Metal Casting

Solidification of Metals in Molds

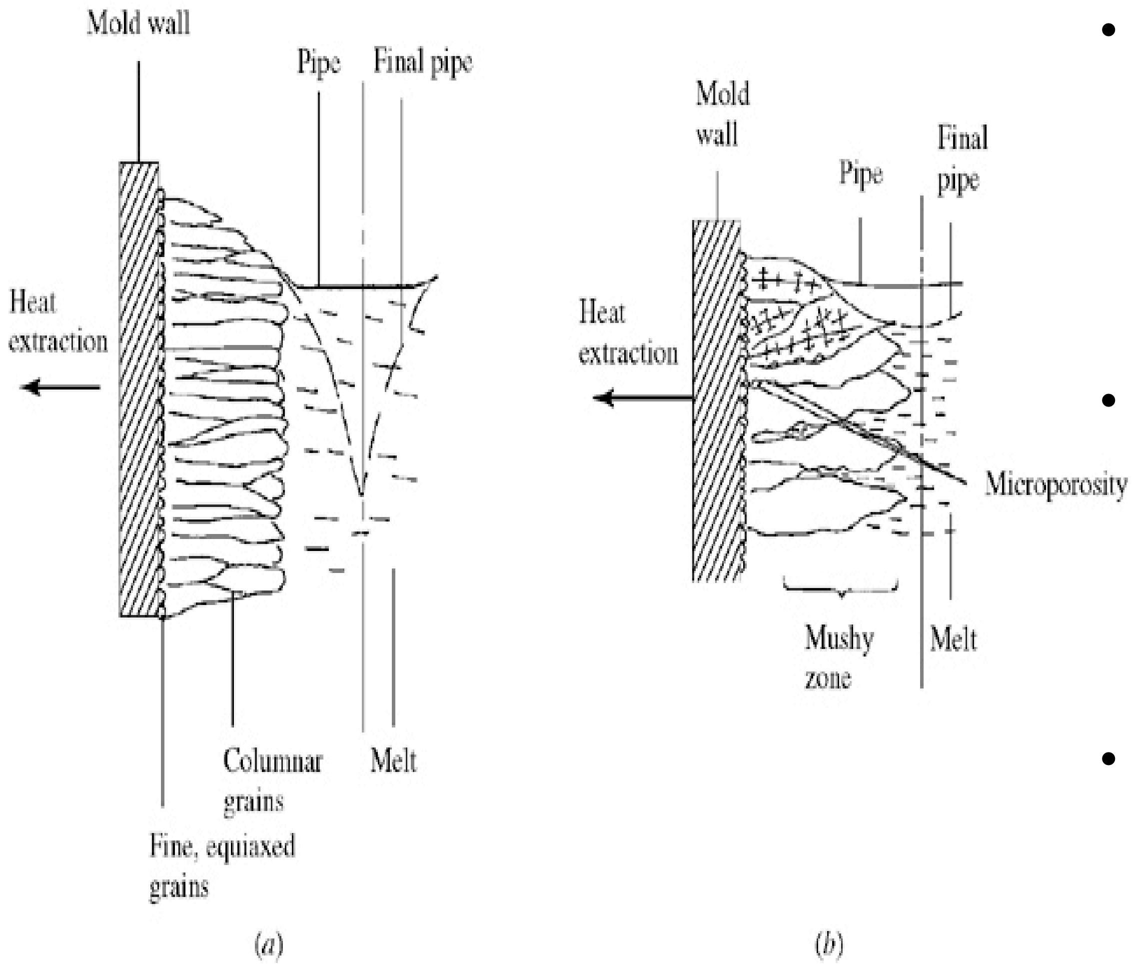


figure 7.1

- Pure Metals -
  - Solidify at a constant temperature
  - Planar solidification front
  - Columnar crystals
- Eutectics -
  - Solidify at a constant temperature
  - Planar solidification front
  - Lamellar crystals
- Solid Solutions
  - Solidify over freezing range (solidus – liquidus)
  - Dendritic structure

Basic Engineering Principles

- Heat Transfer
  - Degree of Superheat
  - Material Properties
  - Die Properties
  - External Heating/Cooling
  - Part Geometry
  - Chvorinov's Rule

$$t_s := C \cdot \left(\frac{V}{A}\right)^2$$

- Fluid Flow
  - Degree of Superheat
  - Part Geometry
  - Material Properties (viscosity)
  - Die Properties
  - Continuity Equation
    - $A_0 v_0 = A_1 v_1$
  - Bernoulli Equation
  - Max Flow without turbulence
    - Reynold's Number

$$Re := \frac{\rho \cdot v \cdot D}{\mu}$$

Microsegregation

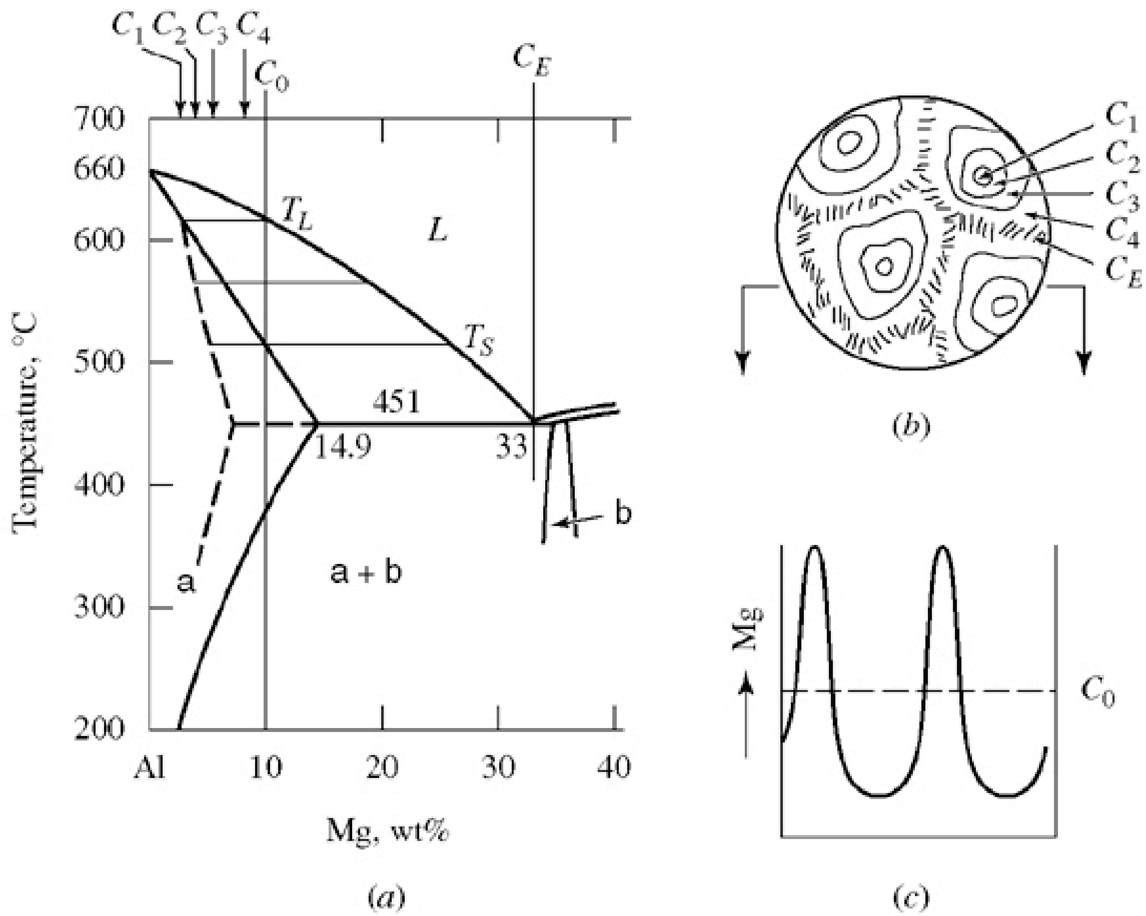
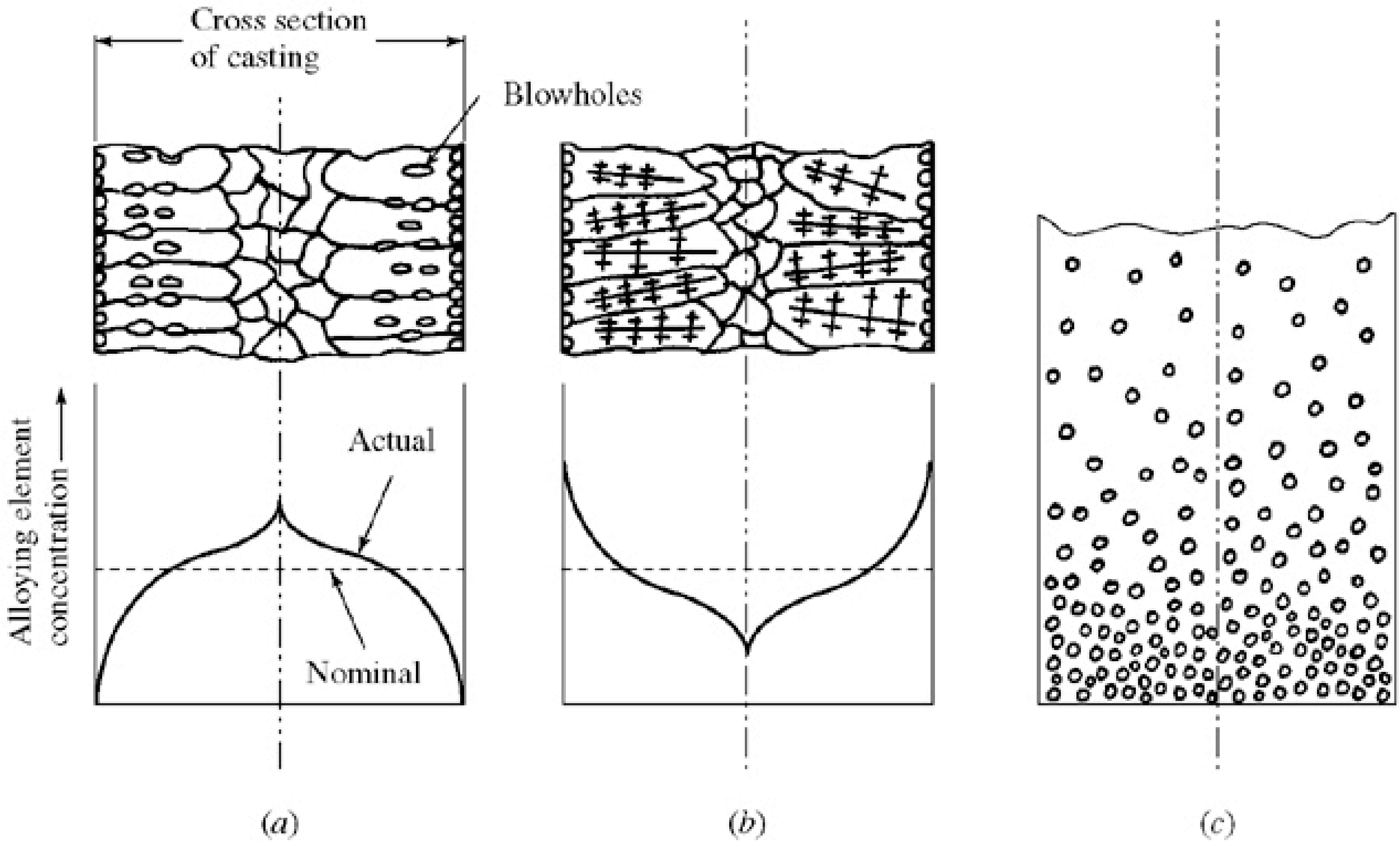


figure 6.9

Microsegregation or coring

Macrosegregation



Macrosegregation caused by compositional difference over long distances within a casting.

Fluidity

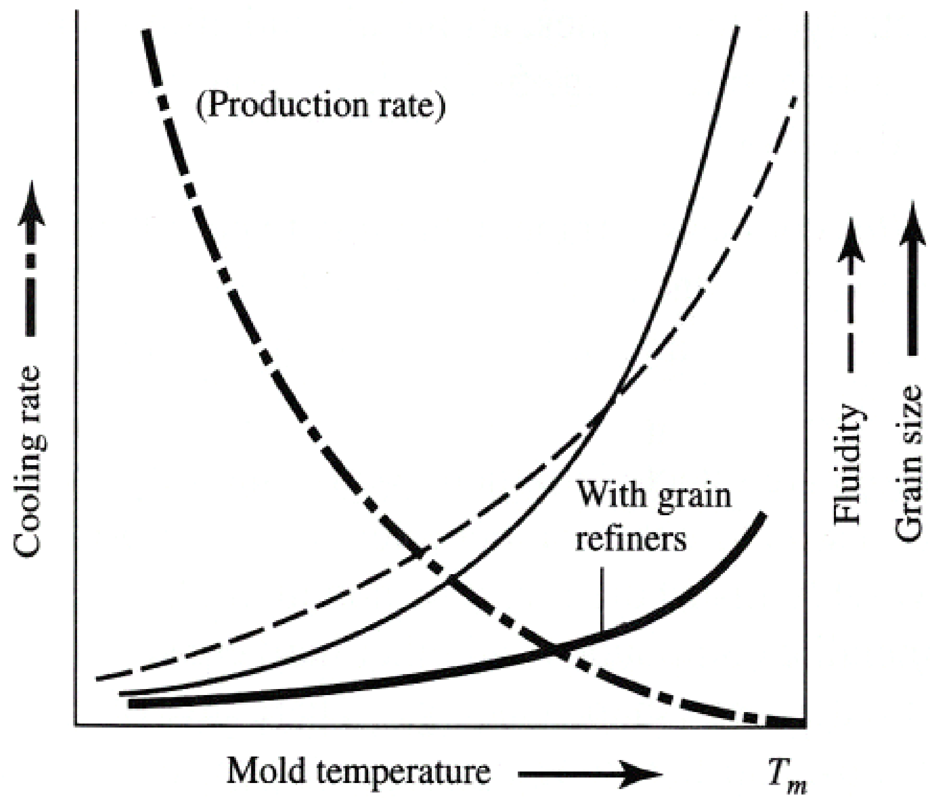


Figure 7–7 Mold temperature is a powerful factor in determining production rates, attainable shape complexity, and mechanical properties.

- Fluidity is used to characterize the mold filling ability, sometimes castability.
- Superheat = $(T_{melt} - T_L)/T_L$

Shape Casting Processes

- Expendable Mold
  - Permanent Pattern
    - Sand Casting
    - Plaster Molding
  - Expendable Pattern
    - Lost Foam
    - Lost Wax (investment casting)
- Permanent Mold
  - Gravity
  - Low Pressure/Vacuum
  - Die casting

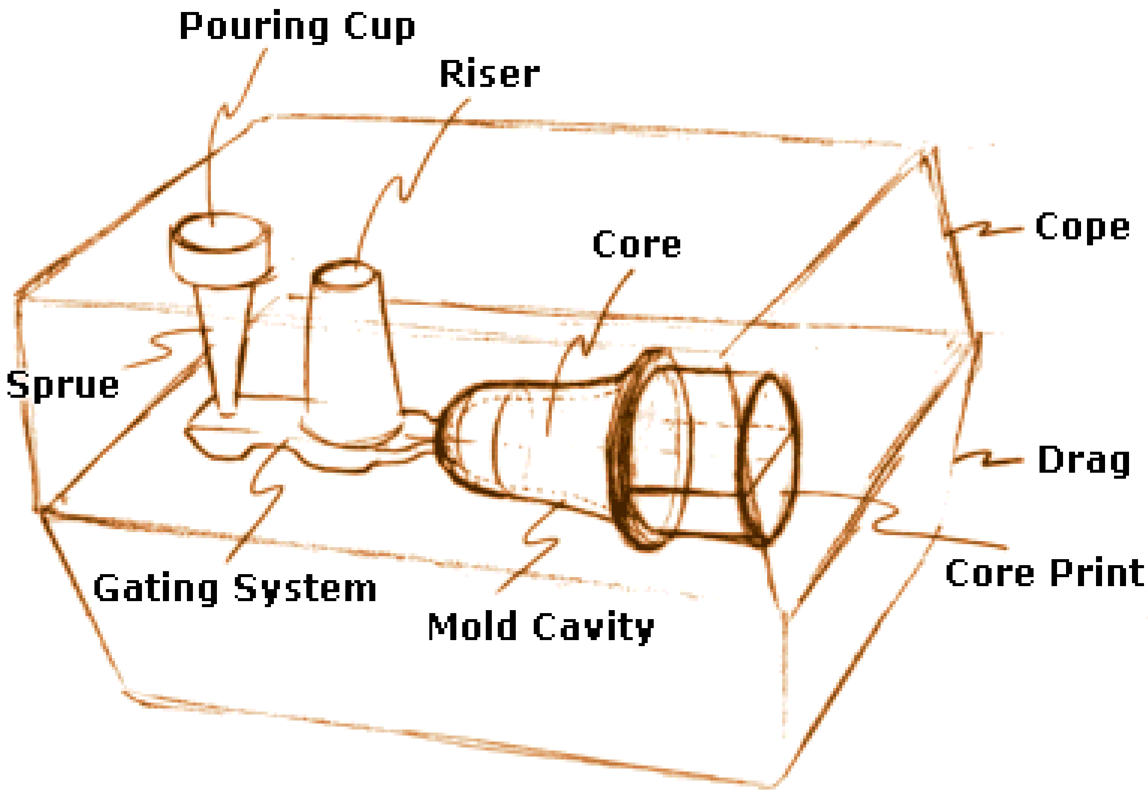
    Moderate to high pressures
    - Hot Chamber
    - Cold Chamber

Sand, Investment, and Lost Foam Casting

- Use gravity to fill the mold
- Mold is destroyed to remove casting
- Metal flow is slow
- Walls are much thicker than in die casting
- Cycle time is longer than die casting because of inability of mold material to remove heat

Sand Casting

- Pattern for shape
- Pack sand around pattern
- Remove Pattern
- Put Cope and Drag together
- Pour - gravity fed
- Take part out of sand - recycle sand.



Casting Terminology

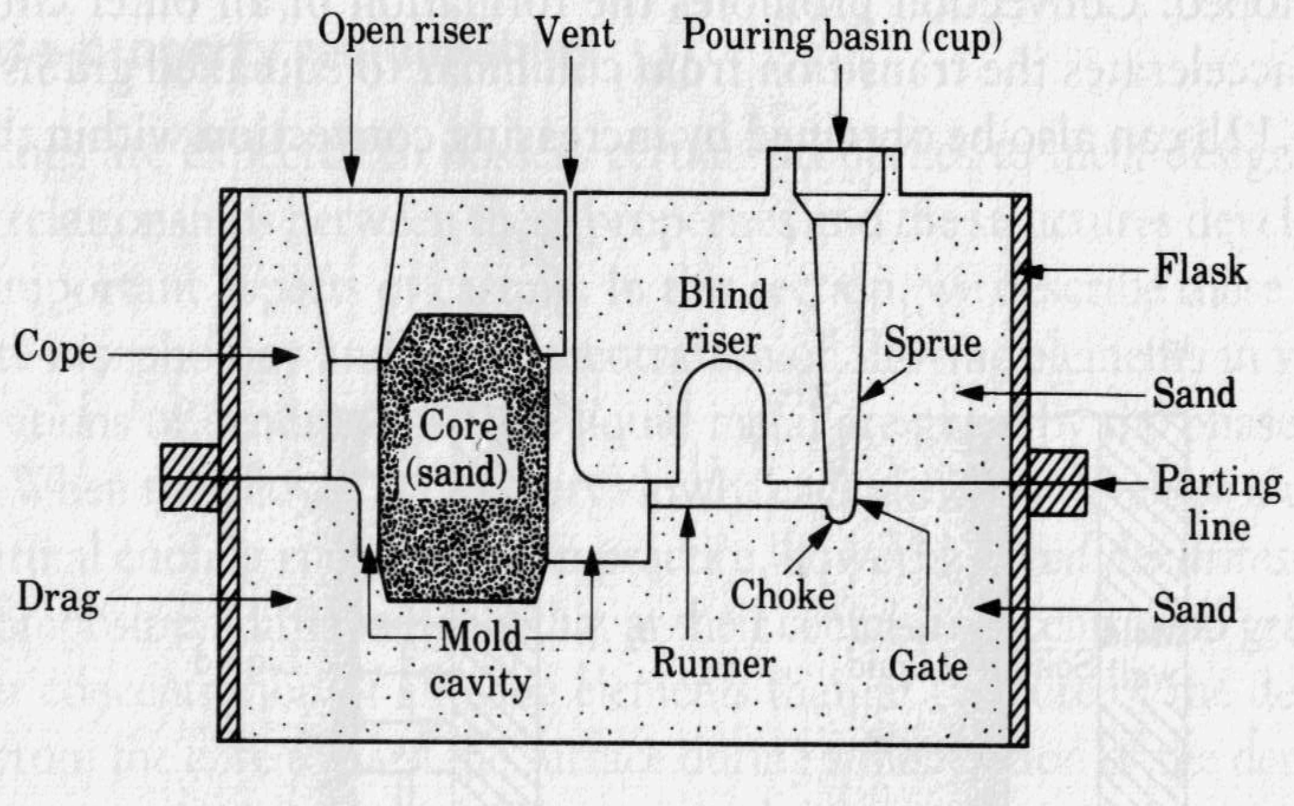


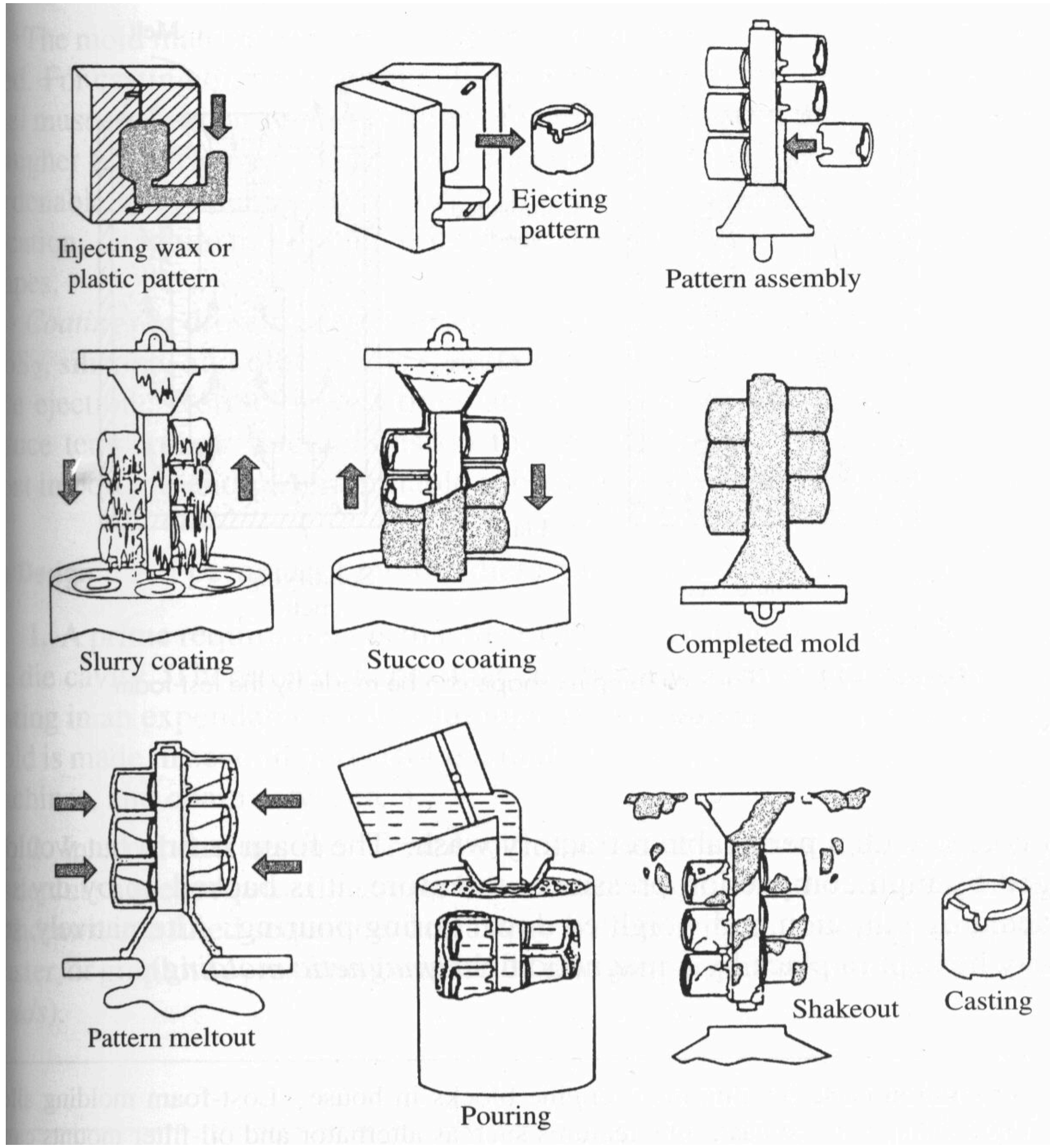
FIGURE 5.14 Schematic illustration of a sand mold showing various features.

Sand Casting Advantages/Disadvantages

- Advantages
  - Inexpensive mold
  - Complex geometry
  - All alloys
  - Unlimited size
  - Economical in low quantities
- Disadvantages
  - Cost per part is higher
    - Labor intensive
    - Slower production rate
  - Rough surface finish
  - Loose tolerances
  - Requires relatively thick walls (0.120”)

Investment Casting

- Create Wax Pattern
- Assemble Wax Tree
- Coat with Ceramic
- Melt out wax
- Pour in molten metal
- Break off ceramic

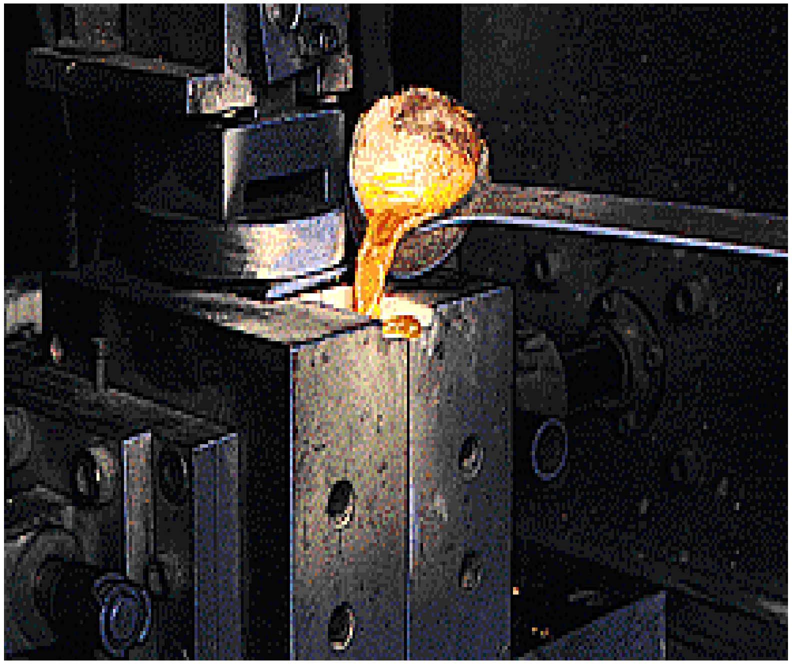


Investment Casting Adv/Disadv

- Advantages
  - Good dimensional accuracy
  - Relatively inexpensive mold
  - Rapid production rates possible
  - Complex shapes
  - Very high temp materials - Titanium
- Disadvantages
  - Long production cycle
    - leads to high cost per part
  - Mold is not reusable

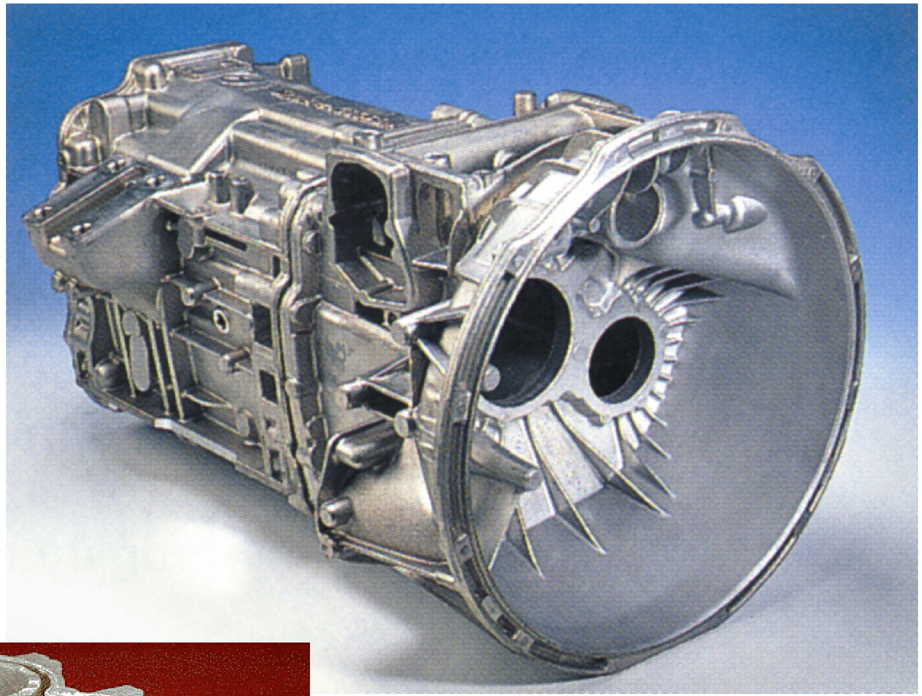
Permanent Mold Casting

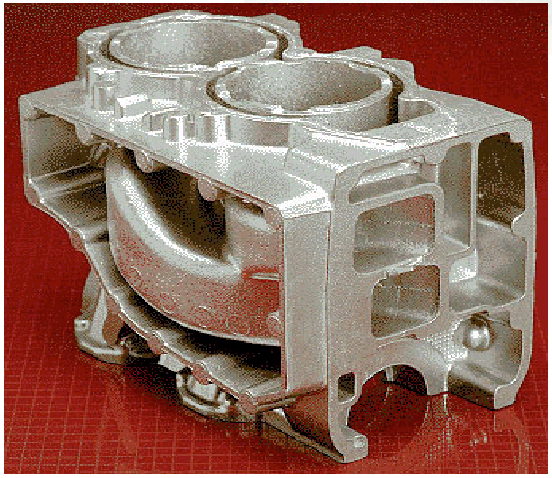
- Mold removed, not destroyed
- Uses gravity to fill mold
- Metal flow is slow
- Mold is steel - has comparatively good thermal conductivity
- Machines smaller

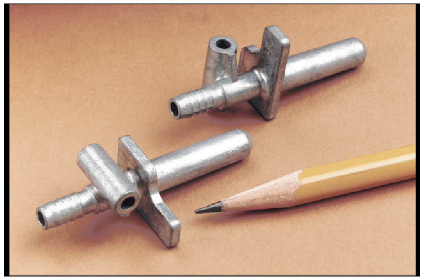


Die Casting

- Liquid metal injected into reusable steel mold, or die, very quickly with high pressures
- Reusable steel tooling and injection of liquid metal with high pressures differentiates die casting from other metal casting processes

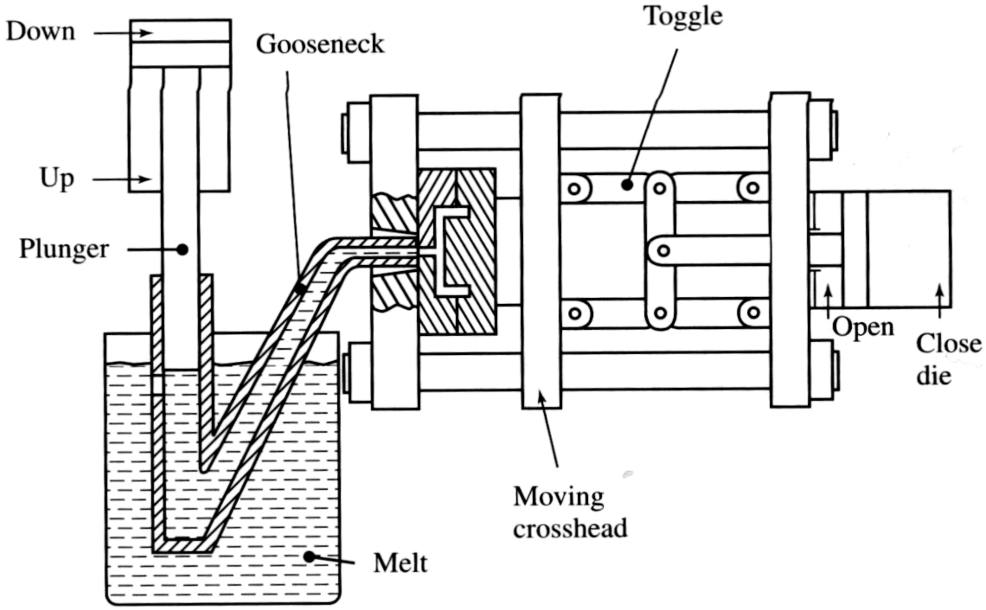


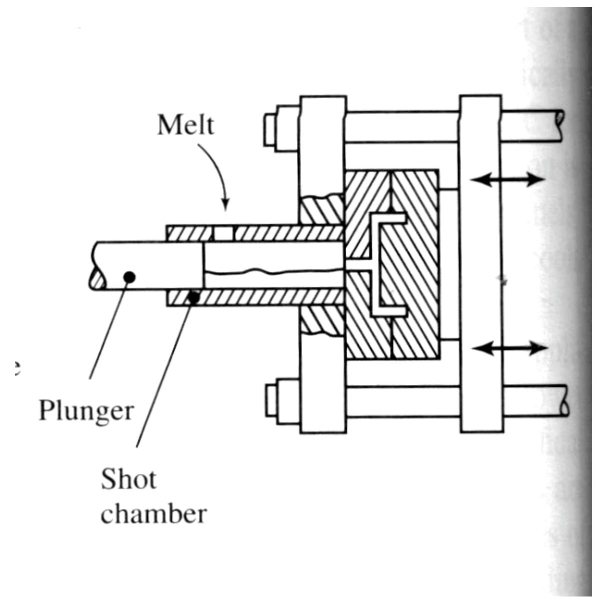




Die Casting - Two Major Types

- Hot Chamber
  - Zn or Zn alloys only
  - Higher production rate 15 cycles per minute for small parts
  - Metal injected directly
- Cold Chamber
  - Al, Mg, Zn
  - Melt is poured into cylinder, which is then shot into chamber



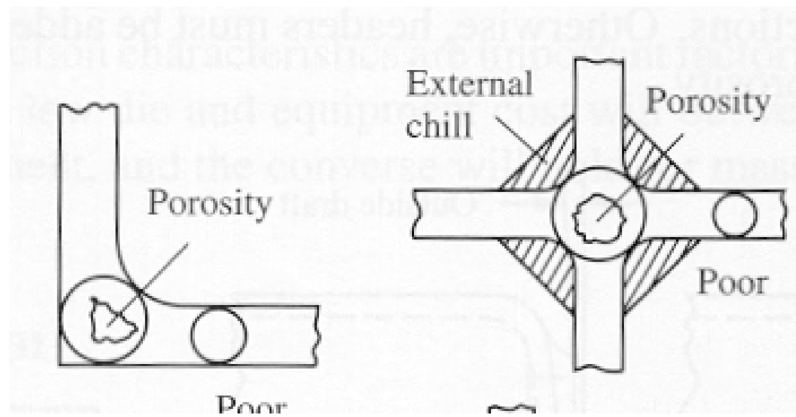


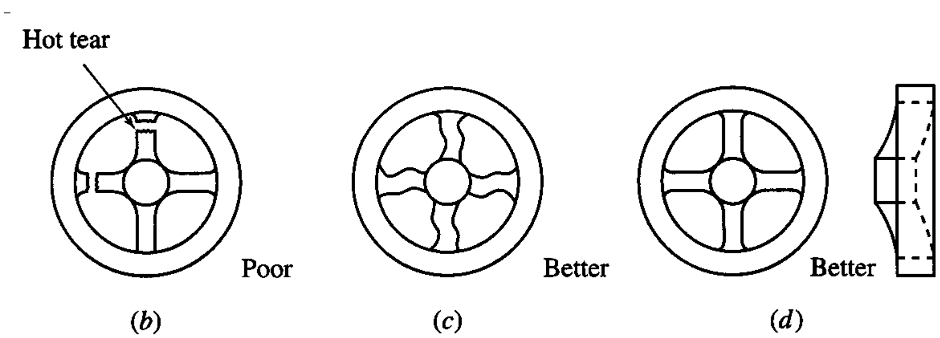
Adv/Disadv of Die Casting

- Advantages
  - High production rates possible, with high level of automation
  - Very thin walls possible (0.020” for Mg die casting)
  - Good surface finish
  - Economical in large quantities
  - Better control of mold temps
- Disadvantages
  - High tooling cost
  - Long lead times (months)
  - Limited size (<25 lbs)
  - Limited in alloys (low temperature only)
    - Zn
    - Al
    - Mg
    - Cu

Casting Defects

- Porosity
- Impurities - oxides
- Cold Shut
- Hot Tearing
- Dimensional tolerance and part geometry
- Warping
- Shrinkage





Casting
Die Design

- Fill completely with metal
- Solidify quickly without defects
- Eject readily from the die

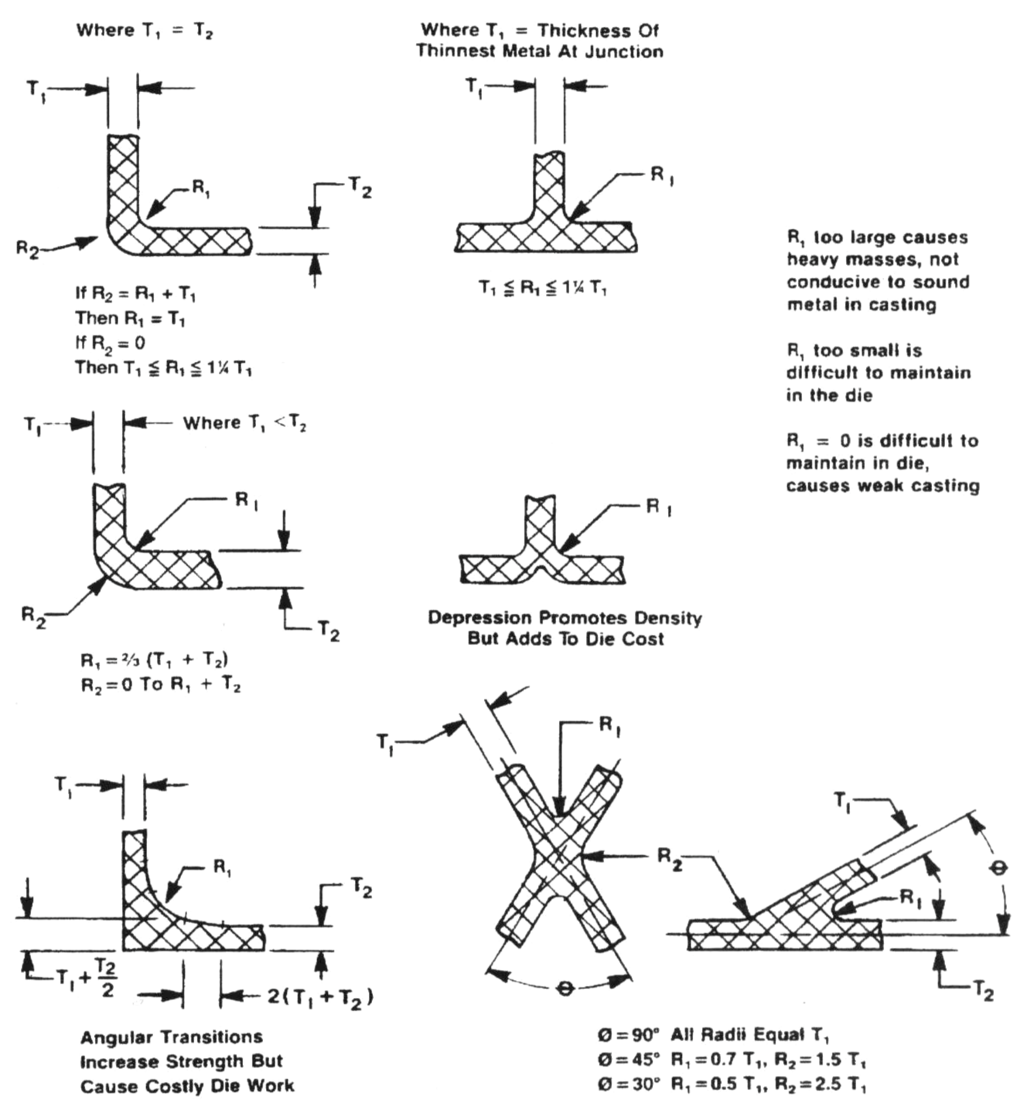
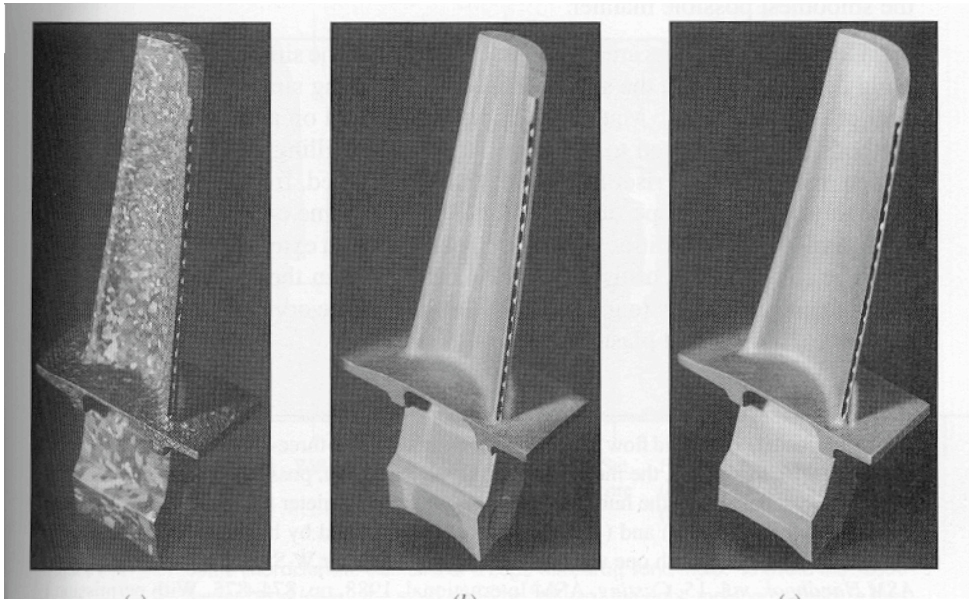


Figure 2-4 *Recommended dimensions for fillets. R1, too large causes heavy masses, not conducive to sound metal in the casting. R1 is too small is difficult to maintain in the die. R1=0 is difficult to maintain in the die causes a weak casting*

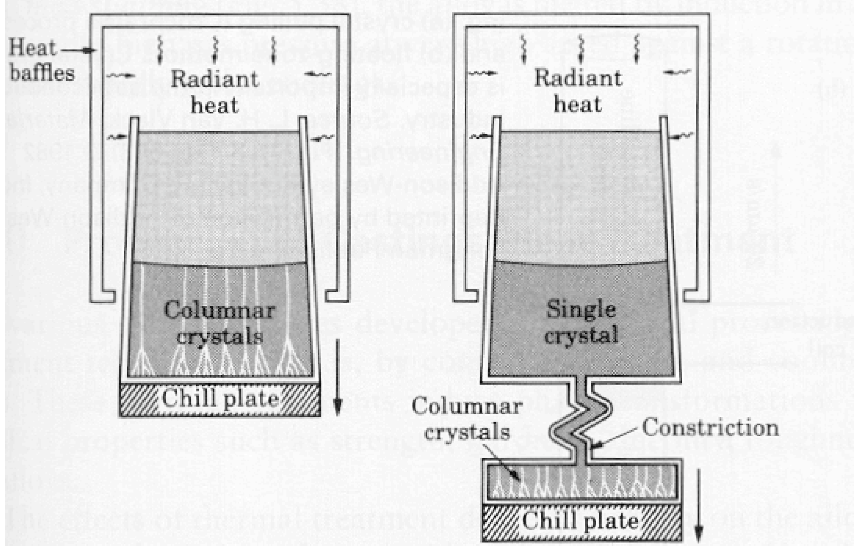
Six Die Design Principles

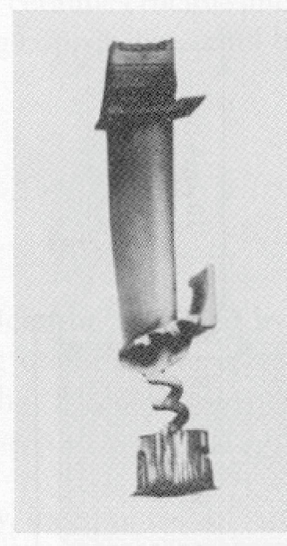
- **Wall thickness should be as consistent as possible**
  - Wall section possesses a dense fine-grained skin. Defects likely in material in between walls. Wall sections should be as uniform as possible. Thinner walls contribute a lesser heat load than heavier walls and will have a longer die life.
- **Intersections of walls, ribs and gussets should blend with transitions and generous radii**
  - Generous radii and transitions promote metal flow and internal integrity. Radii and fillets enhance structural integrity. Fillets reduce heat concentration in both the die and castings.
- **Specify standard draft**
  - Draft is highly desirable on surfaces parallel to the direction of die draw. Recommended draft is determined by the alloy, the length of the dimension parallel to the die draw, and If the dimension is an inside or outside wall
- **Eliminate or minimize sharp corners**
  - Accommodate them at parting lines and at the junctions of die components. Break them with radii or chamfers.
- **Avoid undercuts**
  - May require machining operations or additional die components, such as retractable core slides
- **Dimensions with critical tolerances should relate to only one die member**
  - Precision is reduced for relationships across the parting line or to moving components

Casting of Single Crystal Components



Jet engine turbine blades





Fluid Flow Characteristics

- Mass Continuity $Q = A_1 v_1 = A_2 v_2$
  - where Q is the volumetric rate of flow, m^3/s, A is the cross sectional area of the liquid stream, and *v* is the velocity of the liquid in that location.
- Reynolds number $$\mathrm{Re} = \frac{vD\rho}{\eta}$$
  - where *v* is the velocity of the liquid, *D* is the diameter of the channel, ρ is the density, and η is the viscosity.
  - For casting, Re = 2,000 – 20,000

Bernoulli's Theorem

- Under steady well-developed flow conditions, the total energy of a unit volume of material must be a constant at every part of the system.

$$p_0 + \frac{\rho v_0^2}{2} + \rho g h_0 = p_1 + \frac{\rho v_1^2}{2} + \rho g h_1 + f$$

  - where p is the pressure, v is the velocity, h is the height above a reference plane, f is the energy losses due to friction, and ρ is the density.

Heat Extraction

- The solidification time is a function of the volume of the casting and its surface area (Chvorinov's rule)

$$Solidification\_Time = \left(\frac{volume}{surface\_area} \right)^2$$