Defects in Injection Molded Parts

Molding defects are caused by improper part design, mold design/fabrication and/or molding conditions

- Inappropriate Shrinkage
- Short Shot
- Flash
- Sink Mark
- Weldline
- Warpage

2.008

Thermoforming Process
(Vacuum Forming Process)

Outline

- Overview (Material Behaviors)
- Process Steps
- Process Equipment
- Design for Manufacturing

Overview

- Polymers

  thermoplastic

- Applications

  packaging, container, housing, etc.

Thermoplastic Polymers
Amorphous vs Semicrystalline

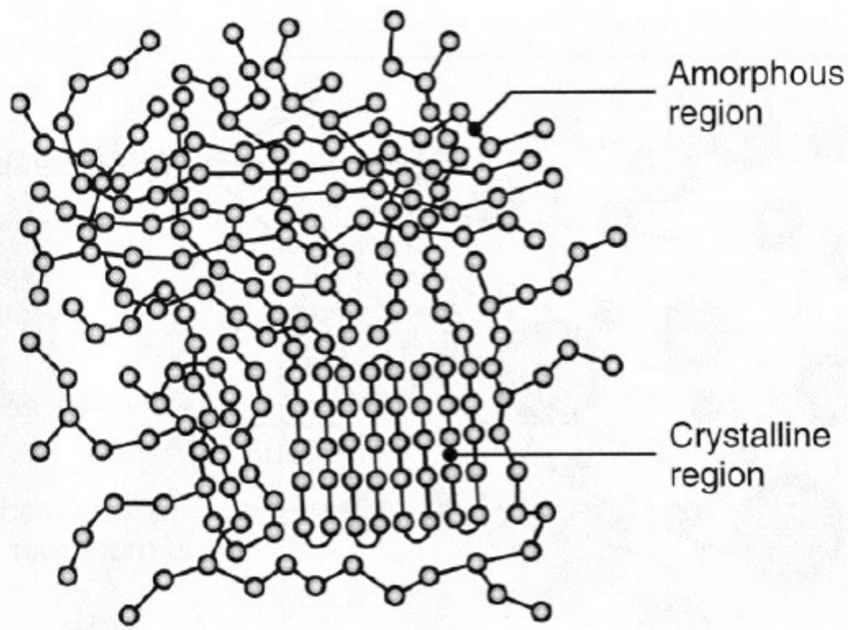
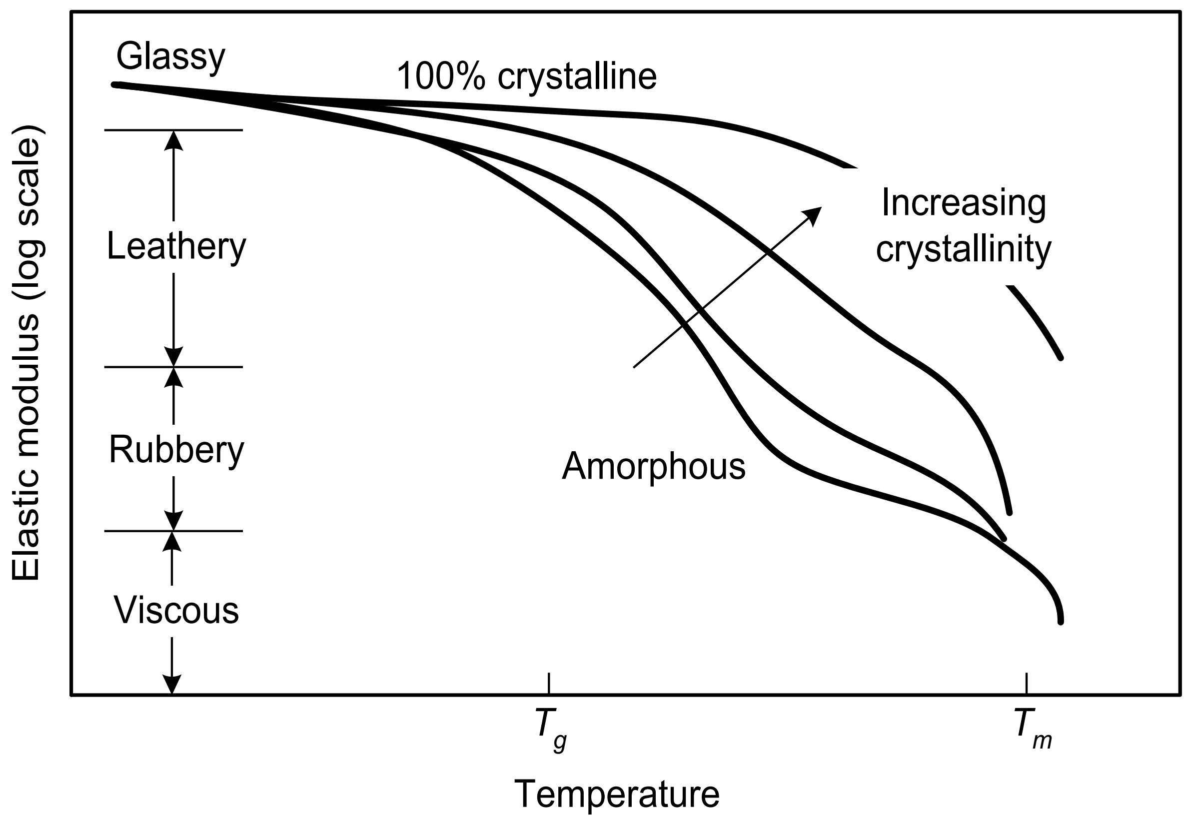


FIGURE 7.8 Amorphous and crystalline regions in a polymer. The crystalline region (crystallite) has an orderly arrangement of molecules. The higher the crystallinity, the harder, stiffer, and less ductile the polymer.

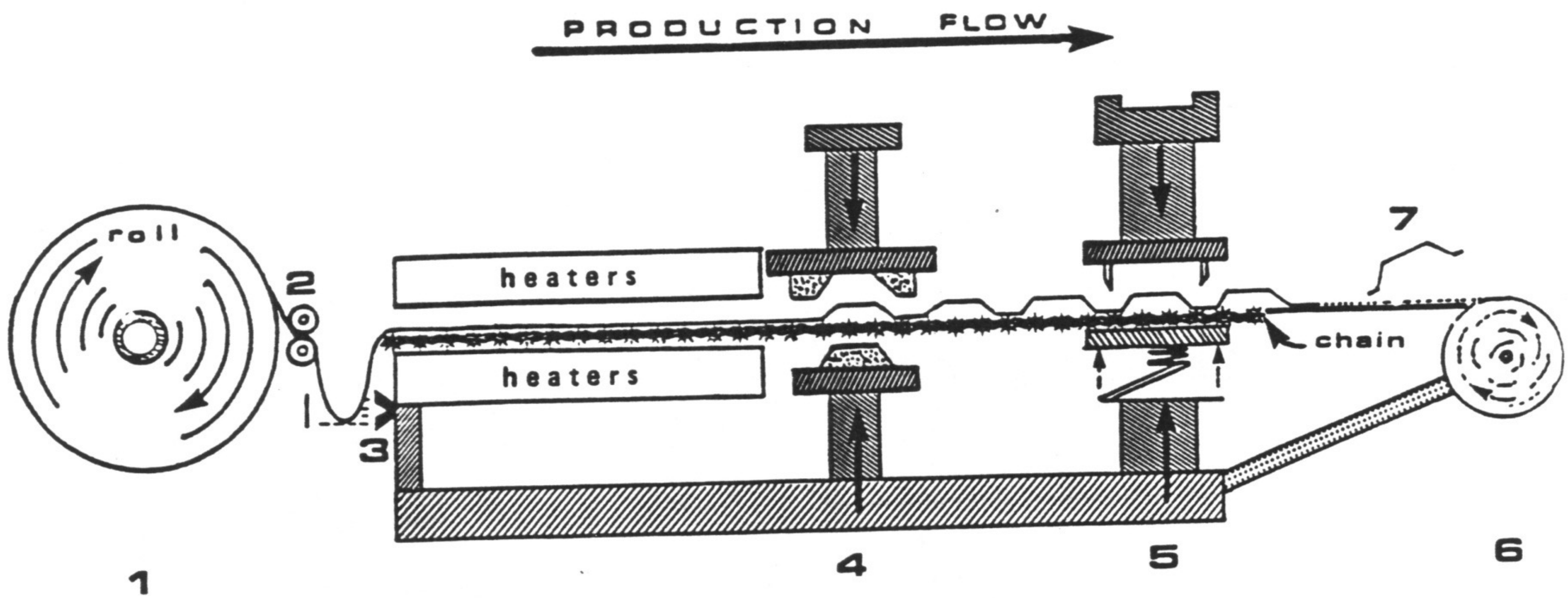
Thermoplastic Polymers
Amorphous vs Semicrystalline



Processing Steps

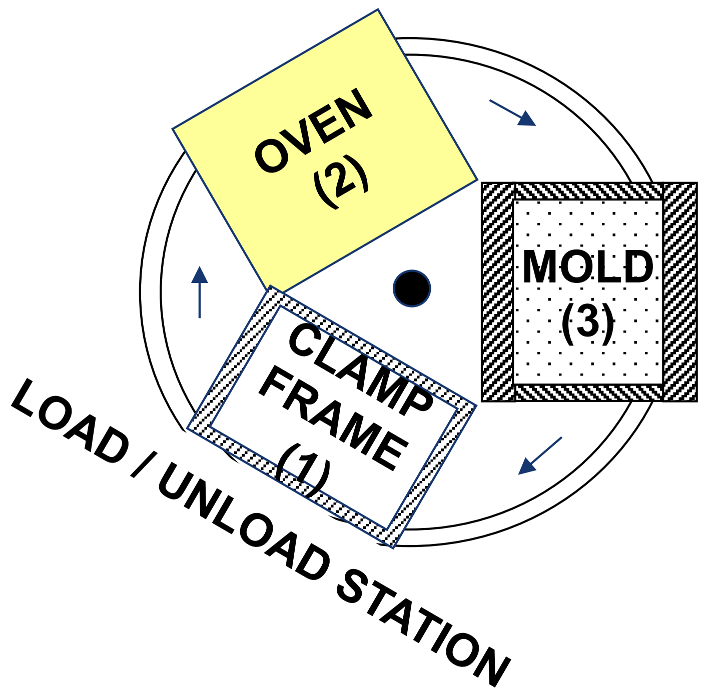
- Sheet
- Heat
- Form
- Cool
- Trim

Typical Production Flow: In-line Arrangement



1. roll stock
2. nip rollers
3. electric eye
4. forming station
5. trimming station
6. scrap wind
7. part stacking

Three-station Thermoforming Machine

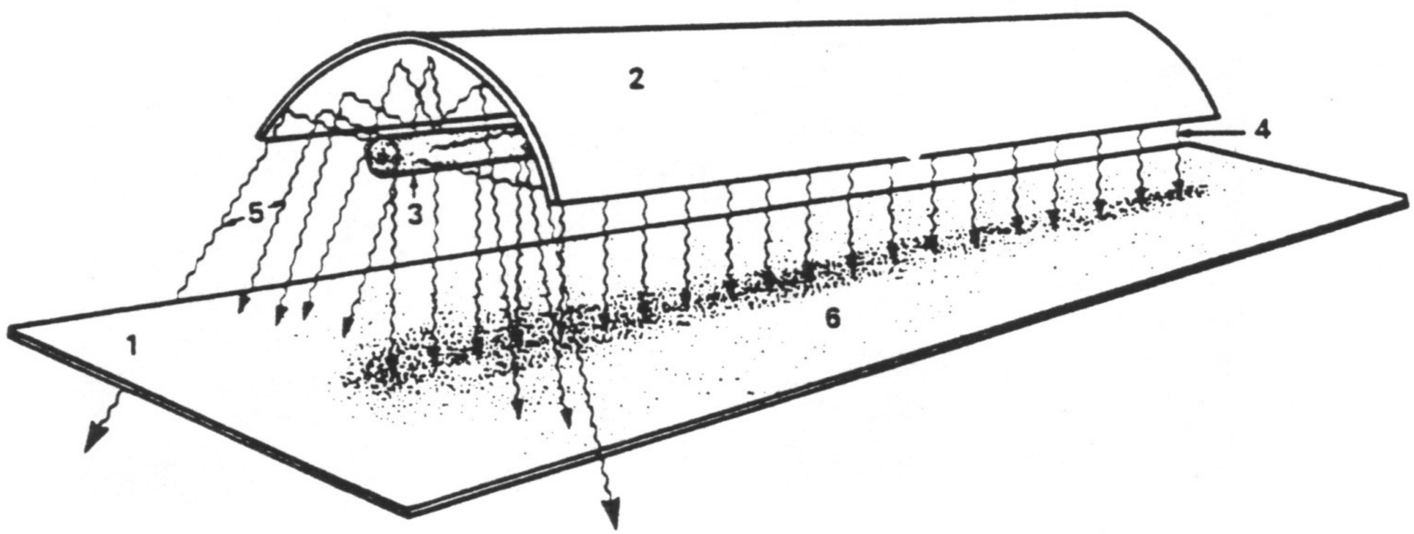


1. loading and unloading station
2. heating station
3. forming station

Heating Methods

- Convection Heating
- Contact Heating
- Radiant Heating

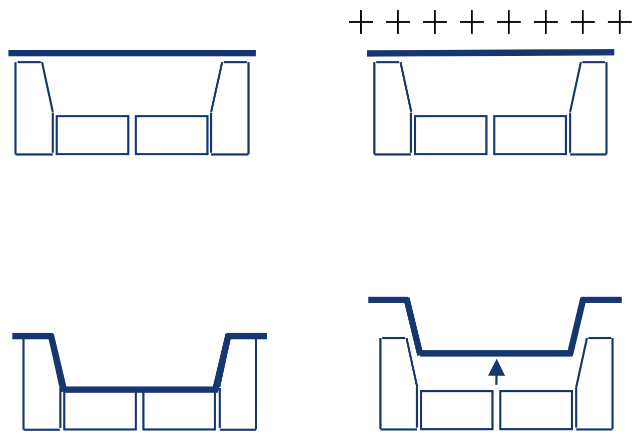
Radiant Heating



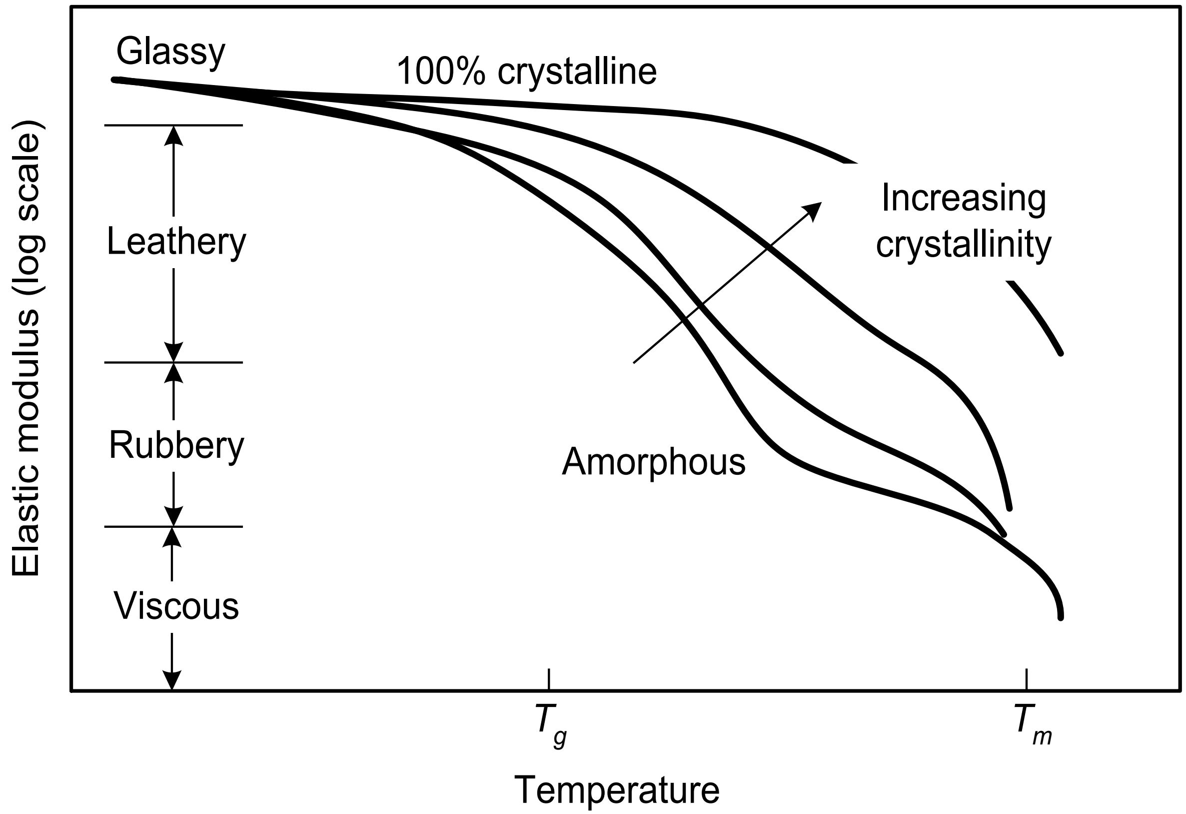
1. thermoplastic sheet
2. reflector
3. tubular heater element
4. direct heat
5. reflected heat
6. actual heat distribution on the plastic sheet

Forming: Pressure or Vacuum

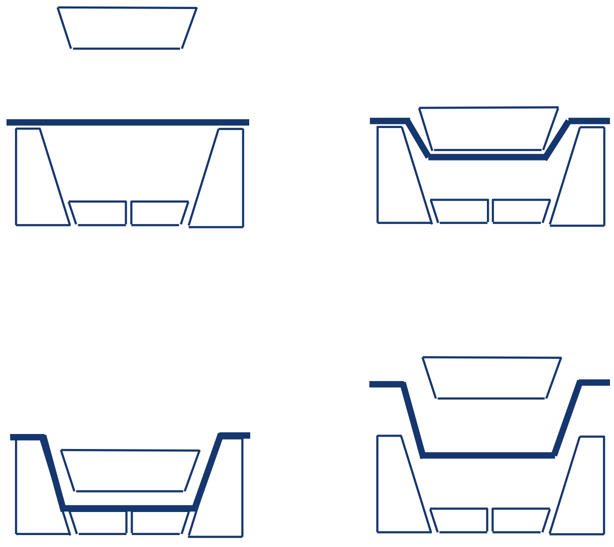
- Positive air pressure (14.5 to 300 psi)
- Faster mold cycle
- Lower temperatures with higher forming pressure



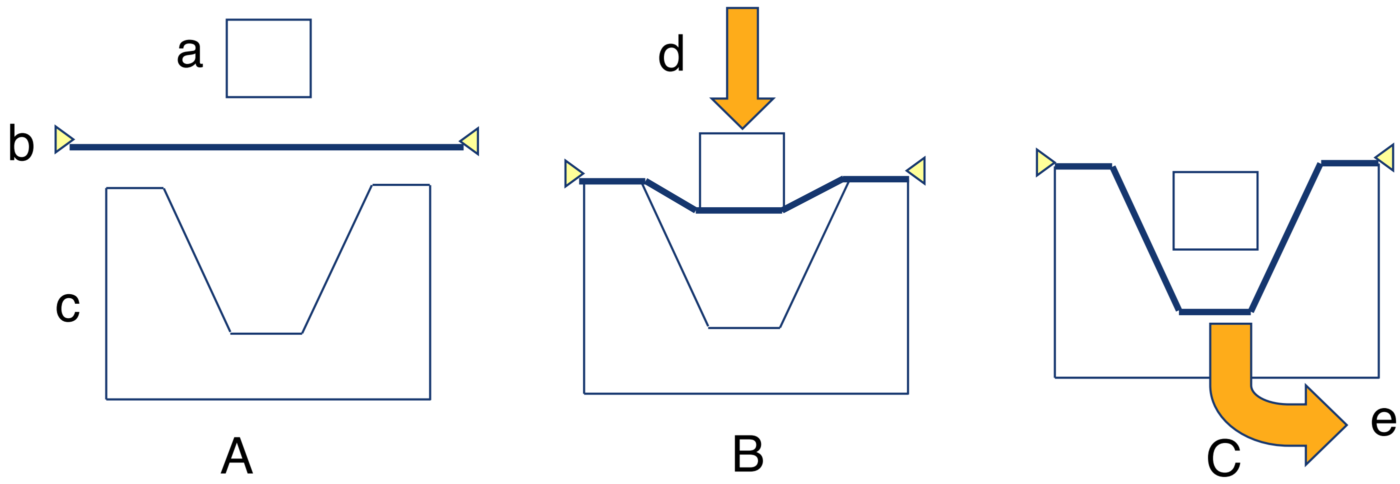
Stiffness of Thermoplastic Polymers Amorphous vs Crystalline



Forming: Match Mold



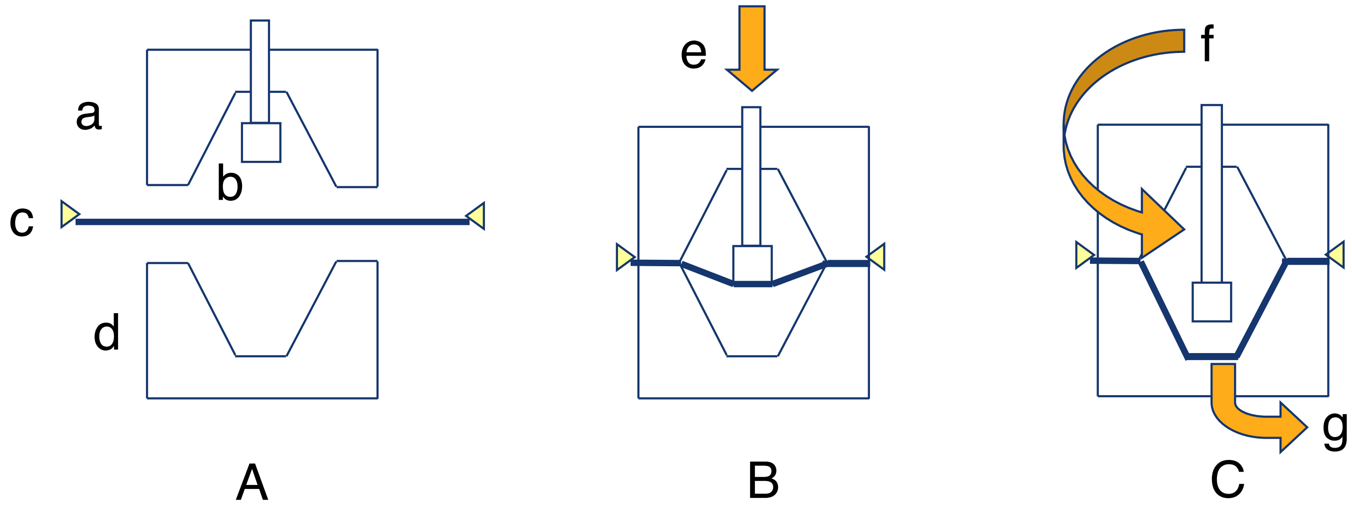
Plug-assist Vacuum Forming



A: preheated sheet prior to forming
B: sheet stretched with moving plug
C: sheet vacuum formed into female cavity

a - plug
b - preheated, clamped, sheet
c - female mold with vacuum holes
d - moving plug
e - vacuum

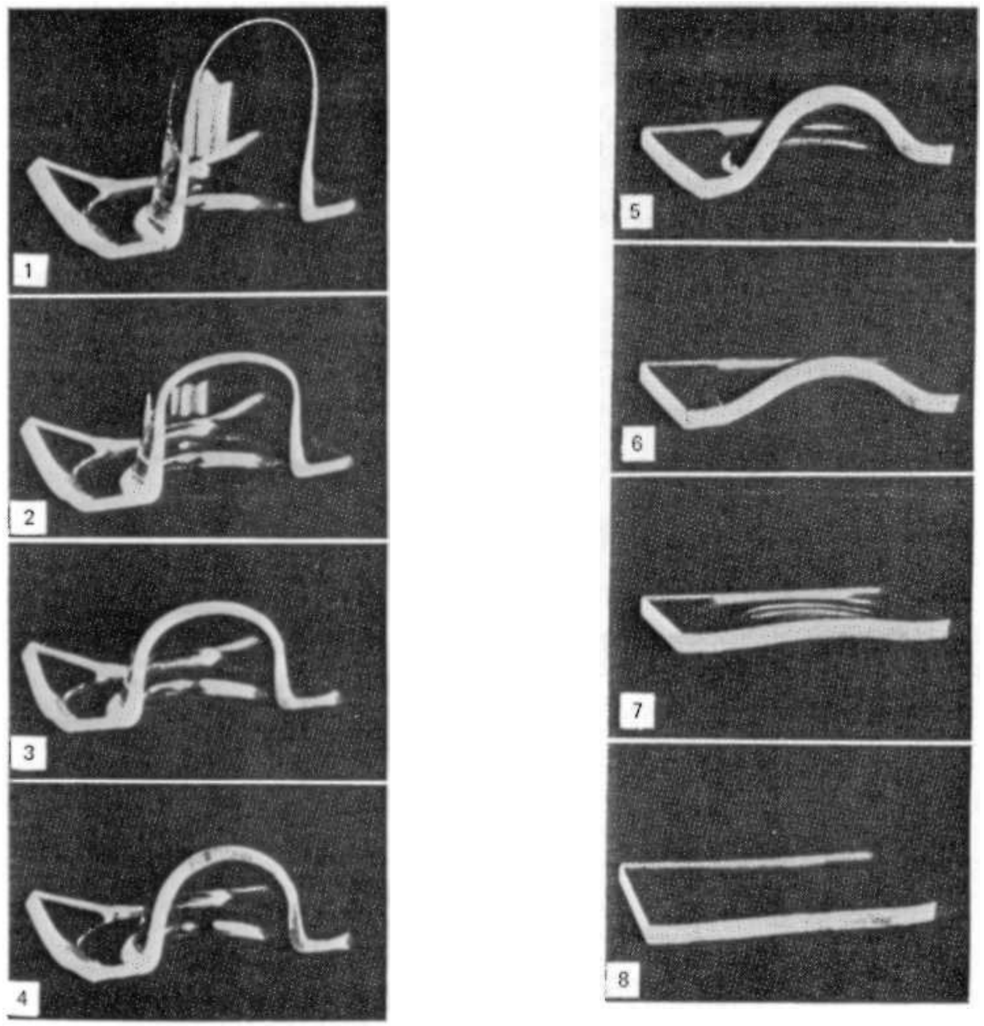
Plug-assist Pressure Forming



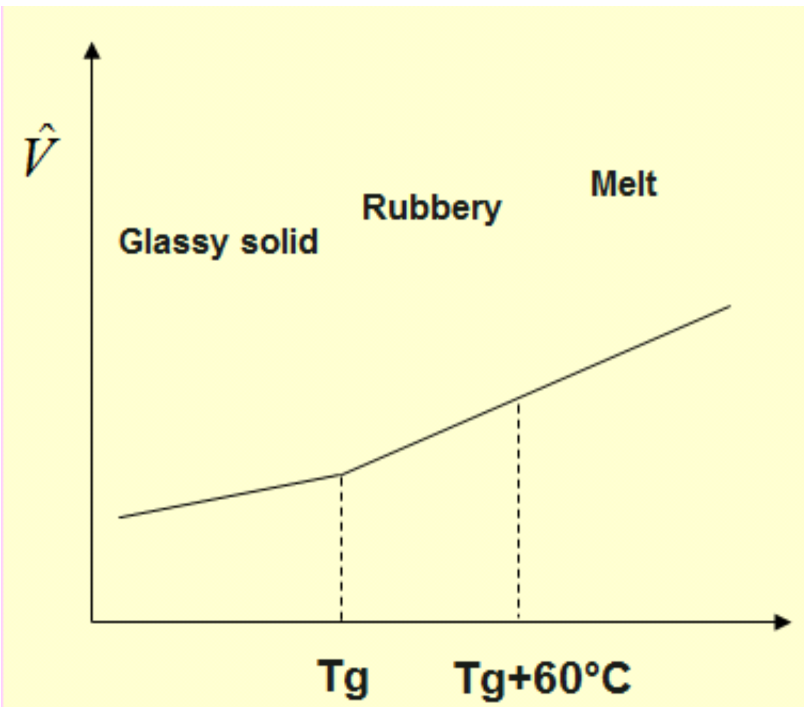
A: preheated sheet prior to forming
B: sheet stretched with mechanical plug advance
C: sheet air-pressure formed into female mold

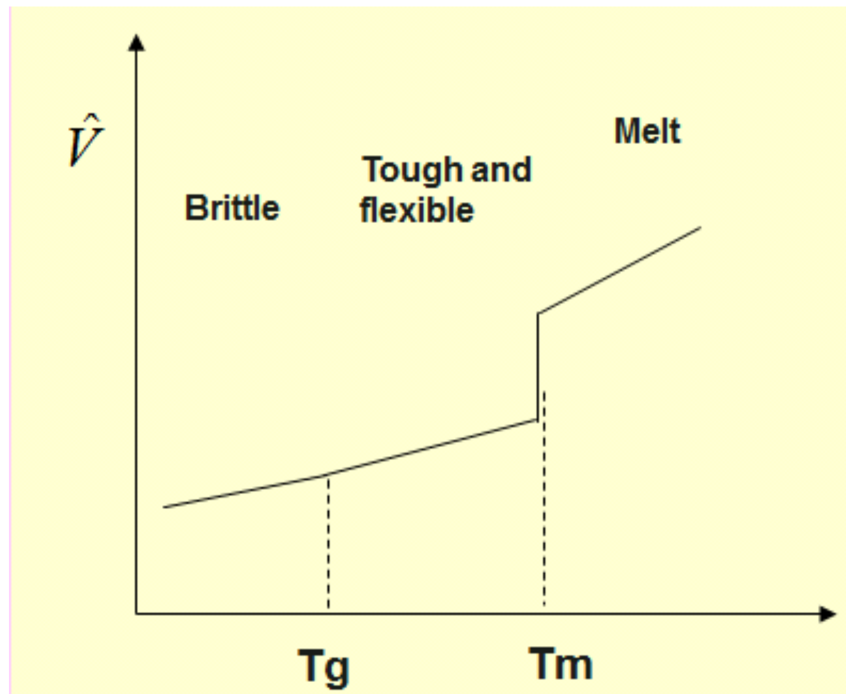
a - pressure box
b - plug
c - preheated, clamped sheet
d - female mode with vent holes
e - moving plug
f - applied air pressure
g - venting air

Forming Mechanism



Forming Considerations: Shrinkage
Amorphous vs. Crystalline

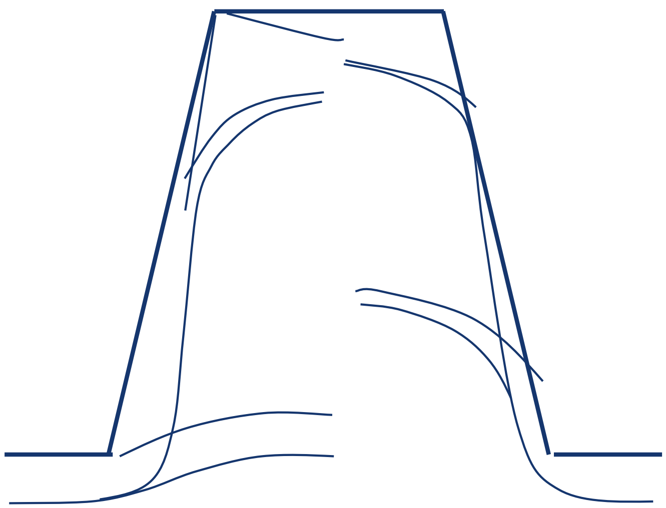


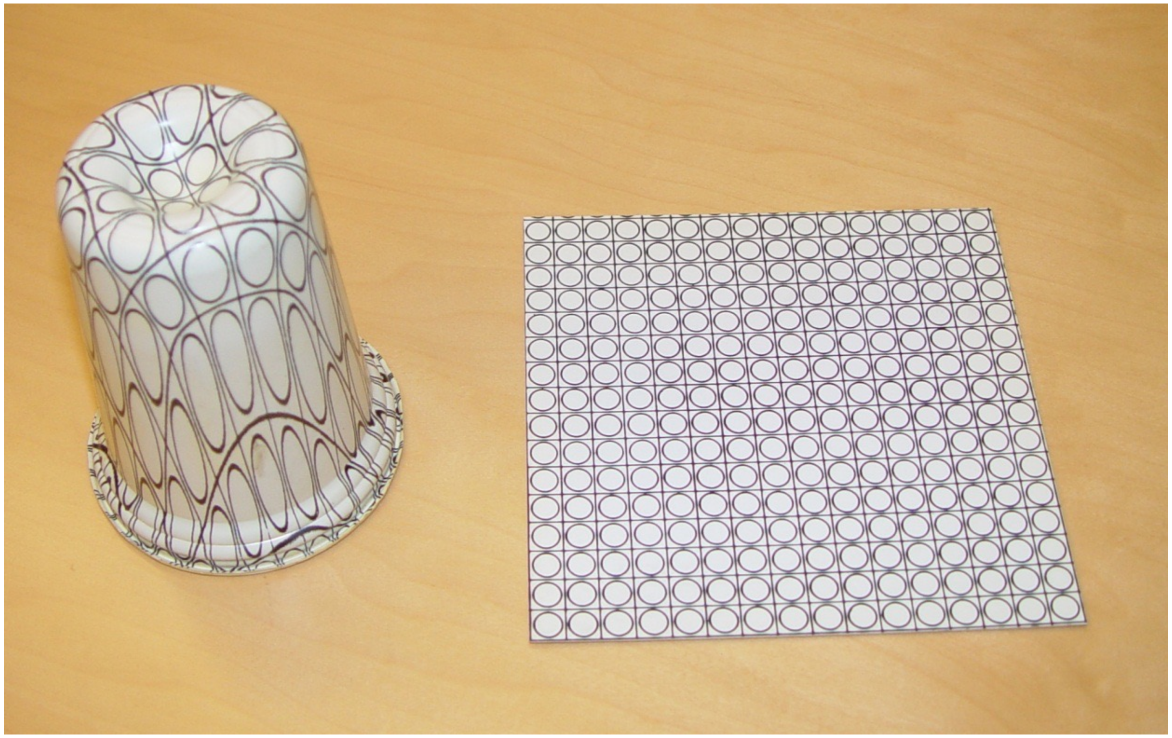


Temperature

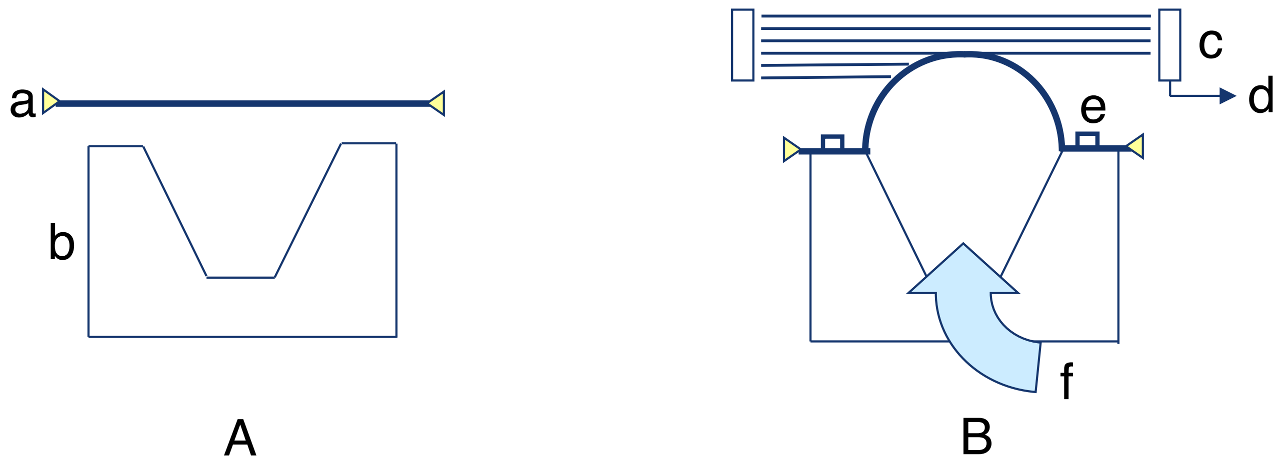
Temperature

Forming Considerations: Part Thickness





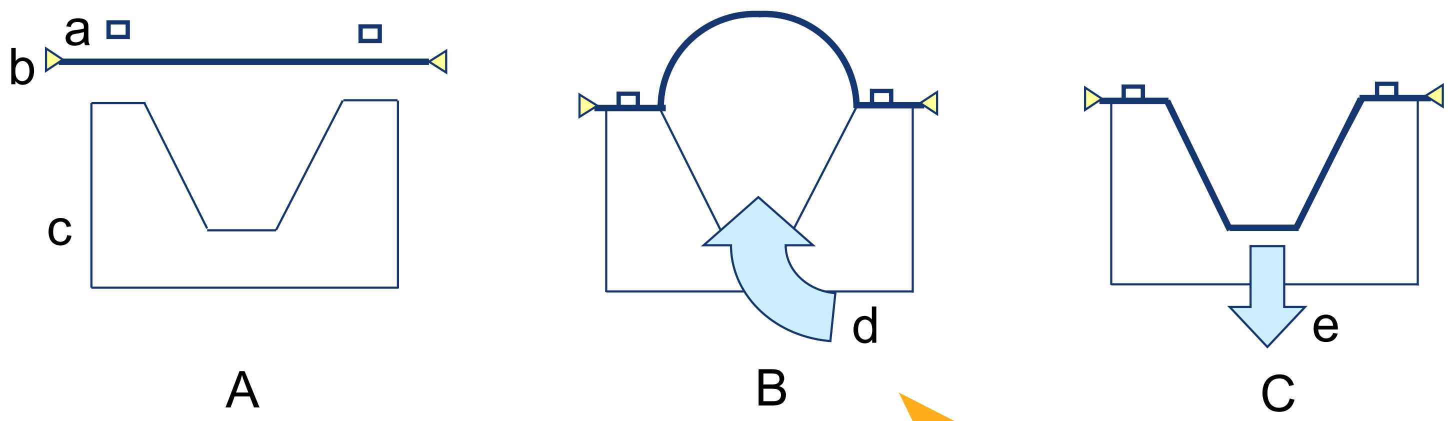
Free Blowing



A: preheated sheet prior to forming
B: free-blown sheet: bubble height determined by photocell monitor.

a - preheated clamped sheet
b - pressure box
c - proportional photocell monitor
d - signal to air pressure
e - hold-down ring
f - air pressure

Billow Vacuum Forming

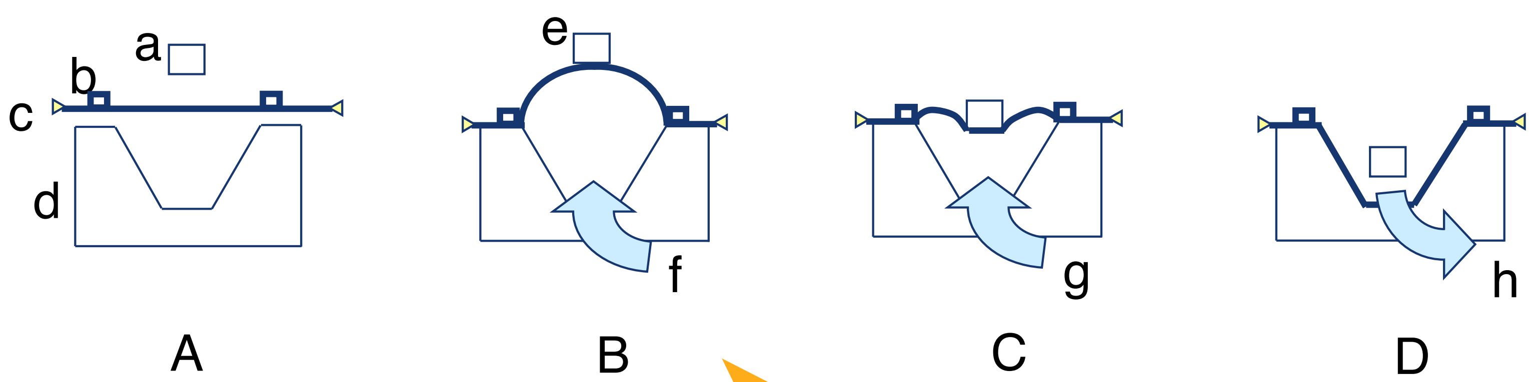


A: preheated sheet prior to forming
B: sheet prestretched with air pres
C: sheet vacuum formed into fema

- Better thickness uniformity
- Deep draw
- Longer cycle time

a - hold down ring b - preheated clamped sheet
c - female mold with pressure/vacuum holes,
d - applied pressure e - vacuum

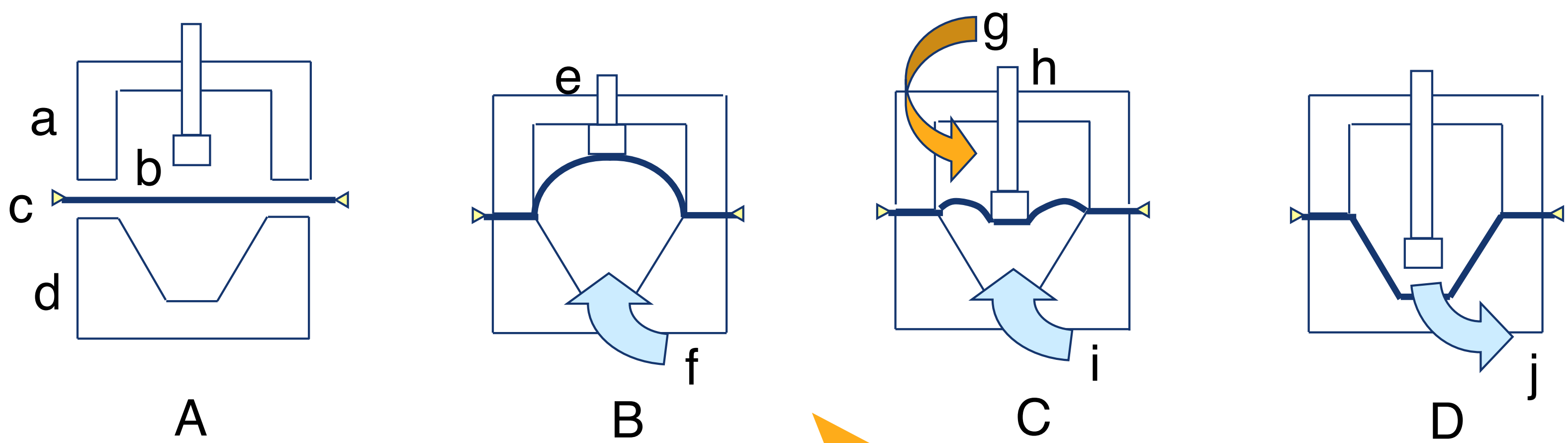
Vacuum Reverse Draw with Plug-assist



- Better thickness uniformity
- Deep draw
- Longer cycle time

A: preheated sheet prior to formin
B: formation of bubble
C: plug moves into billow, air pres
D: vacuum applied pulling sheet i
a) plug, b) hold-down ring, c) preheated, clamped sheet, d) female mold, e) plug motion activated when bubble touches it, f) applied air pressure, g) continuing air pressure as plug advances, h) vacuum

Pressure Reverse Draw with Plug-assist

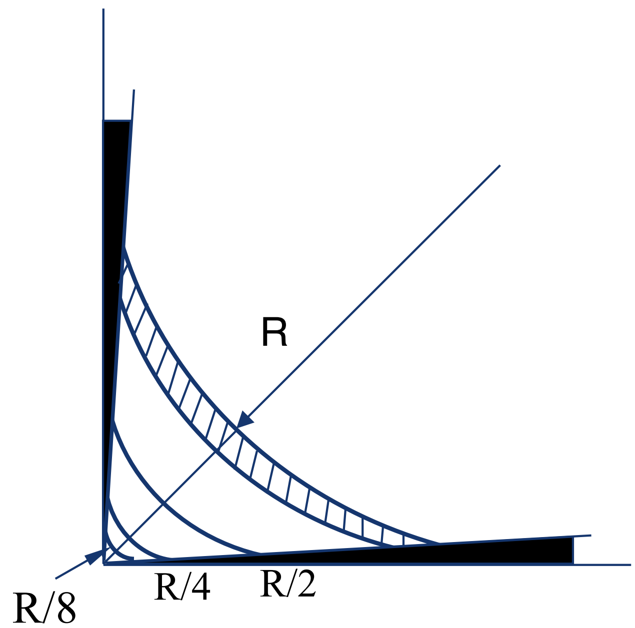


A: preheated sheet prior to forming
B: sheet prestretched into bubble
C: plug moves into sheet while ai
D: sheet vacuum formed into fem

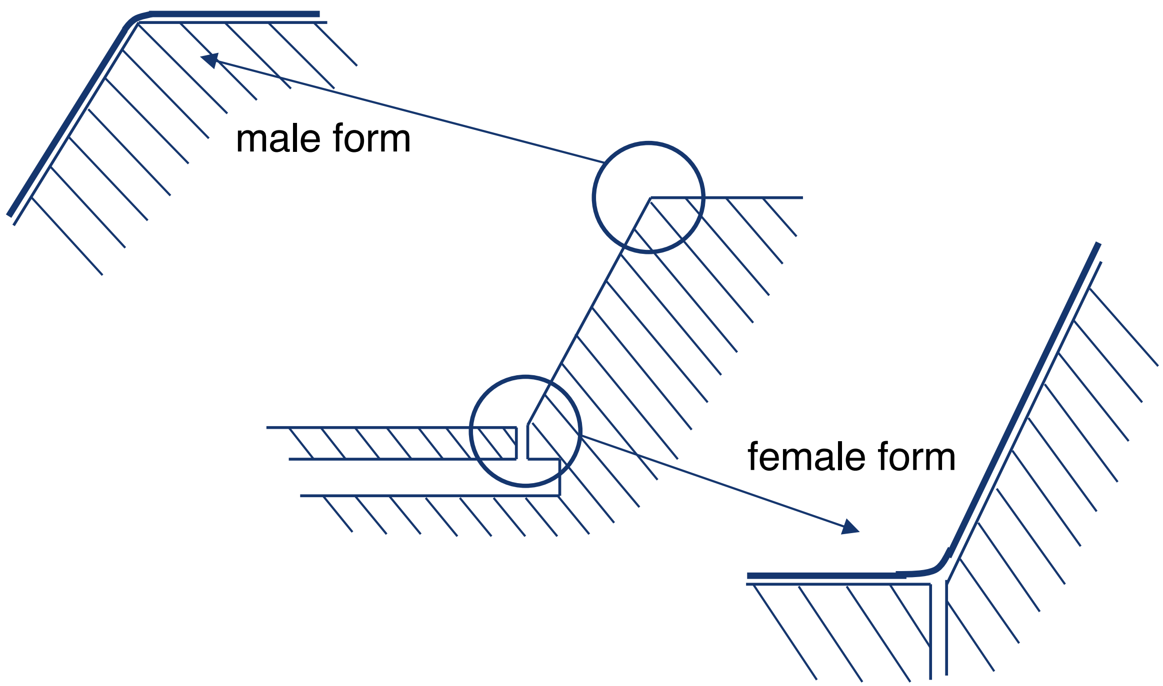
- Better thickness uniformity
- Deep draw
- Longer cycle time

a) pressure box, b) plug, c) preheated, clamped, sheet, d) female mold with air pressure/vacuum holes, e) plug begins to move when billow touches it, f) applied air pressure, g) air pressure, h) plug moving into billow, i) continuing air pressure, j) vacuum

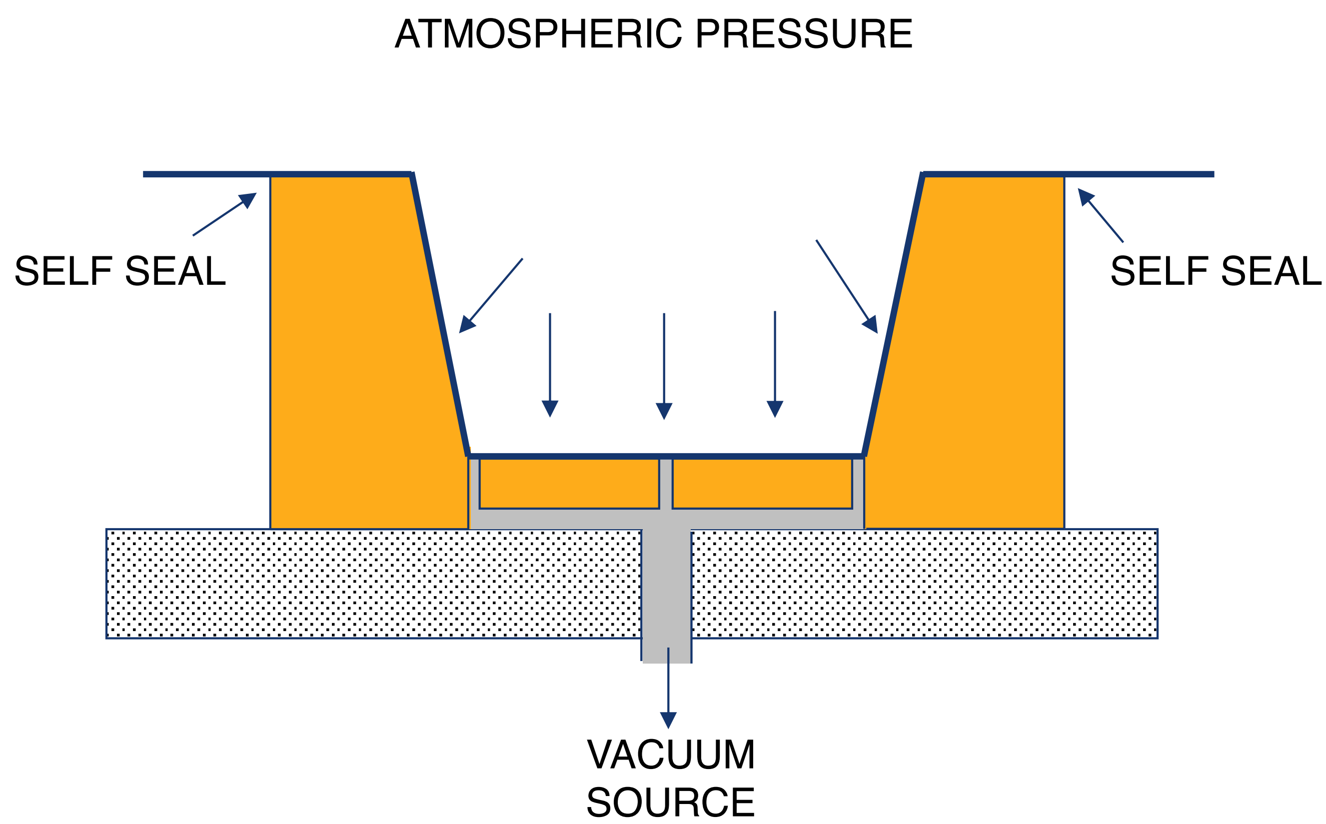
Forming Considerations: Progressive Draw-Down



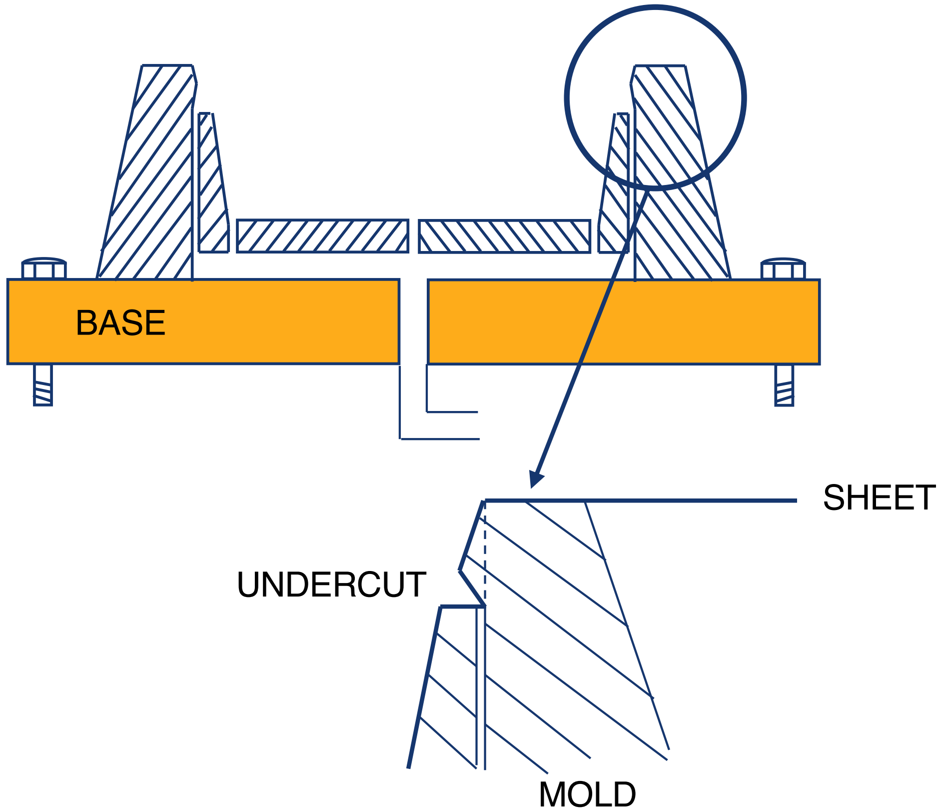
Forming Considerations: Detail Loss



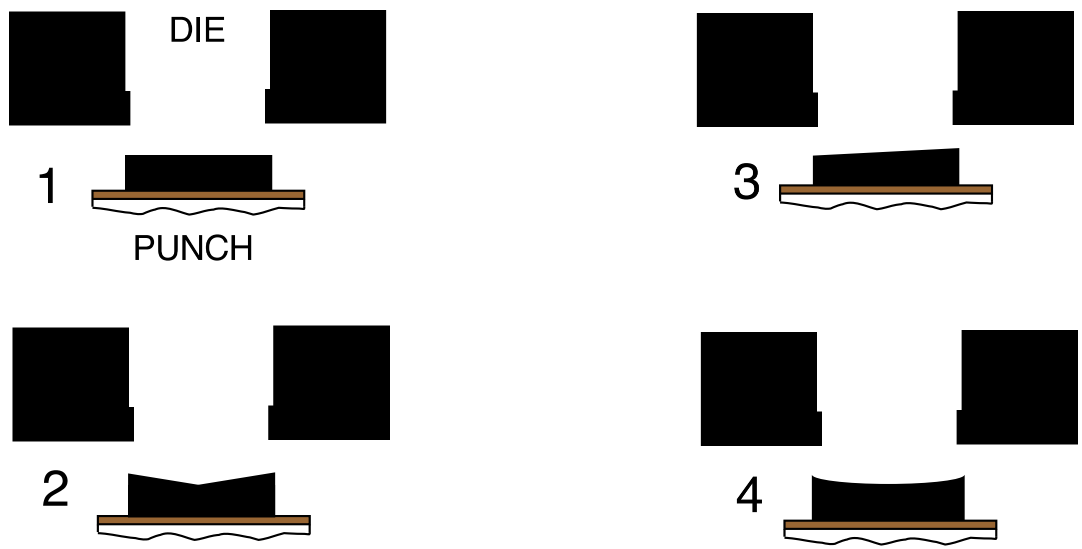
Forming Considerations: Vacuum holes



Forming Considerations: Undercut



Trim



Design for Thermoforming

- Uniform thickness (~10%)
- Simpler shapes (avoid under cuts, etc.)
- Rounded corners (1t min, 4t ideal)
- Draft angle for removal (.5 – 5 degree)
- Depth of draw ratio (< 1:1)
- Stretch ratio (< 2:1)
- Shrinkage
- Design for holes and trim lines

Cost - Thermoforming

- Initial Cost
  - Equipment cost is low to moderate, but can be high if automated
  - Tooling cost is low to moderate depending on the complexity
- Variable Cost
  - Labor cost is low to moderate
  - Moderate to low material utilization : unformed part of the sheet are lost

Rate - Thermoforming

- Cycle time
  - Shorter than melting process : 10 to 60 seconds
- Production rate
  - Usually very fast : but vary with batch size

Quality - Thermoforming

- Dimensional
  - Affected by viscoelastic spring back : rate of change affects spring back
  - Shrinkage
  - Surface finish is good and related to the condition of mold surface
- Mechanical Property
  - Good toughness : orientation related
- Defects
  - Corners tend to become excessively thinner : pre-stretch in opposite direction and apply pressure

Flexibility - Thermoforming

Moderate : Die needs to be changed

Other Thermoplastic Polymer Processes

- Blow Molding
- Insert Molding
- Overmolding
- Reaction Injection Molding
- Casting
- Compression Molding

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