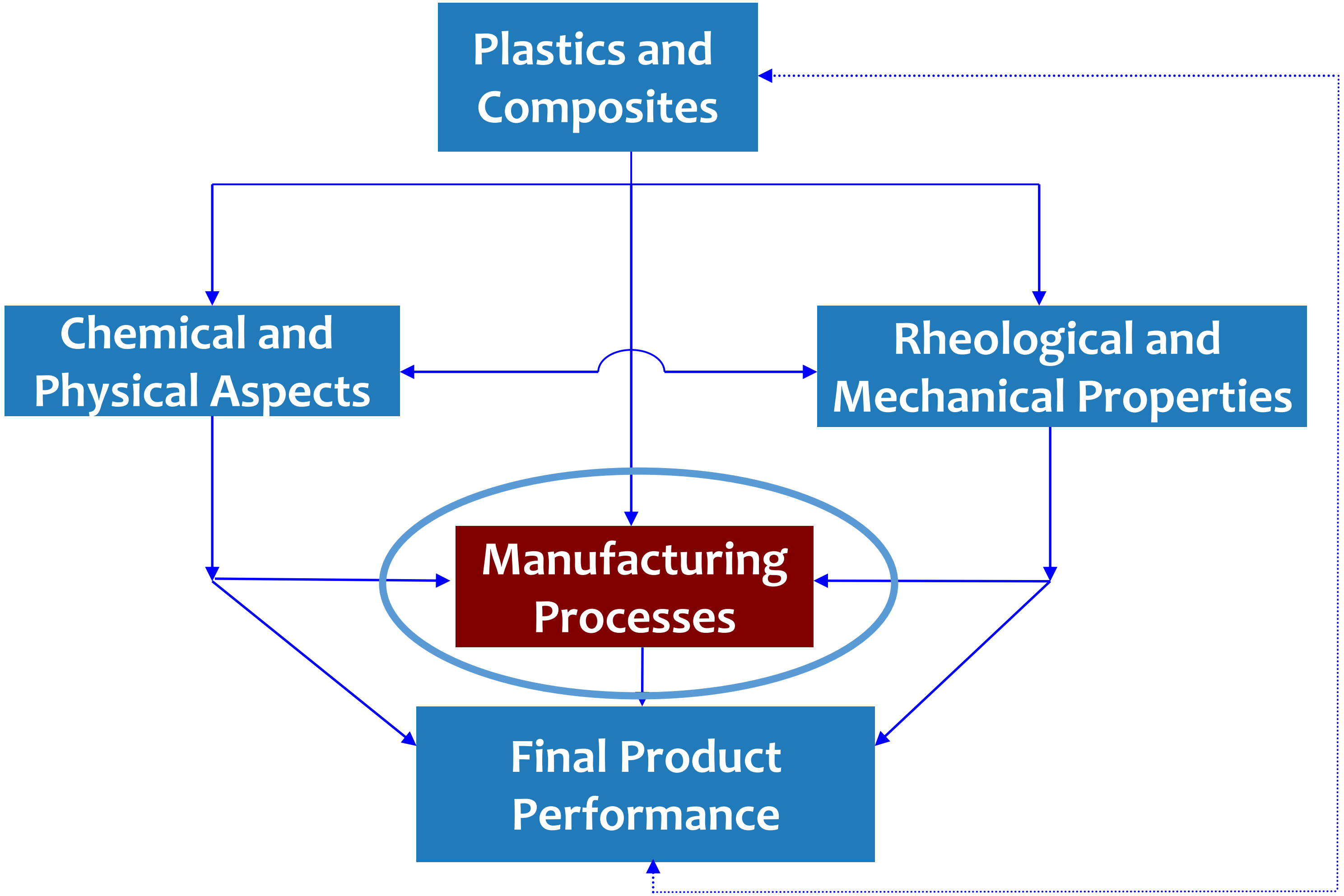
Conceptual map of the course



Tecnológico de Monterrey

Molding

Dr. Jaime Bonilla Ríos

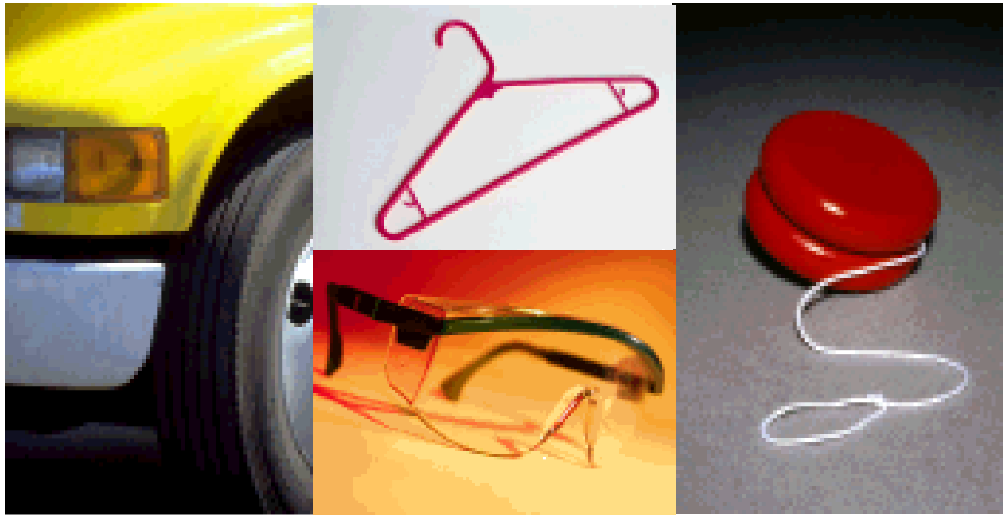
Molding

Molding process

Most common plastic "finishing" process

Many molding methods:

- Injection Molding
- Transfer Molding
- Blow Molding
- Compression Molding
- Rotational Molding
- Reaction Injection Molding



http://www.youtube.com/watch?v=eUthHS3MTdA&feature=related

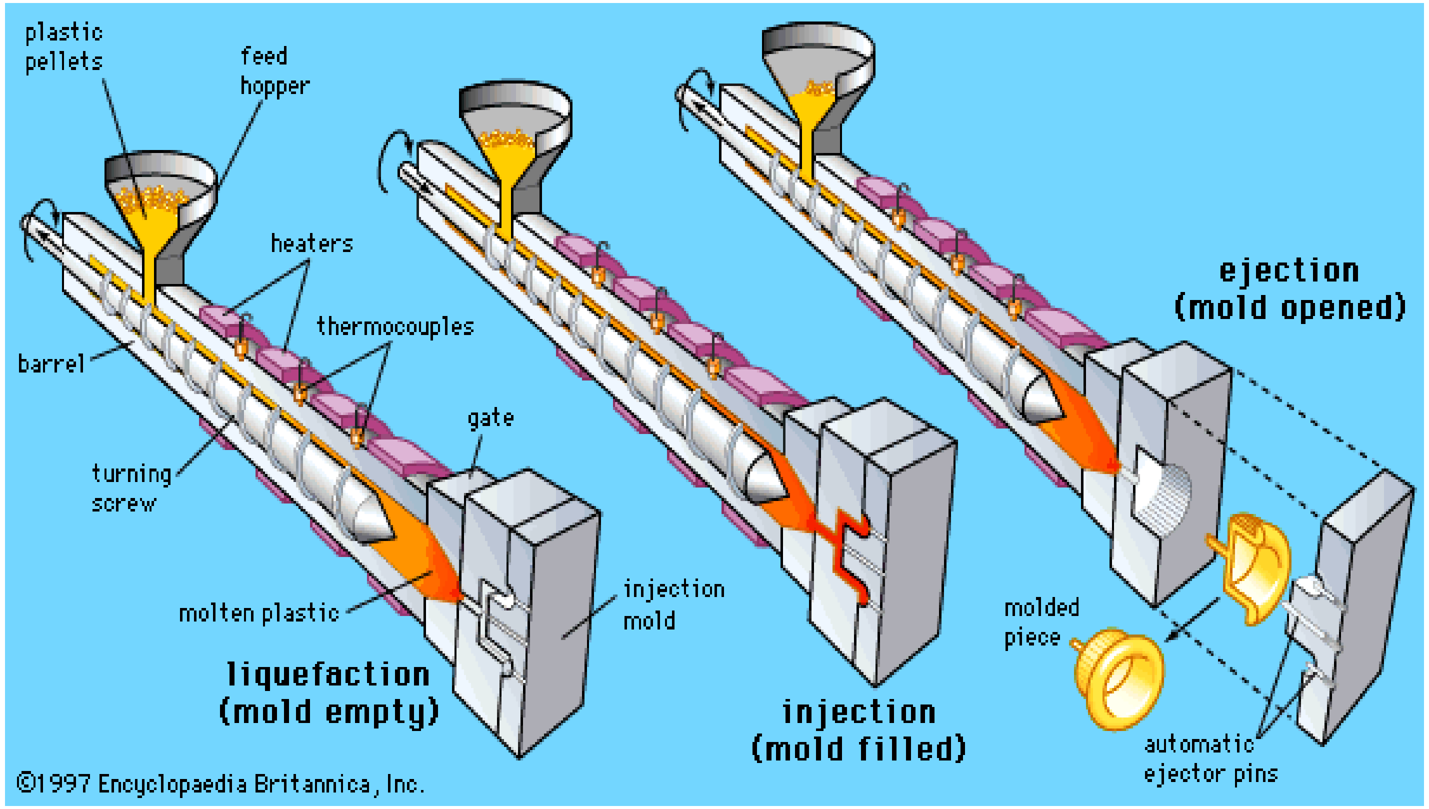
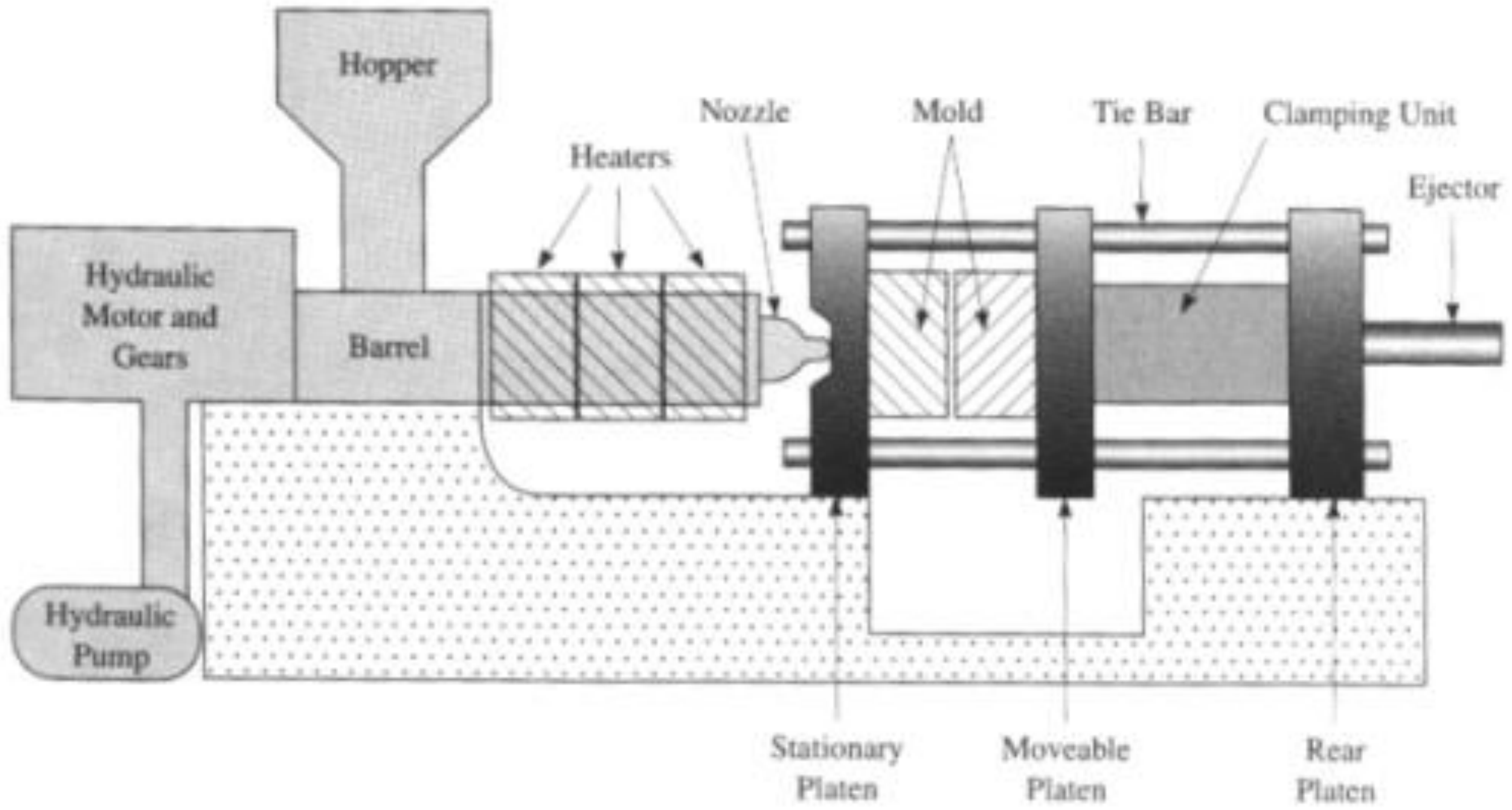


Figure 3: Injection molding of thermoplastic polymers. (Left) Plastic pellets are fed from a hopper into a reciprocating screw injection molding machine, where they are melted by the mechanical energy exerted by a turning screw and by heaters arranged along the barrel. (Centre) The screw moves forward, injecting the molten plastic into a mold. (Right) After the plastic has solidified, the mold is opened and the molded piece ejected.


Hopper
Nozzle
Mold
Tie Bar
Clamping Unit
Heaters
Ejector
Hydraulic
Motor and
Gears
Barrel
Hydraulic
Pump
Stationary
Platen
Moveable
Platen
Rear
Platen

Injection Molding

- Complex Plastic Parts
- Examples: Fittings, Containers, Bottle Tops, Housings

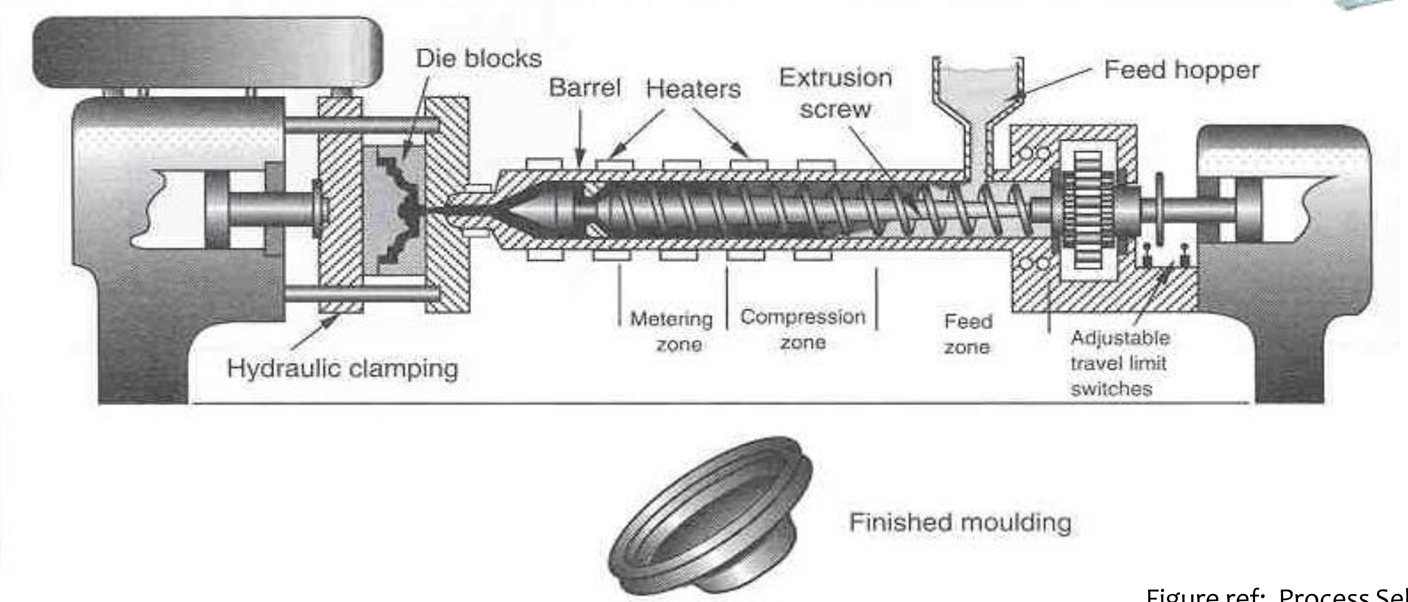
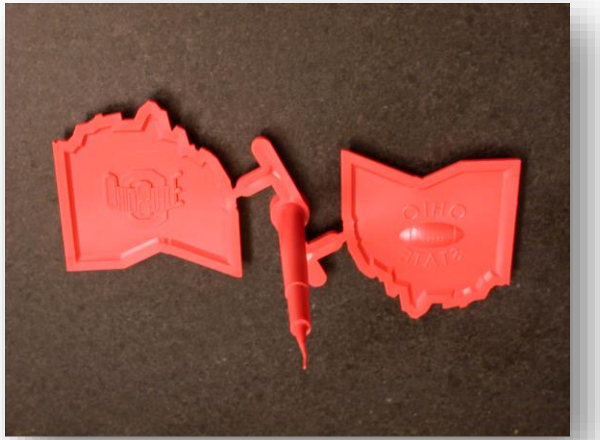


Figure ref: Process Selection, KG Swift and JD Booker, p. 46.

Injection Molding

- **Basic Process--**
  - Plasticize the material
  - Pressurize plastic melt and inject into mold cavity
  - Cool the plastic melt, while keeping mold filled
  - Open mold and eject part



- **Key issues for design of part and mold**

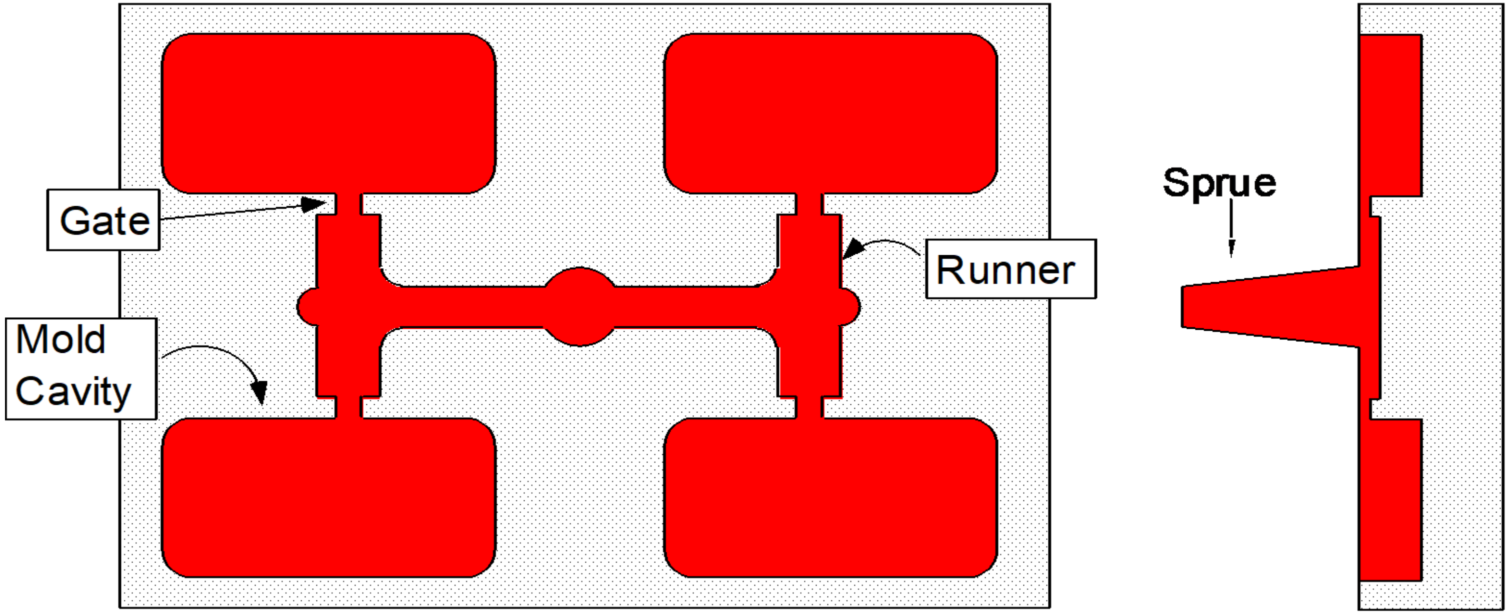
1. **Filling Mold & Holding Pressure**

Mold layout designed to enhance fill (use good fluid flow principles) After part is filled, packing pressure is maintained, so part will not shrink away from walls as it solidifies

2. **Ejecting Part**

Part should hang on moving side as it retracts (pulling free of fixed side) Ejector pins then push part out of moving side of mold Taper or draft required to ensure ejection

Injection Mold Layout



- Plastic flows from injection nozzle into sprue then into the runners and finally through the gate into the part.
- Balance the mold so that all cavities fill at same time.

Injection Molding Screws

Screw plunges forward to provide holding and packing pressure.

Screw rotates as it retracts to meter and plasticize the melt.

Feed Section

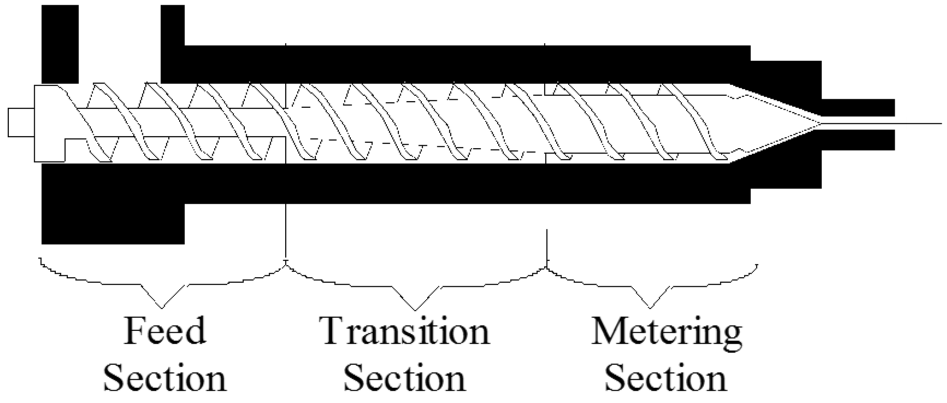
- Draws material from hopper & starts movement into shooting pot

Transition Section

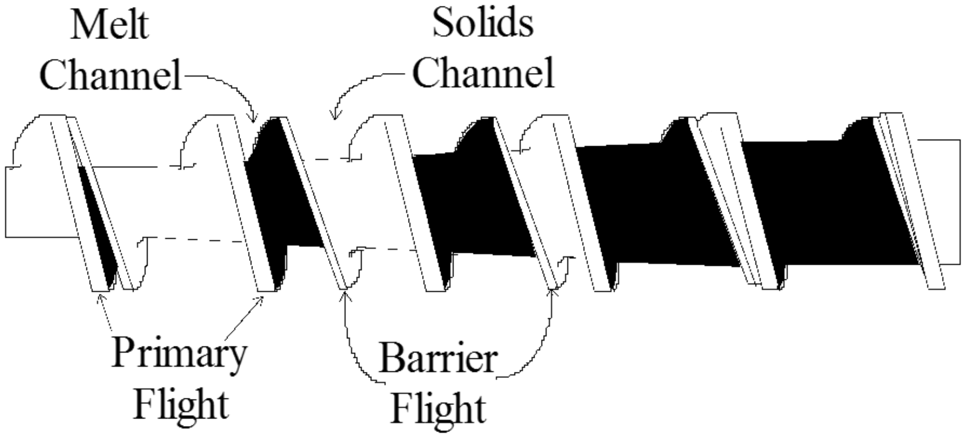
- Compresses plastic melt
- Plasticization
- Decreasing channel depth

Metering Section

- Precisely measures out the correct fill

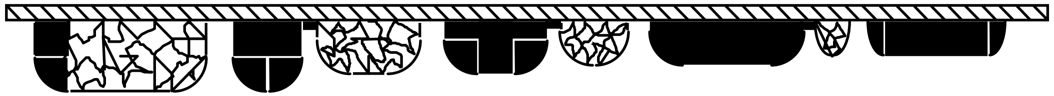


Barrier Flight Screws



- **Barrier, or secondary, flight** - Splits channel into two sections:

  Solids channel and a melt channel. Barrier flight is not quite as large as primary flight, leaving a small passage for melt to flow from solids channel into melt channel.



Press Parameters

3 parameters commonly used to describe press capacity

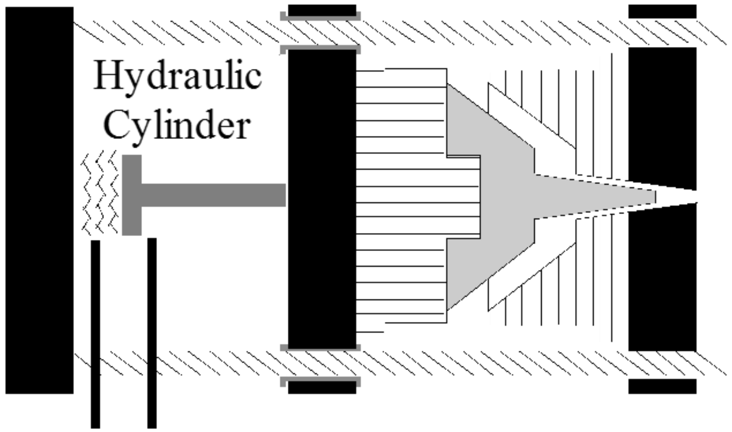
1. **Clamping force** - Force available to hold platens together (tons)

Can be from "In-line" Hydraulic/Pneumatic Cylinder or Mechanical Toggle Clamp Hydromechanical - "In-line" cylinder & toggle.

2. **Shot size** - Amount of material that can be transferred to mold in a shot (given in either cm^3 or ounces).

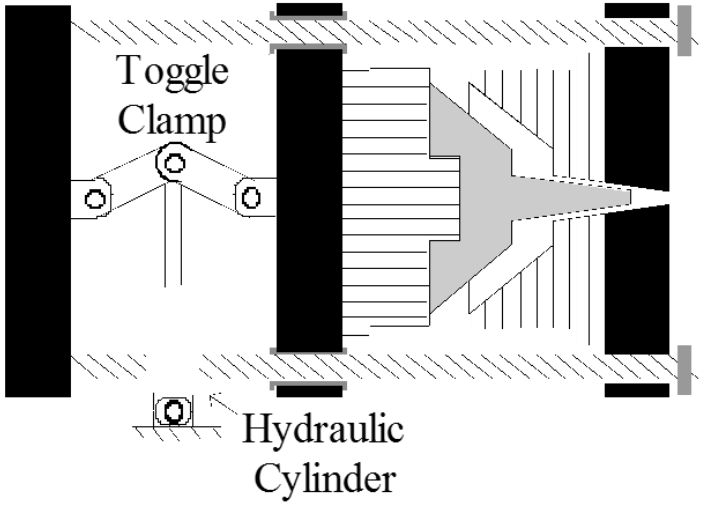
3. **Injection Pressure** - Maximum pressure that can be developed at the sprue to force the plastic into the mold cavity.

Clamping Mechanisms



"In line" hydraulic cylinder

Good Force control, but requires large hydraulics, slow



Toggle Clamp

Fast acting, but Poor Force Control

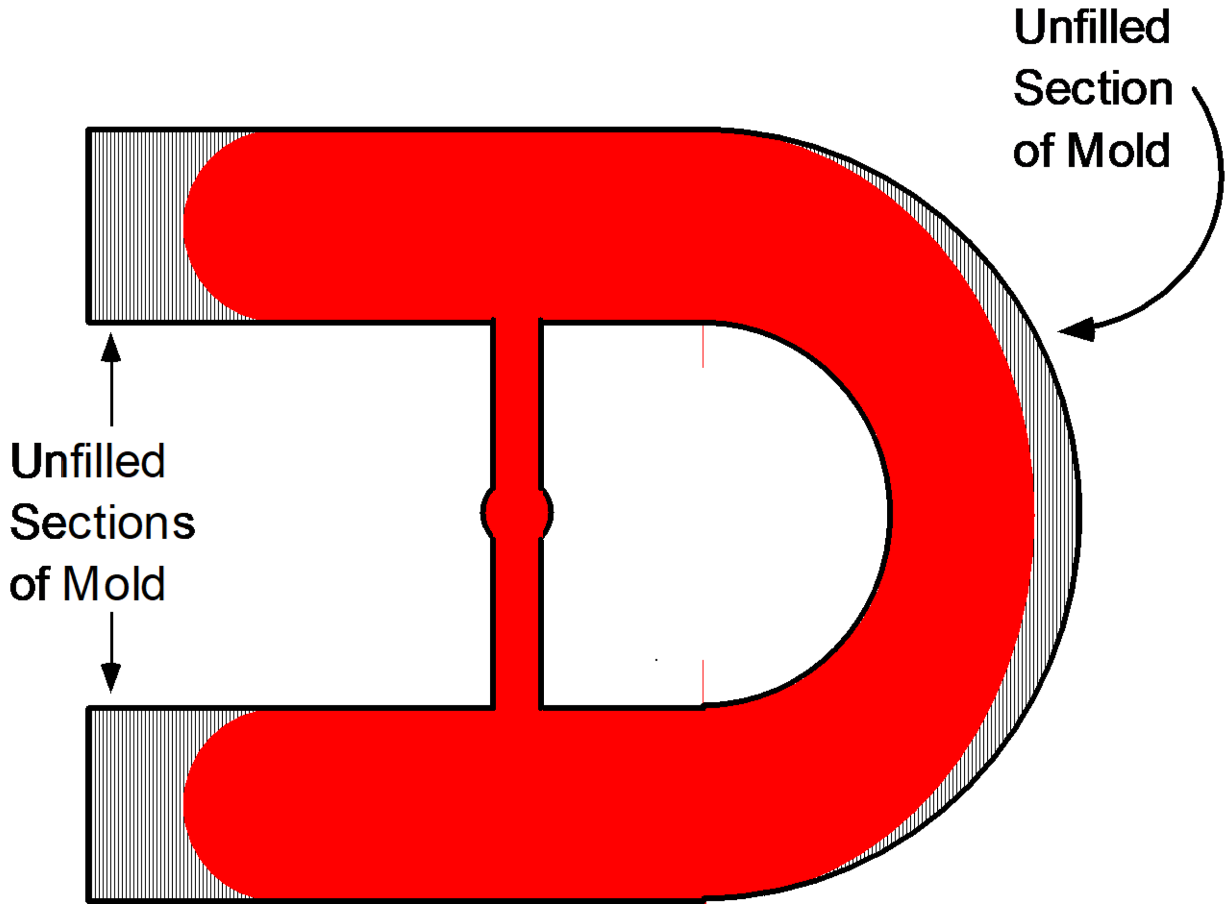
Hydromechanical Clamp

Uses toggle mechanism for *most* of travel, but Locking force is provided by an in line cylinder

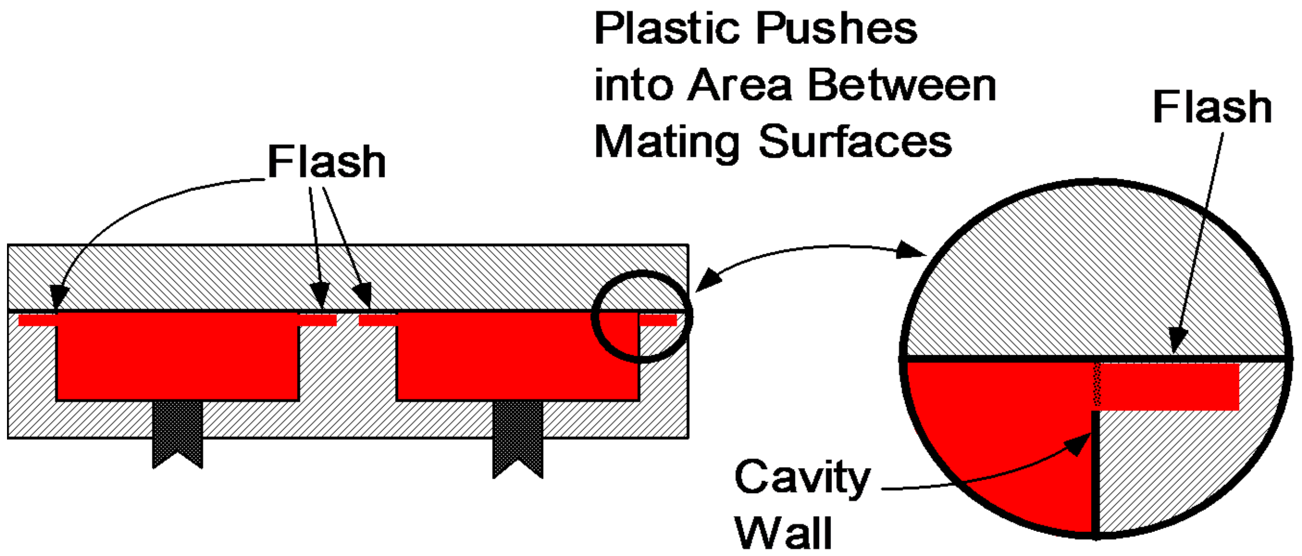
Injection Molding Defects

- Short Shot
- Flashing
- Weld Lines
- Ejector Pin Marks
- Sink Marks
- Residual Stresses
- Jetting

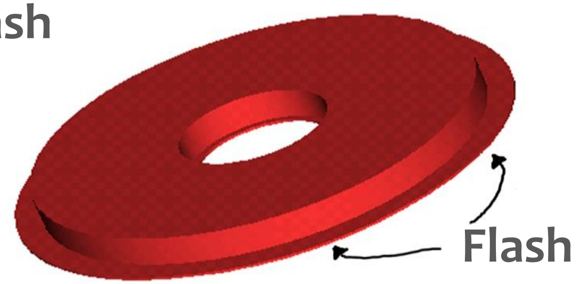
Short Shot



Flash

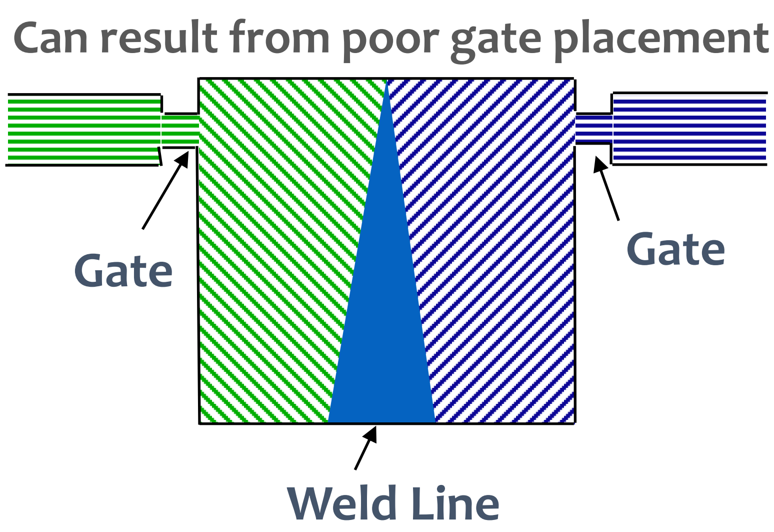


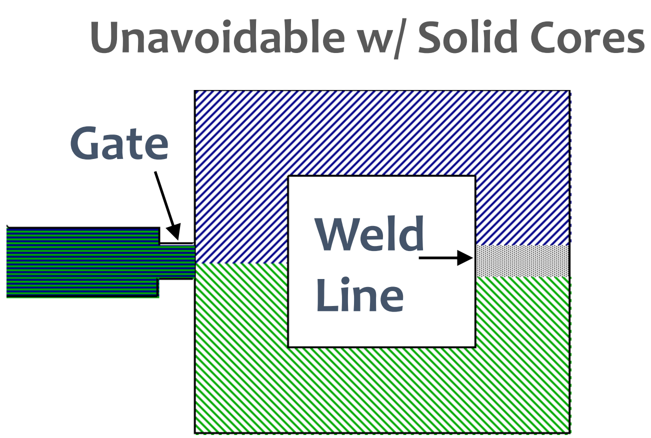
Part w/ Moderate-Heavy Flash



Weld Lines

Weld lines are created when two flow fronts come together in the mold. Weld lines decrease the strength of the part.





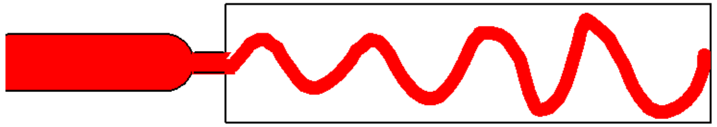
Weld lines are more pronounced if melt is cooler when fronts meet.

Also if flow fronts are moving into one another (butt weld, or weld as opposed to streaming weld, or meld).

Jetting

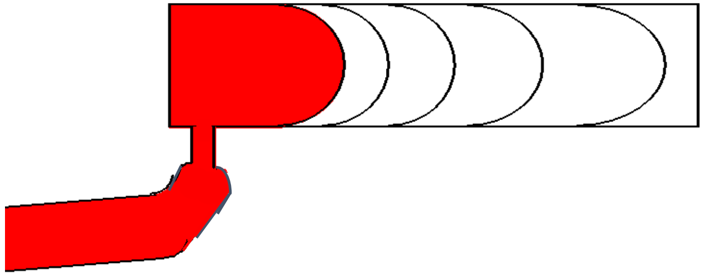
Jetting occurs at high fill rate into large open cavity between the gate and the opposite wall.

Material stream shoots to the opposite wall and freezes. Fresh material folds over cooled flow lines, traps air and creates weak joints.



Jetting

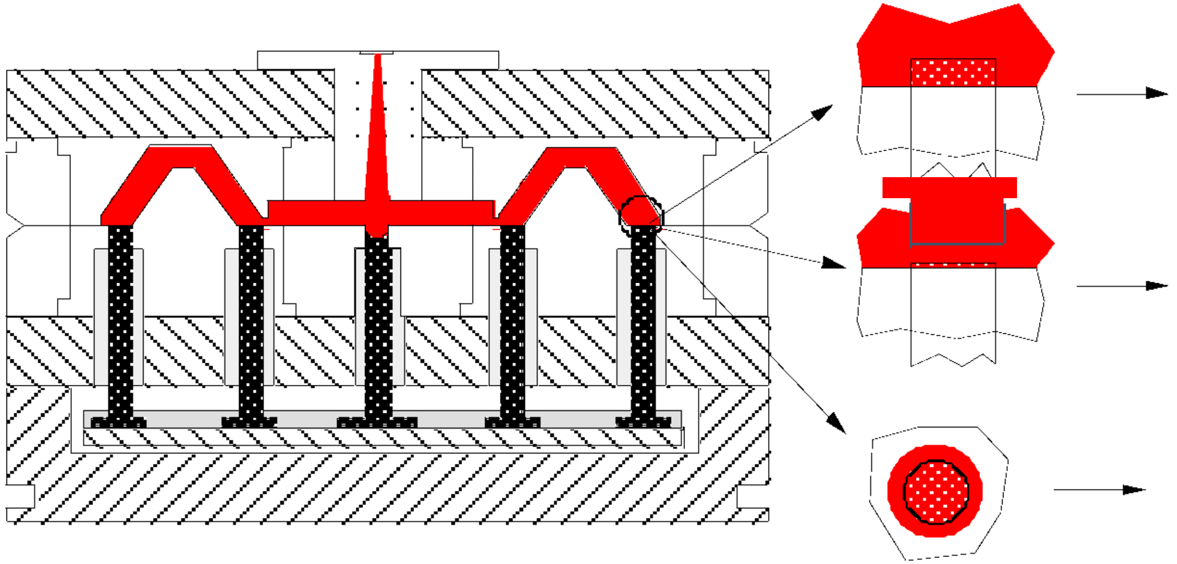
To reduce the chance of jetting, gates should be located so that entering material flows into wall, not into open section.



Alternate gating eliminates jetting

Ejector Pin Marks

- Marks are often left on the part in the area where the ejector pins pushed. Four possible causes:



1) Pin above flush

2) Pin below flush

3) Clearance around pin

4) **One tries to eject the part before it solidifies and pins push through the part.**

➔ Place the ejector pins on hidden areas of the part.

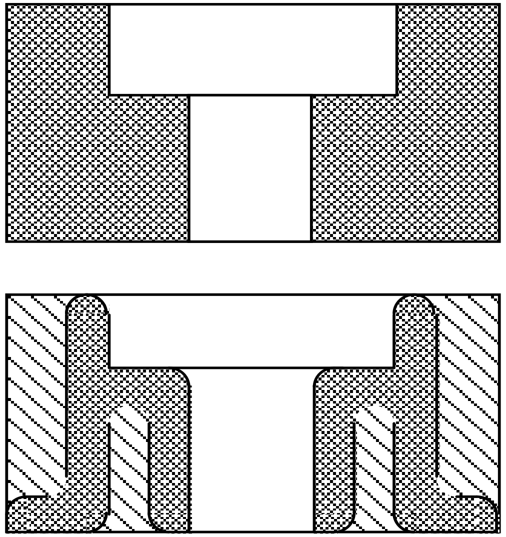
Sink Marks

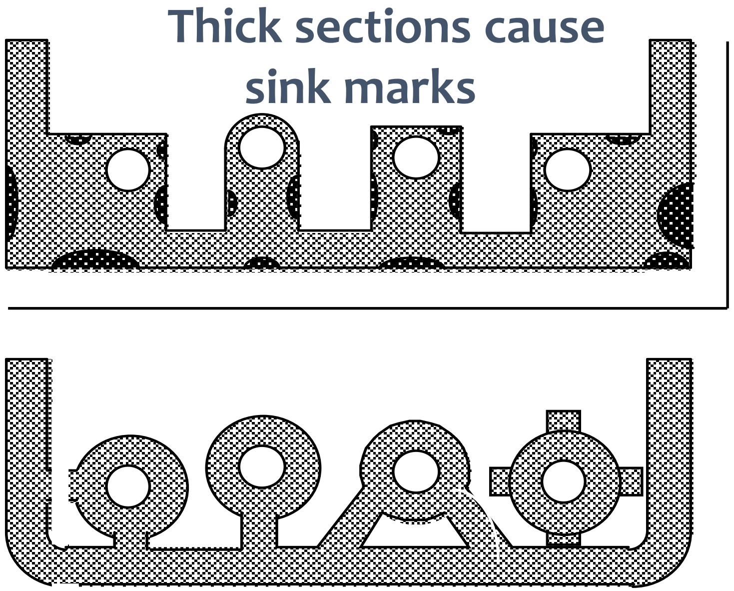
Sink marks occur at excessively thick wall sections, or where there are abrupt changes in thickness- thick sections solidify too late and shrink away from the wall.

Proper design reduces/eliminates sink marks (ribs, core out sections)

Bad Design

Improved Design





When unavoidable, sink marks can be masked by surface texture

Warpage / Residual Stresses

- Warpage
  - “Out of plane” distortion

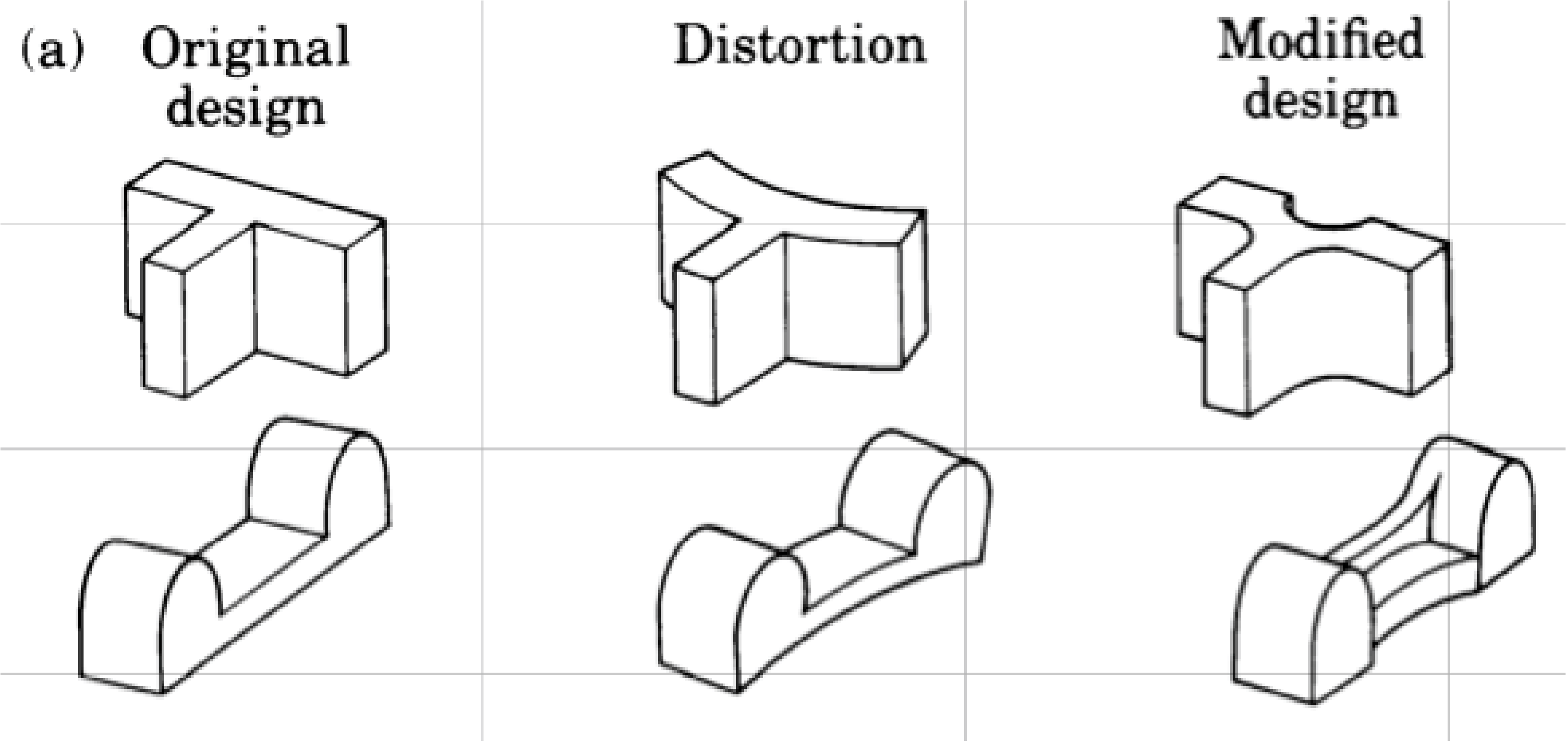
  - Caused by *anisotropic shrinkage*

  Causes:

  Variations in thickness
  Differing shrink rates due to melt orientation
  Uneven cooling
  Differences in the mold cavity pressure

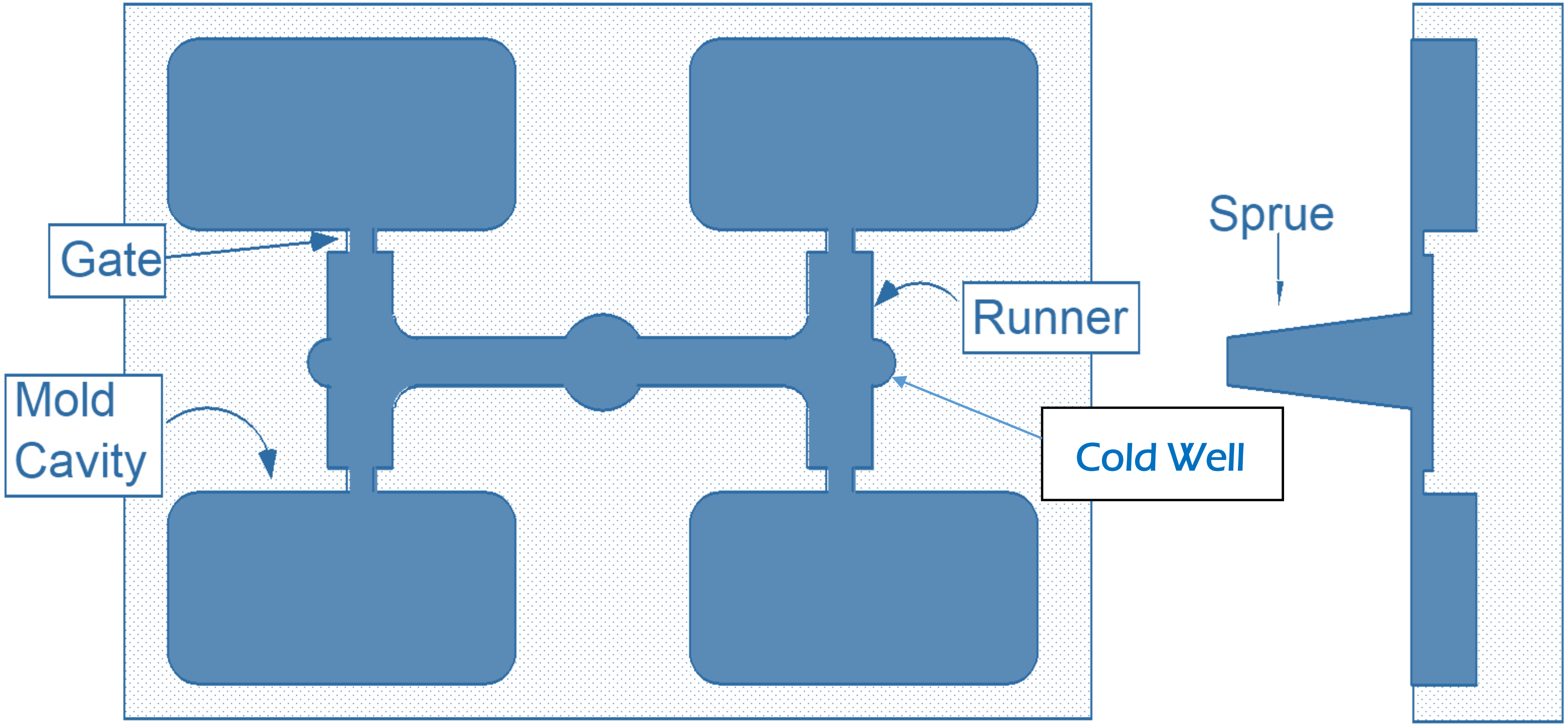
  - *Residual Stress* resist warpage
    - Massive enough part
    - Gates

Warpage Defects



Ref: Figure from: S. Kalpakjian, Manufacturing Processes for Engineering Materials, Second Ed., Addison Wesley, 1991

Gate, Sprue, and Runner System



Runner Design

1. **Keep runners as short as possible**
2. **Use a cold well at the end of each branch- collect solid chunks**
3. **Use cross sections that minimize perimeter for a given area**

Circles are best, followed by rounded trapezoids, then trapezoids.

Squares, rectangles, and half circles are poor.

4. **Use good flow principles (round corners, etc)**
5. **Provide for branches by making the upstream runners larger than the downstream runners that they feed.**

Douglas M. Bryce recommends a "20% rule."

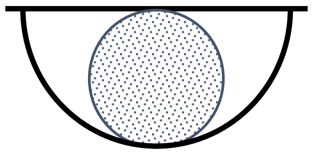
Increase the diameter of the upstream runner by 20% at each 900 turn

When n multiple runners branch off a main feed runner, the diameter of the main runner should be increased by n*20%

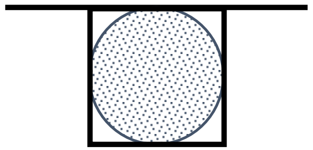
Runner Cross Sections

- Circles are the BEST shapes.
- The “next best” shapes are those which best approximate circles.

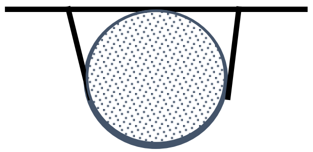
Half circles DO NOT approximate circles.



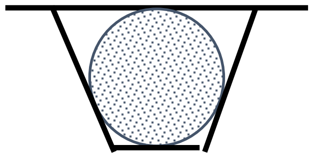
Rectangles DO NOT approximate circles.



Rounded Trapezoids DO approximate circles

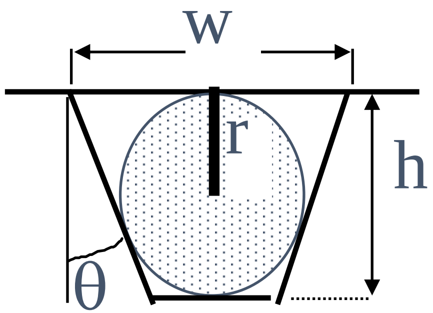


Trapezoids DO approximate circles.



Runner Cross Sections

- Typically, most formulas are in terms of circular runners.
- When DESIGNING trapezoidal runners given the "ideal" circular equivalent, trapezoid dimensions are roughly h » $2r$, w » $2.6r$, q » 15^{o}



- When ANALYZING non-circular runners, the ideal circular equivalent is generally found by equating areas. Analysis programs use shape factors to account for the larger perimeters of NON-circular shapes.

Gate Design

1. **Gate so that material flow hits a nearby wall.**
2. **Gate into the thick sections- so material flows thick to thin.**
3. **Gate into an understressed region of the part.**

(Residual stresses are always present near gates.)

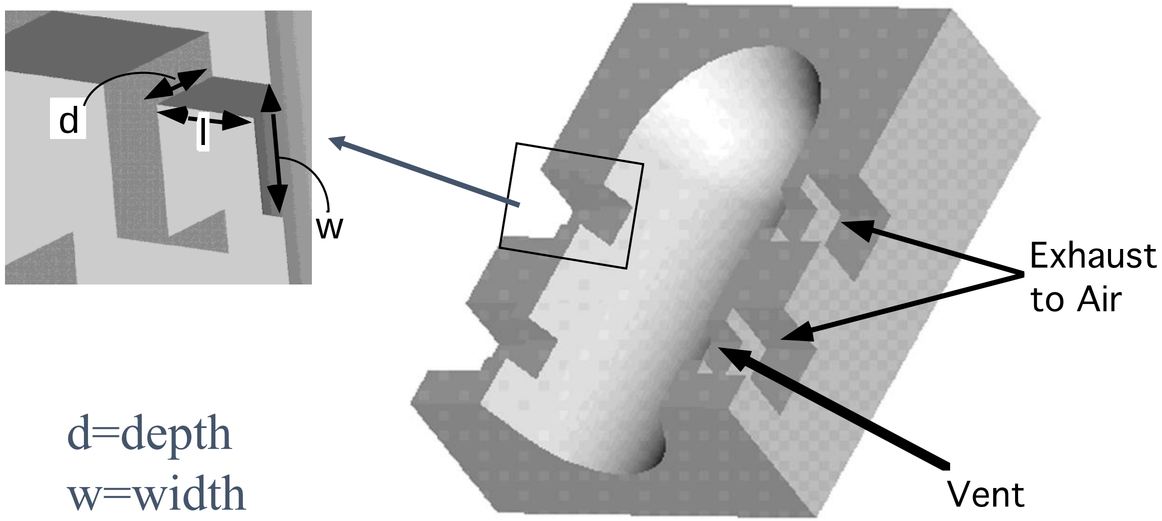
4. **"Hide" gates whenever possible.**
5. **Gate so that fill is "balanced." Ideally, all flow fronts complete filling at the same time.**

Reduces fill time.

Minimizes variations in packing, reducing tendency to warp.

6. **Gate size based on maximum wall thickness and material.**

Venting



d=depth
w=width
l=land

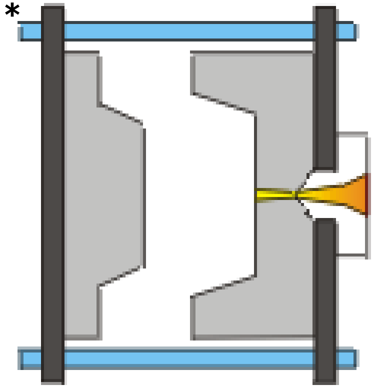
Vents allow air to escape ahead of the plastic melt

Vents help reduce -- Injection pressure and clamping force
Cycle time
Warping & shrinking
Residual stresses

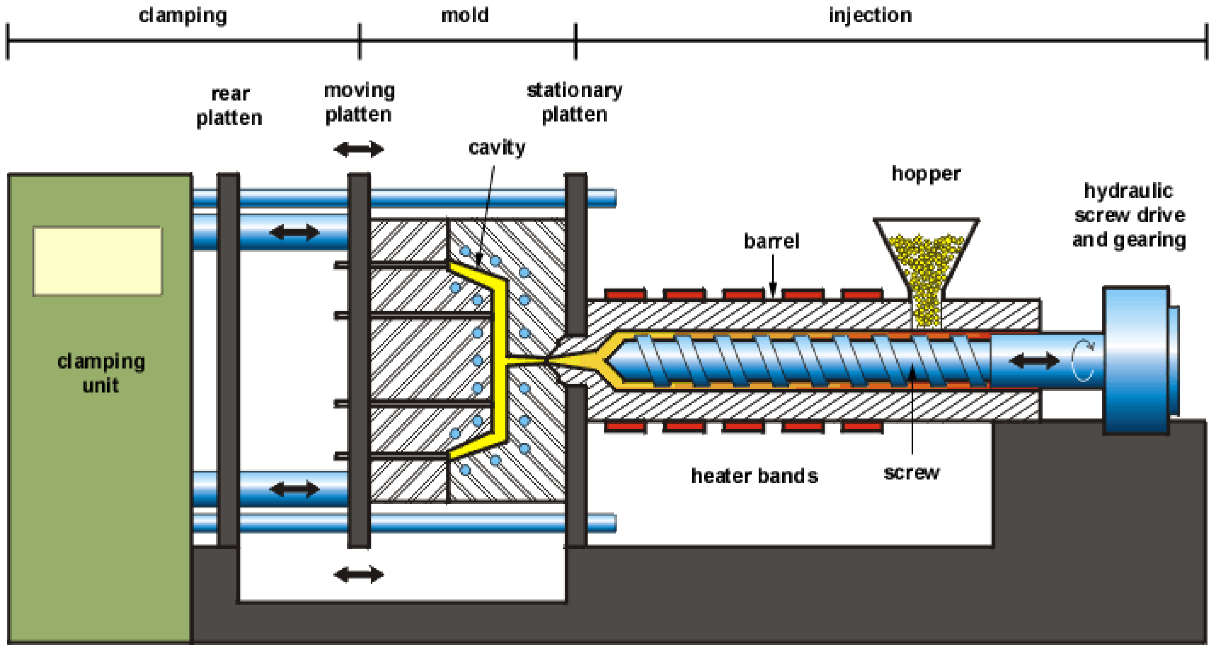
Tecnológico de Monterrey

Process & machine schematics

*



*

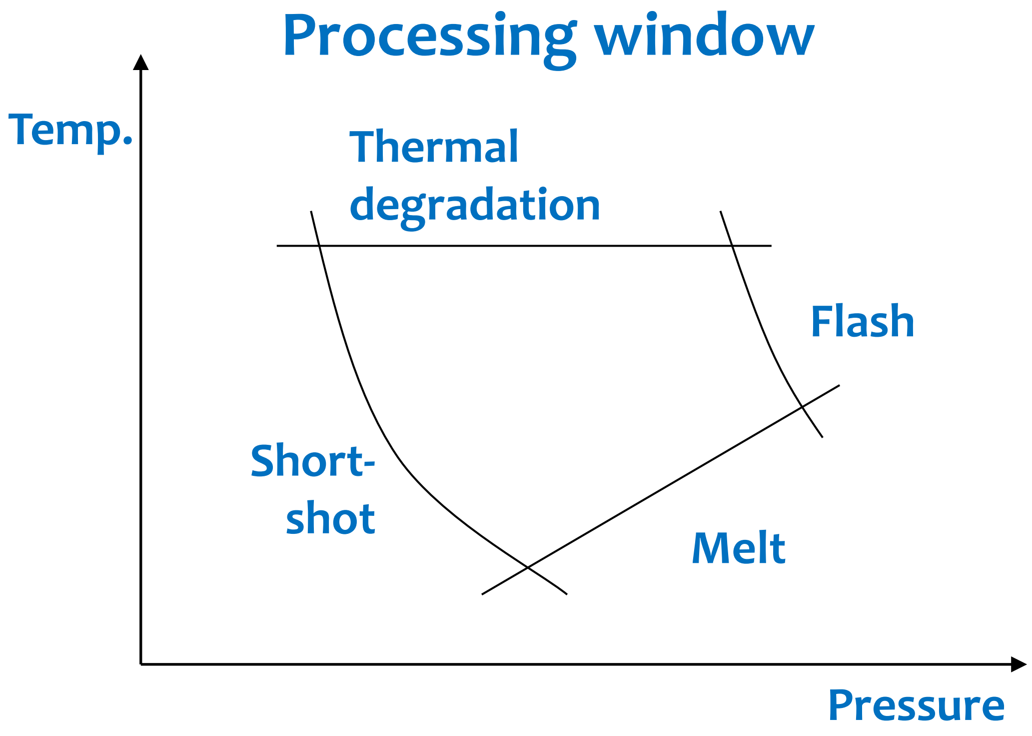


Schematic of thermoplastic Injection molding machine

* Source: http://www.idsa-mp.org/proc/plastic/injection/injection_process.htm

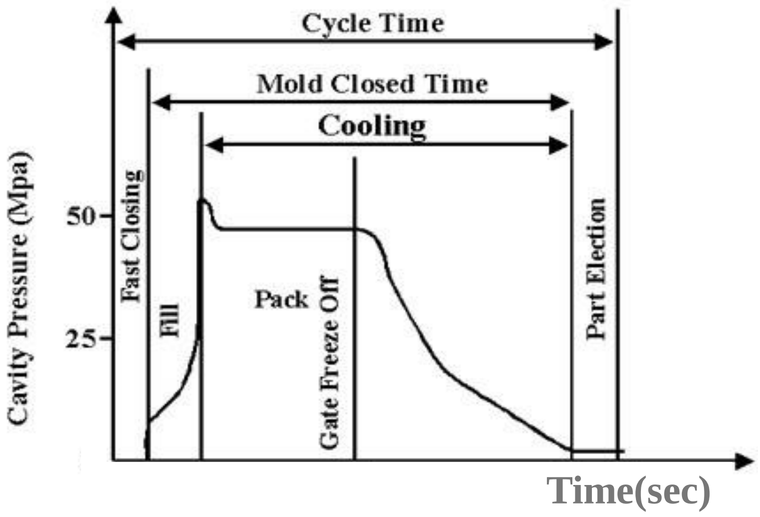
Process Operation

- Temperature: barrel zones, tool, die zone
- Pressures: injection max, hold
- Times: injection, hold, tool opening
- Shot size: screw travel

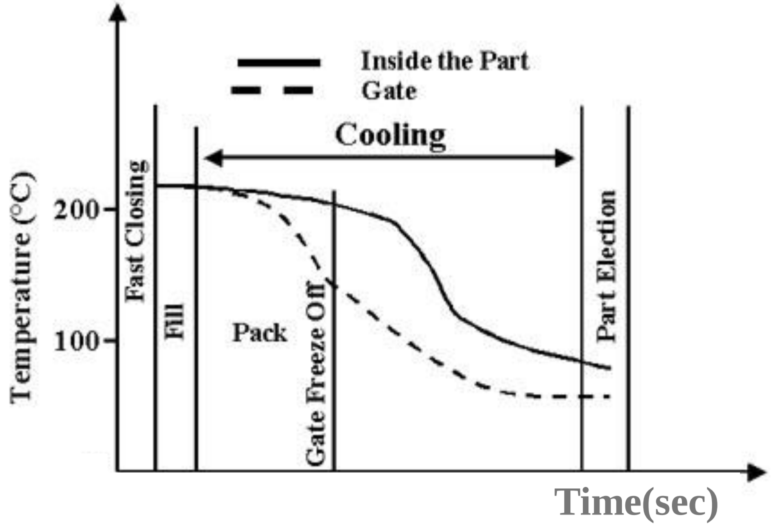


Typical pressure/temperature cycle

*



*



Cooling time generally dominates cycle time

$$t_{cool} = \frac{(\text{half thickness})^2}{\alpha}$$

$$\alpha = 10^{-3}\ cm^3/\text{sec} \ \text{ for polymers}$$

* Source: http://islnotes.cps.msu.edu/trp/inj/inj_time.html

Clamp force and machine cost

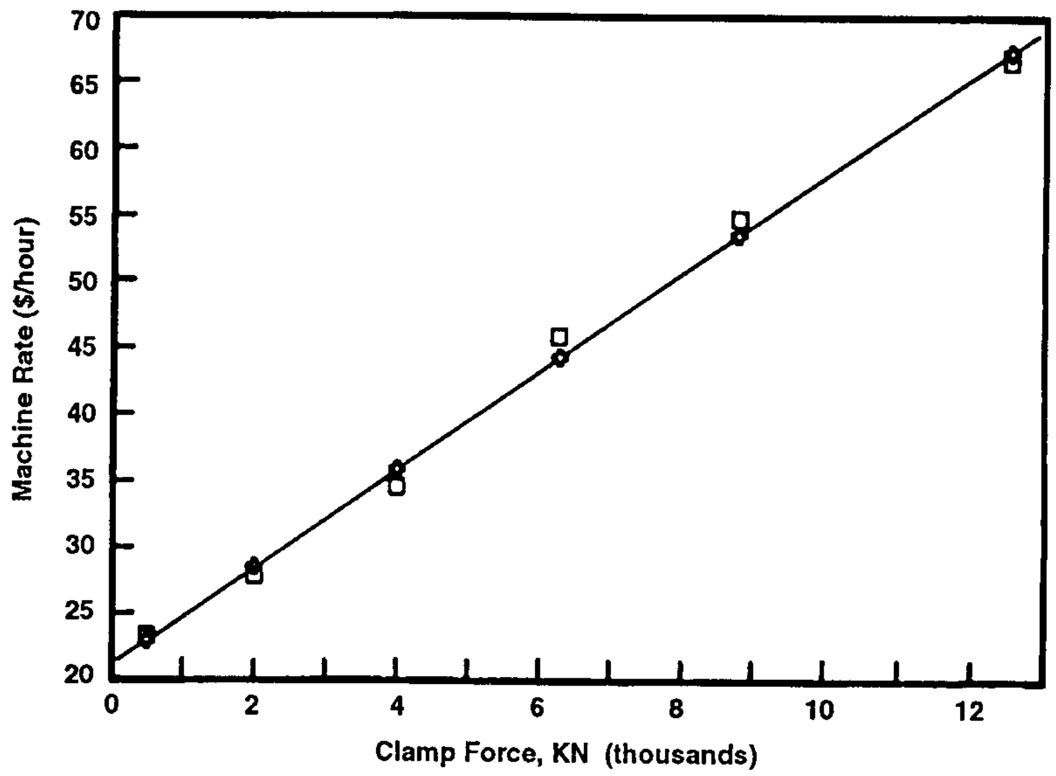


Figure 8.9 National average injection molding machine rates.

Reynolds Number

Reynolds Number:

$$\mathrm{Re} = \frac{\rho \frac{V^2}{L} \quad \text{inertia}}{\mu \frac{V}{L^2} \quad \text{viscous}} = \frac{\rho V L}{\mu}$$

For typical injection molding

$$\rho = 1 g/cm^3 = 10^3 N/m^4/s^2; \quad L_Z = 10^{-3} m \quad \text{thickness}$$

$$V \approx \frac{\text{Part length}}{\text{Fill time}} = \frac{10^{-1}}{1s}; \qquad \mu = 10^3 N \cdot s/m^2$$

$$\boxed{\mathrm{Re} = 10^{-4}}$$

For Die casting

$$\boxed{\mathrm{Re} \approx \frac{3 \cdot 10^3 \times 10^{-1} \times 10^{-3}}{10^{-3}} = 300}$$

* Source: http://www.idsa-mp.org/proc/plastic/injection/injection_process.htm

Viscous Heating

Rate of Heating
= Rate of Viscous Work

$$\frac{P}{Vol} = \frac{F \cdot v}{Vol} = \frac{F}{A} \cdot \frac{v}{h} = \mu \left(\frac{v}{h} \right)^2$$

Rate of Temperature rise

$$\rho \cdot c_p \frac{dT}{dt} = \mu \left(\frac{v}{h} \right)^2 \quad \text{or} \quad \frac{dT}{dt} = \frac{\mu}{\rho \cdot c_p} \left(\frac{v}{h} \right)^2$$

Rate of Conduction out

$$\frac{dT}{dt} = \frac{k}{\rho \cdot c_p} \frac{d^2T}{dx^2} \sim \frac{k}{\rho \cdot c_p} \frac{\Delta T}{h^2}$$

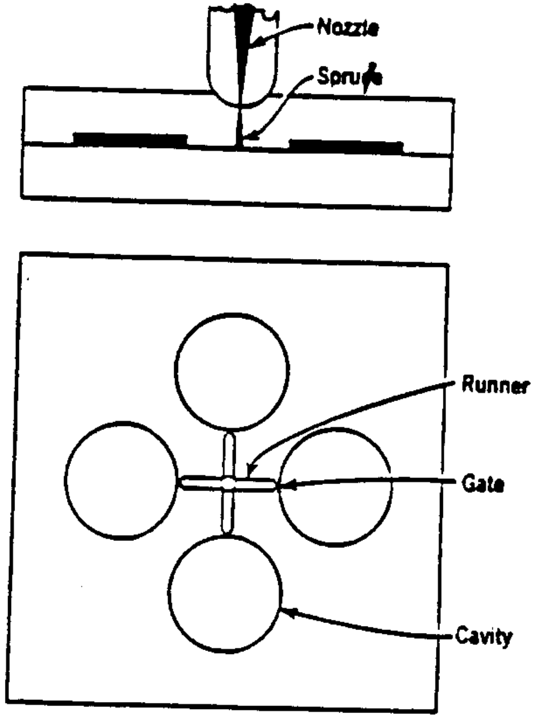
$$\boxed{\frac{\text{Viscous heating}}{\text{Conduction}} = \frac{\mu v^2}{k \Delta T}}$$

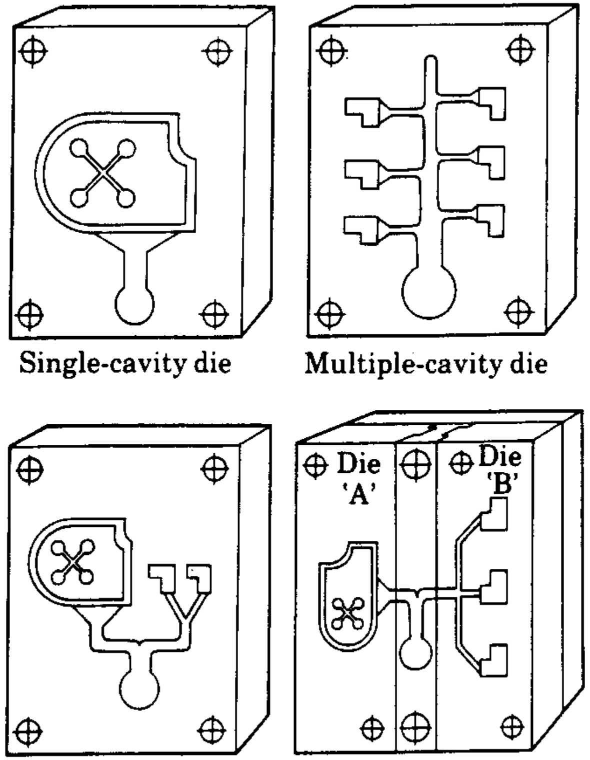
Brinkman number

For injection molding, order of magnitude ~ 0.1 to 10

Injection mold

Die cast mold





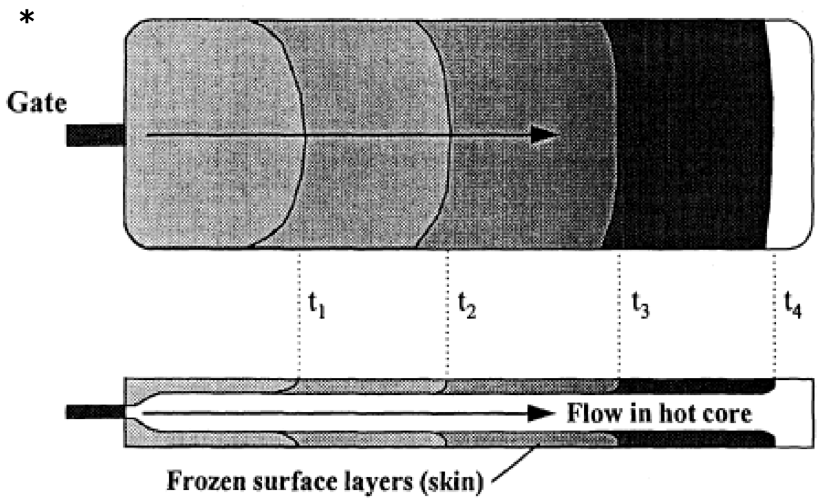
Single-cavity die

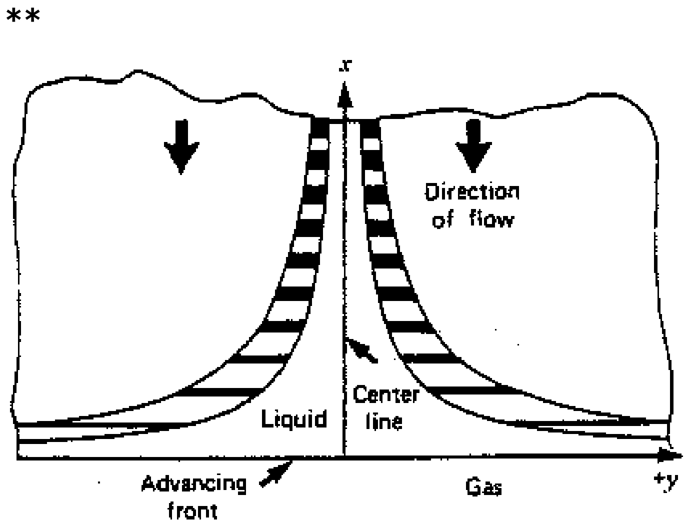
Multiple-cavity die

Combination die

Unit die

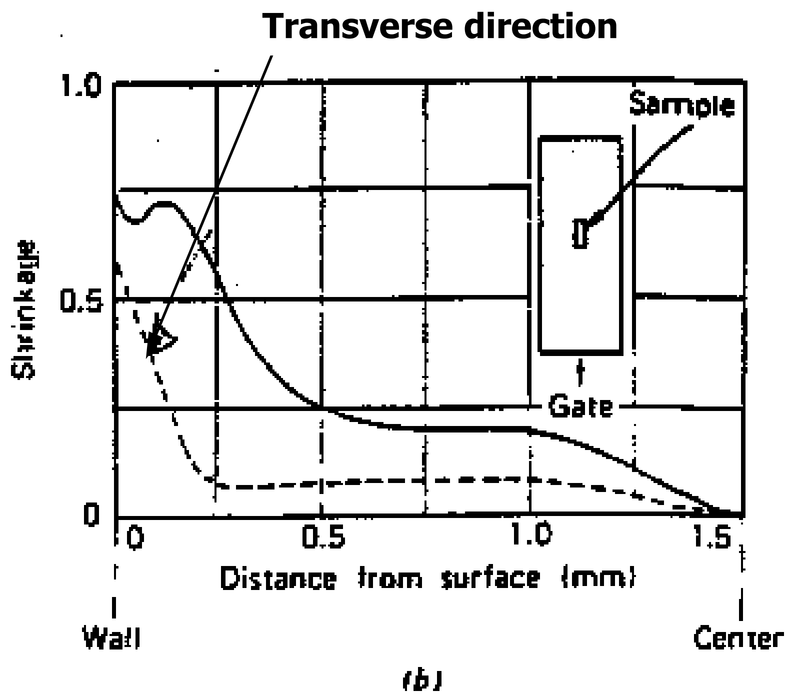
Fountain Flow





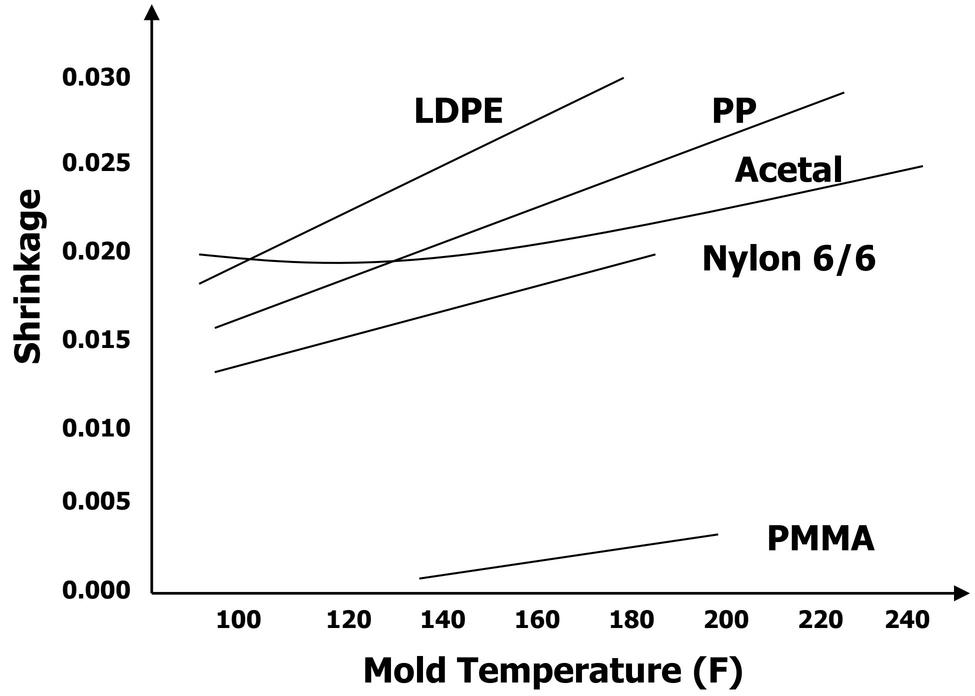
* Source: http://islnotes.cps.msu.edu/trp/inj/flw_froz.html ; ** Z. Tadmore and C. Gogos, "Principles of Polymer Processing"

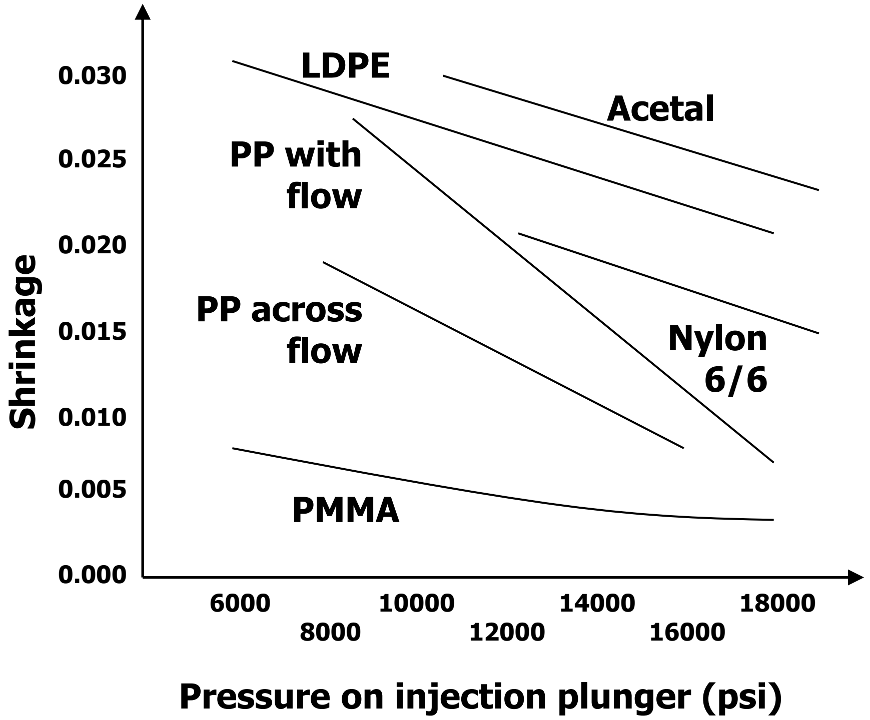
Shrinkage distributions



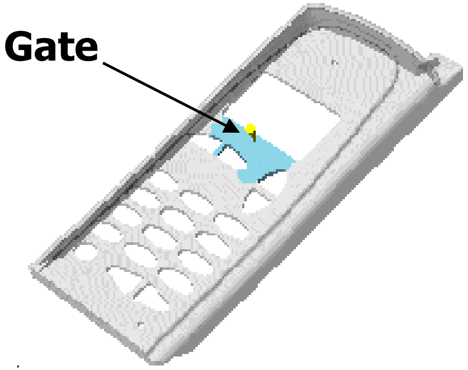
* Source: G. Menges and W. Wubken, “Influence of processing conditions on Molecular Orientation in Injection Molds”

Effects of mold temperature and pressure on shrinkage

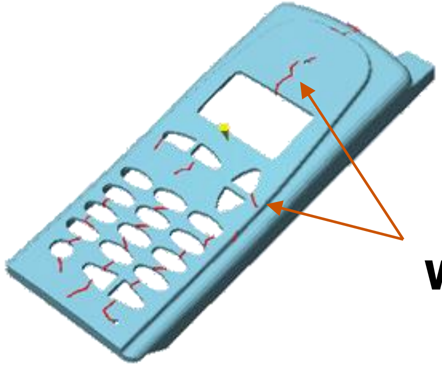




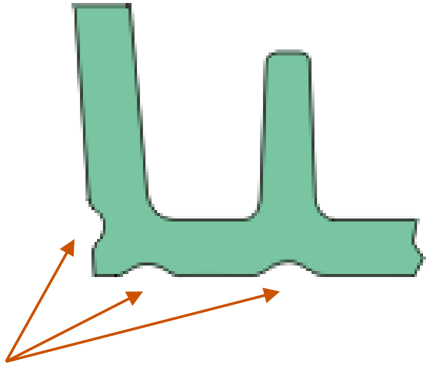
Weld line, Sink mark



Mold Filling

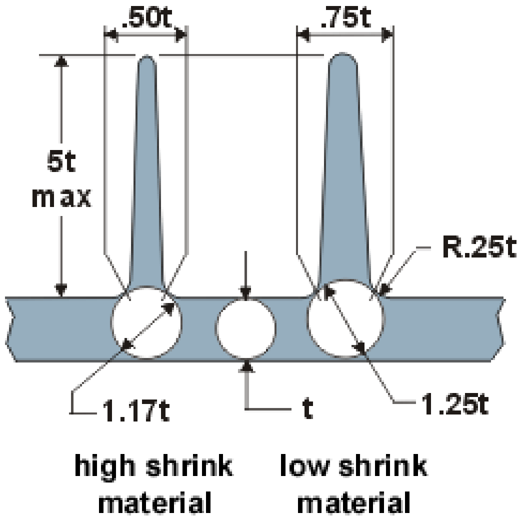


Solidified part



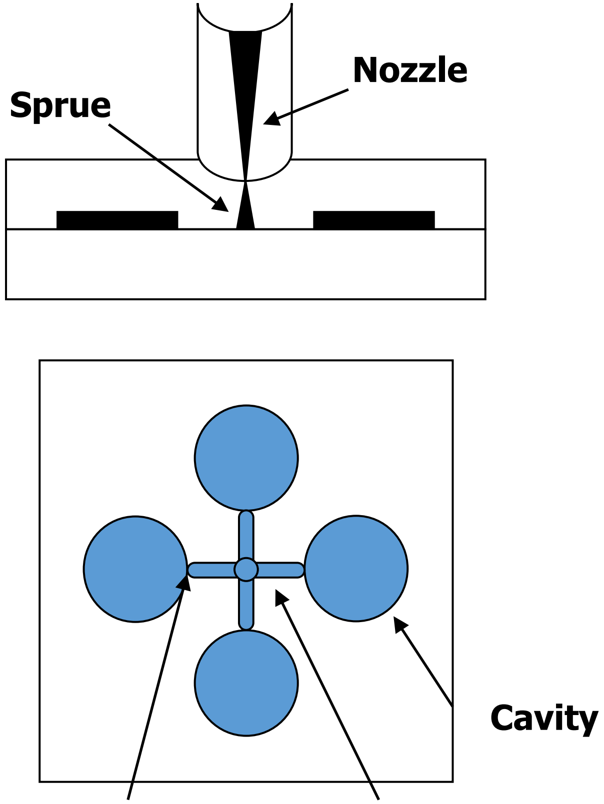
Sink mark

Basic rules in designing ribs to minimize sink marks

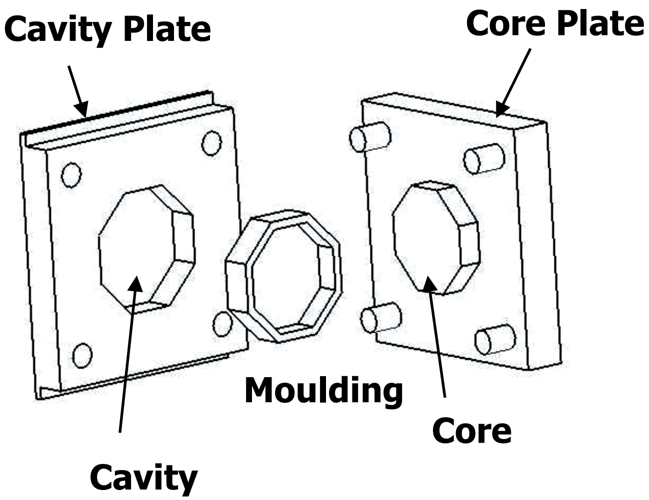


* Source: http://www.idsa-mp.org/proc/plastic/injection/injection_design_7.htm

Tooling Basics

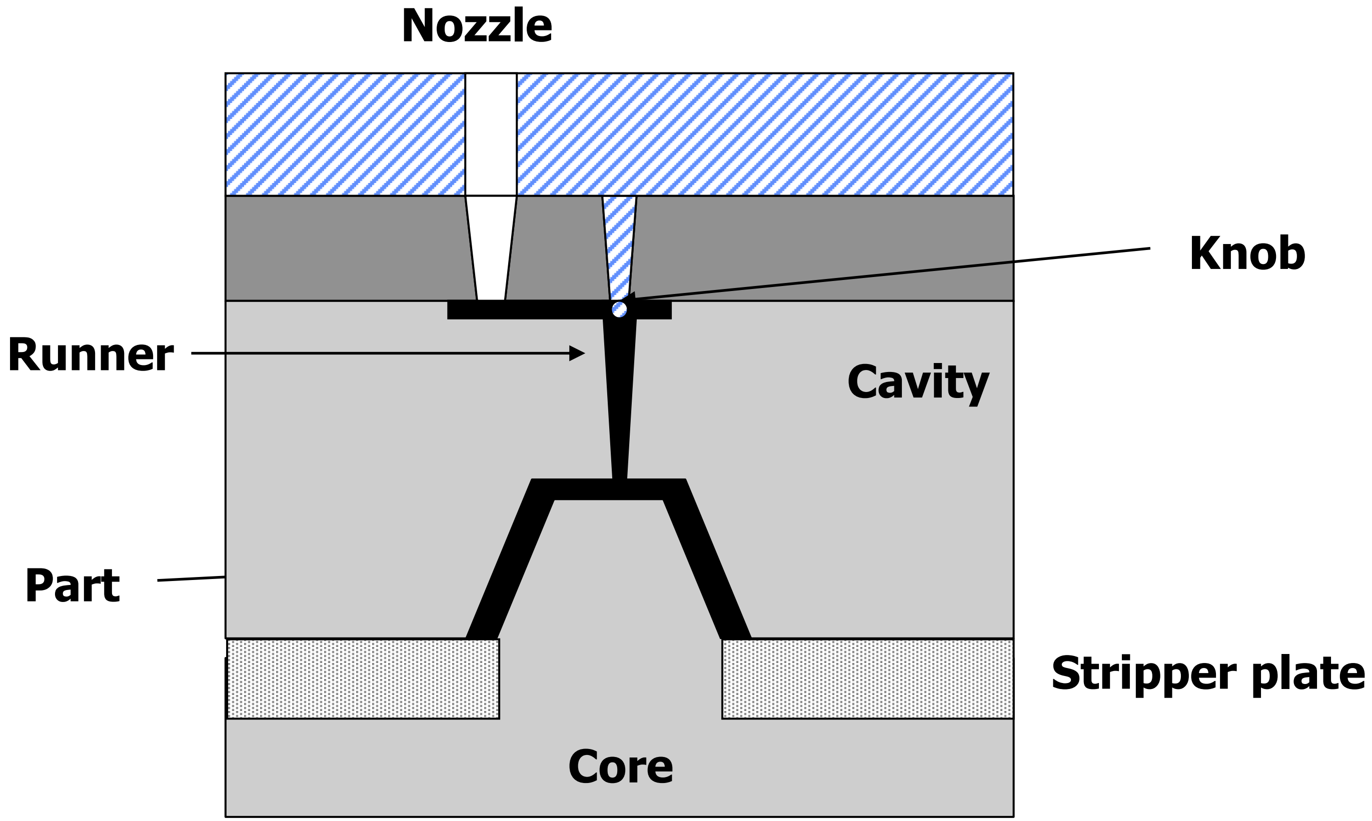


Melt Delivery

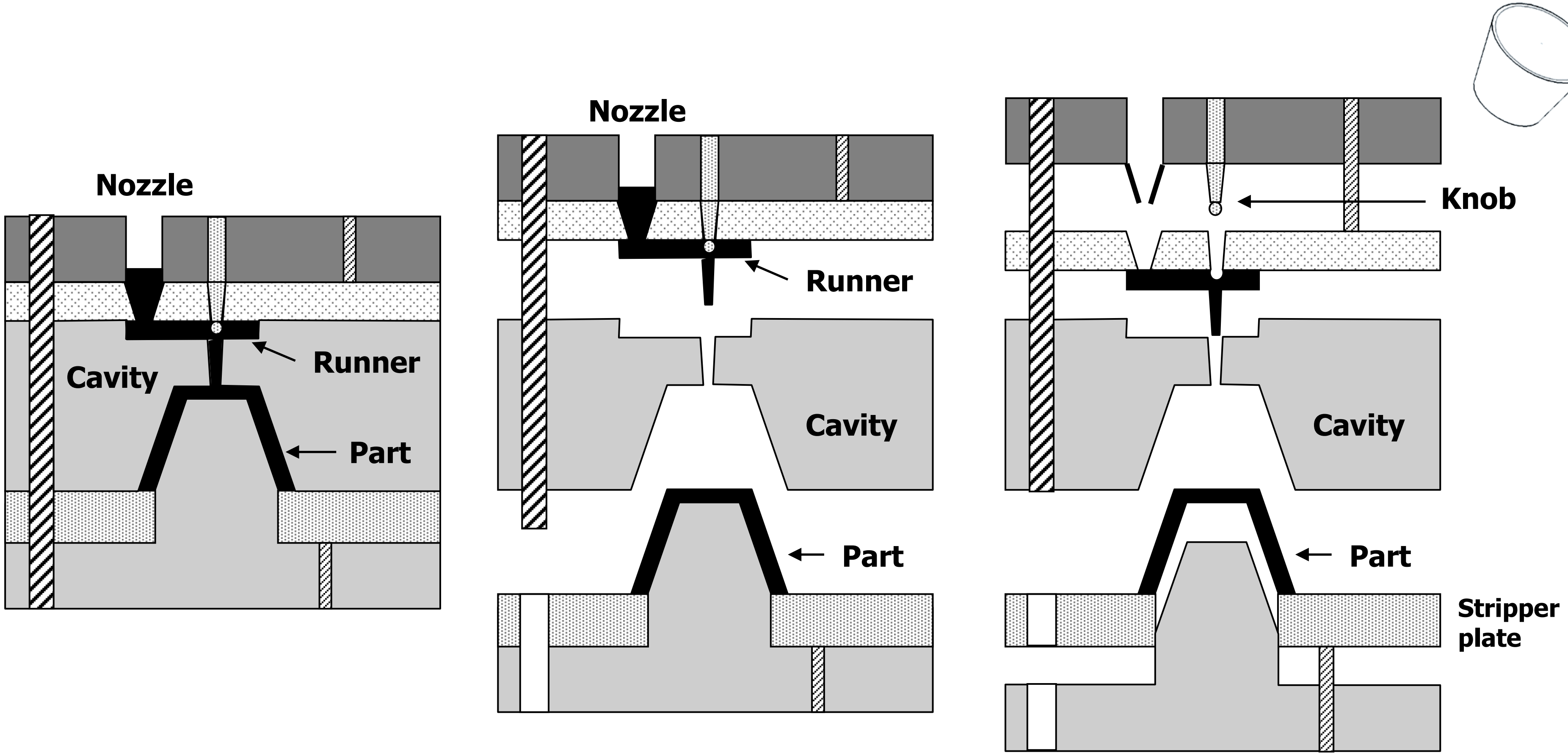


Basic mould consisting of cavity and core plate

Tooling for a plastic cup



Tooling for a plastic cup



Part design rules

- **Simple shapes to reduce tooling cost**
  - No undercuts, etc.
- **Draft angle to remove part**
  - In some cases, small angles (1/4°) will do
  - Problem for gears
- **Even wall thickness**
- **Minimum wall thickness ~ 0.025 in**
- **Avoid sharp corners**
- **Hide weld lines**
  - Holes may be molded 2/3 of the way through the wall only, with final drilling to eliminate weld lines

Compression Molding

- Pre-shaped part placed directly into heated mold.
- Examples: Dishes, Handles, Electrical Components, Fittings and housings

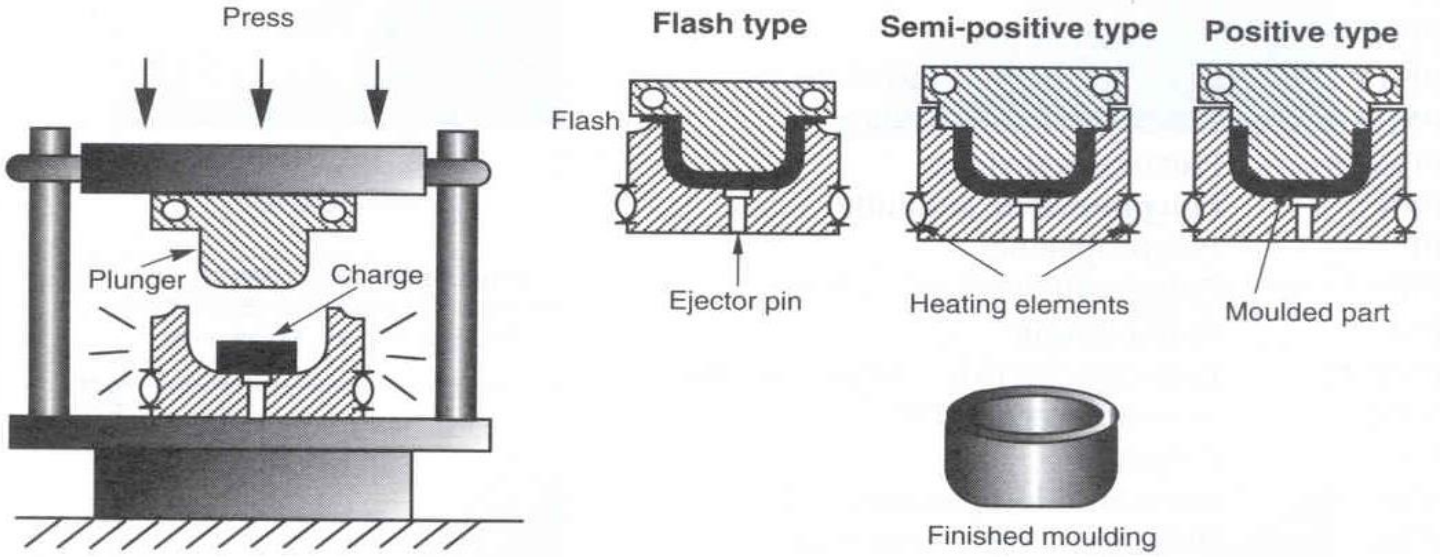
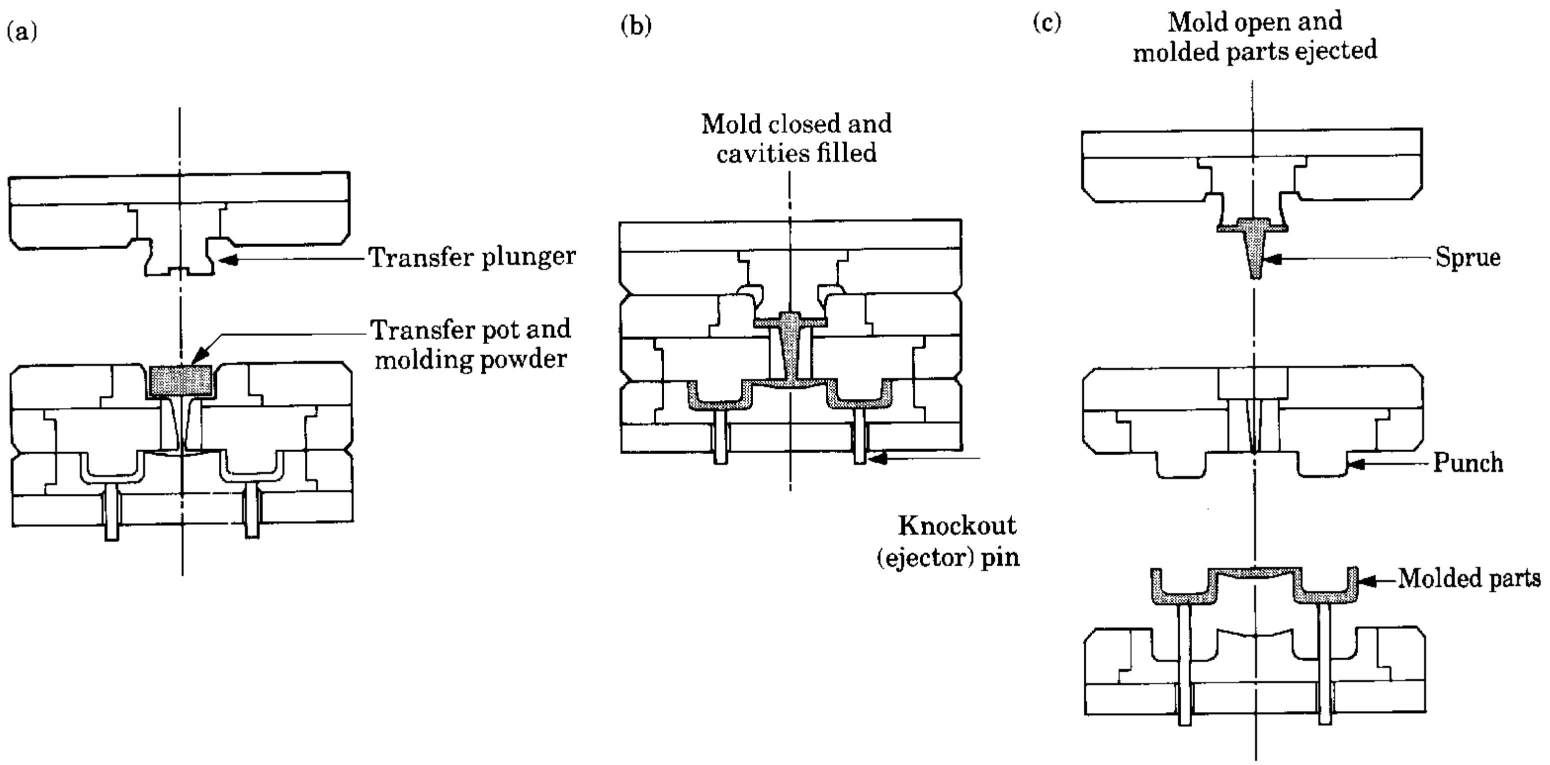


Figure ref: Process Selection, KG Swift and JD Booker, p. 50.

Transfer Molding



Typical parts: electrical and electronic components, rubber and silicone parts.

Ref: Figure from: S. Kalpakjian, Manufacturing Processes for Engineering Materials, Second Ed., Addison Wesley, 1991

http://www.leechind.com/transfer_molding.htm

Transfer molding is similar to compression molding but employs a piston/cylinder device. The material is placed above the closed, heated mold and is forced downward through the gate and into the mold cavities. The mold is held closed while the material cures. This process results in transfer molded parts being cleaner and more consistent than compression molded parts.

Leech designs, builds and runs molds to produce parts in the millions with engineering and commodity grade resins. Transfer molding methods are employed using thermoset materials in custom or industry standard colors.

To ensure manufacturing accuracy and integrity, Leech designs and builds their own **mold tooling**. From design to on-time delivery of finished parts, Leech's proficiency underwrites their legacy of excellence in professional service, precision and customer confidence.

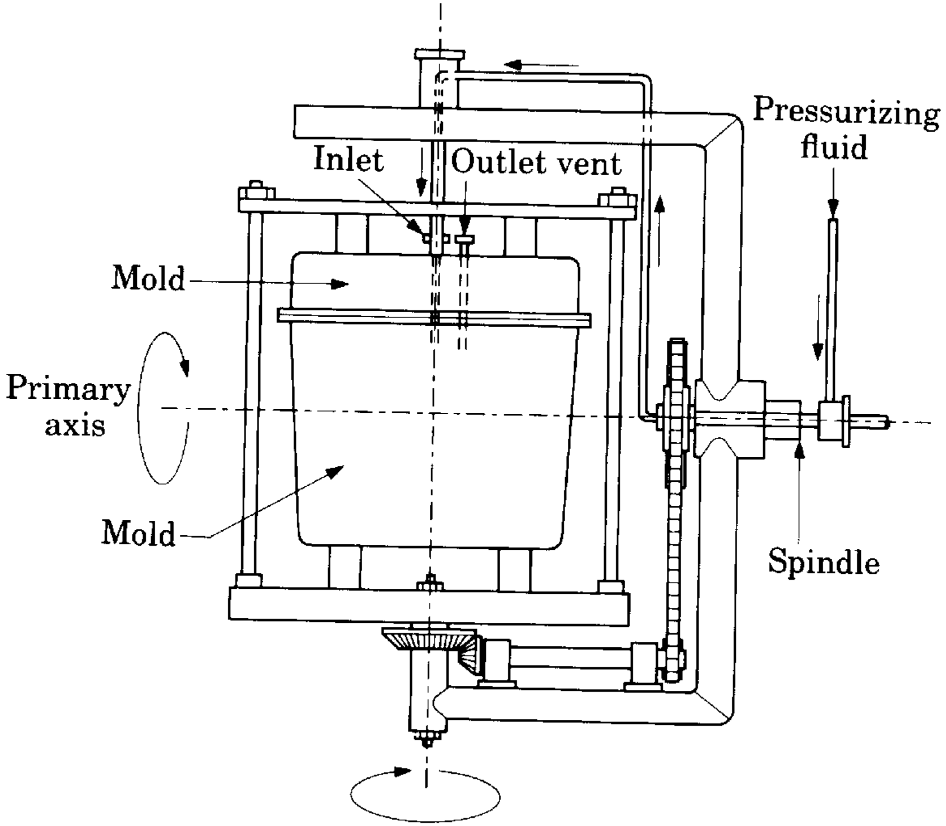
Specific Transfer Molding Capabilities:

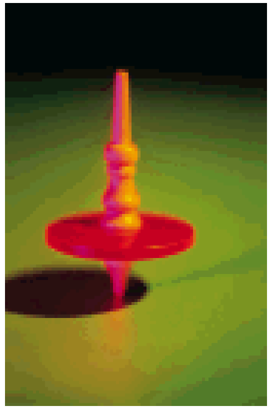
- **(5) Vertical presses ranging from 75 Ton to 200 Ton**
- **Including a new 75 Ton Wabash Transfer Press**
- **Processing Phenolic materials**

Transfere Molding

http://www.youtube.com/watch?v=1u-2GvhghQA

Rotation Molding

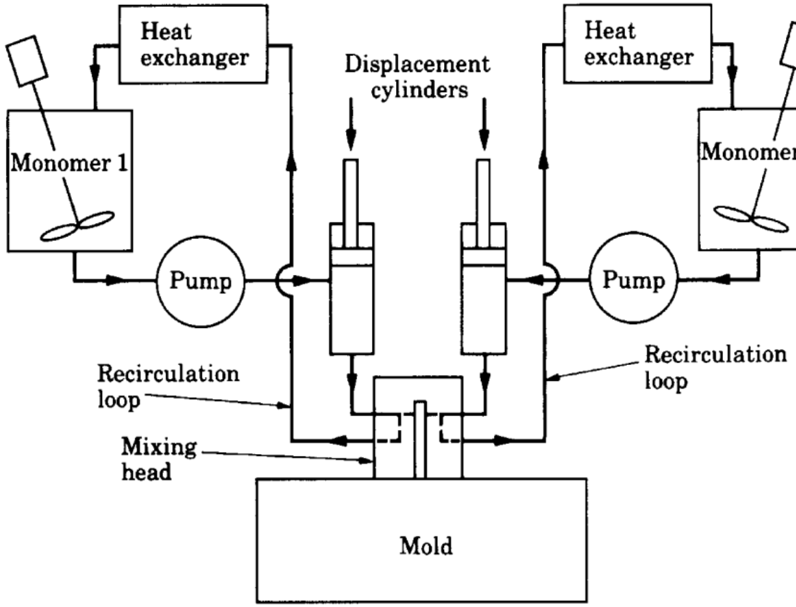


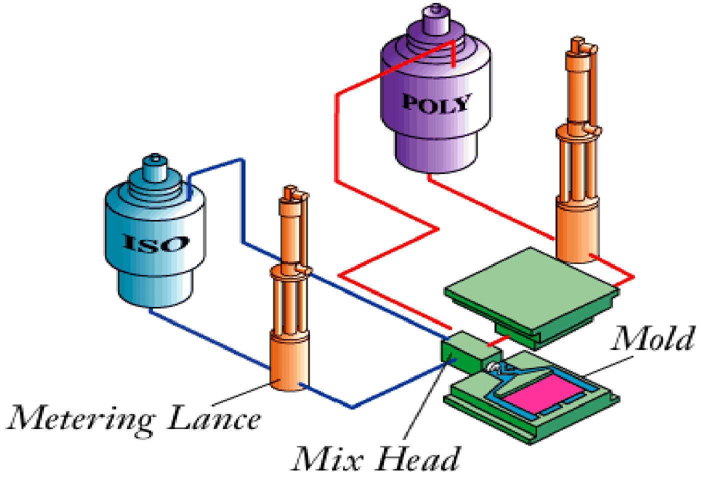


Typical parts: tanks, trash cans, boat hulls, buckets, housings, toys, carrying cases, and footballs.

Ref: Figure from: S. Kalpakjian, Manufacturing Processes for Engineering Materials, Second Ed., Addison Wesley, 1991

Reaction Injection Molding

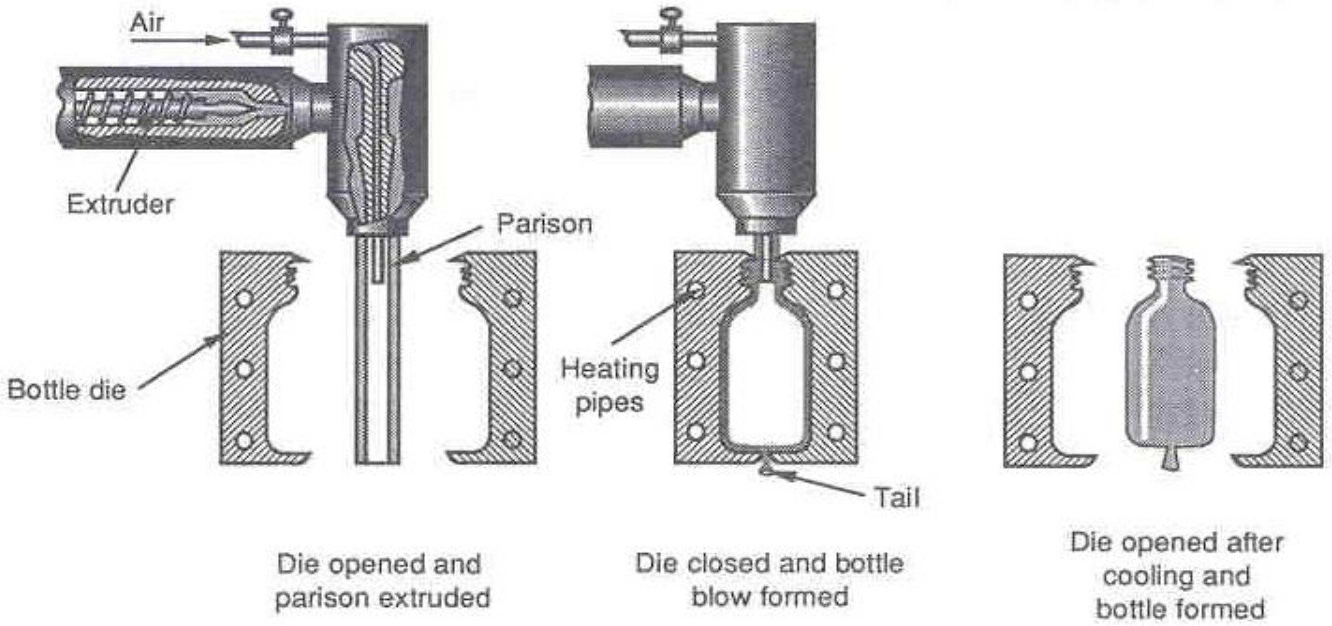




Typical parts: automotive bumpers and fenders, thermal insulation for refrigerators and freezers, and stiffeners for structural components.

Ref: Figure from: S. Kalpakjian, Manufacturing Processes for Engineering Materials, Second Ed., Addison Wesley, 1991

Blow Molding, Bottles



- Hollow plastic parts with relatively thin walls.
- Typical parts: Bottles, Bumpers, Bags, Ducting.

Figure ref: Process Selection, KG Swift and JD Booker, p.55.

Tecnológico de Monterrey

Explaining the process:

http://www.youtube.com/watch?v=eUthHS3MTdA&feature=related ✓

http://www.youtube.com/watch?NR=1&feature=endscreen&v=WaB-dsB1Kfk

Moldeo con insertos

http://www.youtube.com/watch?NR=1&v=0lbtE4y5qB0&feature=endscreen

Dr. Jaime Bonilla Ríos

Correo

Tecnológico de Monterrey