ME 3013
Manufacturing Processes I
Injection Molding
SHAPING PROCESSES FOR POLYMERS

1. Properties of Polymer Melts
2. Extrusion
3. Production of Sheet and Film
4. Fiber and Filament Production (Spinning)
5. Coating Processes
6. Injection Molding
7. Compression and Transfer Molding
8. Blow Molding and Rotational Molding
9. Thermoforming
10. Casting
11. Polymer Foam Processing and Forming
12. Product Design Considerations
Plastic Products

Plastics can be shaped into a wide variety of products:

– Molded parts
– Extruded sections
– Films
– Sheets
– Insulation coatings on electrical wires
– Fibers for textiles
More Plastic Products

• In addition, plastics are often the principal ingredient in other materials, such as
  – Paints and varnishes
  – Adhesives
  – Various polymer matrix composites

• Many plastic shaping processes can be adapted to produce items made of rubbers and polymer matrix composites
Trends in Polymer Processing

• Applications of plastics have increased at a much faster rate than either metals or ceramics during the last 50 years
  – 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 that of metals
Why Plastic Shaping Processes are Important

- Almost unlimited variety of part geometries
- Plastic molding is a net shape process;
- further shaping is not needed
- Less energy is required than for metals
- processing temperatures are much lower
- Handling of product is simplified during production because of lower temperatures
- Painting or plating is usually not required
• the handle of the razor has several different colors, textures, and surface finishes.

• designed to be held in your hand and be comfortable and easy to use,

• the **mechanical properties** of the materials and the **texture** that is formed is important

• all these **different materials** are processed using injection molding,
IM Feedstock: Polymer pellets
Extruded PP granules Polypropylene/PP Crush/ Granules hot sell !!

FOB Price: US $950 - 1,550 / Metric Ton | Get Latest Price
Min.Order Quantity: 5 Metric Ton/Metric Tons
Supply Ability: 2000 Metric Ton/Metric Tons per Month
Port: xingang port
Payment Terms: L/C,T/T,Western Union,MoneyGram
**Poly** (many) + **mer** (structural unit)

\[-[C_2H_4]_n- = \text{poly}[\text{ethylene}]\]
The ‘families’ of materials: modulus vs. density
**FIGURE 7.10** General terminology describing the behavior of three types of plastics. PTFE (polytetrafluoroethylene) has Teflon as its trade name. *Source:* After R.L.E. Brown.
Break

Yield Point

Increasing Temperature

Glass Transition

Strain Hardening

Elongational Strain

Stress
Glass Transition Temperature $T_G$
<table>
<thead>
<tr>
<th>Material</th>
<th>$T_g$ (°C)</th>
<th>$T_m$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nylon 6,6</td>
<td>57</td>
<td>265</td>
</tr>
<tr>
<td>Polycarbonate</td>
<td>150</td>
<td>265</td>
</tr>
<tr>
<td>Polyester</td>
<td>73</td>
<td>265</td>
</tr>
<tr>
<td>Polyethylene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High density</td>
<td>−90</td>
<td>137</td>
</tr>
<tr>
<td>Low density</td>
<td>−110</td>
<td>115</td>
</tr>
<tr>
<td>Polymethylmethacrylate</td>
<td>105</td>
<td>—</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>−14</td>
<td>176</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>100</td>
<td>239</td>
</tr>
<tr>
<td>Polytetrafluoroethylene</td>
<td>−90</td>
<td>327</td>
</tr>
<tr>
<td>Polyvinyl chloride</td>
<td>87</td>
<td>212</td>
</tr>
<tr>
<td>Rubber</td>
<td>−73</td>
<td>—</td>
</tr>
</tbody>
</table>
Viscosity: resistance to shear

\[ \tau = \mu \frac{\partial U}{\partial y} \]

\[ U_x(H) = U_x \]

\[ U_x(0) = 0 \]

<table>
<thead>
<tr>
<th>Material</th>
<th>Dynamic viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (room temp)</td>
<td>$1 \times 10^{-3}$ kg/m-s [Pa-s]</td>
</tr>
<tr>
<td>Honey</td>
<td>10</td>
</tr>
<tr>
<td>Liquid thermoplastic*</td>
<td>$10^2$-$10^3$</td>
</tr>
<tr>
<td>Molten aluminum (600 C)</td>
<td>$3 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

*at typical injection shear rate and melt temperature
Two Types of Plastics

1. Thermoplastics
   – Chemical structure remains unchanged during heating and shaping
   – More important commercially, comprising more than 70% of total plastics tonnage

2. Thermosets
   – Undergo a curing process during heating and shaping, causing a permanent change (cross-linking) in molecular structure
   – Once cured, they cannot be remelted
Thermoforming

1. Thermoplastic Sheet
2. Plastic is heated to soften
3. Sheet is placed on mold
4. Vacuum draws plastic to mold
5. Part is trimmed from sheet
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
Polymer Melts

• 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
Viscosity of Polymer Melts

Fluid property that relates shear stress to shear rate during flow

• Due to its high molecular weight, a polymer melt is a thick fluid with high viscosity

• Most polymer shaping processes involve flow through small channels or die openings
  – Flow rates are often large, leading to high shear rates and shear stresses, so significant pressures are required to accomplish the processes
Extrusion

Compression process in which material is forced to flow through a die orifice to provide long continuous product whose cross-sectional shape is determined by the shape of the orifice

- Widely used for thermoplastics and elastomers to mass produce items such as tubing, pipes, hose, structural shapes, sheet and film, continuous filaments, and coated electrical wire
- Carried out as a continuous process; extrudate is then cut into desired lengths
Extruder

Components and features of a (single-screw) extruder for plastics and elastomers
Two Main Components of an Extruder

1. Barrel
2. Screw
   • Die - not an extruder component
     – Special tool that must be fabricated for particular profile to be produced
Die Configurations and Extruded Products

• The **shape** of the **die orifice** determines the cross-sectional shape of the extrudate

• Common die profiles and corresponding extruded shapes:
  – **Solid** profiles
  – **Hollow** profiles, such as tubes
  – Wire and cable **coating**
  – **Sheet** and film
  – Filaments

Generally, **plastic film** is made from thicknesses of 0.06mm to 0.25mm. Anything thicker is considered **plastic sheet**.
WIRE COATING IN MELT
Extrusion of Solid Profiles

• Regular shapes such as
  – Rounds
  – Squares

• Irregular cross sections such as
  – Structural shapes
  – Door and window moldings
  – Automobile trim
  – House siding
Fiber and Filament Products

• Definitions:
  – **Fiber** - a long, thin strand whose length is at least 100 times its cross-section
  – **Filament** - a fiber of continuous length

• Applications:
  – Fibers and filaments for **textiles**
    • Most important application
  – Reinforcing materials in polymer composites
    • Growing application,
Materials for Fibers and Filaments

Fibers can be natural or synthetic

- **Natural fibers** constitute ~ 25% of total market
  - **Cotton** is by far the most important staple
  - **Wool** production is significantly less than cotton

- **Synthetic fibers** constitute ~ 75% of total fiber market
  - **Polyester** is the most important
  - Others: nylon, acrylics, and rayon
Fiber and Filament Production - Spinning

For synthetic fibers, spinning = extrusion of polymer melt or solution through a spinneret, then drawing and winding onto a bobbin

- **Spinneret** = die with multiple small small holes
- methods used to **draw** and **twist** natural fibers into yarn or thread
- Three variations, depending on polymer:
  1. Melt spinning
  2. Dry spinning
  3. Wet spinning
Stages in the wet spinning of polymeric fibres.
Melt Spinning

Starting polymer is heated to molten state and pumped through spinneret

- Typical spinneret is 6 mm (0.25 in) thick and contains approximately 50 holes of diameter 0.25 mm (0.010 in)
- Filaments are drawn and air cooled before being spooled onto bobbin
- Significant extension and **thinning** of filaments occur while polymer is still molten, so final diameter wound onto bobbin may be only 1/10 of extruded size
- Used for **polyester** and **nylon filaments**
Dry Spinning

Similar to melt spinning, but starting polymer is in solution and solvent can be separated by evaporation

- First step is extrusion through spinneret
- Extrudate is pulled through a heated chamber which removes the solvent, leaving the polymer
- Used for filaments of cellulose acetate and acrylics
Injection Molding

• **polymers or plastics** are made in immense quantities.
• Every year over 300 million metric tons of plastics are produced.
• The number has gone up 300-fold in the past 50 or 60 years.
• In 1950 it was one million, and in 2014 it was over 300 million.
• this significant increase is due to many things—advances in technology, manufacturing materials, as well as growth in the world's population.
• the volume of plastics produced is increasing about 3% to 5% every year
Adapter plate for movable side
Spacer block
Core
Adapter plate for fixed side
Product
Cavity
Locating ring
Sprue
Runner
Ejector pin
Ejector plate
Injection Molding

• Injection molding is a big part of 300 million tons.
• In North America and Europe only, over 10 million tons or 10 billion kilograms per year of polymers are injection molded.
• A distribution of the different applications of injection molded parts tells us that injection molding touches arguably every industry,
• The biggest application of injection molded parts is packaging—things like plastic drink bottles.
• The extraction of materials, plastics from injection molding, their use and their recycling, if possible, is a really important topic as well.
• **Sustainability**: the implications of such high volume manufacturing processes.
In North America and Europe, injection molding is used to process >10 million tons of polymers per year.
https://www.youtube.com/watch?v=QPzOh54hG9A
Injection Molding Machine

Two principal components:

1. Injection unit
   - Melts and delivers polymer melt
   - Operates much like an extruder

2. Clamping unit
   - Opens and closes mold each injection cycle
Injection Molding Machine

A large (3000 ton capacity) injection molding machine (Photo courtesy of Cincinnati Milacron).
Injection Molding Machine

Diagram of an injection molding machine, reciprocating screw type (some mechanical details are simplified).
Typical molding cycle: (1) mold is closed
Figure 12.22  Typical molding cycle: (2) melt is injected into cavity.
Typical molding cycle: (3) screw is retracted.
Typical molding cycle: (4) mold opens and part is ejected.
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:

<table>
<thead>
<tr>
<th>Plastic</th>
<th>Shrinkage, mm/mm (in/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nylon-6,6</td>
<td>0.020</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>0.025</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>0.004</td>
</tr>
<tr>
<td>PVC</td>
<td>0.005</td>
</tr>
</tbody>
</table>
Shrinkage Factors

- **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.
Reaction Injection Molding (RIM)

Two **highly reactive** liquid ingredients are mixed and immediately injected into a mold cavity where **chemical reactions leading to solidification** occur.

- RIM was developed with **polyurethane** to produce **large automotive parts** such as **bumpers** and fenders.
  - RIM polyurethane parts possess a **foam internal structure** surrounded by a **dense outer skin**.
- Other materials used in RIM: epoxies, and **urea-formaldehyde**.
Compression Molding

- A widely used molding process for **thermosetting** plastics
- Also used for **rubber tires** and polymer matrix composite parts
- Molding compound available in several forms: powders or pellets, liquid, or preform
- Amount of **charge** must be **precisely controlled** to obtain repeatable **consistency** in the molded product
Compression Molding

Compression molding for thermosetting plastics: (1) charge is loaded, (2) and (3) charge is compressed and cured, and (4) part is ejected and removed.
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
Compression Molding

• Molding materials:
  – Phenolics, melamine, urea-formaldehyde, epoxies, urethanes, and elastomers

• Typical compression-molded products:
  – Electric plugs, sockets, and housings; pot handles, and dinnerware plates
Blow Molding

Molding process in which **air pressure** is used to **inflate** soft plastic into a **mold cavity**

- Important for making one-piece hollow plastic parts with **thin walls**, such as bottles
- used for consumer beverages in mass markets,
- production is typically organized for **very high quantities**
Materials and Products in Blow Molding

• 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
Blow Molding Process

• 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 molding
Extrusion Blow Molding

Extrusion blow molding: (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 mold come together; (3) the tube is inflated so that it takes the shape of the mold cavity; and (4) mold is opened to remove the solidified part.
Extrusion blow molding
**Injection Blow Molding**

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

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

- 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.
Vacuum Thermoforming

Vacuum thermoforming: (1) a flat plastic sheet is softened by heating.
Vacuum Thermoforming

Vacuum thermoforming: (2) the softened sheet is placed over a concave mold cavity
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.
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
Polymer Foam

A polymer-and-gas mixture that gives the material a porous or cellular structure

• Most common polymer foams: polystyrene (Styrofoam, a trademark), polyurethane
• Other polymers: natural rubber ("foamed rubber") and polyvinylchloride (PVC)
Properties of a Foamed Polymer

• Low density
• High strength per unit weight
• Good thermal insulation
• Good energy absorbing qualities
Applications of Polymer Foams

• Characteristic properties of polymer foams, and the ability to control elastic behavior by selection of base polymer, make these materials suitable for certain applications

• Applications: hot beverage cups, heat insulating structural materials, cores for structural panels, packaging materials, cushion materials for furniture and bedding, padding for automobile dashboards, and products requiring buoyancy
Polymer Foam Structures

Two polymer foam structures: (a) *closed* cell and (b) *open* cell.
Product Design Guidelines: General

• **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

**Creep resistance** is a solid material's ability to resist “creep,” the tendency of a material to slowly deform over a long period of exposure to high levels of stress.
Product Design Guidelines: General

• **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

• **Thermal expansion**
  – Dimensional changes due to temperature changes much more significant than for metals
Product Design Guidelines: General

- 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