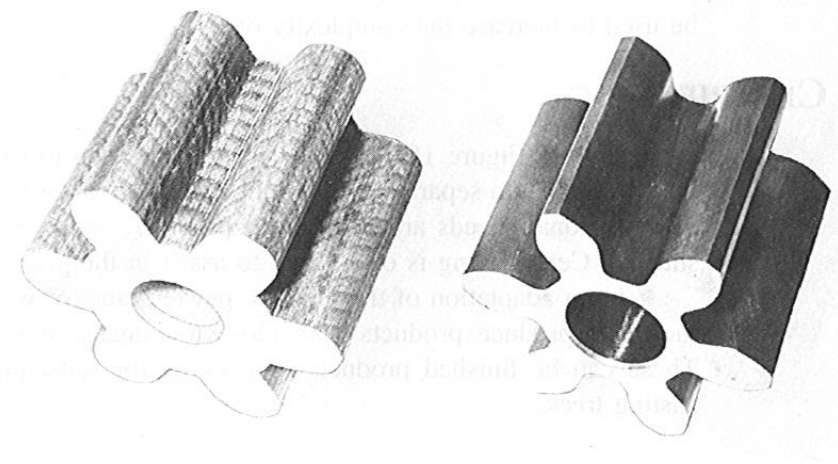


FIGURE 15-13 Gear produced by continuous casting. (*Left*) As-cast material; (*right*) after machining. *(Courtesy of American Smelting and Refining Company.)*

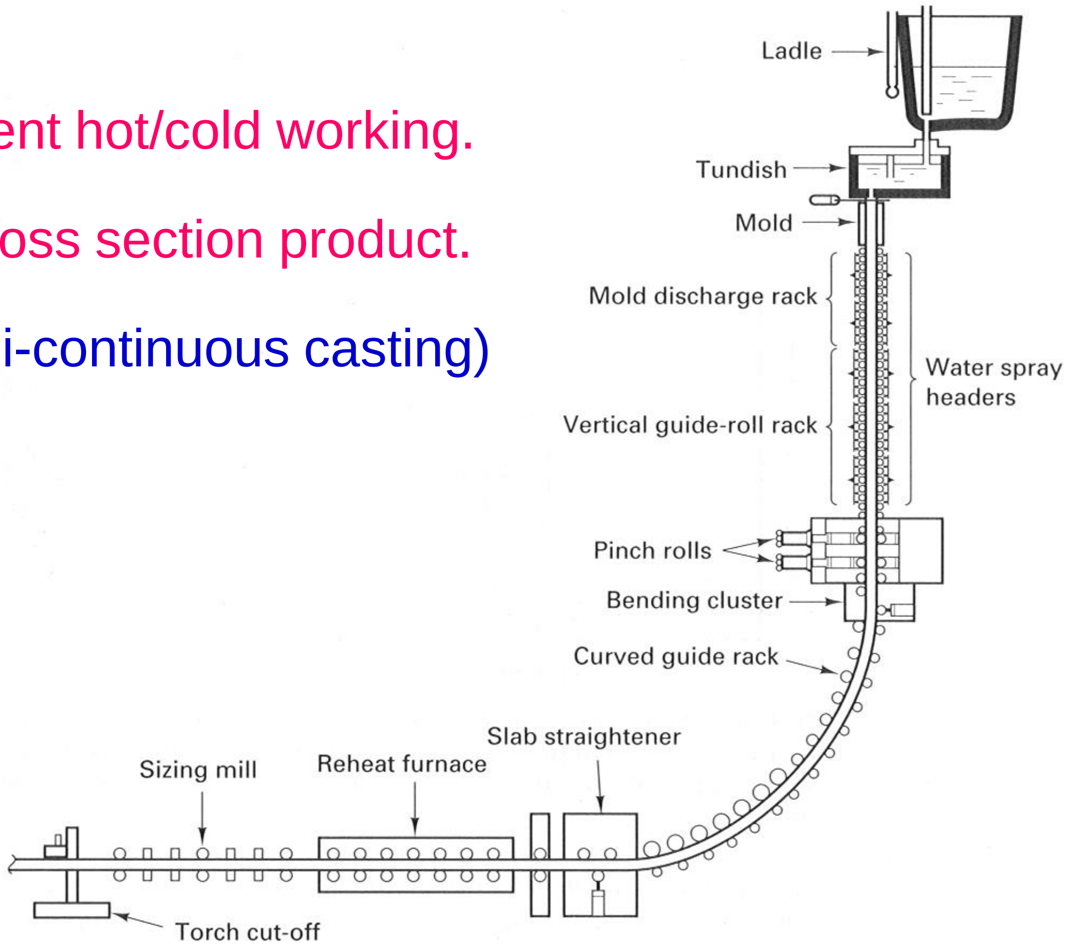


FIGURE 6-6 Schematic representation of the continuous casting process for producing billets, slabs, and bars. *(Courtesy of Materials Engineering.)*

Melting and Pouring

- System needs to produce molten metal:
  - at right temperature
  - with desired chemistry (not gaining or losing elements)
  - minimum contamination
  - long holding times without deterioration of quality
  - economical
  - environmentally friendly

Melting Procedure

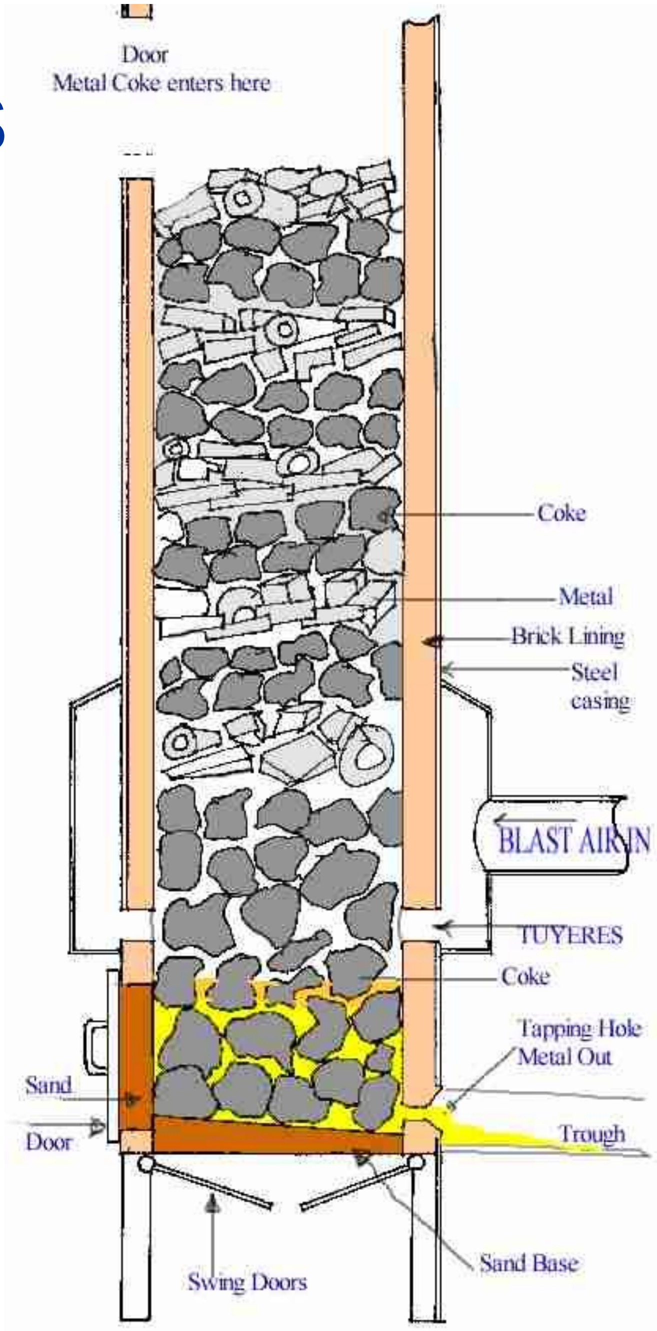
- Furnace/melting procedure depends on:
- temperatures required (including superheat)
- alloy being melted (and additions required)
- melting rate required
- metal quality (cleanliness)
- fuel costs
- variety of metals to be melted
- batch or continuous
- emission levels
- capital and operating systems

Melting Procedure

- Feedstock varies:
  - pre-alloyed ingot,
  - primary metal ingots + alloying elements (pure or master alloys),
  - commercial scrap.
- Often pre-heated. Increases melting rate by 30%

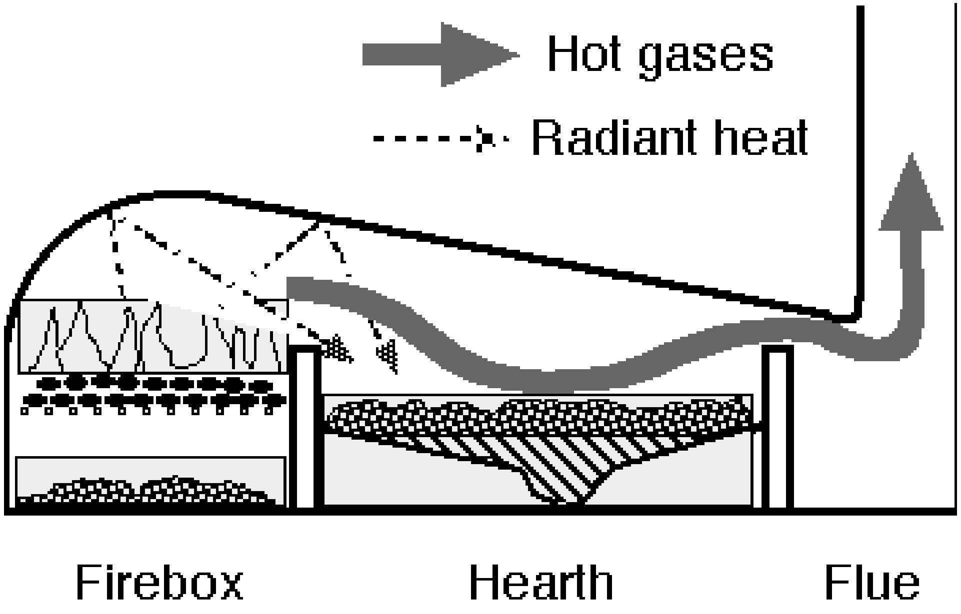
Furnaces

- Cupola - old-fashioned method of heating cast irons
  - Vertical, refractory lined shell with layers of coke, pig iron/scrap, limestone/flux, additions. Melted under forced air draft (like blast furnace). Molten metal collects at bottom, tapped off as needed.
  - Chemistry and temperature difficult to control



Furnaces

- Indirect Fuel Fired Furnaces
  - small batches of non-ferrous metals, Crucible is heated on outside by flame
- Direct Fuel Fired Furnaces
  - Surface of metal heated directly by burning fuel, larger than crucible, non-ferrous or cast iron holding furnace



Furnaces

- Arc Furnaces
  - Uses electrodes to pass electric arc to charge and back.
  - Rapid heating. Good for holding molten metal
  - Easier for pollution control

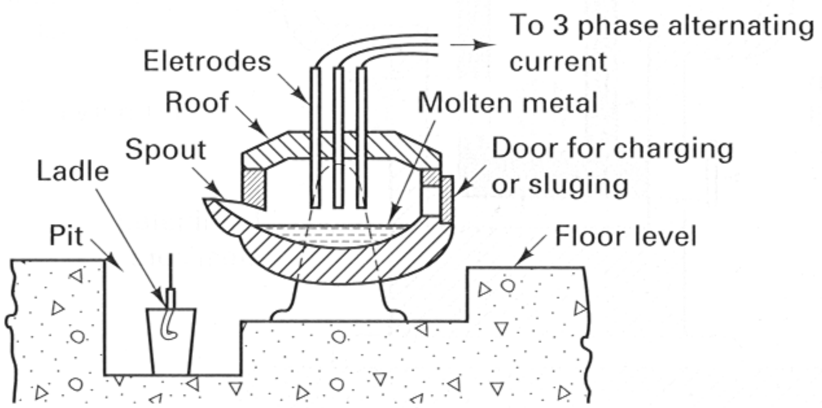


FIGURE 15-16 Schematic diagram of a three-phase electric arc furnace.

Furnaces

- Arc Furnaces
  - Open top, put charge in, replace top, lower electrodes to create arc.
  - Fluxes are added to protect molten metal (up to 200 tons, up to 25 tons more common).
  - Often used for steel, stainless steel. Good mixing, noisy, high consumables cost

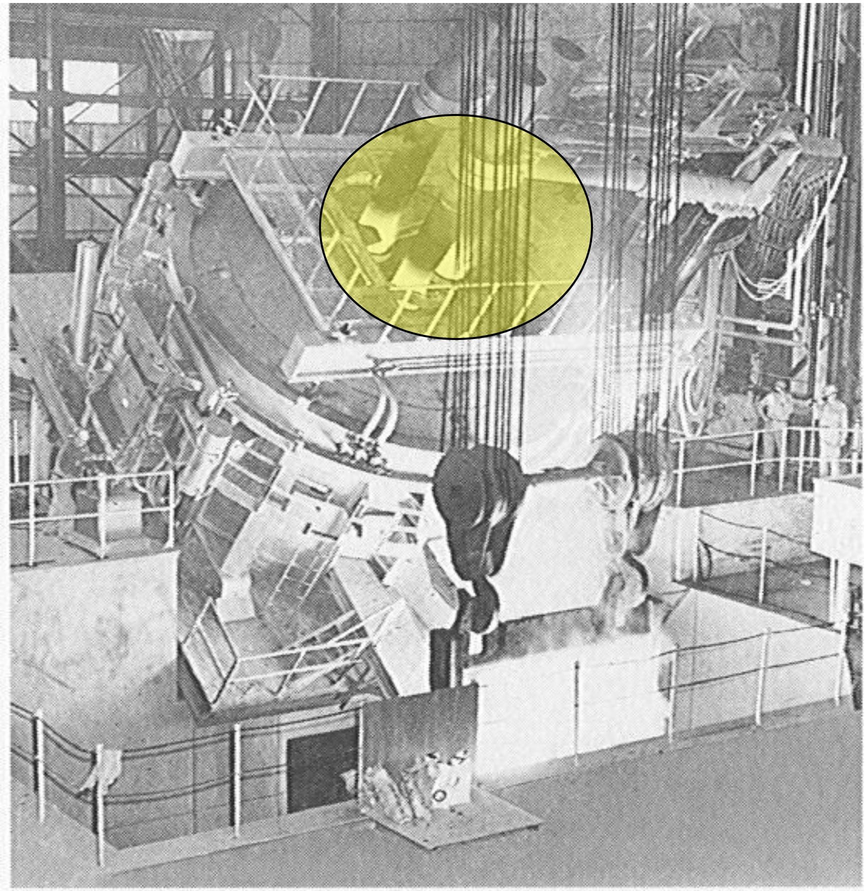


FIGURE 15-17 Electric arc furnace, tilted for pouring. *(Courtesy of Pittsburgh Lectromelt Furnace Corporation.)*

Furnaces

- Induction Furnaces
  - Electric induction. Rapid melting rates
  - Easier pollution control. Popular
- High-Frequency/coreless Units
  - crucible is surrounded by water cooled copper coil carrying high frequency electrical current. Creates alternating magnetic field which induces secondary currents in metal causing rapid heating.
  - All common alloys. Max temp. limited only by crucible lining
  - good temperature and compositional control
  - Up to 65 tons capacity, no contamination from heat source, pure

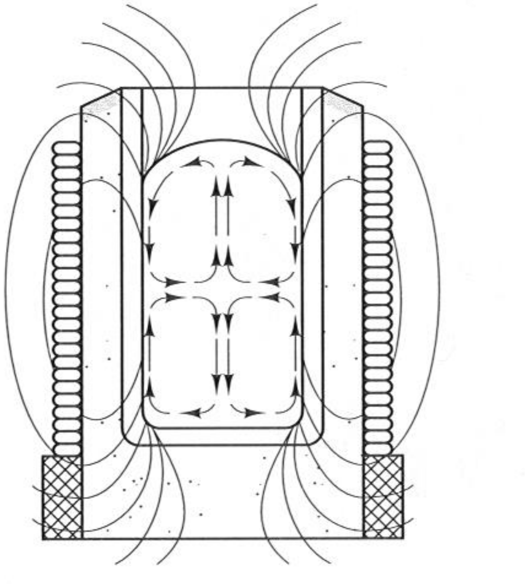


FIGURE 15-18 Schematic showing the basic principle of a coreless induction furnace.

Furnaces

- Low frequency/channel-type units
  - Primary coil surrounds a small channel through which molten metal flows to form secondary coil. Metal circulates through channel to be heated.

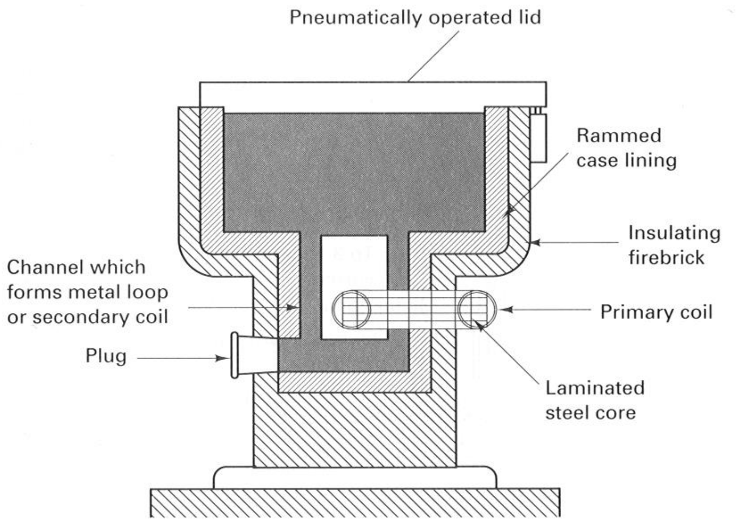


FIGURE 15-19 Cross section showing the principle of the low-frequency or channel-type induction furnace.

  - Accurate control, rapid heating
  - Must charge initially with enough molten metal to fill secondary coil.
  - Remaining metal can be any form
  - Often used as holding furnace, to maintain temperature for extended time. Capacities up to 250 tons

Pouring Practice

- Pouring device (LADLE) usually used to transfer molten metal from furnace to mould.
    - Maintain metal at appropriate temperature
    - deliver only high quality metal to mould (I.e. no dross/slag etc.)

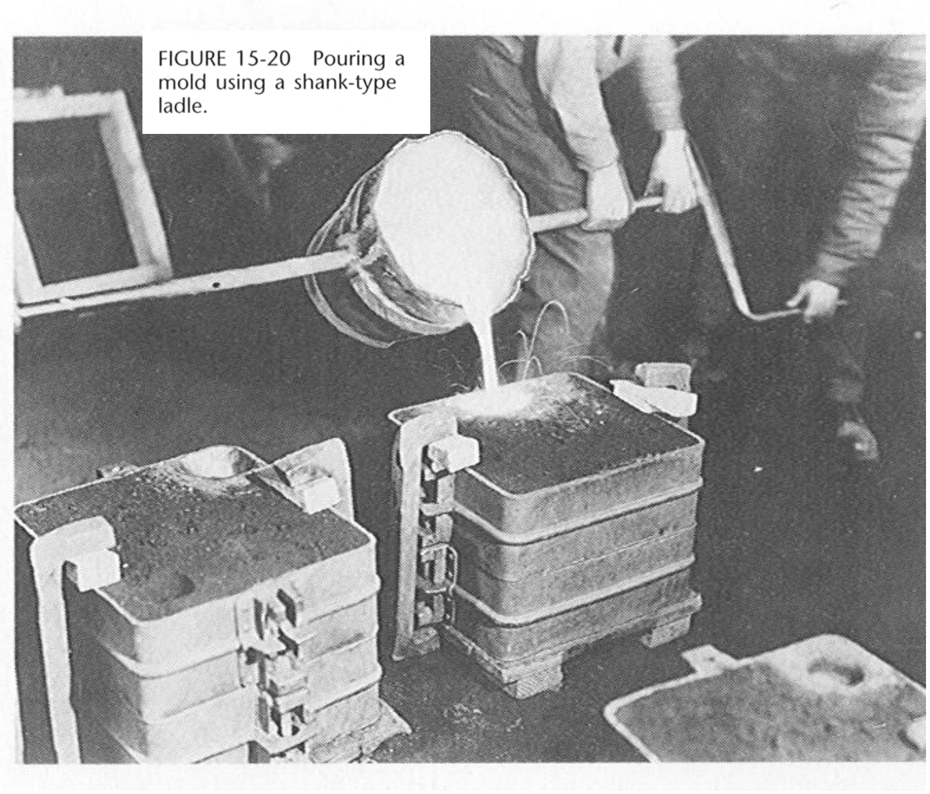


FIGURE 15-20 Pouring a mold using a shank-type ladle.

- hand-held for small foundries/castings
- machine held, bottom pour ladles in larger foundries/castings

Melting and Pouring

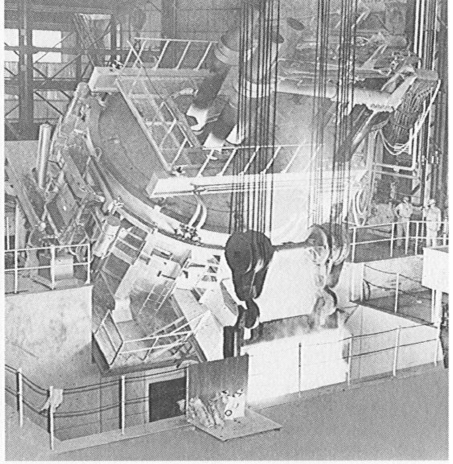


FIGURE 15-17 Electric arc furnace, tilted for pouring. *(Courtesy of Pittsburgh Lectromelt Furnace Corporation.)*

- Automatic pouring machines in mass-production foundries.
  - Molten metal transferred from main melting furnace to holding furnace
  - Measured quantity transferred to pouring ladles
  - And into corresponding moulds as they move in pouring station
  - Laser based position control

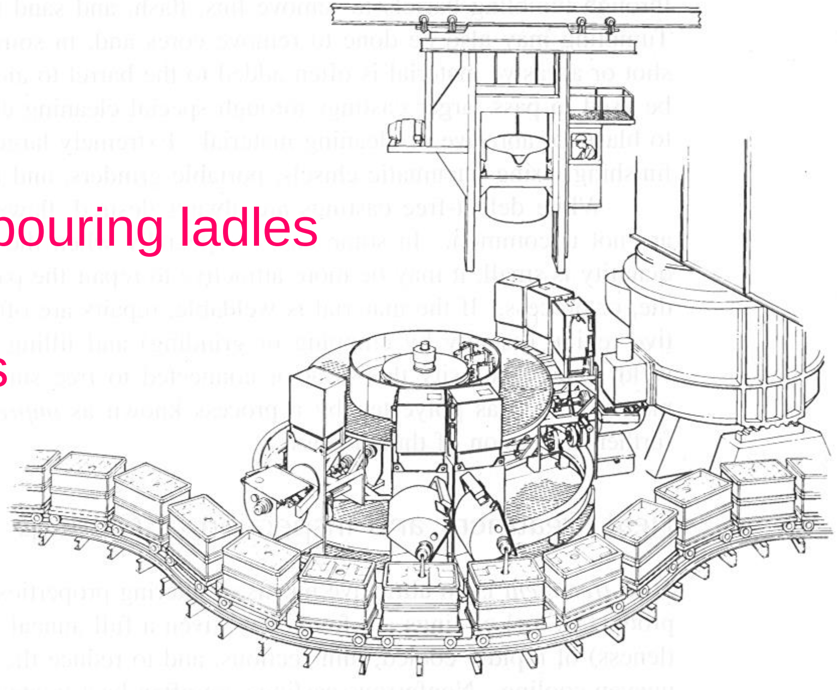


FIGURE 15-21 Machine for automatic pouring of molds on a conveyor line. *(Courtesy of Roberts Corporation.)*

Cleaning & Finishing

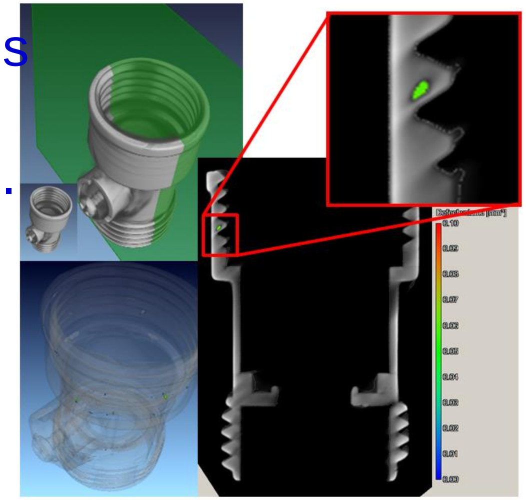
- Once removed from mould, most casting castings require some cleaning and/or finishing. E.g.
  - Removing cores (shaking, chemical dissolving of binder).
  - Removing gates, risers (small castings - knocked off, larger castings - cut off - cut-off wheel, hacksaw, plasma/gas cutter)
  - Remove fins, flash, rough spots (tumbling with metal shot, sand blasting, manual cutting, dressing for large castings)
  - Cleaning the surface (as above)
  - Repairing large castings (small castings remelted but large castings often cheaper to repair - grind/chip defect out then weld (or cast a patch). Pores can be filled with resin for some applications.

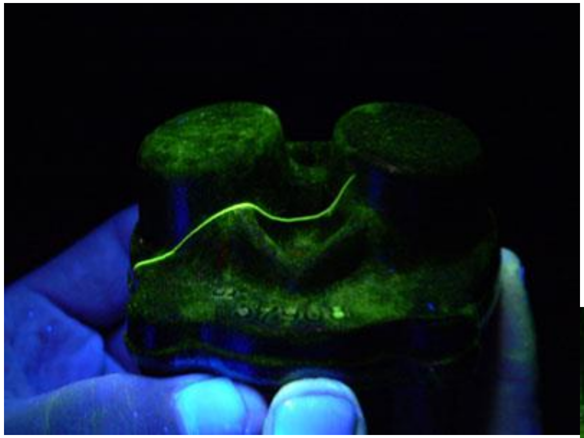
Heat Treating & Inspection

- Heat Treatment - main way of changing properties without affecting shape
- Steel castings annealed to reduce brittleness of rapidly cooled thin sections and for stress relief
- Quench & temper treatments possible on most ferrous alloys
- Age-hardening treatments possible on some alloys

Heat Treating & Inspection

- Non destructive testing often carried out on castings to check for defects; cracks, pores, internal defects.
  - X-ray radiography
  - neutron radiography
  - liquid penetrant
  - magnetic particle





Process Selection

- Some factors independent of casting method (metal & energy cost) but others are dependent (mould, pattern, machining, & labor costs)
- Pattern & Mould costs (sand casting – cheap, die casting – expensive)
- But as quantities of castings increase:
  - sand casting still needs new mould per casting, price per unit not strongly affected.
  - Die-casting can use same mould so price per unit comes down.

Process Selection

- Each casting process has its own benefits/ disadvantages:
  - Costs, batch sizes,
  - Quality, mass production
  - Alloys, complexity
  - compositional control
  - surface finish

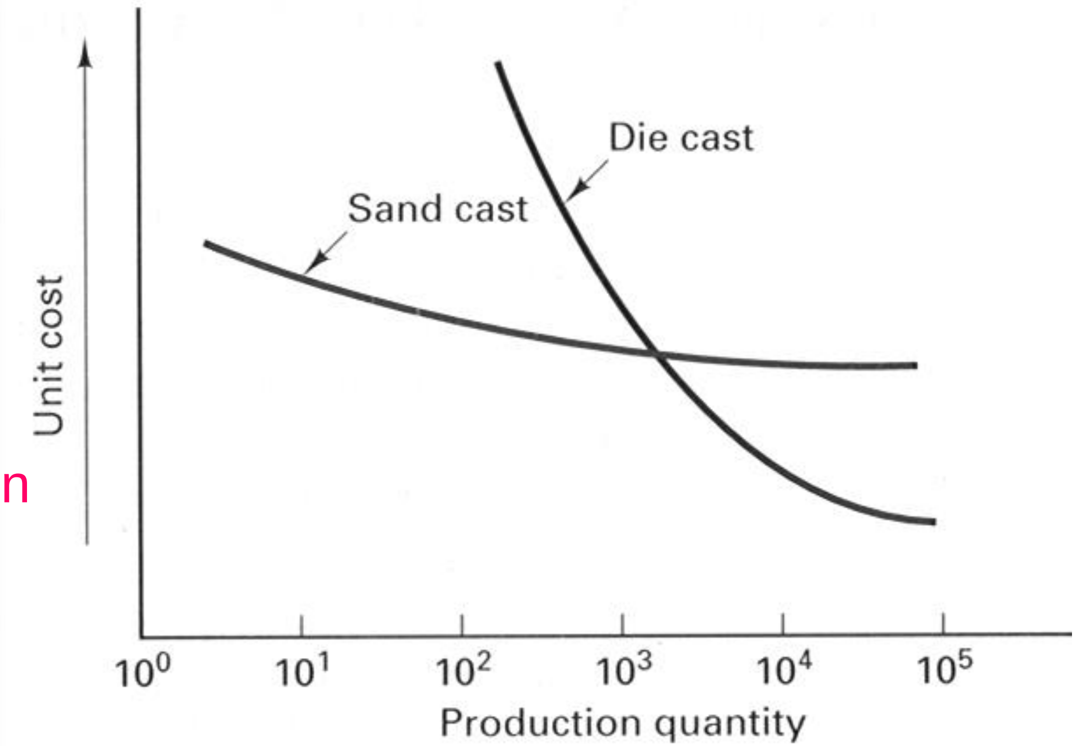


FIGURE 15-22 Typical unit cost of castings for both sand casting and die casting.

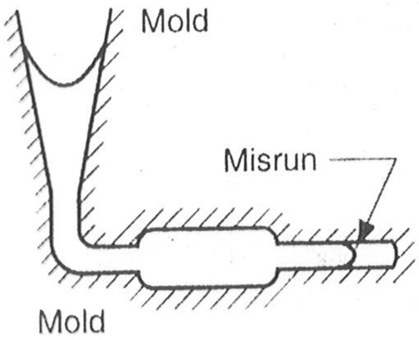
Casting Defects

- Some defects are common to all casting processes.

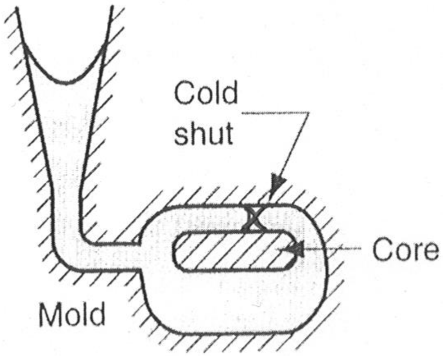
a. Misruns: casting solidifies before complete filling of cavity. Due to: (1) low fluidity (2) low pouring temperature, (3) slow pouring and/or (4) thin cross section of the mold cavity.

b. Cold shut: lack of fusion between two portions of the metal flow due to premature freezing. Causes are similar to those of a misrun.

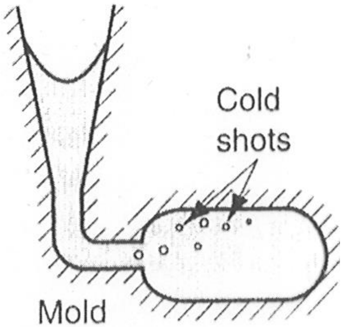
c. Cold shots: solid globules of metal are formed that become entrapped in the casting due to splattering during pouring.



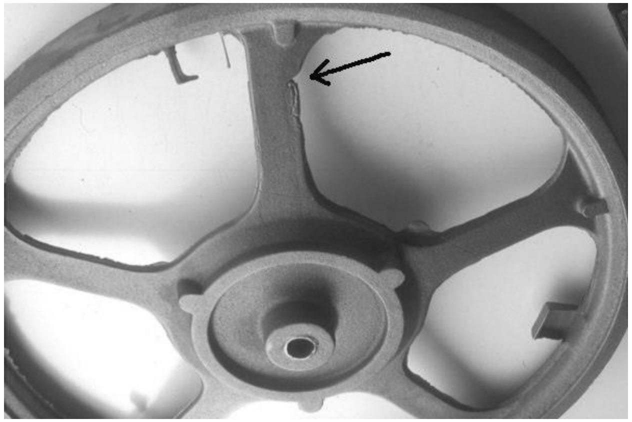
(a)



(b)



(c)



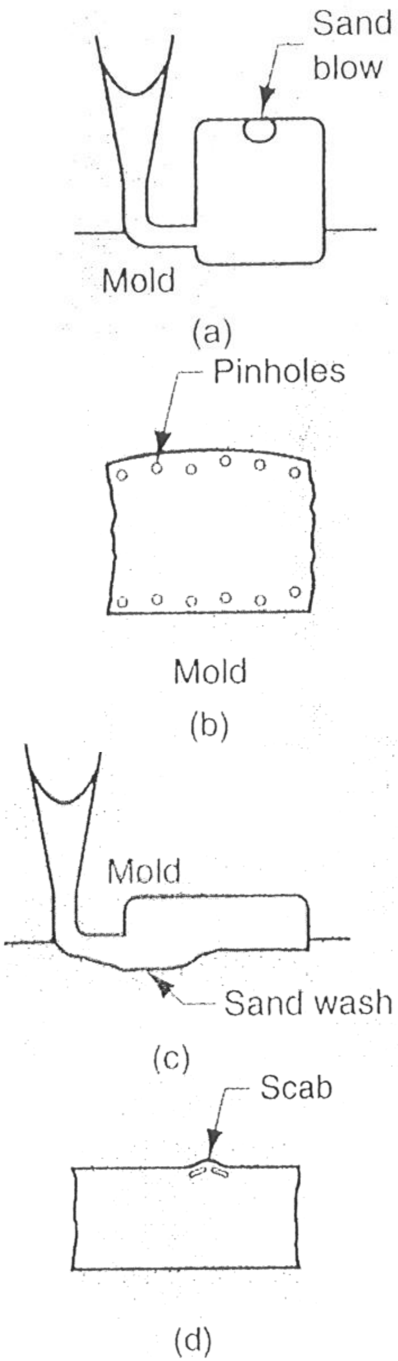
Sand Casting Defects

a. Sand blow – a balloon-shaped gas cavity caused by release of mold gases during pouring. At or below the casting surface near the casting top. Low permeability; poor venting, and high moisture contents in sand mold are the usual causes.

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

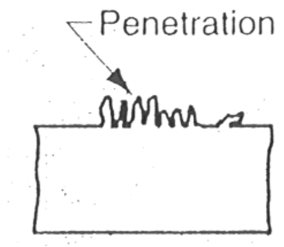
c. Sand wash –irregularity in the casting surface that results from erosion of sand mold during pouring

d. Scab - rough area on the casting surface due to encrustations of sand and metal. Caused by mold surface flaking off and embedding in the casting surface.



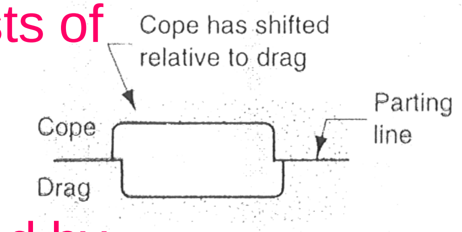
Sand Casting Defects

e. Penetration- fluidity of the liquid is too high, penetrates into the sand mold or sand core. Surface of casting consists of sand grains and metal. Harder packing reduces this



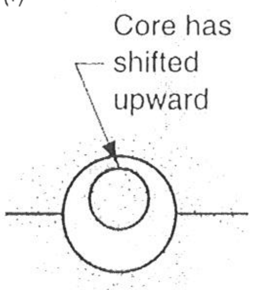
(e)

f. Mold shift -step in the casting at the parting line caused by shift of cope/drag.



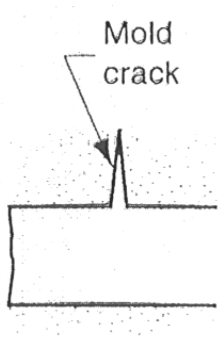
(f)

g. Core shift -similar thing happens with the core, but the displacement is usually vertical. Core shift and mold shift are caused by buoyancy of the molten metal.



(g)

h. Mold crack – If mould strength is insufficient, a crack may develop, into which liquid metal can seep to form a "fin" on the final casting.



(h)


Sand & Slag Inclusions
Blowhole