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Two Types - Polymer Melts



- Thermoplastics
  - Chemical structure remains unchanged during heating and shaping
  - More important commercially, comprising more than 70% of total plastics tonnage.
  - To shape a thermoplastic polymer it must be heated so that it softens to the consistency of a liquid
    - In this form, it is called a polymer melt
    - Important properties of polymer melts:
      - Viscosity
      - Viscoelasticity
- Thermosets
  - Undergo a curing process during heating and shaping, causing a permanent change (cross-linking) in molecular structure
  - Once cured, they cannot be remelted

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Short History of Polymers

- 1862 - First synthetic plastic
- 1866 - Celluloid
- 1891 - Rayon
- 1907 - Bakelite
- 1913 - Cellophane
- 1926 - PVC
- 1933 - Polyethylene
- 1938 - Teflon
- 1957 - Velcro

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Classification of Shaping Processes

- Extruded products with constant cross-section
- Continuous sheets and films
- Continuous filaments (fibers)
- Molded parts that are mostly solid
- Hollow molded parts with relatively thin walls
- Discrete parts made of formed sheets and films
- Castings
- Foamed products

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Short History of Polymers



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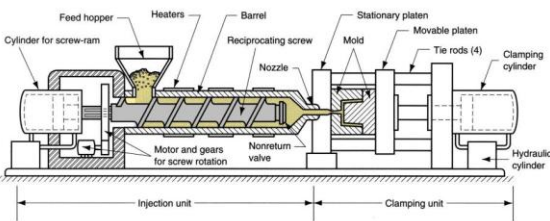


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Polymer Injection Moulding

Injection Moulding machine



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Polymer Injection Moulding

- Many parts previously made of metals are now being made of plastics
- Plastic containers have been largely substituted for glass bottles and jars
- Total volume of polymers (plastics and rubbers) now exceeds metals
- Almost unlimited variety of part geometries
- Plastic molding is a *net shape* proces - Further shaping is not needed



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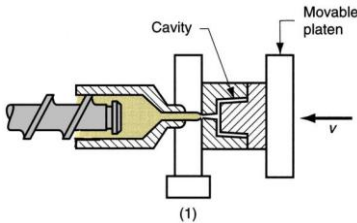
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Polymer Injection Moulding

- Typical molding cycle; Step 1 - Mould is closed



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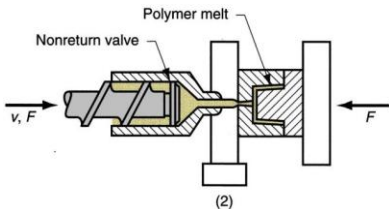
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Polymer Injection Moulding

- Typical molding cycle; Step 2 - Melt is injected into cavity.



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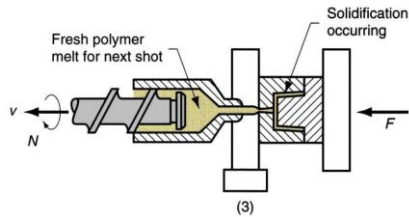
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Polymer Injection Moulding

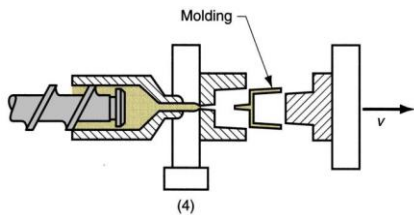
- Typical molding cycle; Step 3 - Screw is retracted.



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Polymer Injection Moulding

- Typical molding cycle; Step 4 - Mould opens and part is ejected.



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Text

Text

- The special tool in injection moulding
- Custom-designed and fabricated for the part to be produced
- When production run is finished, the mould is replaced with a new mould for the next part
- Various types of mould for injection molding:
  - Two-plate mould
  - Three-plate mould
  - Hot-runner mould

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**Polymer Injection Moulding – Shrinkage**

What factors affect the shrinkage of parts?

- Fillers in the plastic tend to reduce shrinkage
- Injection pressure – higher pressures force more material into mold cavity to reduce shrinkage
- Compaction time - similar effect – longer time forces more material into cavity to reduce shrinkage
- Molding temperature - higher temperatures lower polymer melt viscosity, allowing more material to be packed into mold to reduce shrinkage



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**Polymer Injection Moulding**

Process

- Injection molding machines differ in both injection unit and clamping unit
- Name of injection molding machine is based on the type of injection unit used
  - Reciprocating-screw injection molding machine
  - Plunger-type injection molding machine
- Several clamping designs
  - Mechanical (toggle)
  - Hydraulic



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**Polymer Injection Moulding – Melt Temperature**

- Why is melt temperature critical? It affects;
  - Part dimensional accuracy, repeatability and reproducibility (shrinkage and warping)
  - Surface quality
  - Part robustness
- What factors affect melt temperature?
  - Barrel temperature settings
  - Screw speed and Screw back pressure
  - Residence time
  - Cycle time
  - Material Condition



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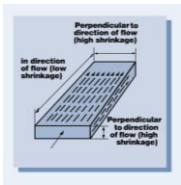
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Polymer Injection Moulding - Shrinkage

- Reduction in linear size during cooling from molding to room temperature
- Polymers have high thermal expansion coefficients, so significant shrinkage occurs during solidification and cooling in mold
- Typical shrinkage values:

| Plastic      | Shrinkage, mm/mm |
|--------------|------------------|
| Nylon 6.6    | 0.020            |
| Polyethylene | 0.025            |
| Polystyrene  | 0.004            |
| PVC          | 0.005            |



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Polymer Injection Moulding – Shrinkage

Text

- Dimensions of mold cavity must be larger than specified part dimensions:
- $D_c = D_p + D_p S + D_p S^2$ 
  - where  $D_c$  = dimension of cavity;  $D_p$  = molded part dimension, and  $S$  = shrinkage value
- Third term on right hand side corrects for shrinkage in the shrinkage

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Thermoplastic Foam Injection Molding

Molding of thermoplastic parts that possess dense outer skin surrounding lightweight foam center.

- Part has high stiffness-to-weight ratio suited to structural applications
- Produced either by introducing a gas into molten plastic in injection unit or by mixing a gas-producing ingredient with starting pellets
- A small amount of melt is injected into mold cavity, where it expands to fill cavity
- Foam in contact with cold mold surface collapses to form dense skin, while core retains cellular structure

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Thermoplastic Foam Injection Molding

Can you think of some applications of this process?

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Injection Moulding of Thermosets

- Equipment and operating procedure must be modified to avoid premature cross-linking of thermoset polymer
  - Reciprocating-screw injection unit with shorter barrel length
- Temperatures in barrel are relatively low
- Melt is injected into a heated mould, where cross-linking occurs to cure the plastic
  - Curing in the mold is the most time-consuming step in the cycle
- Mould is then opened and part is removed

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Compression Moulding

A widely used moulding process for thermosetting plastics

- Also used for rubber tires and polymer matrix composite parts
- Moulding compound available in several forms: powders or pellets, liquid, or preform
- Amount of charge must be precisely controlled to obtain repeatable consistency in the moulded product

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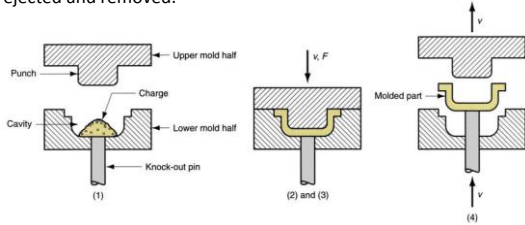
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Compression Moulding

Compression moulding for thermosetting plastics; (1) Charge is loaded, (2) and (3) charge is compressed and cured, and (4) part is ejected and removed.



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Molds for Compression Molding

- Simpler than injection molds
- No sprue and runner system in a compression mold
- Process itself generally limited to simpler part geometries due to lower flow capabilities of TS materials
- Mold must be heated, usually by electric resistance, steam, or hot oil circulation
- Molding materials:
  - Phenolics, melamine, urea-formaldehyde, epoxies, urethanes, and elastomers
- Typical compression-molded products:
  - Electric plugs, sockets, and housings; pot handles, and dinnerware plates

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Transfer Molding

- Thermoset charge is loaded into a chamber immediately ahead of mould cavity, where it is heated; pressure is then applied to force soft polymer to flow into heated mould where it cures
- Two variants:
  - Pot transfer moulding - charge is injected from a "pot" through a vertical sprue channel into cavity
  - Plunger transfer moulding - plunger injects charge from a heated well through channels into cavity

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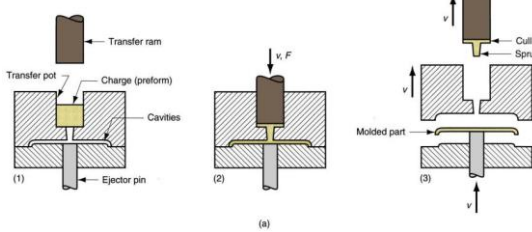
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Pot Transfer Molding

Pot transfer moulding: (1) charge is loaded into pot, (2) softened polymer is pressed into mold cavity and cured, and (3) part is ejected.



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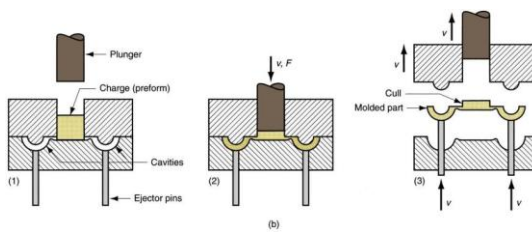
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Plunger Transfer Molding

Plunger transfer moulding: (1) charge is loaded into pot, (2) softened polymer is pressed into mold cavity and cured, and (3) part is ejected.



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Compression vs. Transfer Moulding

- In both processes, scrap is produced each cycle as leftover material, called the cull
- The Thermoset scrap cannot be recovered
- Transfer moulding is capable of moulding more intricate part shapes than compression moulding but not as intricate as injection moulding
- Transfer moulding lends itself to moulding with inserts, in which a metal or ceramic insert is placed into cavity prior to injection, and the plastic bonds to insert during moulding

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Blow Moulding

Moulding process in which air pressure is used to inflate soft plastic into a mould cavity

- Important for making one-piece hollow plastic parts with thin walls, such as bottles
- Because these items are used for consumer beverages in mass markets, production is typically organized for very high quantities
- Accomplished in two steps:
  1. Fabrication of a starting tube, called a parison
  2. Inflation of the tube to desired final shape
- Forming the parison is accomplished by either
  - Extrusion or
  - Injection moulding



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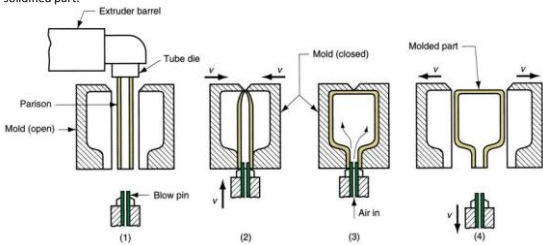
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Extrusion Blow Moulding

Extrusion blow moulding: (1) extrusion of parison; (2) parison is pinched at the top and sealed at the bottom around a metal blow pin as the two halves of the mould come together; (3) the tube is inflated so that it takes the shape of the mould cavity; and (4) mould is opened to remove the solidified part.



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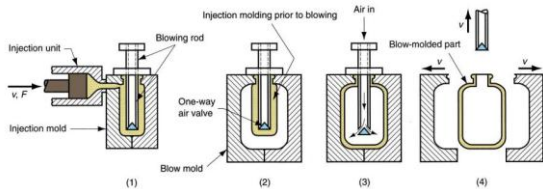
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Injection Blow Moulding

Injection blow moulding: (1) parison is injected moulded around a blowing rod; (2) injection mould is opened and parison is transferred to a blow mould; (3) soft polymer is inflated to conform to the blow mould; and (4) blow mould is opened and blown product is removed.



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Materials and Products in Blow Moulding

- Blow molding is limited to thermoplastics
- Materials: high density polyethylene, polypropylene (PP), polyvinylchloride (PVC), and polyethylene terephthalate
- Products: disposable containers for beverages and other liquid consumer goods, large shipping drums (55 gallon) for liquids and powders, large storage tanks (2000 gallon), gasoline tanks, toys, and hulls for sail boards and small boats

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Thermoforming

Flat thermoplastic sheet or film is heated and deformed into desired shape using a mould

- Heating usually accomplished by radiant electric heaters located on one or both sides of starting plastic sheet or film
- Widely used in packaging of products and to fabricate large items such as bathtubs, contoured skylights, and internal door liners for refrigerators

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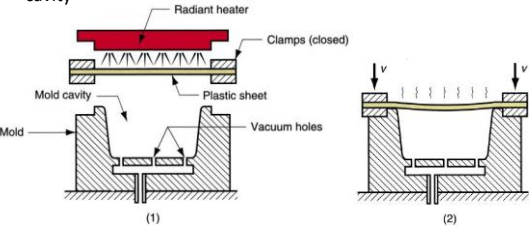
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Vacuum Thermoforming

- Vacuum thermoforming: (1) a flat plastic sheet is softened by heating (2) the softened sheet is placed over a concave mold cavity



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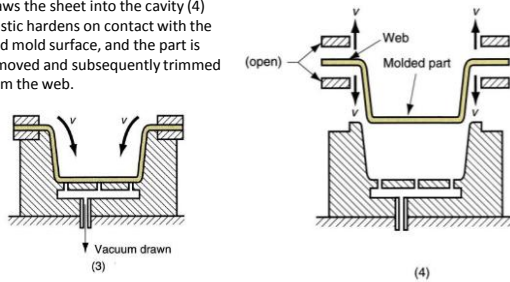
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Vacuum Thermoforming

Vacuum thermoforming: (3) a vacuum draws the sheet into the cavity (4) plastic hardens on contact with the cold mold surface, and the part is removed and subsequently trimmed from the web.



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Negative Molds vs. Positive Molds

Negative mold has concave cavity  
Positive mold has convex shape

- Both types are used in thermoforming
- For positive mold, heated sheet is draped over convex form and negative or positive pressure forces plastic against mold surface

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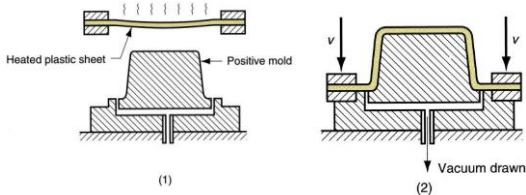
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Vacuum Thermoforming - Positive Molds

- Use of a positive mold in vacuum thermoforming: (1) The heated plastic sheet is positioned above the convex mold. (2) The clamp is lowered into position, draping the sheet over the mold as a vacuum forces the sheet against the mold surface



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Materials for Thermoforming

- Only thermoplastics can be thermoformed,
  - Extruded sheets of thermosetting or elastomeric polymers have already been cross-linked and cannot be softened by reheating
- Common Thermoplastic polymers: polystyrene, cellulose acetate, cellulose acetate butyrate, ABS, PVC, acrylic (polymethylmethacrylate), polyethylene, and polypropylene



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Applications of Thermoforming

- Thin films: blister packs and skin packs for packaging commodity products such as cosmetics, toiletries, small tools, and fasteners (nails, screws, etc.)
  - For best efficiency, filling process to containerize item(s) is immediately downstream from thermoforming
- Thicker sheet stock: boat hulls, shower stalls, advertising displays and signs, bathtubs, certain toys, contoured skylights, internal door liners for refrigerators



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Polymer Casting

Pouring liquid resin into a mold, using gravity to fill cavity, where polymer hardens

- Both thermoplastics and thermosets are cast;
  - Thermoplastics: acrylics, polystyrene, polyamides (nylons) and PVC
  - Thermosetting polymers: polyurethane, unsaturated polyesters, phenolics, and epoxies
- Simpler mold
- Suited to low quantities



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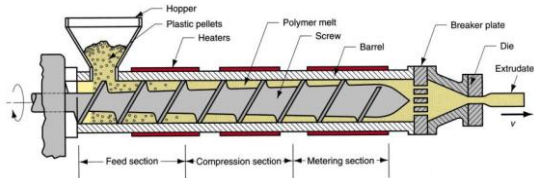
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Extrusion Moulding

- Components and features of a (single-screw) extruder for plastics and elastomers. Main components;
  - Barrel
  - Screw
  - Die – Tool that must be fabricated for particular profile to be produced



Extrusion Moulding – Extruder Screw

- Progress of polymer melt through barrel leads ultimately to the die zone
- Before reaching die, the melt passes through a screen pack - series of wire meshes supported by a stiff plate containing small axial holes
- Functions of screen pack:
  - Filter out contaminants and hard lumps
  - Build pressure in metering section
  - Straighten flow of polymer melt and remove its "memory" of circular motion from screw

Extrusion Moulding

- Divided into sections to serve several functions:
  - Feed section - feedstock is moved from hopper and preheated.
  - Compression section - polymer is transformed into fluid, air mixed with pellets is extracted from melt, and material is compressed.
  - Metering section - melt is homogenized and sufficient pressure developed to pump it through die opening



Extrusion Moulding – Extruder Screw

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Extrusion Moulding – Extruder Screw

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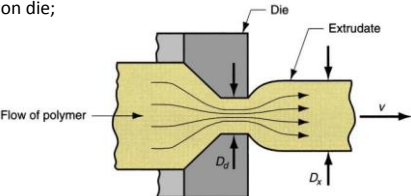
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Extrusion Moulding – Die Swell

- Extruded polymer "remembers" its previous shape when in the larger cross section of the extruder, tries to return to it after leaving the die orifice. Die swell, a manifestation of viscoelasticity in polymer melts, as depicted here on exiting an extrusion die;



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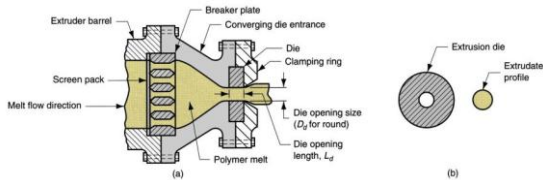
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Extrusion Moulding – Solid profiles

- Side view cross-section of an extrusion die for solid regular shapes, such as round stock; (b) front view of die, with profile of extrudate. Die swell is evident in both views



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Extrusion Moulding – Hollow profiles

- Examples: tubes, pipes, hoses, and other cross-sections containing holes
- Hollow profiles require mandrel to form the shape
- Mandrel held in place using a spider
  - Polymer melt flows around legs supporting the mandrel to reunite into a monolithic tube wall
- Mandrel often includes an air channel through which air is blown to maintain hollow form of extrudate during hardening

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Polymer Sheet and Film

- Film - thickness below 0.5 mm (0.020 in.)
  - Packaging - product wrapping material, grocery bags, garbage bags
  - Stock for photographic film
  - Pool covers and liners for irrigation ditches
- Sheet - thickness from 0.5 mm to about 12.5 mm
  - Flat window glazing
  - Thermoforming stock
- Materials, all thermoplastic polymers
  - Polyethylene, mostly low density PE
  - Polypropylene
  - Polyvinylchloride
  - Cellophane

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Polymer Sheet and Film Processing

- Most widely used processes are continuous, high production operations
- Processes include:
  - Slit-Die Extrusion of Sheet and Film
  - Blown-Film Extrusion Process
  - Calendering

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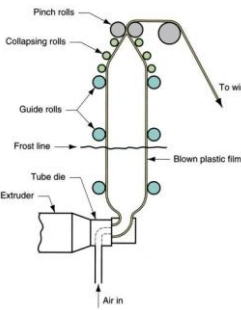
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Blown-Film Extrusion Process



- Combines extrusion and blowing to produce a tube of thin film.
- Process;
  - Extrusion of tube
  - Tube is drawn upward while still molten and simultaneously expanded by air inflated into it through die
  - Air is blown into tube to maintain uniform film thickness and tube diameter

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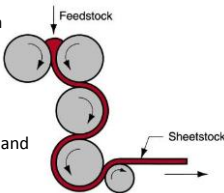
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Calendering

- Feedstock is passed through a series of rolls to reduce thickness to desired gage
- Expensive equipment, high production rates
- Process is noted for good surface finish and high gage accuracy
- Typical materials: rubber or rubbery thermoplastics such as plasticized PVC
- Products: PVC floor covering, shower curtains, vinyl table cloths, pool liners, and inflatable boats and toys



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Polymer Sheet and Film Processing

- Most widely used processes are continuous, high production operations
- Processes include:
  - Slit-Die Extrusion of Sheet and Film
  - Blown-Film Extrusion Process
  - Calendering

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Manufacturing Technology



General Product Design Guidelines

- Strength and stiffness
  - Plastics are not as strong or stiff as metals
  - Avoid applications where high stresses will be encountered
  - Creep resistance is also a limitation
  - Strength-to-weight ratios for some plastics are competitive with metals in certain applications
- Impact Resistance
  - Capacity of plastics to absorb impact is generally good; plastics compare favorably with most metals
- Service temperatures
  - Limited relative to metals and ceramics

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Manufacturing Technology



General Product Design Guidelines

- Thermal expansion
  - Dimensional changes due to temperature changes much more significant than for metals
- Many plastics are subject to degradation from sunlight and other forms of radiation
- Some plastics degrade in oxygen and ozone atmospheres
- Plastics are soluble in many common solvents
- Plastics are resistant to conventional corrosion mechanisms that afflict many metals

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General Product Design Guidelines

- Wall thickness
  - Uniform wall thickness is desirable in an extruded cross section
  - Variations in wall thickness result in non-uniform plastic flow and uneven cooling which tend to warp extrudate
- Hollow sections
  - Hollow sections complicate die design and plastic flow
  - Desirable to use extruded cross-sections that are not hollow yet satisfy functional requirements
- Corners
  - Sharp corners, inside and outside, should be avoided in extruded cross sections
  - They result in uneven flow during processing and stress concentrations in the final product



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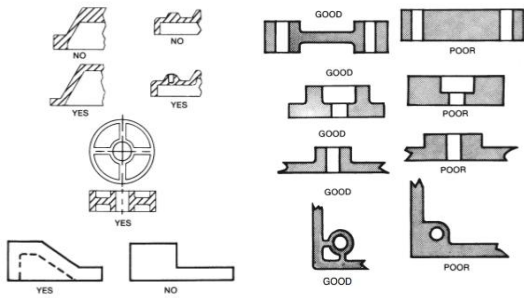
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General Product Design Guidelines



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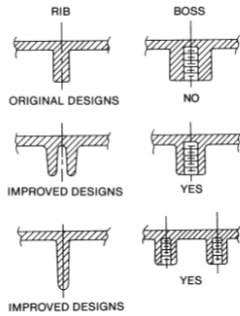
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General Product Design Guidelines



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General Product Design Guidelines

- Economic production quantities
  - Each part requires a unique mold, and the mold for any molding process can be costly, particularly for injection molding
  - Minimum production quantities for injection molding are usually around 10,000 pieces
  - For compression molding, minimum quantities are ~1000 parts, due to simpler mold designs
  - Transfer molding lies between injection molding and compression molding
- Wall thickness
  - Thick cross sections are wasteful of material, more likely to cause warping due to shrinkage, and take longer to harden



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General Product Design Guidelines

- Part complexity
  - An advantage of plastic molding is that it allows multiple functional features to be combined into one part
  - Although more complex part geometries mean more costly molds, it may nevertheless be economical to design a complex molding if the alternative involves many individual components that must be assembled.
- Reinforcing rib
  - Achieves increased stiffness without excessive wall thickness
  - Ribs should be made thinner than the walls they reinforce to minimize sink marks on outside wall



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General Product Design Guidelines

- Holes
  - Holes are quite feasible in plastic moldings, but they complicate mold design and part removal
- Draft
  - A molded part should be designed with a draft on its sides to facilitate removal from mold
  - Especially important on inside wall of a cup-shaped part because plastic contracts against positive mold shape. Recommended draft:
  - For thermosets; ~ 0.5° to 1°
  - For thermoplastics; ~ 0.125° to 0.5°



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General Product Design Guidelines

- Tolerances
  - Although shrinkage is predictable under closely controlled conditions, generous tolerances are desirable for injection moldings because of
  - Variations in process parameters that affect shrinkage
  - Diversity of part geometries encountered
- Corner radii and fillets
  - Sharp corners, both external and internal, are undesirable in molded parts
  - They interrupt smooth flow of the melt, tend to create surface defects, and cause stress concentrations in the part

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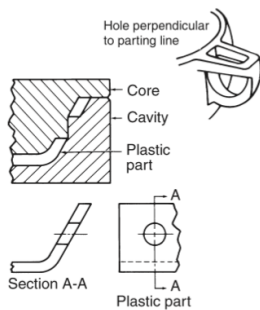
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General Product Design Guidelines



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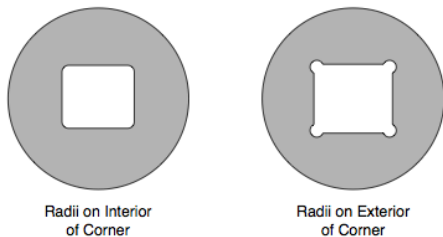
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General Product Design Guidelines



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What have we learnt in the past 2 sessions?

- 2 different types of plastics;
  - Thermosets and thermoplastics
- Moulding processes;
  - Injection Moulding
  - Compression Moulding
  - Pot & Plunger Transfer Molding
  - Extrusion Blow Moulding
  - Injection Blow Moulding
  - Thermoforming
- Moulding design guidelines



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