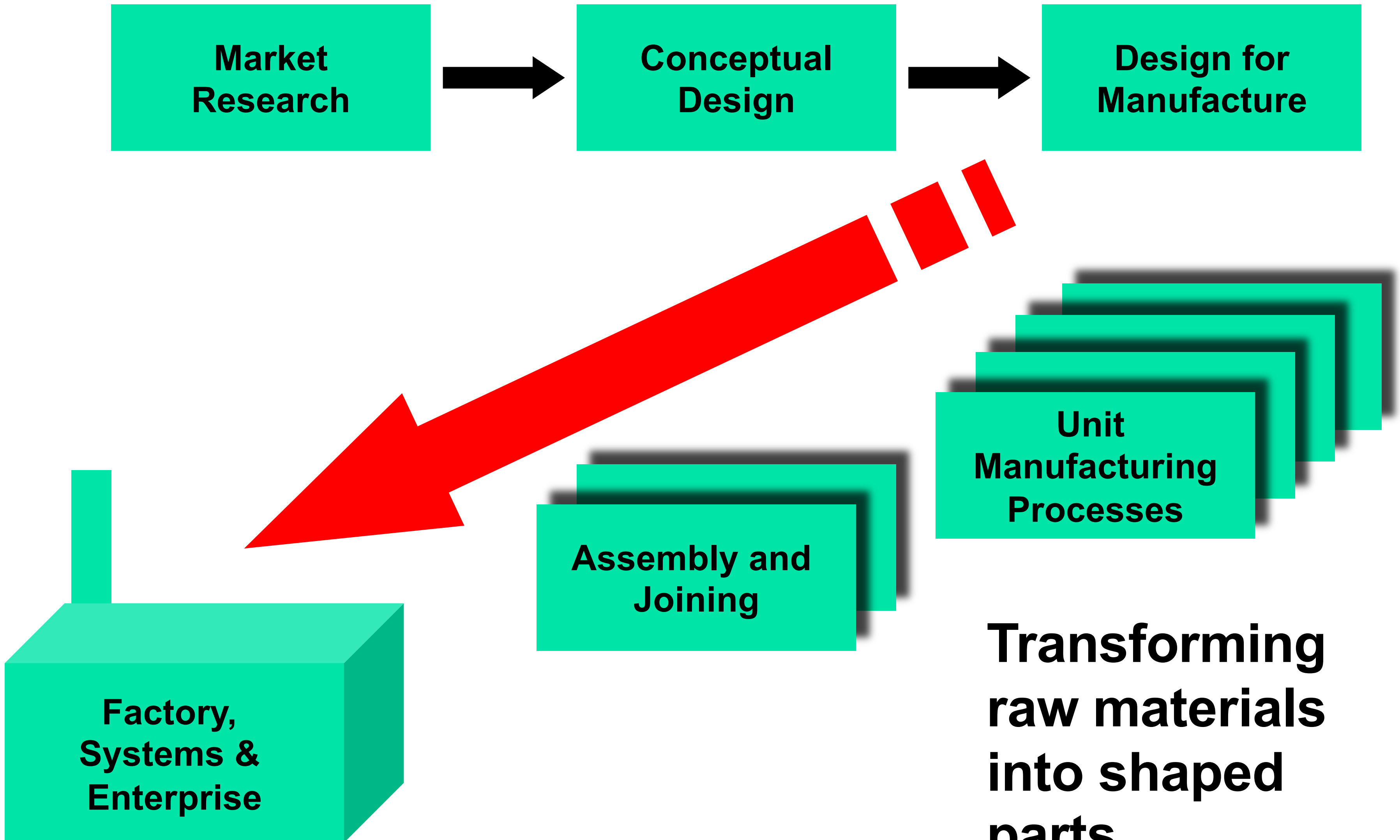
Manufacture



Transforming raw materials into shaped parts

2.008

Injection Molding I

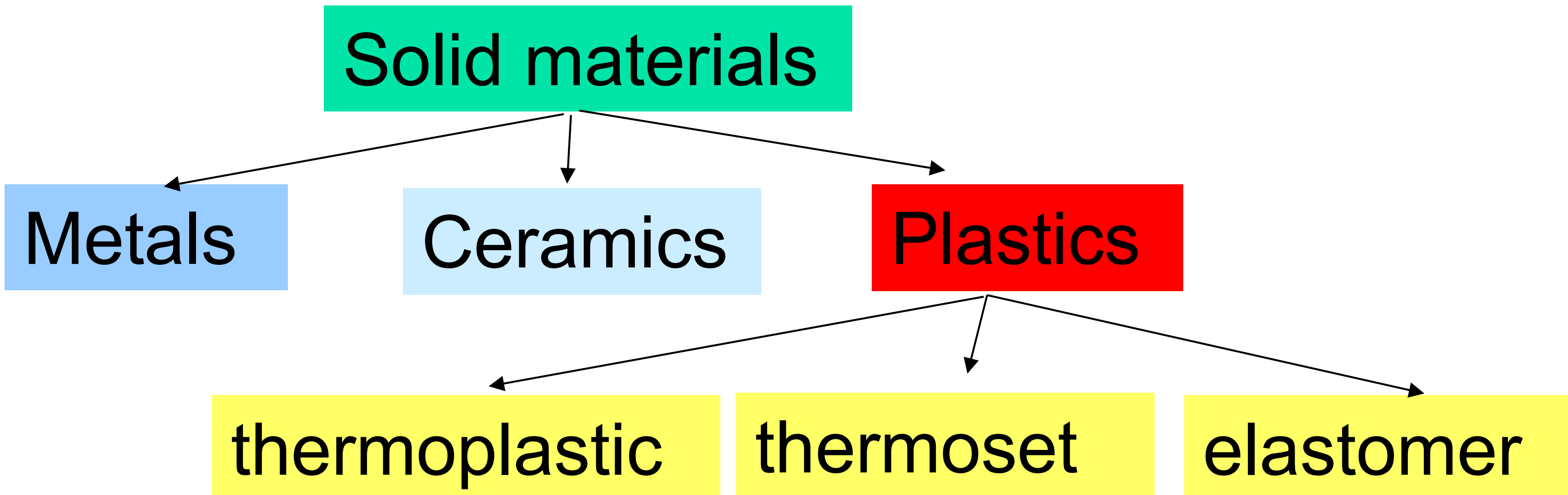
Outline

- Polymer
- Process steps and equipment
- Considerations for process parameters
- Design for manufacturing, tooling and defects

Objectives

- Internalize quality, cost, rate and flexibility as mfg attributes.
- Apply physics to understand the factors that influence the quality, cost, rate and flexibility of processes.
- Apply an understanding of variation to the factors that influence the quality, cost, rate and flexibility of processes and systems.
- Understand the impact of manufacturing constraints on product design and process planning.

Materials



Plastic: Greek, *plastikos*, means to form or mold

Plastics

- Over $500 billion shipments in the US in 2023.
- Employment growth: 1.1 % annually since 2013 vs. 0.7% for total manufacturing.

(plasticsindustry.org)

- Applications

  Name it
  - Containers
  - No-sticking TEFLON
  - Stre-e-e-tching SPANDEX
  - Automotive

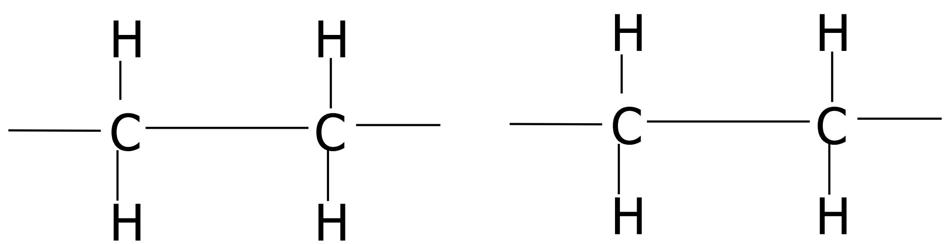
Automotive Plastics and Composites Use

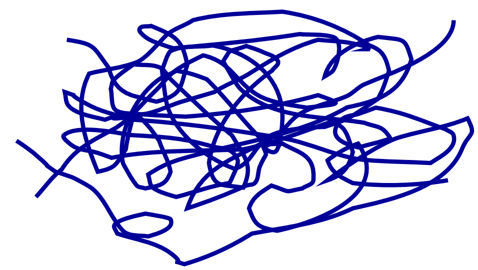
- Exterior
  - doors
  - hoods
  - fenders
  - bumper covers (most cars have soft fascia)
- Interior
  - instrument panels, door trim, seats, consoles
- Engine
  - valve covers, intake manifolds, fluid containers, etc.

Polymers: Macromolecules

- Poly (many) + mer (structural unit)
  -$[C_2H_4]_n$- , poly[ethylene]

spaghetti

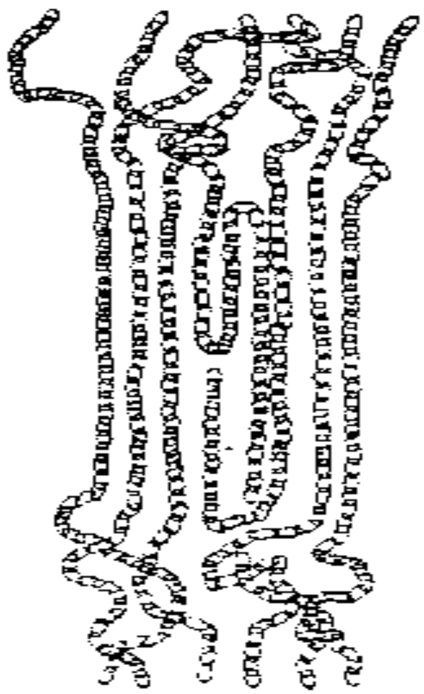




- Metal: single atoms, metallic bond
- Ceramic: metallic oxides, ionic bond or dipole interactions, van der Waals bonds

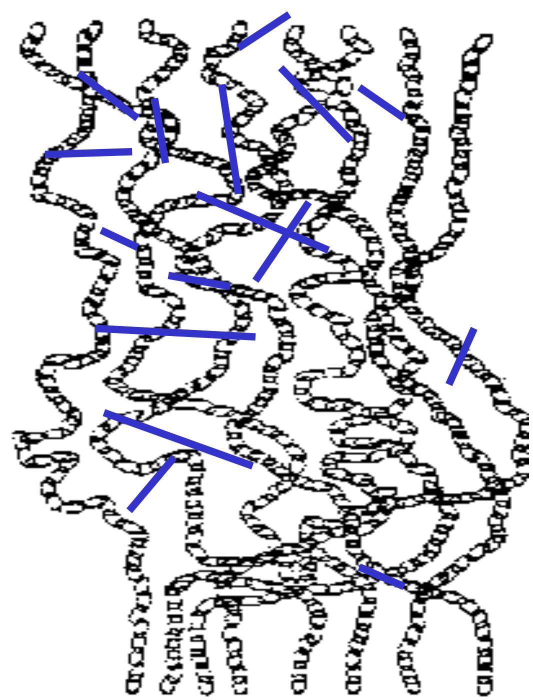
Thermoplastic vs. Thermoset

- Amorphous
- Crystalline



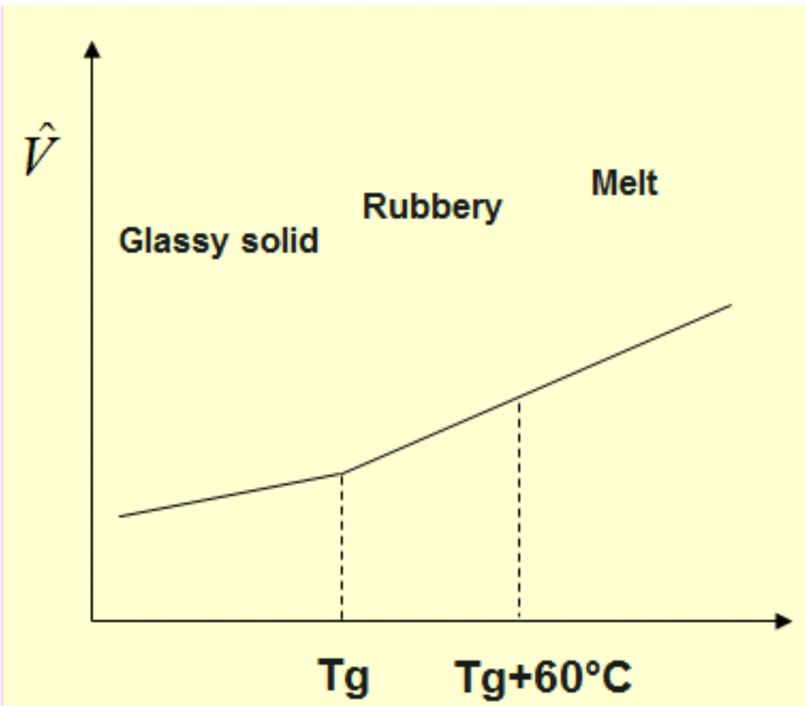
crystallization

- Cross-linked (3D network)

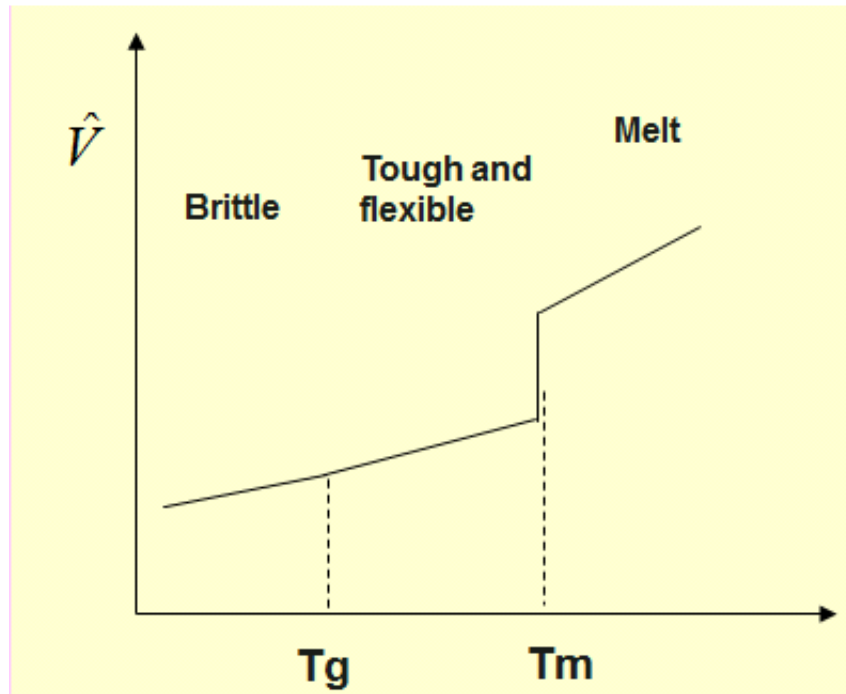


cross – linking

Specific Volume of Thermoplastics: Amorphous vs. Crystalline

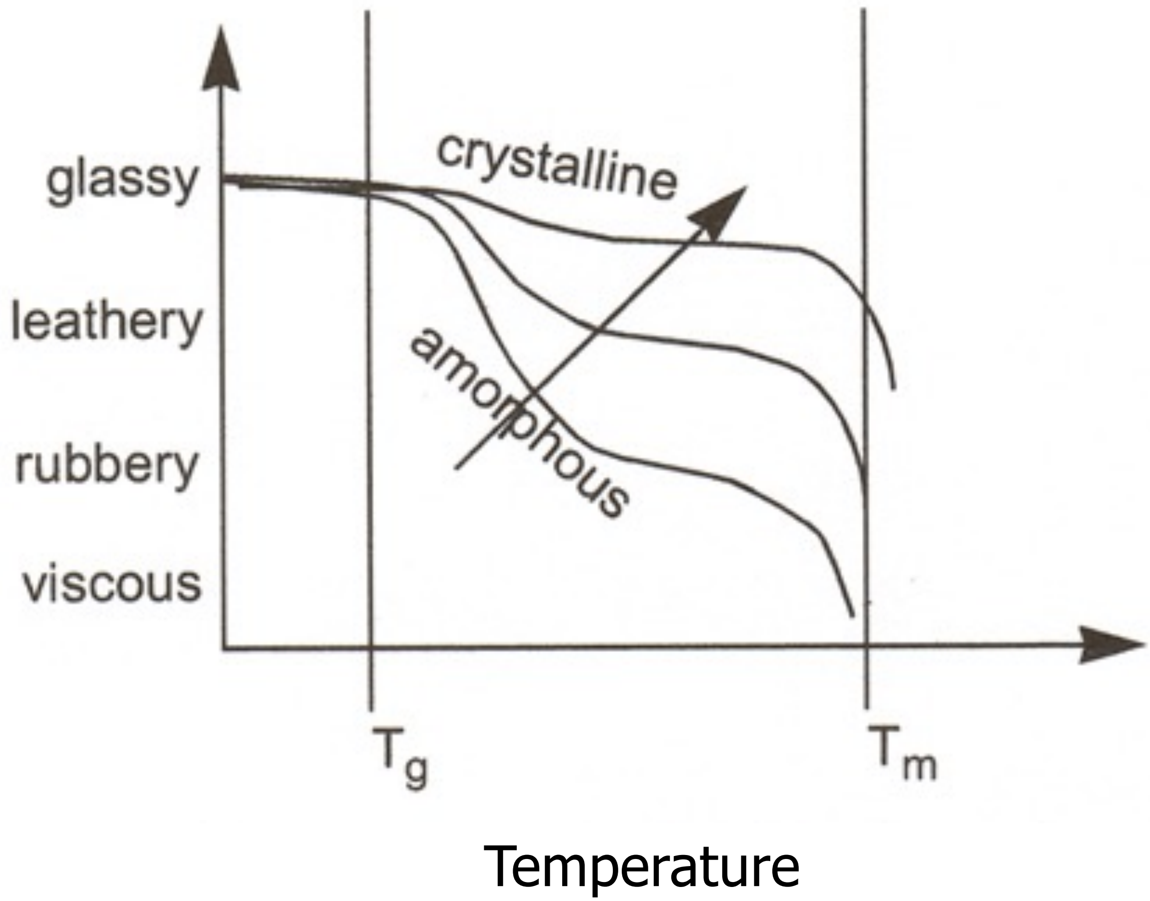


Temperature



Temperature

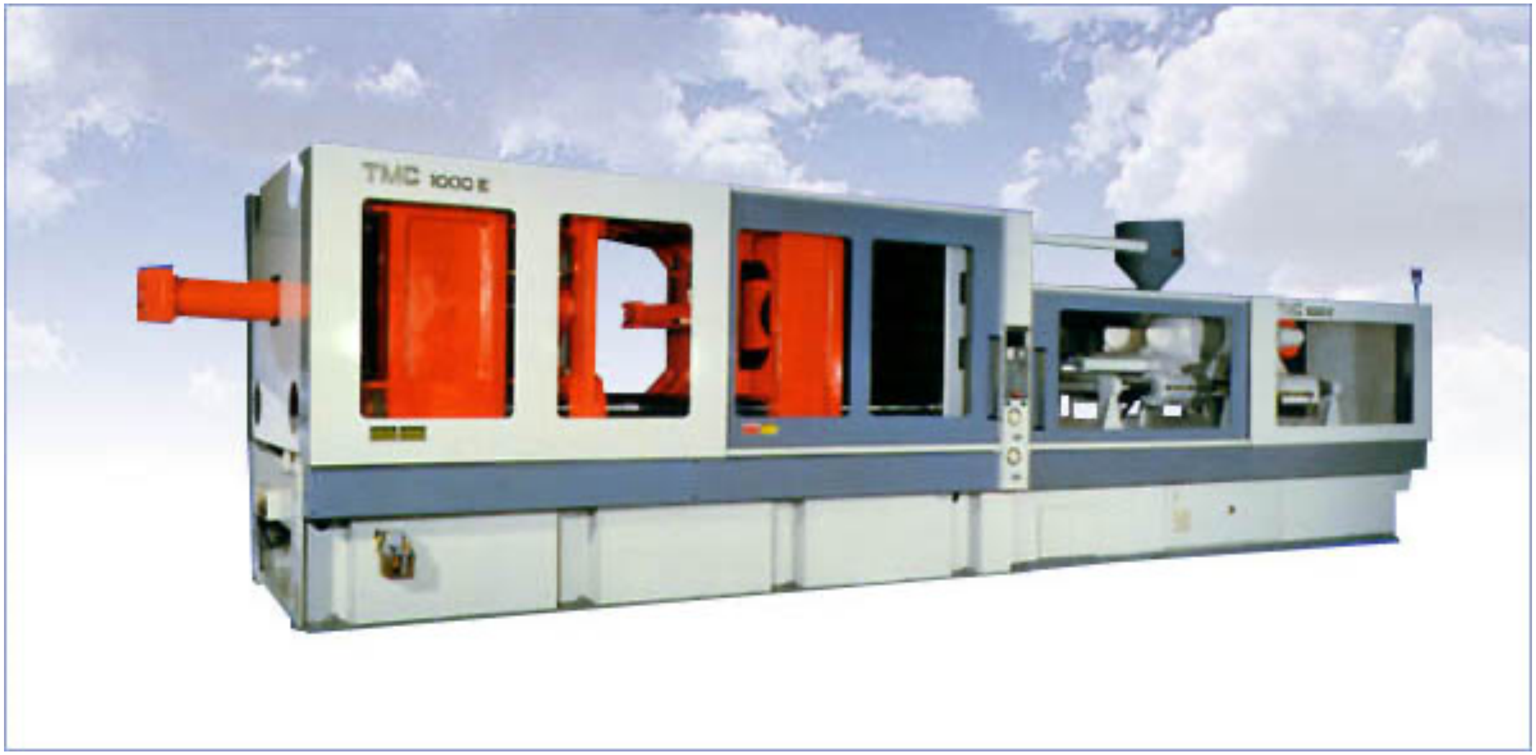
Stiffness of Thermoplastics



Flow and thermal properties

- Viscosity
  - High or low?
  - Why?
- Thermal diffusivity

Injection Molding Machine



Melt Preparation

- Melt Temperature Control
  - Through Cylinder(Barrel)
    - Frictional Heating
    - Heating bands for 3 zones
      - Rear zone
      - Center zone (10F-20F hotter)
      - Front Zone (10F-20F hotter)
  - Nozzle

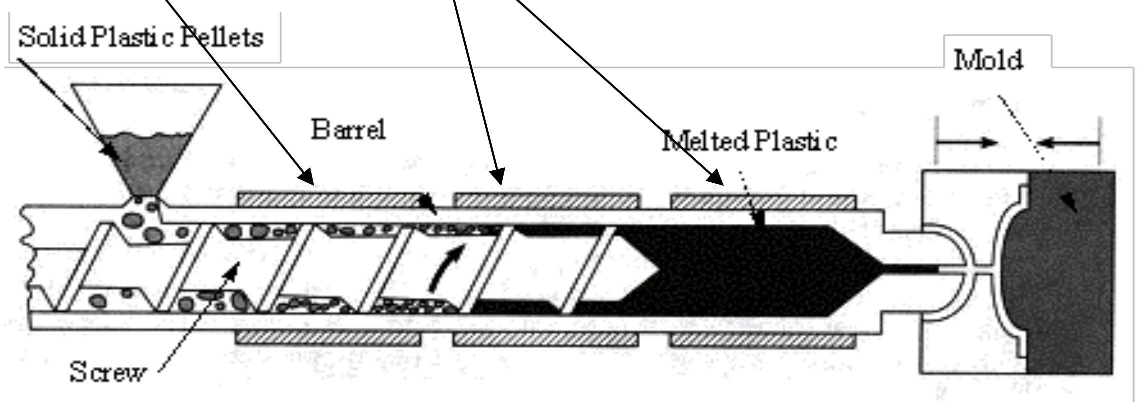
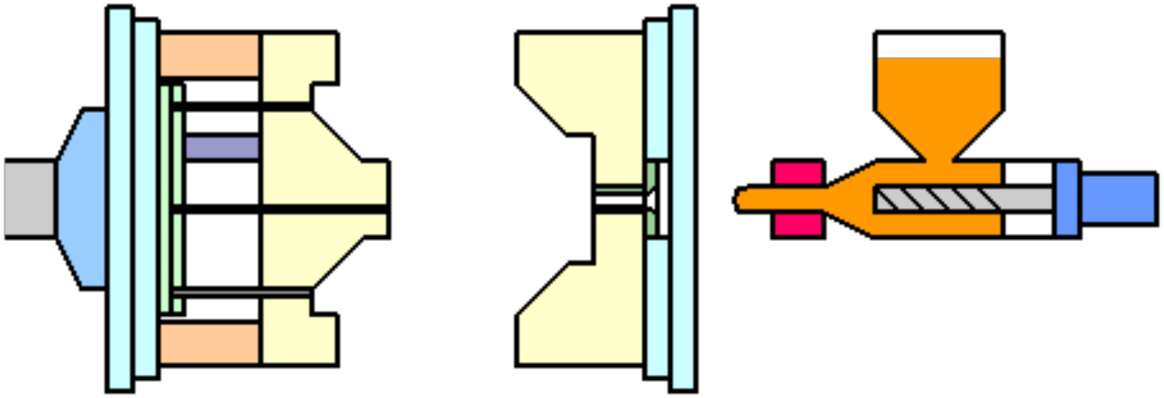


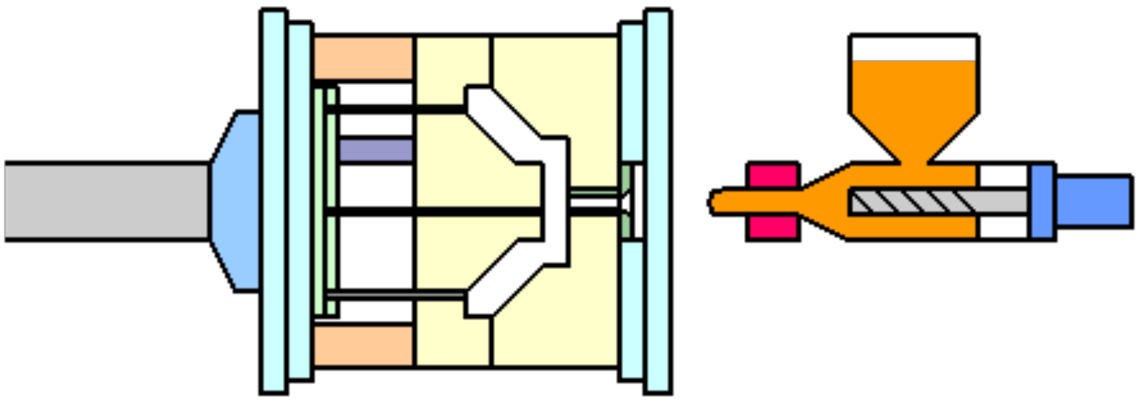
Figure 2: Detail of Screw and Barrel

Steps of Injection Molding: Mold closing



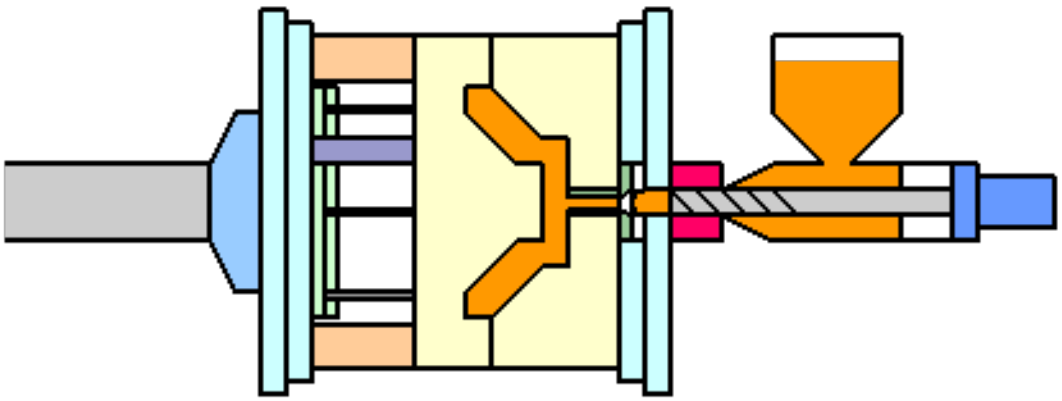
When closing a mold, first close it with low pressure,
and then with high pressure just before completion to close it firmly.

Mold filling



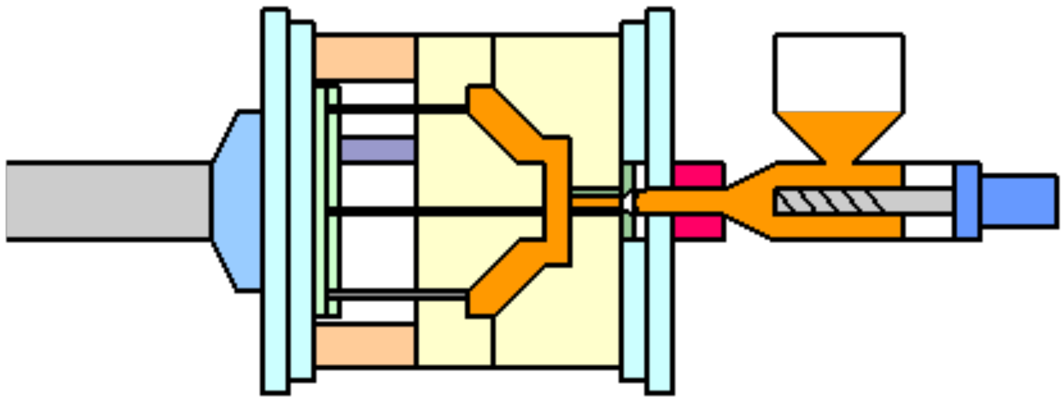
The nozzle will touch the locate ring and then the molten plastic will be injected into the mold

Packing, Holding, Cooling



While the molten plastic is being cooled and solidified in the mold, the molding material for the next molding will be plasticized.

Mold opening, Part removal

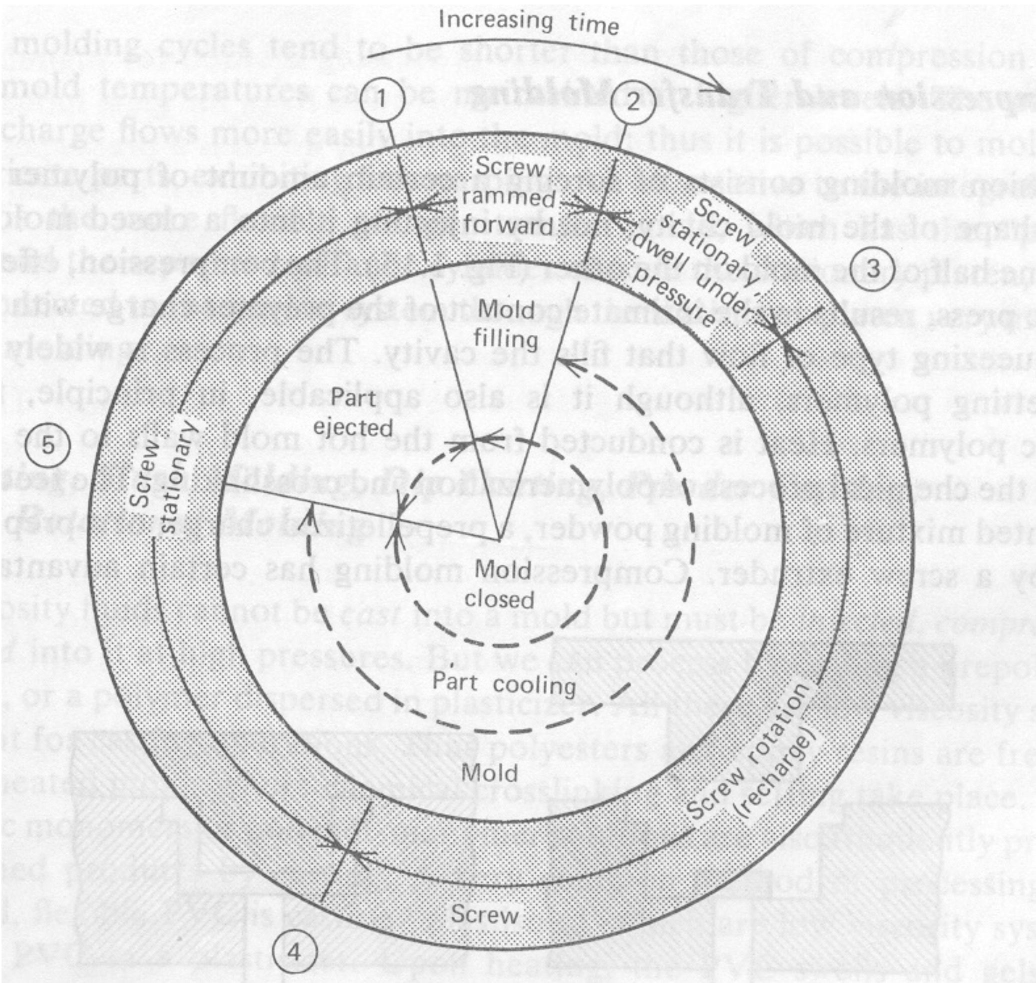


The injection nozzle is separated from the mold,
the mold is opened to remove the part.

Ejector pins


tronicarts SPGM 100
www.tronicarts.de

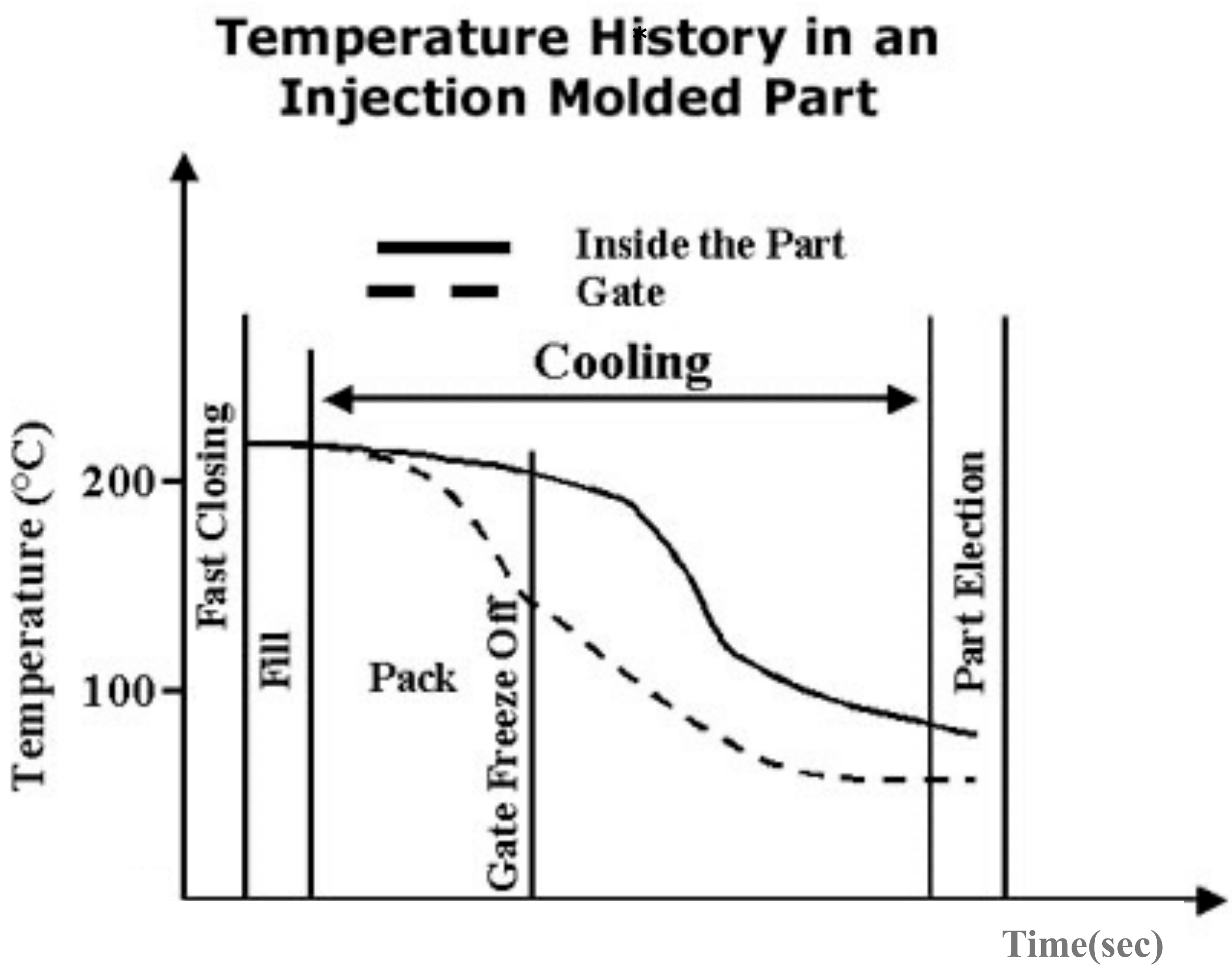
Injection Molding Cycle



Tadmor & Gogos

Typical Temperature Cycle

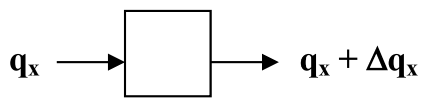
*



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

Heat Transfer Note; $\alpha_{\text{Tool}} \geq \alpha_{\text{polymer}}$

1-dimensional heat conduction equation:



$$\frac{\partial}{\partial t}(\rho \cdot c_p \cdot T)\Delta x \Delta y = -\frac{\partial q_x}{\partial x}\Delta x \Delta y$$

Fourier's law

$$q_x = -k\frac{\partial T}{\partial x}$$

$$\rho \cdot c_p \frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial x^2} \quad \text{or} \quad \frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2}$$

Boundary conditions:

1st kind $$T(x = x') = \text{constant}$$

2nd kind $$-k\frac{\partial T}{\partial x}(x = x') = \text{constant}$$

3rd kind $$-k\frac{\partial T}{\partial x}(x = x') = \bar{h}(T - T_\infty)$$

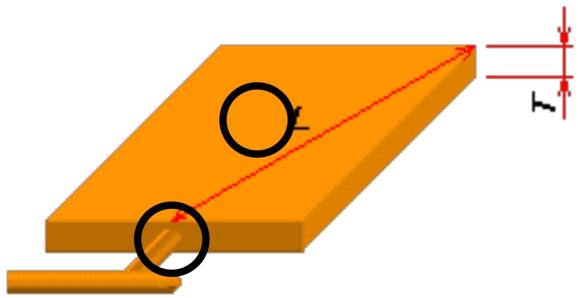
The boundary condition of 1st kind applies to injection molding since the tool is often maintained at a constant temperature

Injection Cycle Time

- $$$
- Typical Cycle of Injection Molding

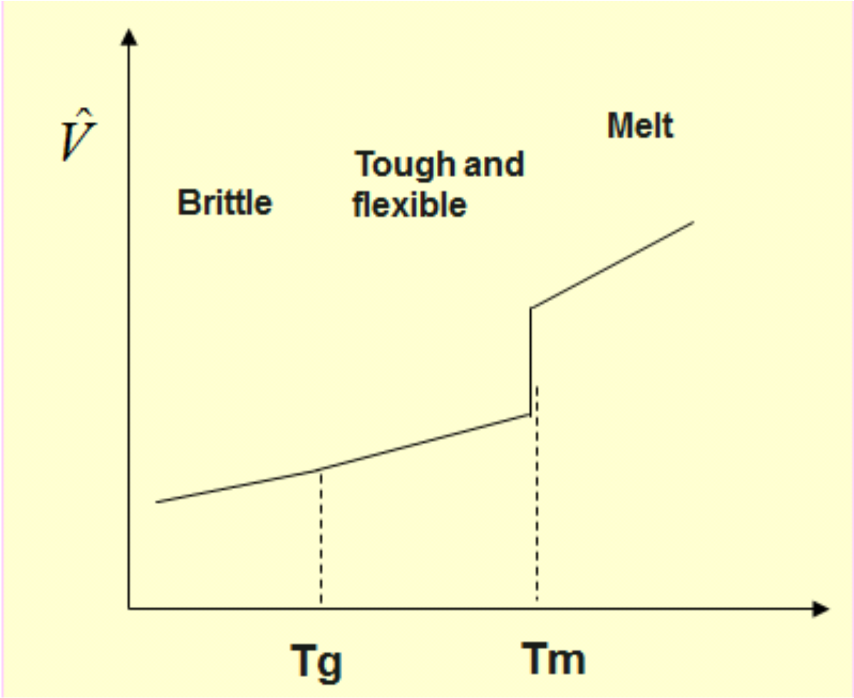
Mold Close	1-2 sec
Injection	2-5 sec
Pack and Hold	8-10 sec
Part Cool	10-20 sec
Screw return	2-5 sec
Mold open	1 sec
Ejection	1 sec

Pressure Control



- Pressure distribution
- Injection unit
  - Initial injection pressure
    - Applied to the molten plastic and resulting from the main hydraulic pressure pushing against the back end of the injection screw (or plunger).
  - Packing pressure
  - Injection pressure inside mold
    - Usually 1,000 psi to 5,000 psi
    - Lower than hold and pack pressure between 10,000psi and 20,000 psi

Specific Volume of Crystalline Thermoplastics

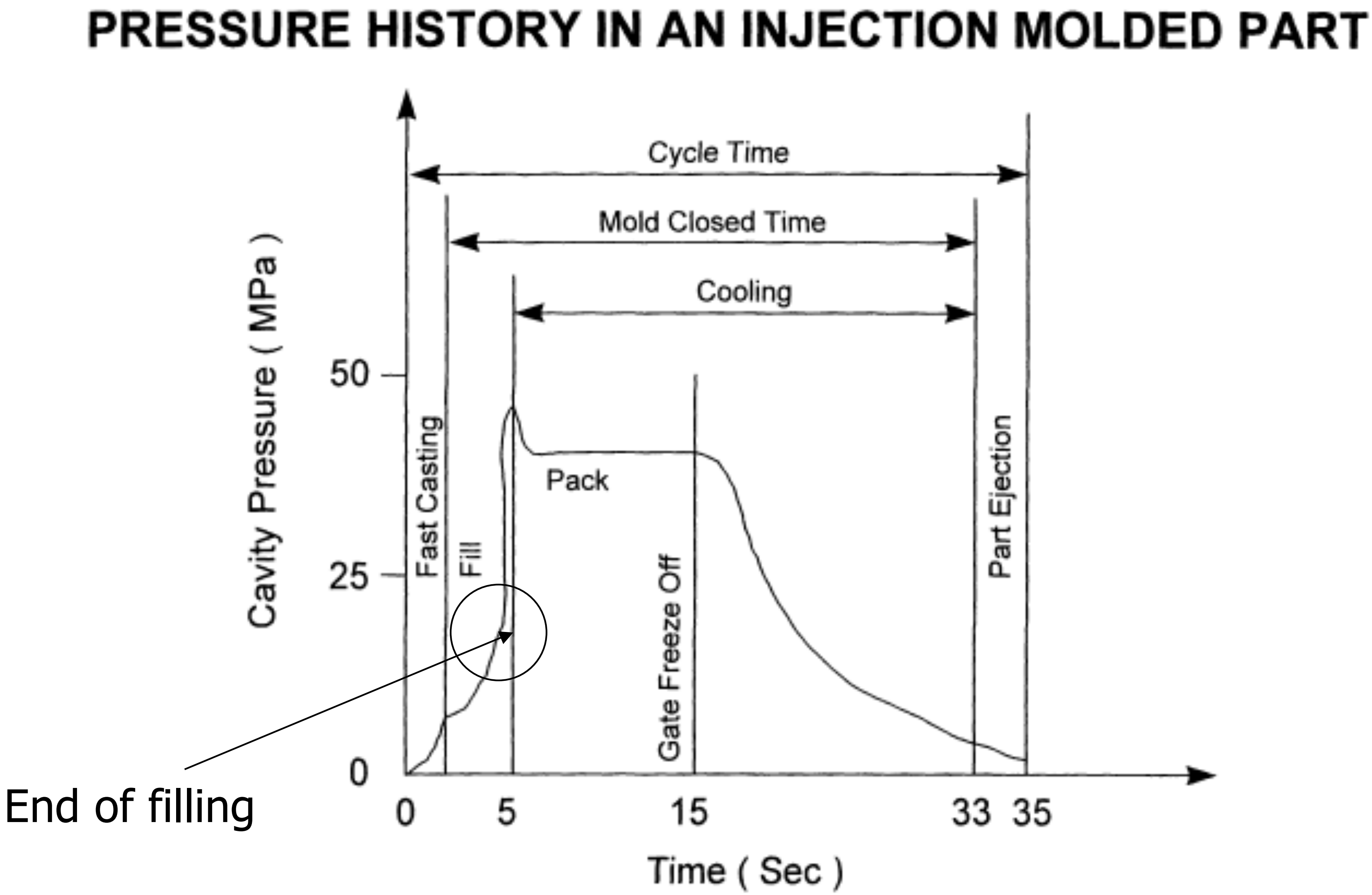


Temperature

Pressure Control (Continued)

- Hold pressure (packing)
  - Compensate shrinkage
  - Rule of thumb: Hold pressure = 150% of injection pressure.
  - Applied at the end of the initial injection stroke, and is intended to complete the final filling of the mold and hold pressure till gate closure

Pressure History



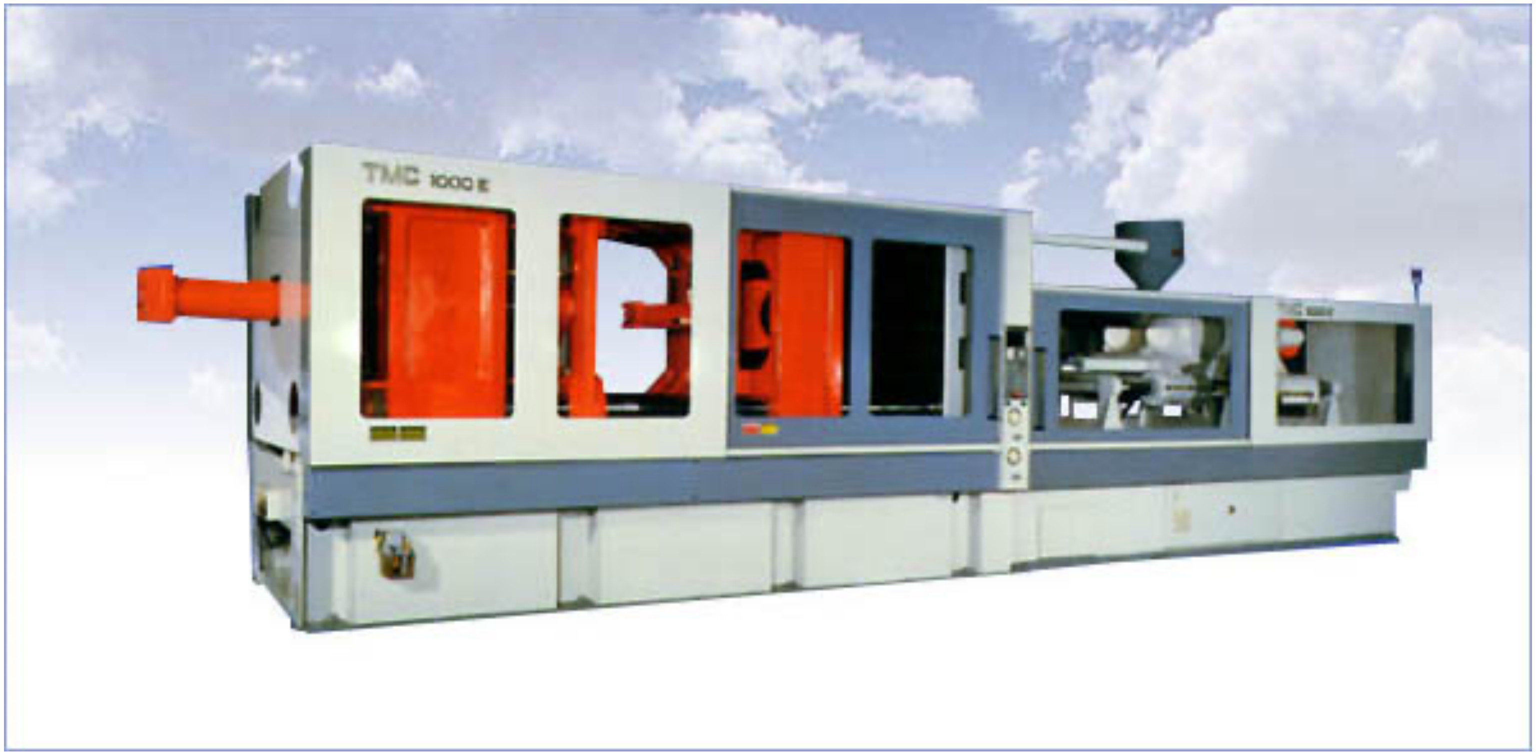
Clamp Force

Total force = projected area times injection pressure (A X P)

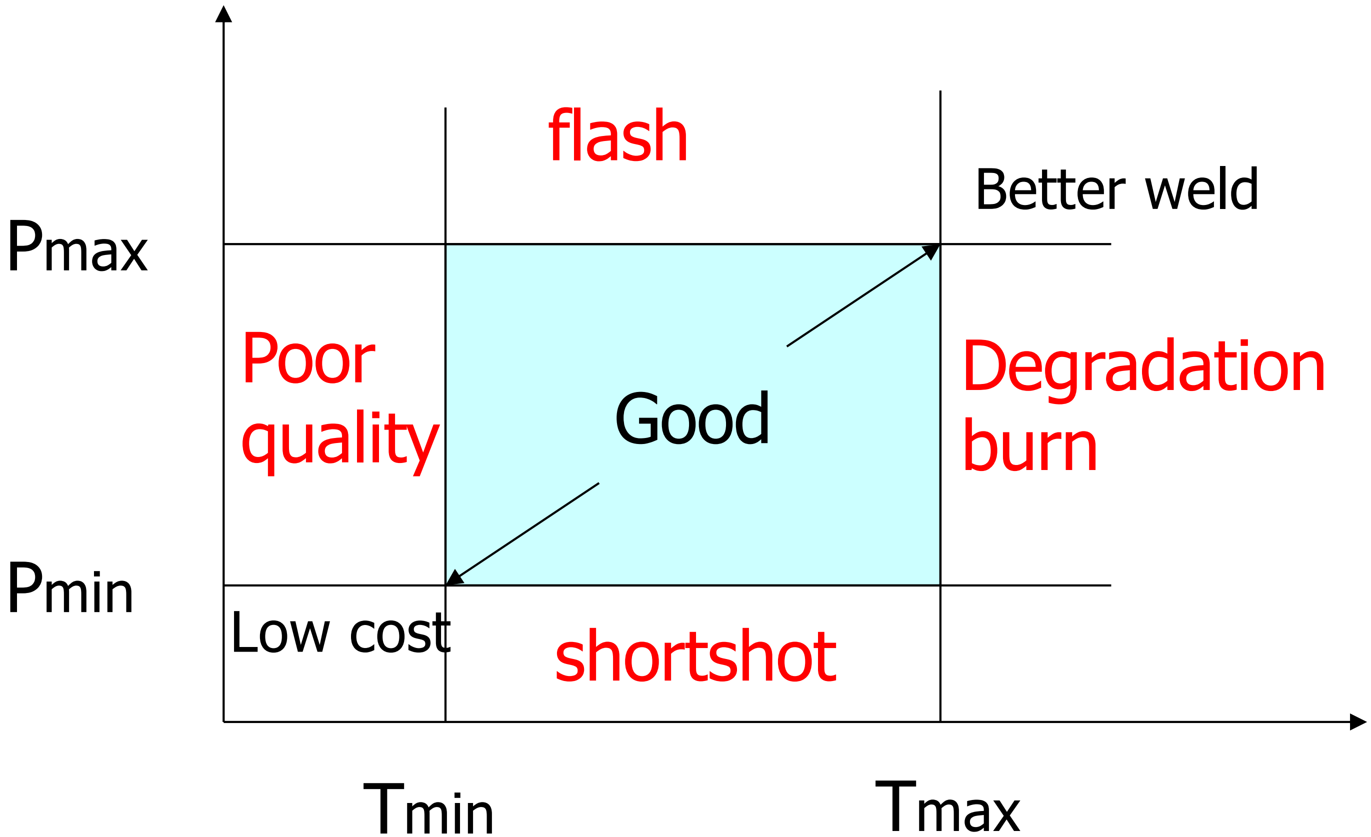
- Rule of thumb 4 to 5 tons/in^2 can be used for most plastics.
- Example,
  - Projected area
  - Injection Pressure
  - Tonnage required to keep mold closed

Parting line ?

Injection Molding Machine

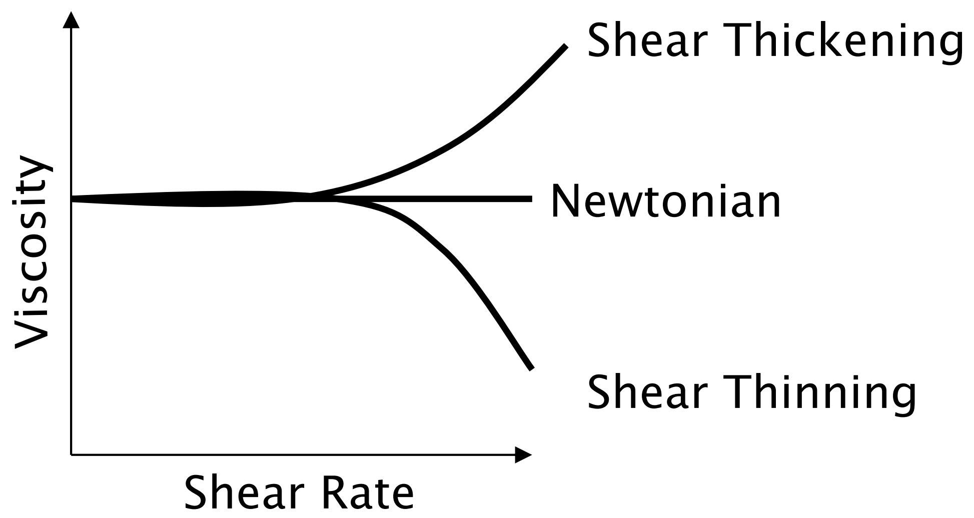


Injection Molding Process Window

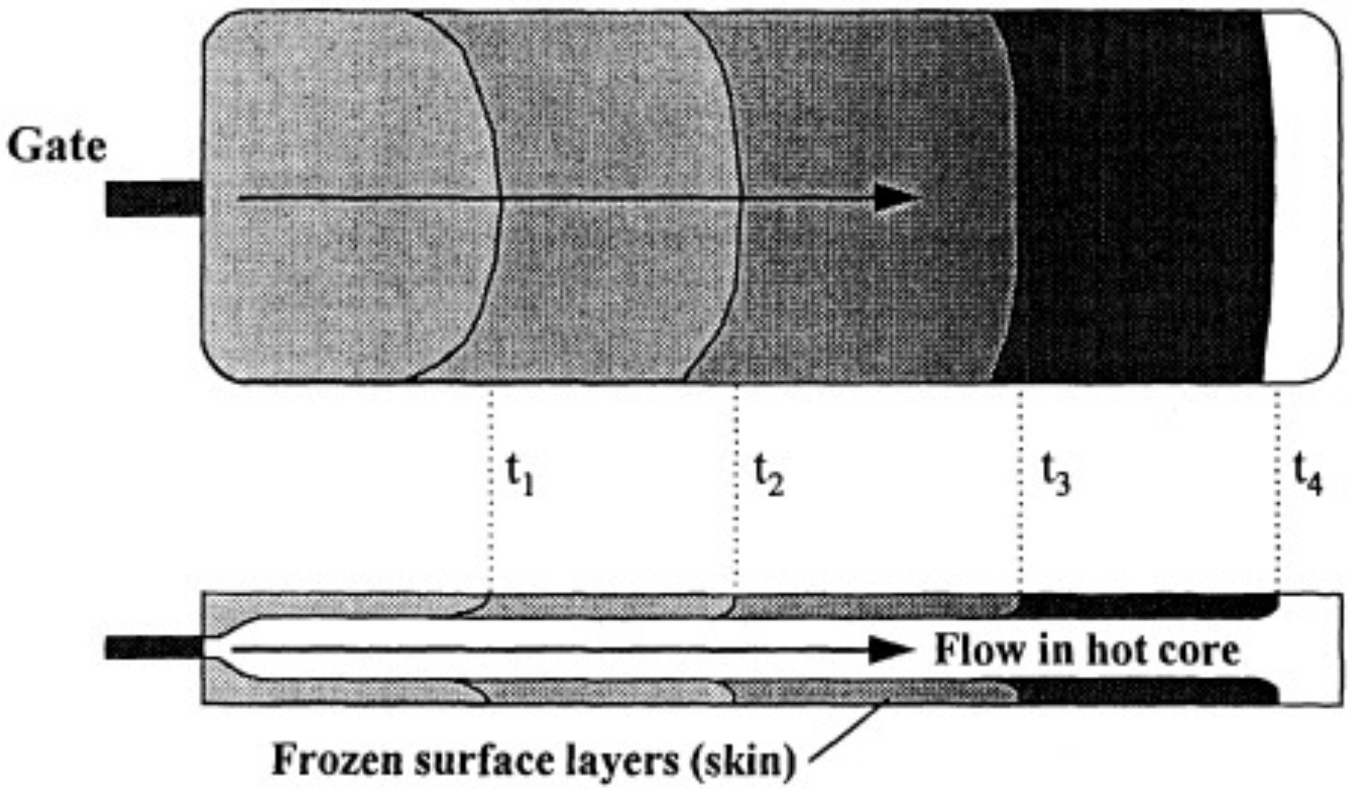


Viscosity

- Shear rate dependency

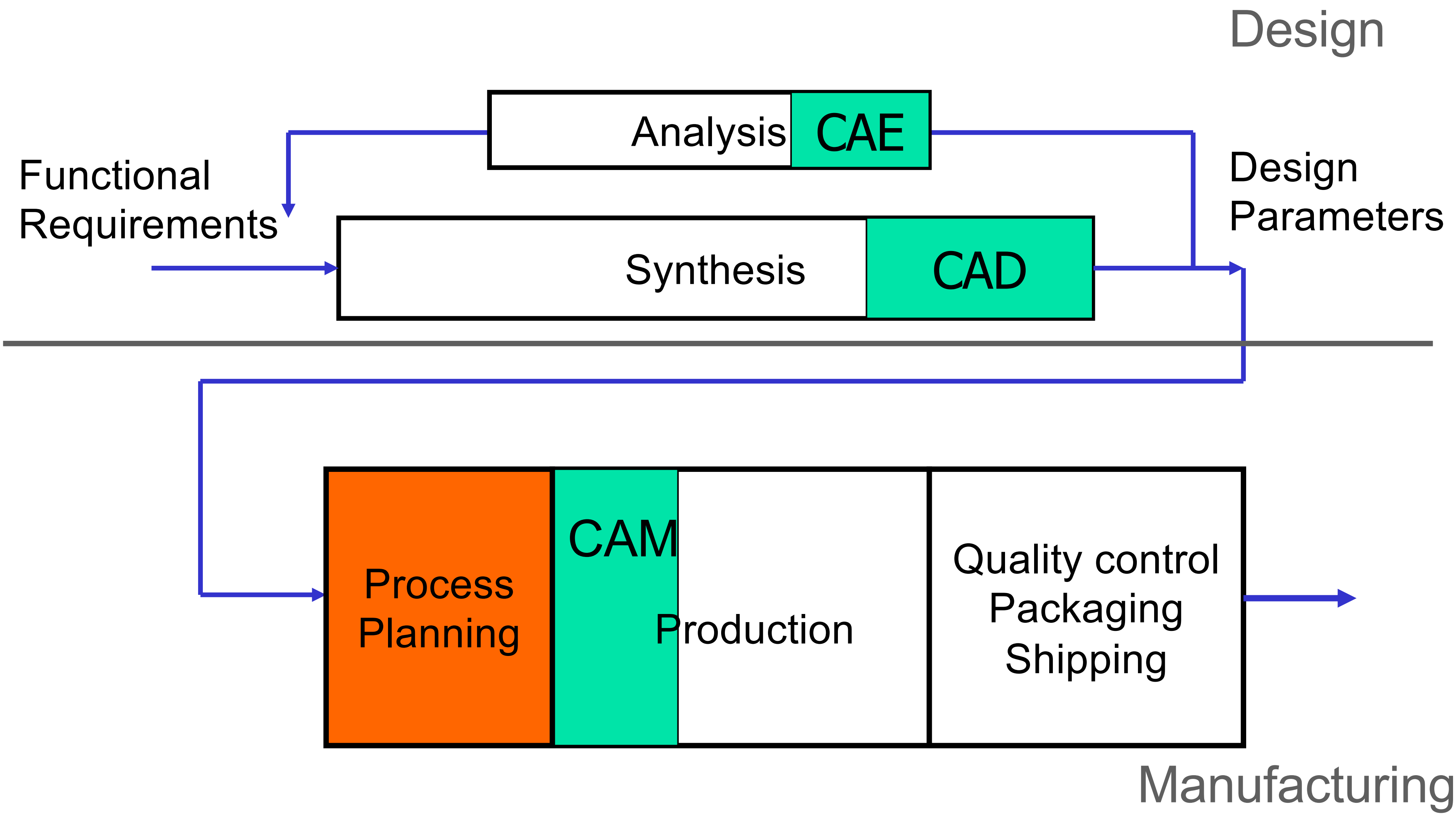


Non-isothermal Flow

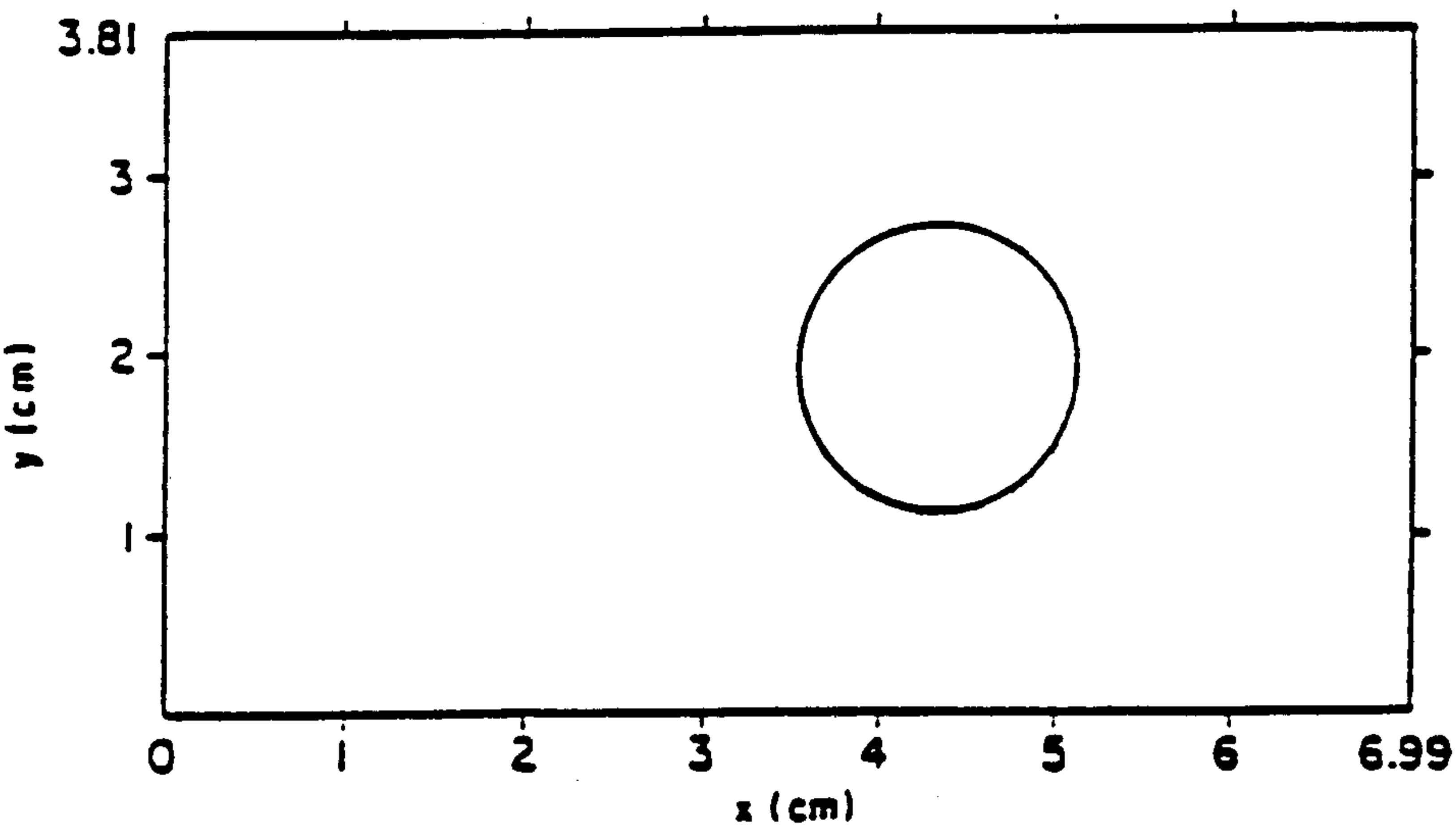


* Source: http://islnotes.cps.msu.edu/trp/inj/flw_froz.html ; ** Z. Tadmore and C. Gogos, "Principles of Polymer Processing"

Product Development Cycle



Simulated vs. Actual Mold Flow



Simulation: Dotted Line
Actual: Solid Line

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