Chapter 18
Forming and Shaping Plastics and Composite Materials
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Extrusion
Thermoplastic pellets, granules, or powder are placed into a hopper and fed into the extruder barrel.
A screw blends the pellets and conveys them down the barrel.
Internal friction and heaters, heat the pellets to a liquid form.

Extrusion (cont.)
Molten metal is then extruded through a die.
Product is cooled by air or by passing it through a water filled channel.

Figure 18.2

Characteristics of Forming and Shaping Processes for Plastics and Composite Materials

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<th>Process</th>
<th>Characteristics</th>
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<td>Extrusion</td>
<td>Long, uniform, solid or hollow complex cross sections; high production rates; low tooling costs; wide tolerances.</td>
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<td>Injection molding</td>
<td>Complex shapes of various sizes, eliminating assembly; high production rates; costly tooling; good dimensional accuracy.</td>
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<td>Structural foam molding</td>
<td>Large parts with high stiffness-to-weight ratios; low tooling costs; high production rates; low cost for making components.</td>
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<td>Blow molding</td>
<td>Hollow thin-walled parts of various sizes; high production rates; low tooling costs.</td>
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<td>Rotational molding</td>
<td>Large hollow shapes of relatively simple shapes; low tooling costs; high production rates.</td>
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<td>Transfer molding</td>
<td>Similar to rotational molding, relatively inexpensive tooling; medium tooling costs.</td>
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<td>Casting</td>
<td>Surface of molded parts made with flexible molds; low production rates.</td>
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Introduction

- Plastics melt or cure at low temperatures
  - Easy to handle
  - Require less energy to process
- Shipped to manufacturing plants as pellets or powders
  - Melted at manufacturing plant (for thermoplastics) just before shaping process
  - Plastic is also available in sheets, plate, tubing
  - Liquid plastics are used in making reinforced plastic parts
- Thermosets
  - Two liquid components (typically)
  - Thermoplastics
    - Nylons, ABS, acrylics
  - Thermosets
    - Epoxy, phenolics, polyurethanes

Extrusion

- Thermoplastic pellets, granules, or powder are placed into a hopper and fed into the extruder barrel.
- A screw blends the pellets and conveys them down the barrel.
- Internal friction and heaters, heat the pellets to a liquid form.
- Screw has three sections
  - A fill: conveys the material from the hopper to the central section
  - A pump: the material is conveyed due to friction and heating
  - A feeding section: additional mixing occurs and pressure builds up.
Injection Molding
- Similar process as hot-chambered die casting
  - Injection molding typically uses plastic
  - Hot-chambered die casting typically shapes metals
- Barrel is heated to promote melting
  - Much of the energy required to heat the polymer comes from friction
- Newer equipment
  - Reciprocating screw
    - The screw stops momentarily and is then hydraulically pushed forward to force the molten plastic into the mold cavity
- Products made:
  - Cups, containers, tool handles, knobs...
- Temperature of the mold
  - Thermoplastics: Relatively cold molds
  - Thermosets: heated molds
- Once parts are cooled, the mold is opened and the part is ejected
  - Complex shapes and good dimensional accuracy can be achieved
  - Mandrels can be used
  - Mold components may include: cores, cycles, cooling channels, inserts, knockout pin systems
- Metallic components such as screws can be placed in the mold cavity

Examples of Injection Molding
- A mixture of resin and 2 or more reactive fluids is forced into the mold cavity at high speeds
- Chemical reaction takes place rapidly
- Thermoset part
- Applications: automotive bumpers, thermal insulation for fridge/freezer, water-skis, stiffness for structural components

Reaction-Injection Molding
- A modification of extrusion – and injection-molding processes
  - Reaction blow molding
    - A tube is extruded
    - Tube is then clamped in a cavity much larger than the tube diameter
    - Tube is then blown into the shape of the cavity
    - The mold closes around the tubing forming a part that contains parts are made
    - Used to make milk jugs
  - Injection blow molding
    - A short tube (called a parison) is first injection molded
    - The parison is then transferred to a blow-molding die
    - Heat is then blown into the parison
    - Mold closes around the cavity
    - Used to make beverage bottles and hollow containers
  - Multilayer blow molding
    - Coextruded tubes are used as a parison
    - Used for multi-layered packaging plastics

Injection-Molding Machine
- A 2.2-MN (250-ton) injection-molding machine. The tonnage is the force applied to keep the dies closed during injection of molten plastic into the mold cavity.

Blow Molding
- A modification of extrusion – and injection-molding processes
  - Extrusion blow molding
  - A tube is first extruded
  - Tube is then clamped in a cavity much larger than the tube diameter
  - Tube is then blown into the shape of the cavity
  - The mold closes around the tubing forming a part that contains parts are made
  - Used to make milk jugs
  - Injection blow molding
    - A short tube (called a parison) is first injection molded
    - The parison is then transferred to a blow-molding die
    - Heat is then blown into the parison
    - Mold closes around the cavity
    - Used to make beverage bottles and hollow containers
  - Multilayer blow molding
    - Coextruded tubes are used as a parison
    - Used for multi-layered packaging plastics (odor barrier...)

Figure 18.5 Injection molding with (a) plunger, (b) reciprocating rotating screw

Figure 18.6 Typical products made by injection molding, including examples of insert molding. Source: Plainfield Molding Inc.

Figure 18.7 A 2.2-MN (250-ton) injection-molding machine. The tonnage is the force applied to keep the dies closed during injection of molten plastic into the mold cavities. Source: Courtesy of Cincinnati Milacron, Plastics Machinery Divisions.

Figure 18.8 Schematic illustration of the reaction-injection molding process. Source: Modern Plastics Encyclopedia.

Figure 18.9 Schematic illustrations of (a) the blow-molding process for making plastic beverage bottles, and (b) a three-station reaction blow-molding machine. Source: Encyclopedia of Polymer Science and Engineering, 3rd ed. Copyright ©1985. Reprinted by permission of John Wiley & Sons, Inc.
**Compression Molding**
- Plastic material is placed directly into the heated mold cavity.
- Forming is done by applying pressure from a plug or from the upper half of the die.
- Cycles form the flash, removed by trimming parts made.
- Dies: Dishes, handles, container cups, fittings.
- Design considerations:
  - Undercuts are not recommended.
  - Dies can be designed to open the mold.
- Dies are typically less expensive than for injection molding, partially due to the simplicity of the dies.

**Casting**
- Both thermoplastics and thermosets.
- Parts made:
  - Tanks, chemical vessels, boat hulls, pump housing.
  - Components are made from a variety of materials (aluminum, bronze, etc.).
- Design considerations:
  - Solid-phase casting.
  - Centrifugal casting: same technique as described previously (now applied to plastics).
  - Potting and encapsulation: plastic serves as a dielectric.

**Thermoforming**
- Process used to form thermoplastic film over a mold by applying heat and pressure.
- Sheet is heated in an oven to a set point (soft, but not melted).
- Sheet is removed from oven and placed over the mold.
- Plastic sheet is forced against the mold through the application of vacuum.
- Material may be soft enough to where vacuum is enough.
- Sometimes it is necessary to apply additional air pressure or force by mechanical means.
- Used in forming:
  - Advertising signs, refrigerator liners, packaging, appliance housings, panels for shower stalls.
  - Molds:
  - Glass may be made of a material with strengths lower than typical molds: aluminum is OK.
  - Taps are made in the mold to allow for vacuum pull.

**Transfer molding**
- Development of compression molding.
- Thermosetting material is used.
- Material is placed in a heated transfer pot of chamber.
- Material is then heated.
- A cope is used to force the material to flow through the narrow channels into the mold cavity.
- The flow generates heat which raises the temperature of the material and homogenizes it.
- Parts made:
  - Electrical and electronic components.
  - Silicone parts.
  - Intricate parts of varying wall thickness.

**Cold Forming and Solid-phase forming**
- Cold metal working:
  - Processes can be applied to many thermoplastics:
    - Materials: Rolling, deep drawing, extrusion, closed-die forging.
    - Typical materials:
      - Polyethylene, polypropylene, ABS, PVC.
- Necessary attributes for cold forming:
  - Ductile at room temperature.
  - Deformations must be reversible (minimize springback and creep).
- Solid-phase forming:
  - At temperatures 10-20°C lower than the melting temperature.
  - Springback is lower than for cold forming.
Processing Reinforced Plastics

- Reinforced plastics is a type of composite.
- Used to increase strength-to-weight ratio, stiffness-to-weight ratio, and creep resistance.
- Composite consists of:
  - Fibers: used to strengthen the material.
  - Matrix: surrounds the fibers, is typically less expensive and has a lower weight.
- Processing cost is high.
- Fibers may be very short or long.
- Process of making prepregs:
  - Fibers are aligned and subjected to surface treatment to ensure better adhesion to the polymer matrix.
  - Fibers are then dipped in a resin bath to make them into a sheet or tape.


Molding Processes

- Molding of reinforced plastics:
  - Compression molding:
    - Material is placed between two molds
    - At room temperature or heated
    - Fiber length: 3-5 mm (typically)
  - Vacuum-bag molding:
    - Prepregs are laid in a mold to form the desired shape.
    - The lay-up is covered with a plastic bag and a vacuum is applied.
  - Contact molding:
    - Single male or female mold is used.
    - Hand lay-up or spray-up technique is used.
- Reinforced materials can include ceramics and metals also.

Figure 18.21 Manual methods of processing reinforced plastics: (a) hand lay-up and (b) spray-up. These methods are also called open-mold processing.

Tape Laying

- Fiber reinforced sheets are assembled into laminated structures.
- Horizontal stabilizer for the F-14 fighter aircraft.
- Computer controlled tape-laying machine.

Figure 18.18 (a) Single-ply lay-up of boron-epoxy prepreg for the horizontal stabilizer of the F-14 fighter aircraft. Source: Grumman Aircraft Corporation. (b) A 10 axis computer numerical controlled tape-laying system. The machine is capable of laying up to 10 tapes to ±5° in width at speeds of up to 60 m/min (17 ft/s). Source: Courtesy of Crompton Corporation.

Design Modifications to Minimize Distortion

- Examples of design modifications to eliminate or minimize distortion of plastic parts:
  - Suggested design changes to minimize distortion. Source: E. Strasser.
  - Die design for extrusion of square sections. Without this design, product cross-sections swell because of the recovery of the material; this effect is known as die swell. (c) Design change in a rib to minimize pull-in caused by shrinkage during cooling. (d) Stiffening the bottoms of thin plastic containers by doming - this technique is similar to the process used to make the bottoms of aluminum beverage cans.