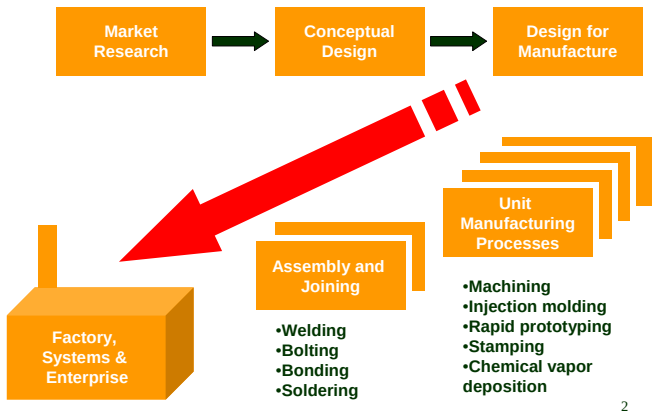
Thermoforming Process

(Vacuum Forming Process)

1

Manufacture



2

Outline

- Overview
- Process Steps
- Process Equipment
- Design for Manufacturing

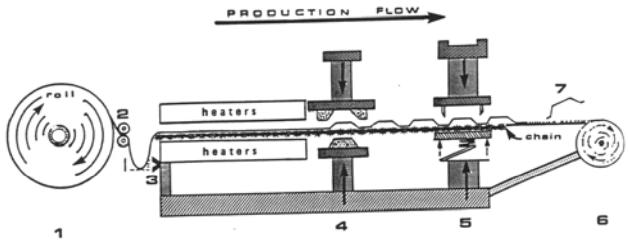
3

Overview

- Polymers
  thermoplastic
- Applications
  packaging, container, housing, etc.
- Materials
  ABS (~15%), PMMA (~15%), PS (~20%)

4

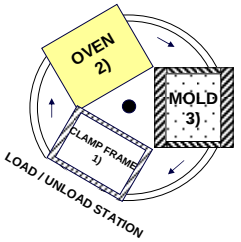
Typical Production Flow: In-line Arrangement



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

5

Three-station Thermoforming Machine



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

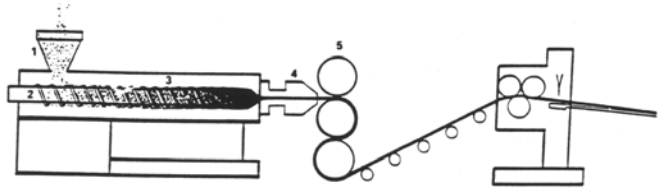
6

Processing Steps

- Sheet
- Heat
- Form
- Cool
- Trim

7

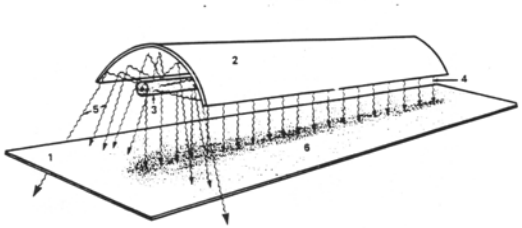
Plastic Sheet Making: Extrusion



1. feed hopper
2. extruder screw
3. extruder barrel
4. die
5. roller stack

8

Heating Methods: 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

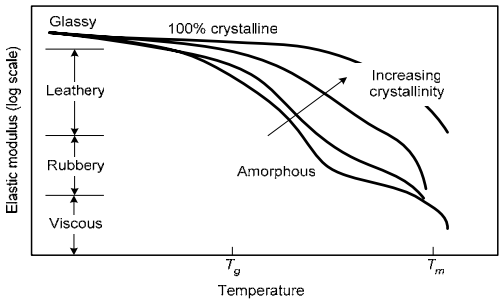
9

Other Heating Methods

- Convection Heating
- Contact Heating

10

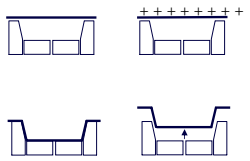
Polymers Amorphous vs Semicrystalline



11

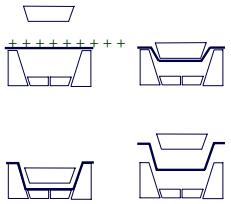
Forming: Vacuum or Pressure

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



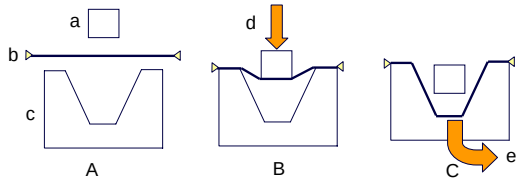
12

Forming: Match Mold



13

Plug-assist Vacuum Forming

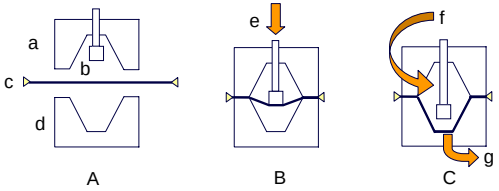


A: preheated sheet prior to forming
B: sheet stretched with moving plug
C: sheet vacuum formed into female cavity

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

14

Plug-assist Pressure Forming

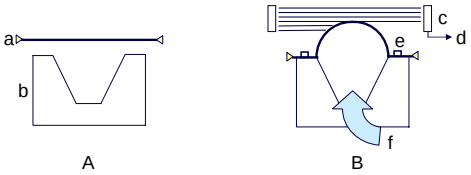


A: preheated sheet prior to forming
B: sheet stretched with mechanical plug advance
C: sheet air-pressure formed into female mold

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

15

Free Blowing

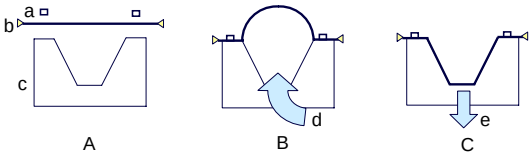


A: preheated sheet prior to forming
B: free-blown sheet: bubble height determined by photocell monitor.

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

16

Billow Vacuum Forming

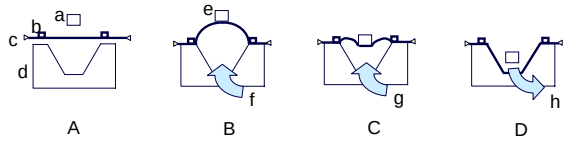


A: preheated sheet prior to forming
B: sheet prestretched with air press
C: sheet vacuum formed into fema

- Better thickness uniformity
- Deep draw
- Longer cycle time

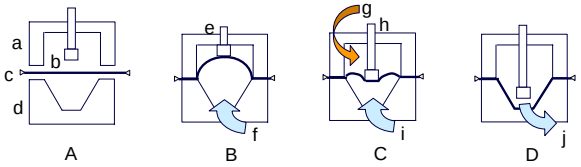
a - hold down ring b - preheated clamped sheet
c - female mold with pressure/vacuum holes,
d - applied pressure e - vacuum

Vacuum Reverse Draw with Plug-assist



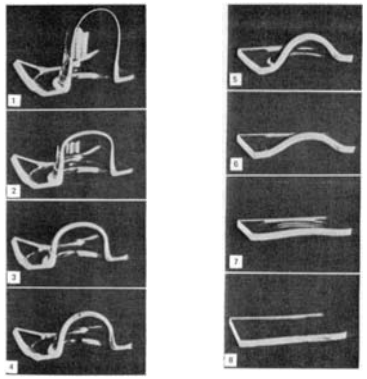
A: preheated sheet prior to forming
B: formation of bubble
C: plug moves into billow, air pressure continues
D: vacuum applied pulling sheet into female mold
a) plug, b) hold-down ring, c) preheated, clamped sheet, d) female mold, e) plug motion activated when bubble touches it, f) applied air pressure,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

Pressure Reverse Draw with Plug-assist

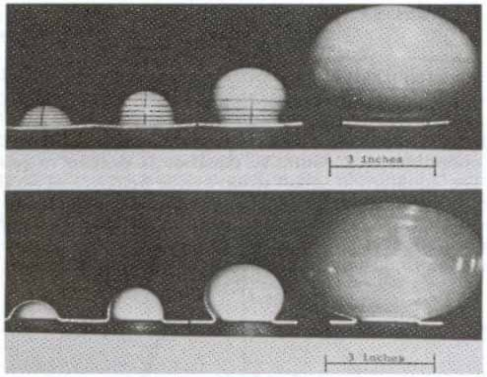


A: preheated sheet prior to forming
B: sheet prestretched into bubble with air pressure
C: plug moves into sheet while air pressure still on
D: sheet vacuum formed into female mold
a) pressure box, b) plug, c) preheated, clamped, sheet, d) female mold with air pressure/vacuum holes, e) plug begins to move when billow touches it, f) applied air pressure, g) air pressure, h) plug moving into billow, i) continuing air pressure, j) vacuum

Forming Mechanism



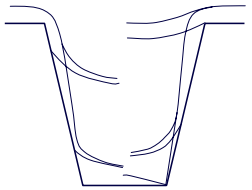
Thickness Uniformity



21

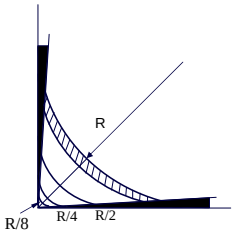
Forming Considerations: Part Thickness

- Draw ratio
  - depth of part / width of part
- Draw ratio should be less than
  - 2:1 for female molds
  - 7:1 for male mold
- Area ration for blank sheet size estimation
- Draft angle : .5 to 5 degree



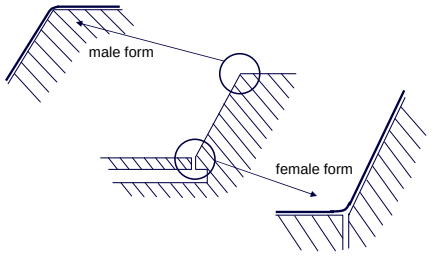
22

Forming Considerations: Progressive Draw-Down



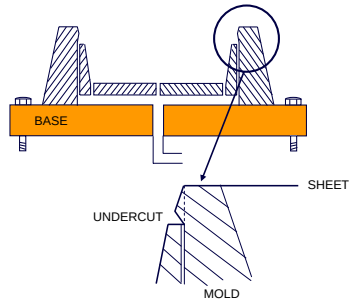
23

Forming Considerations: Detail Loss



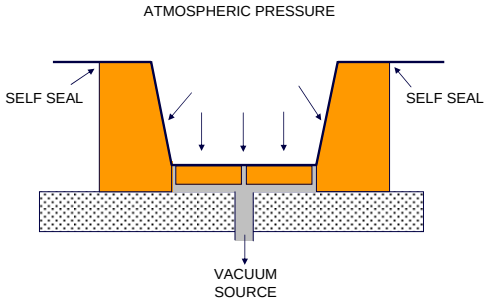
24

Forming Considerations: Undercut



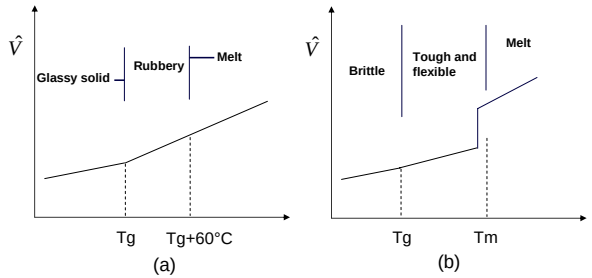
25

Forming Considerations: Vacuum holes



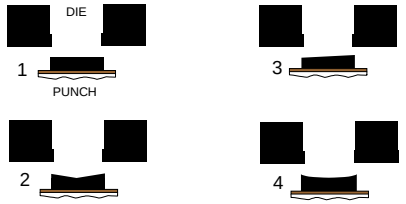
26

Cooling Amorphous vs Semicrystalline



27

Trim



Punch and die trim tools with different types of punches
1. broad punch 2. shearing punch
3. double-angle shearing punch
4. hollow-ground punch

28

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

29

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

30

Rate - Thermoforming

- Development time
  - Die design time : a few days to weeks
- Cycle time
  - Shorter than melting process : 10 to 60 seconds
- Production rate
  - Usually very fast : but vary with batch size

31

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

32

Flexibility - Thermoforming

Moderate : Die needs to be changed

33