Manufacturing Engineering Technology in SI Units, 6th Edition

Chapter 19:
Plastics and Composite Materials: Forming and Shaping

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Chapter Outline

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Introduction

- Processing of plastics and elastomers is similar to forming and shaping of metals
- Thermoplastics melt and thermosets cure at low temperatures, easy to handle and require less force and energy to process
- Plastics an be molded, cast, formed and machined with ease and at high production rates

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Introduction

General Characteristics of Forming and Shaping Processes for Plastics and Composite Materials

Process	Characteristics
Extrusion	Continuous, uniformly solid or hollow, and complex cross sections; high production rates; relatively low tooling costs; wide tolerances
Injection molding	Complex shapes of various sizes; thin walls; very high production rates; costly tooling; good dimensional accuracy
Structural foam molding	Large parts with high stiffness-to-weight ratio; less expensive tooling than in injection molding; low production rates
Blow molding	Hollow, thin-walled parts and bottles of various sizes; high production rates; relatively low tooling costs
Rotational molding	Large, hollow items of relatively simple shape; relatively low tooling costs; relatively low production rates
Thermoforming	Shallow or relatively deep cavities; low tooling costs; medium production rates
Compression molding	Parts similar to impression-die forging; expensive tooling; medium production rates
Transfer molding	More complex parts than compression molding; higher production rates; high tooling costs; some scrap loss
Casting	Simple or intricate shapes made with rigid or flexible low-cost molds; low production rates
Processing of composite materials	Long cycle times; expensive operation; tooling costs depend on process

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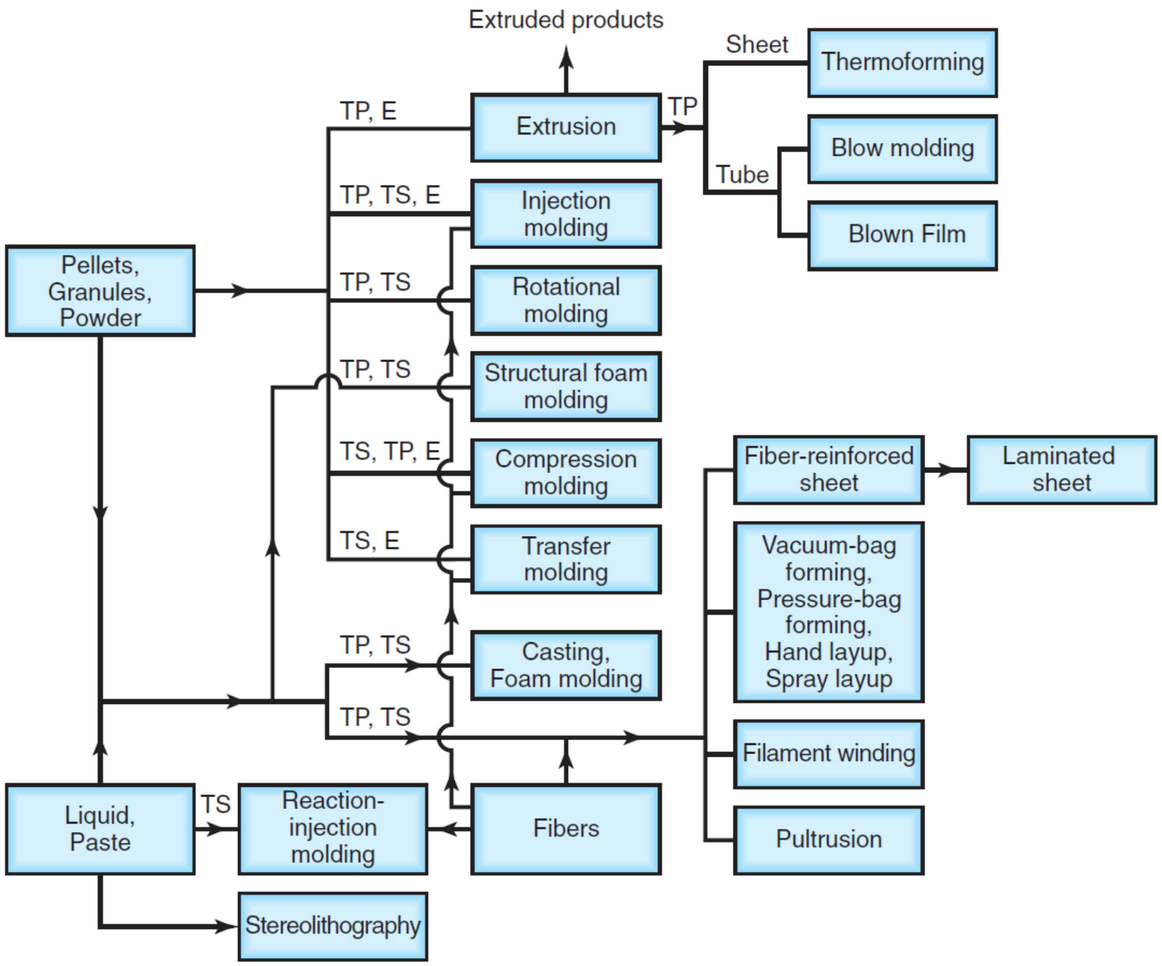
Introduction



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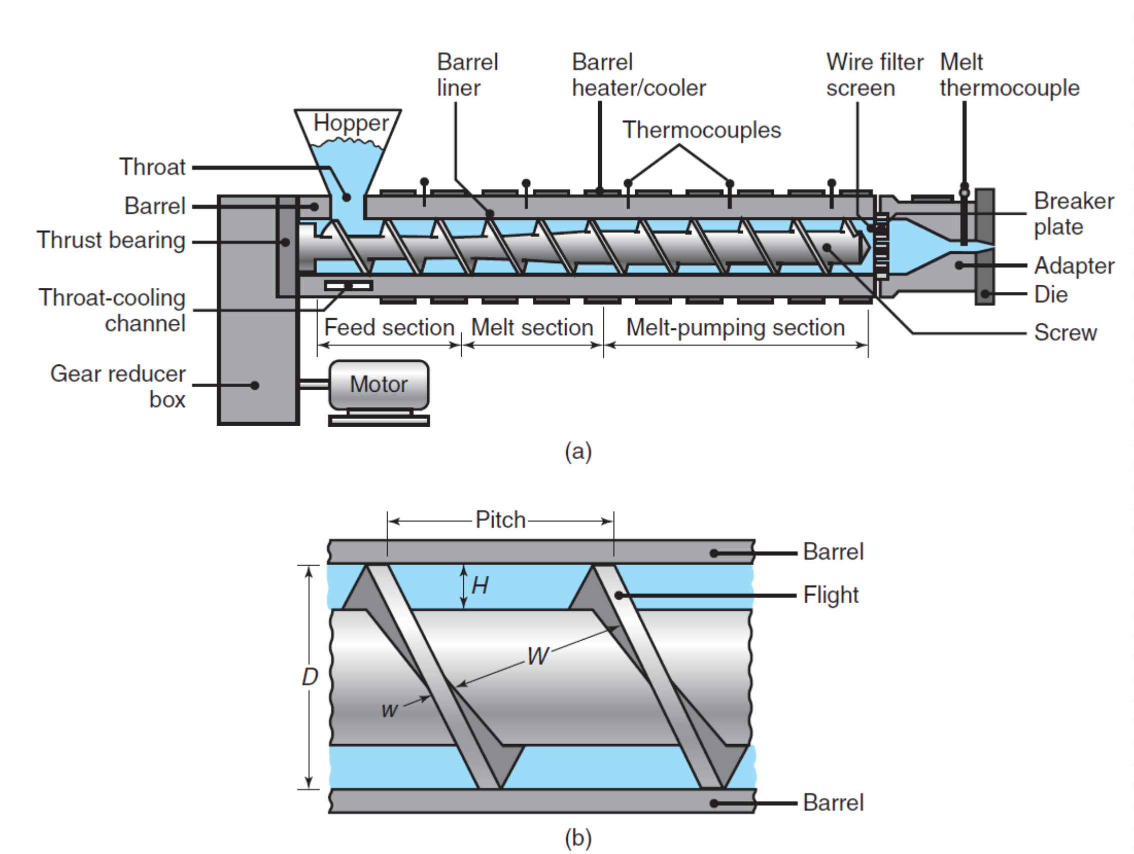
Extrusion

- In *extrusion, the r*aw materials are in the form of thermoplastic pellets, granules or powder



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Extrusion

- Screws have three distinct sections:
1. *Feed section*
2. *Melt section*
3. *Metering* or *pumping section*
- Molten plastic is forced through a die in a process similar to that of extruding metals
- Controlling the rate and uniformity of cooling is important to minimize product shrinkage and distortion
- Complex shapes with constant cross section can be extruded with inexpensive tooling

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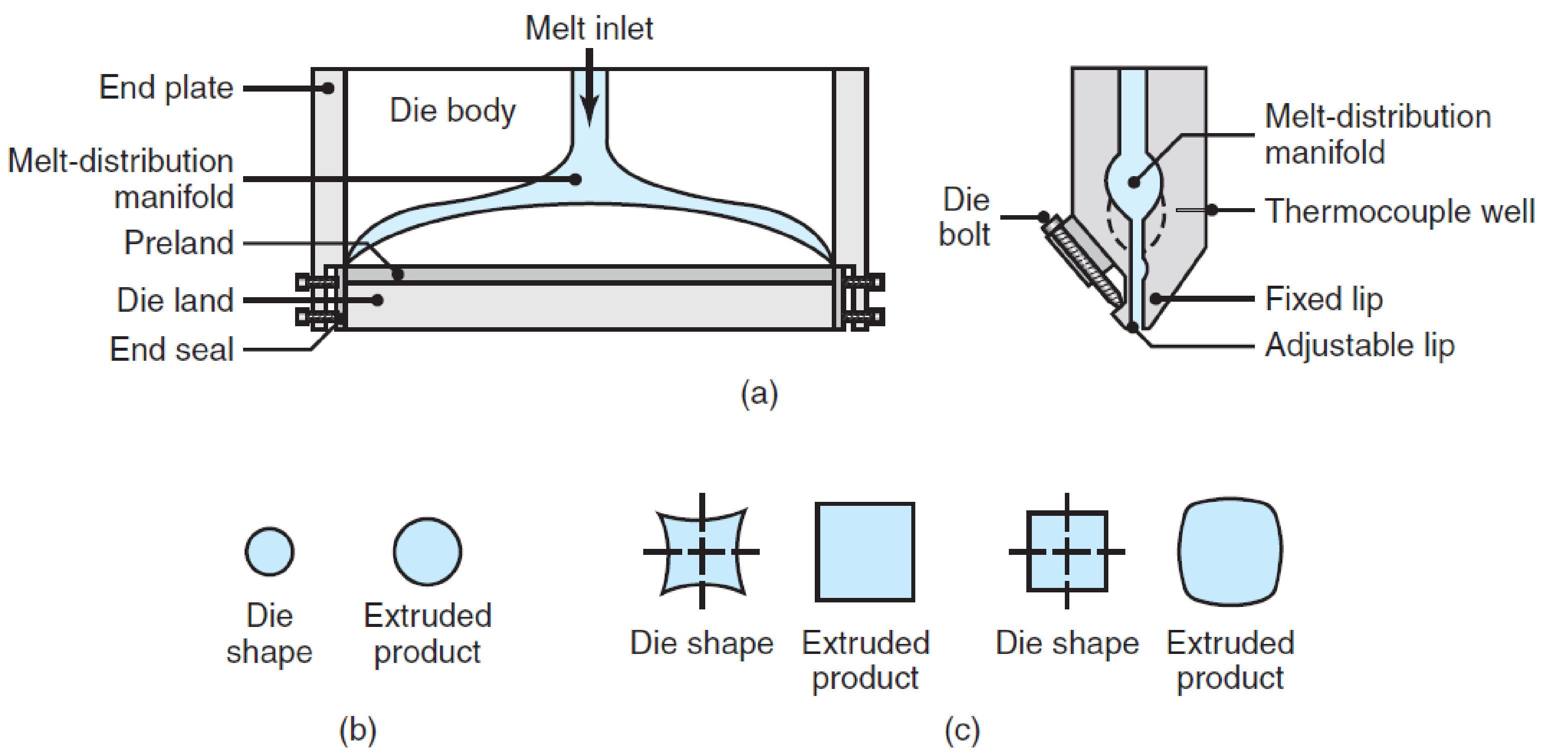
Extrusion



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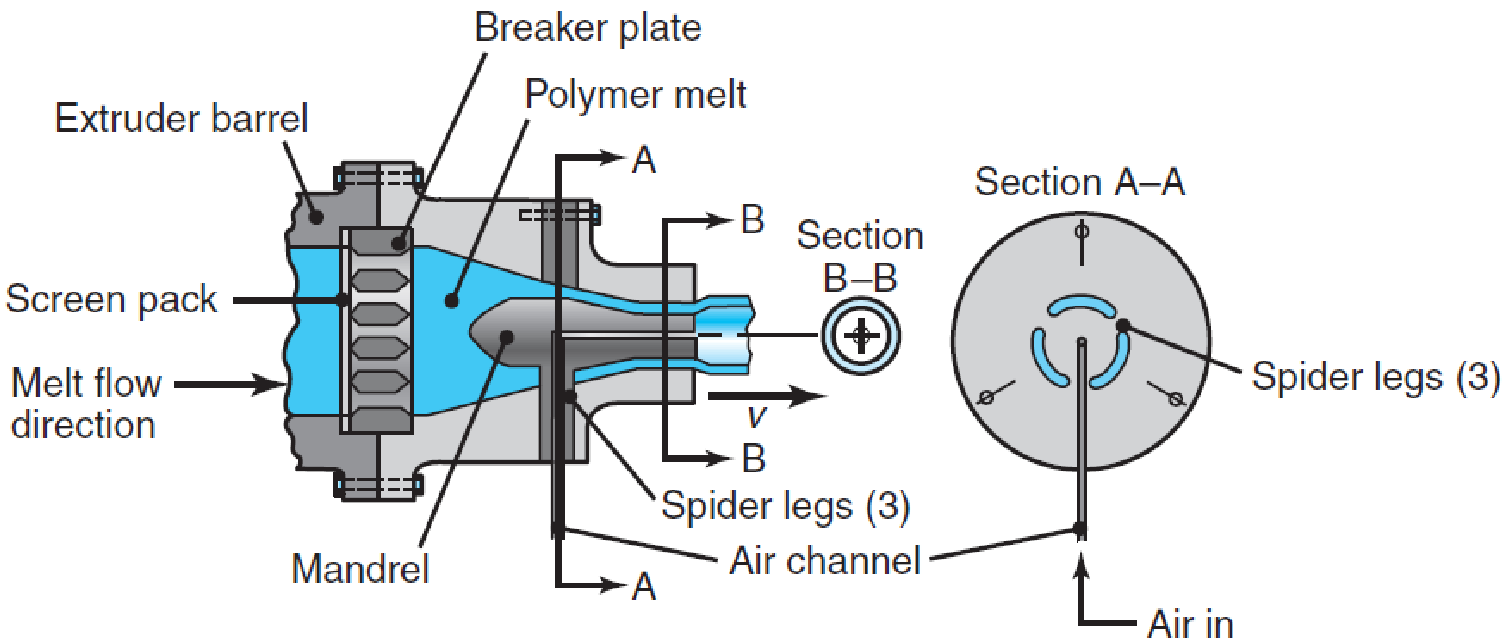
Extrusion : Miscellaneous Extrusion Processes

Plastic Tubes and Pipes

- These are produced in an extruder with a *spider die*



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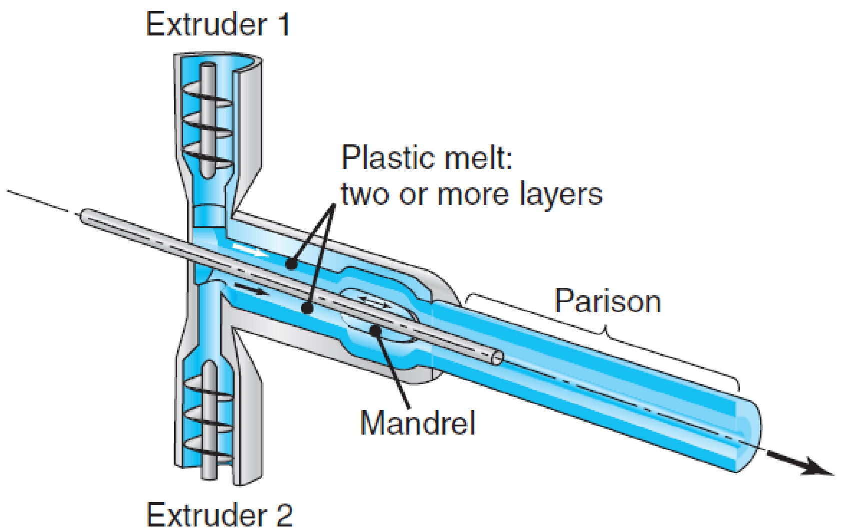
Extrusion : Miscellaneous Extrusion Processes

Rigid Plastic Tubing

- The die is *rotated* and rigid plastic tubing causes the polymer to be sheared and biaxially oriented during extrusion

Coextrusion

- Involves simultaneous extrusion of two or more polymers through a single die



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Extrusion : Miscellaneous Extrusion Processes

Plastic-coated Electrical Wire

- Electrical wire, cable, and strips are extruded and coated with plastic by this process

Polymer Sheets and Films

- These can be produced by using a specially designed flat-extrusion die
- Also known as the *coat-hanger die*
- Designed to distribute the polymer melt evenly throughout the width

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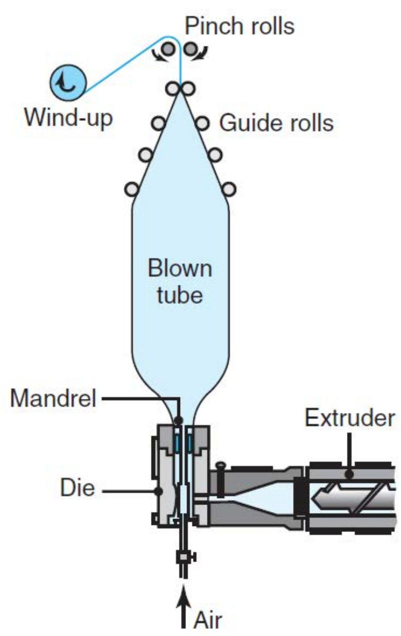
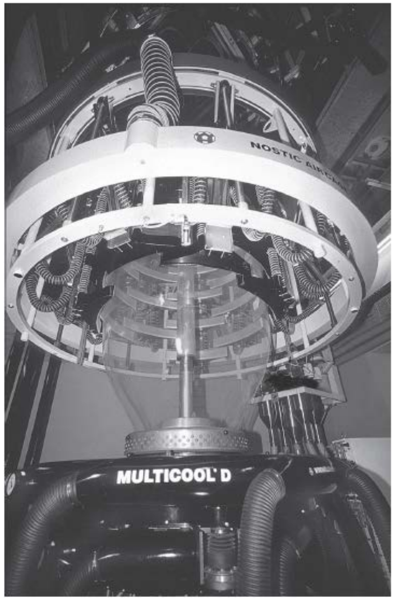
Extrusion : Miscellaneous Extrusion Processes

Thin Polymer Films

- Common *plastic bags* and other thin polymer film products are made from **blown film**, which in turn is made from a thin-walled tube produced by an extruder





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Extrusion : Miscellaneous Extrusion Processes

EXAMPLE 19.1

Blown Film

Assume that a typical plastic shopping bag made by blown film has a lateral dimension (width) of 400 mm.

(a) What should be the extrusion-die diameter?

(b) These bags are relatively strong in use. How is this strength achieved?

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Extrusion : Miscellaneous Extrusion Processes

Solution

Blown Film

a. The perimeter is (2) (400) = 800mm

Blown diameter should be $\pi D = 800 \rightarrow D = 255$mm

For 2.5 times, the die diameter is 255/2.5 = 100mm

b. The resulting biaxial orientation of the polymer molecules significantly improves the strength and toughness of the plastic bag

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Extrusion : Production of Polymer Reinforcing Fibers

- Synthetic fibers used in reinforced plastics are polymers that are extruded through the tiny holes of a device called a **spinneret**
- Process of extrusion and solidification of continuous filaments is called **spinning**
- *Spinning* is used for the production of natural textiles where short pieces of fiber are twisted into yarn
- There are 4 methods of spinning fibers: melt, wet, dry, and gel spinning

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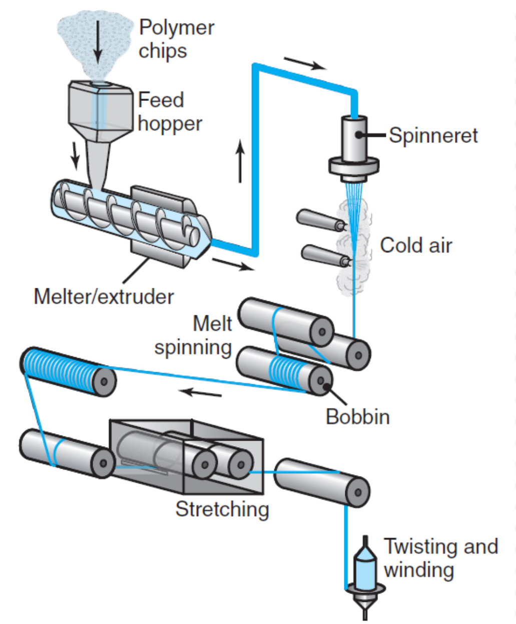
Extrusion : Production of Polymer Reinforcing Fibers

- **In melt spinning,** the polymer is melted for extrusion through the spinneret and then solidified directly by cooling
- **Wet spinning** is the process for fiber production and used for polymers that have been dissolved in a solvent
- **Dry spinning** is used for thermosets carried by a solvent
- **Gel spinning** is used to obtain high strength or special fiber properties



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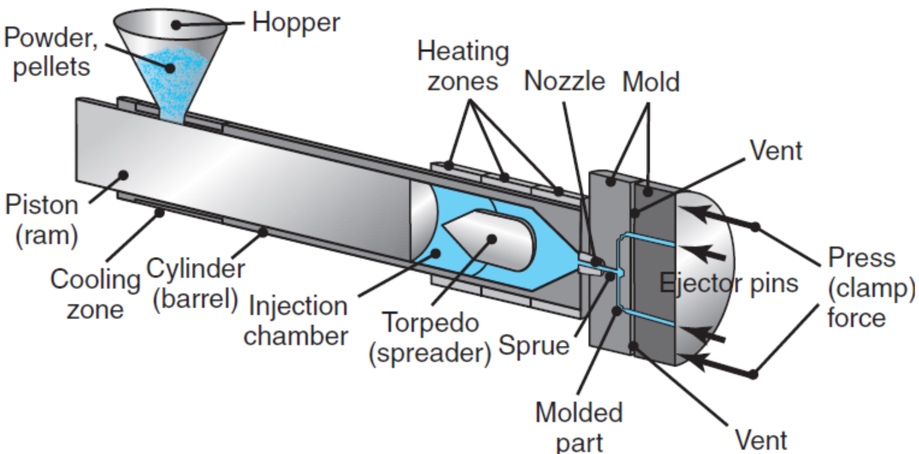
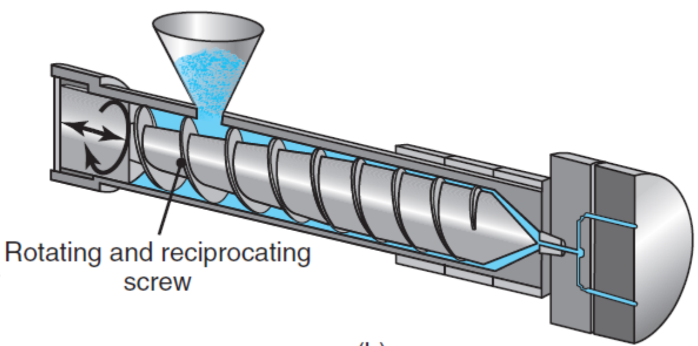
Injection Molding

- *Injection molding* is similar to hot-chamber die casting



(a)



(b)

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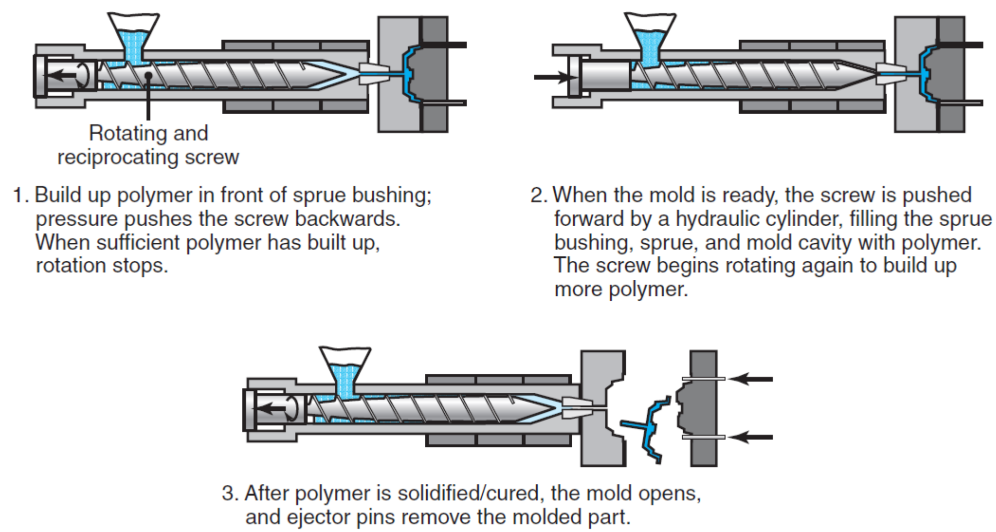
Injection Molding

- Pellets or granules are fed into the heated cylinder
- The melt is forced into the mold either by a hydraulic *plunger* or by the *rotating screw* system of an extruder
- Modern machines are of the *reciprocating* or *plasticating screw type*



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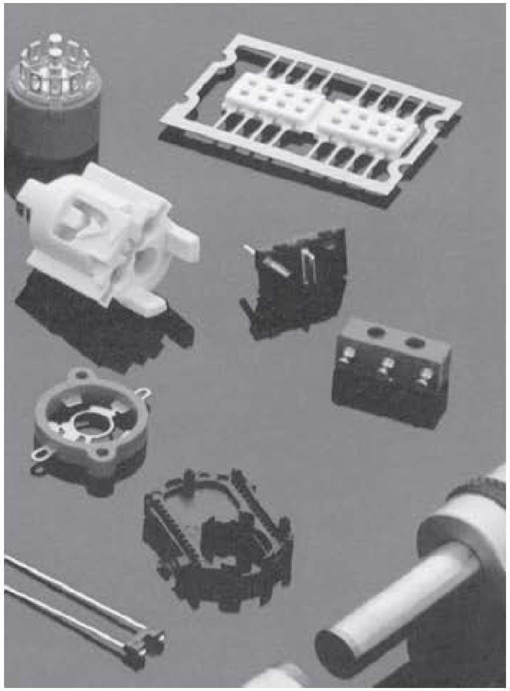
Injection Molding

- Some injection-molded products



(a)

(b)

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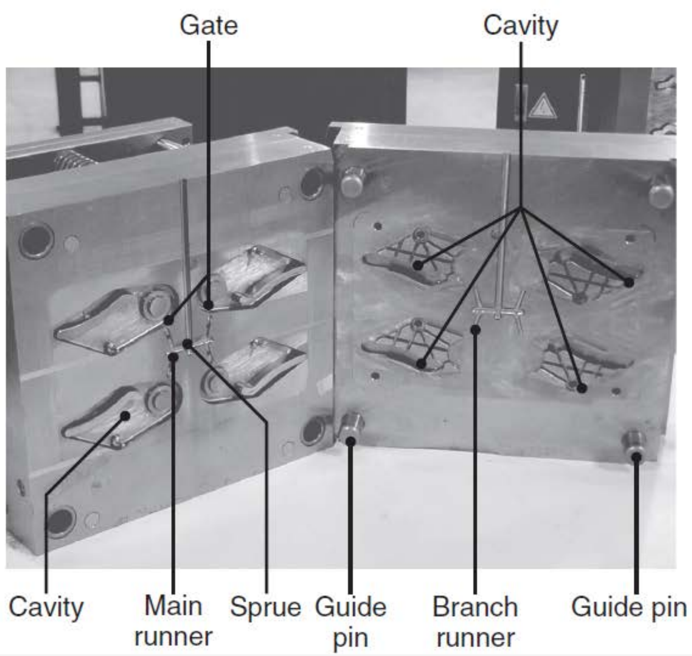
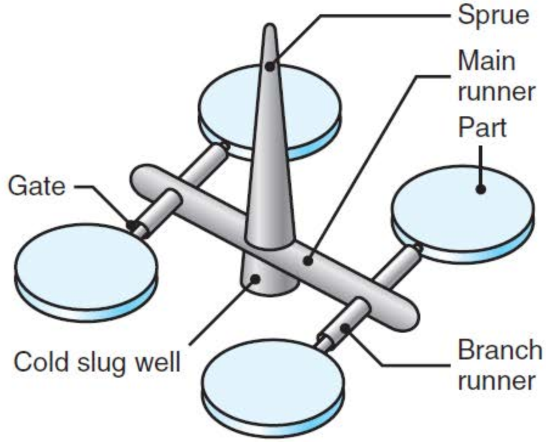
Injection Molding

- Molds with moving and unscrewing mandrels are used in injection molding
- They allow the molding of parts to have multiple cavities or internal and external threaded features





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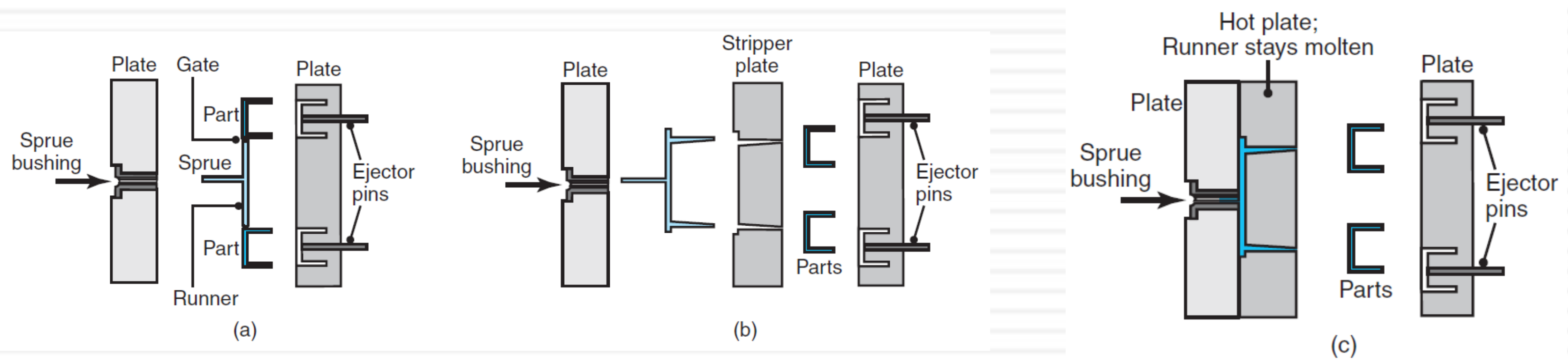
Injection Molding

- 3 basic types of molds:

1. **Cold-runner, two-plate mold**
2. **Cold-runner, three-plate mold**
3. **Hot-runner mold**



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Injection Molding

- **Multicomponent injection molding** allows the forming of parts with a combination of various colors and shapes
- **Insert molding** involves metallic components that are placed in the mold cavity prior to injection and then becoming an integral part of the molded product

Overmolding

- A process for making products in one operation and without the need for postmolding assembly

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Injection Molding

Overmolding

- In **ice-cold molding**, the same type of plastic is used to form both components of the joint
- Operation is carried out in a standard injection-molding machine and in one cycle

Process Capabilities

- Injection molding is a high-rate production process and permits good dimensional control
- Capable of producing complex shapes with good dimensional accuracy

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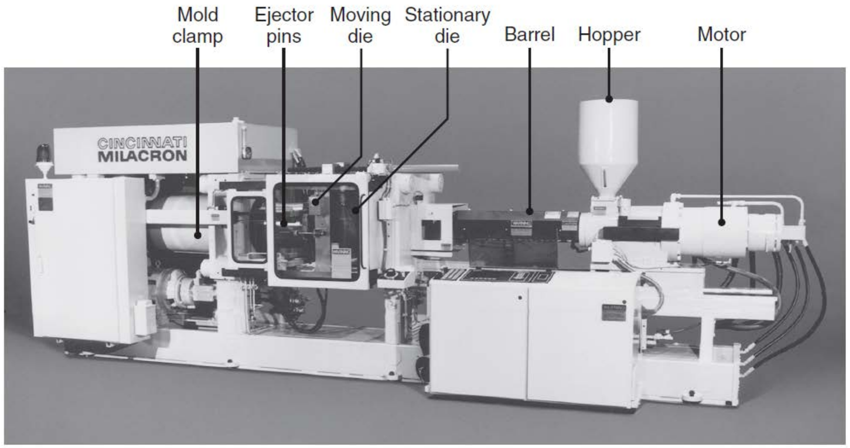
Injection Molding

Machines

- Injection-molding machines are horizontal
- Vertical machines are used for making small, close-tolerance parts and for insert molding
- Machines are rated according to the capacity of the mold and the clamping force
- High-volume production is essential to justify high expenditure



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Injection Molding

EXAMPLE 19.2

Force Required in Injection Molding

A 2.2-MNn injection-molding machine is to be used to make spur gears 110 mm in diameter and 2.5 mm thick. The gears have a fine-tooth profile. How many gears can be injection molded in one set of molds? Does the thickness of the gears influence your answer?

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Injection Molding

Solution

Force Required in Injection Molding

The pressures required in the mold cavity will be on the order of 100 MPa.

Cross-sectional (projected) area of the gear is $\pi(100^2)/4 = 9500\text{mm}^2$

The force required is (9500)(100) = 0.95 MN

We have 22 MN of clamping force available, the mold can accommodate two cavities and produce two gears per cycle.

As it does not influence the crosssectional area of the gear, the thickness of the gear does have influence.

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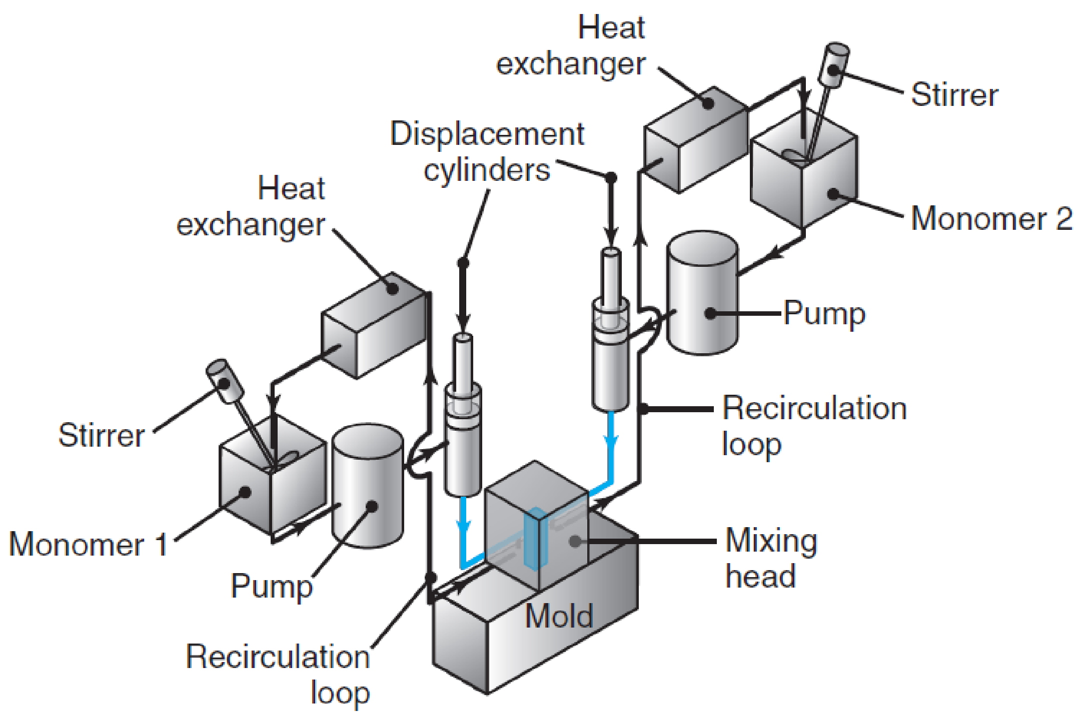
Injection Molding: Reaction-injection Molding

- In the *reaction-injection molding* (RIM) process, a monomer and two or more reactive fluids are forced at high speed into a mixing chamber and into the mold cavity



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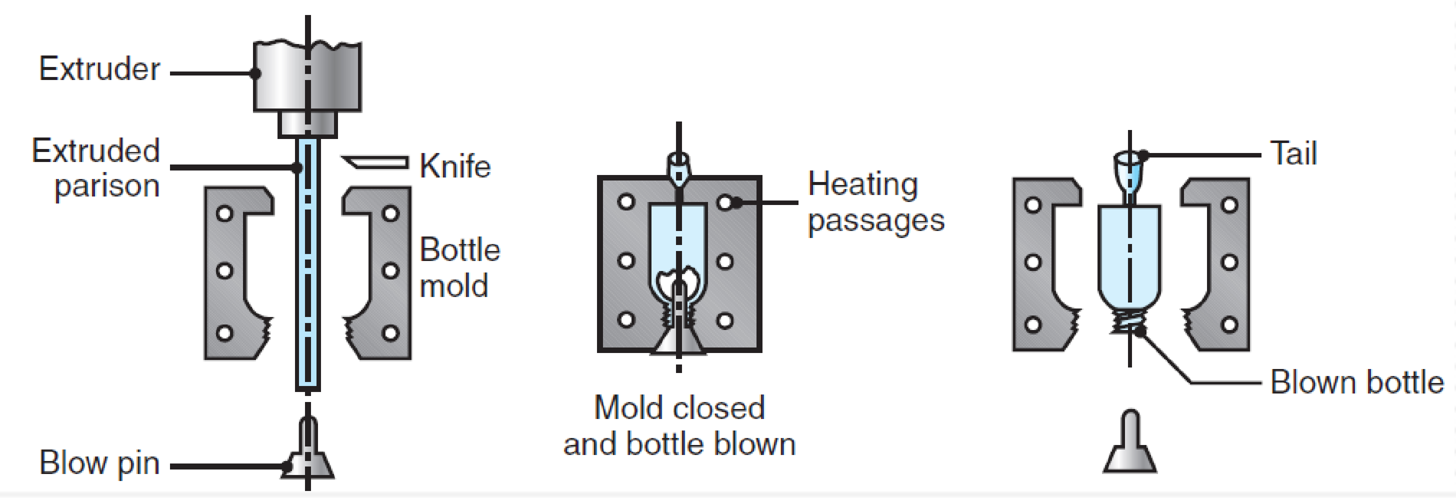
Blow Molding

- *Blow molding* is a modified extrusion- and injection-molding process
- In **extrusion blow molding**, a tube is first extruded, then clamped into a mold with a cavity and blown outward to fill the mold cavity



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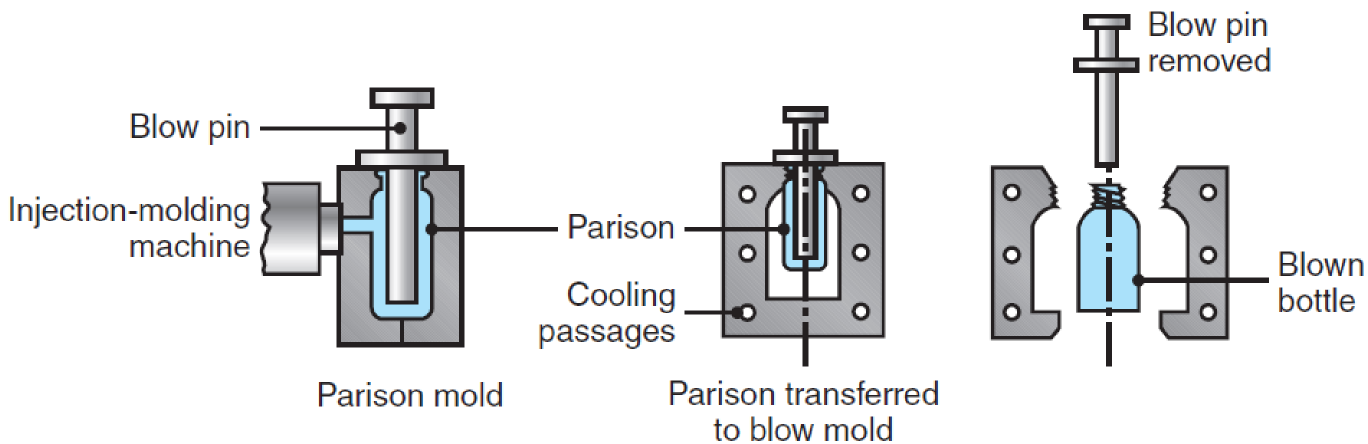
Blow Molding

- In **injection blow molding**, a short tubular piece (**parison**) is injection molded into cool dies



- The dies then open and the parison is transferred to a blow-molding die by an indexing mechanism

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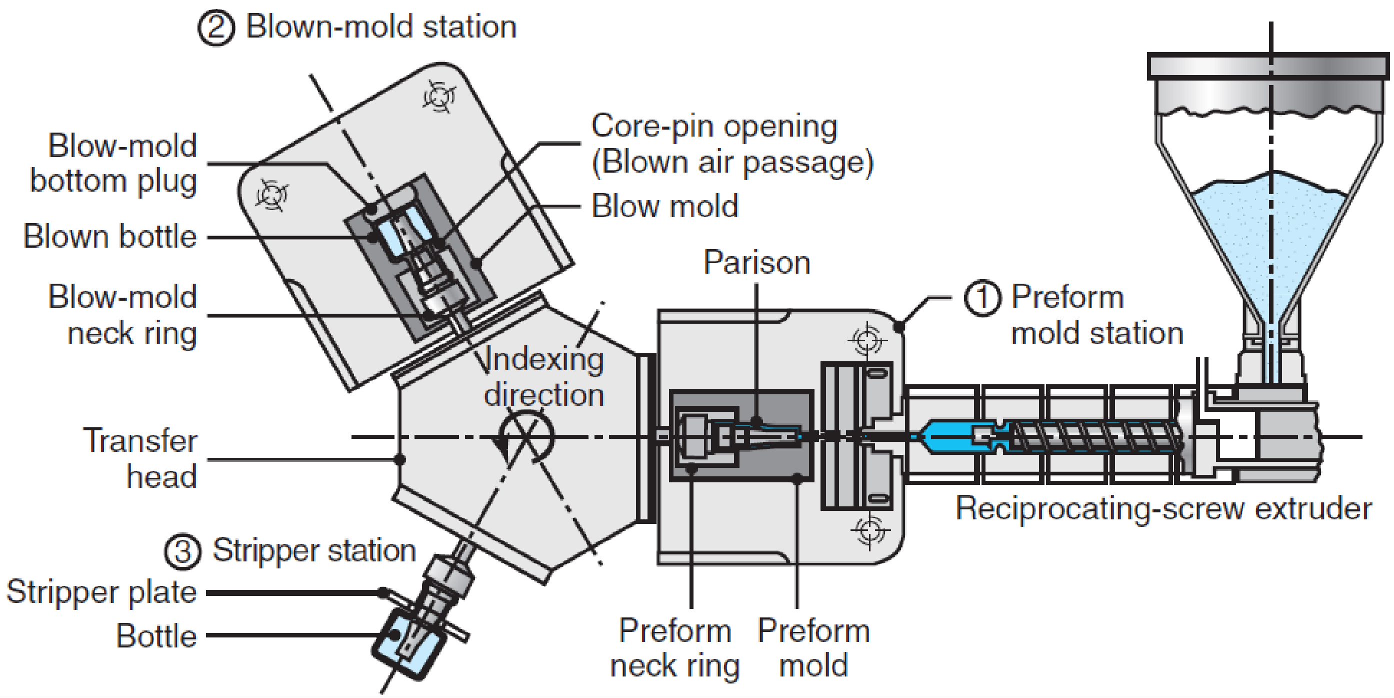
Blow Molding



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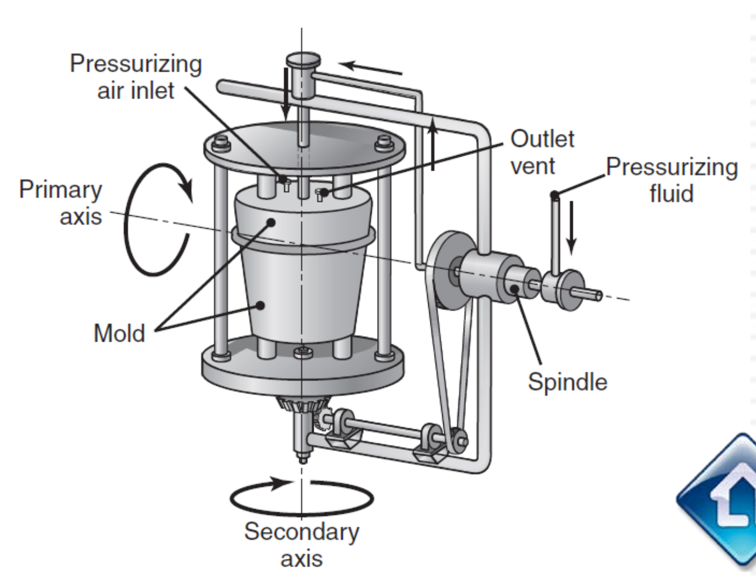
Rotational Molding

- Thermoplastics and thermosets can be formed into large, hollow parts by *rotational molding*
- A thin-walled metal mold is made in two pieces and is designed to be rotated about two perpendicular axes
- Liquid polymers (**plastisols**) can be used in rotational molding
- The mold is heated and rotated simultaneously



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Rotational Molding

Process Capabilities

- Can produce parts with complex, hollow shapes with small wall thicknesses
- Produce large parts volume
- Outer surface finish of the part is a replica of the surface finish of the inside mold walls
- Quality-control considerations usually involve accurate weight of the powder, proper rotational speed of the mold

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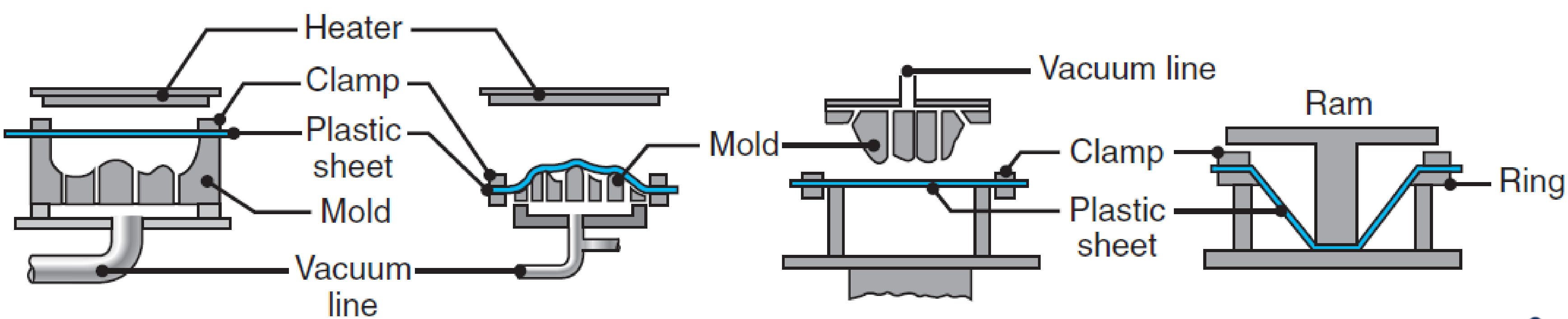
Thermoforming

- *Thermoforming* is a process for forming thermoplastic sheets or films over a mold through heat and pressure
- Due to low strength of the materials formed, the pressure difference caused by a vacuum is sufficient for forming



(a) Straight vacuum forming (b) Drape vacuum forming (c) Force above sheet (d) Plug and ring forming

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Thermoforming

Process Capabilities

- Used to produce packaging, trays for cookies and candy, advertising signs and refrigerator liners
- The material must exhibit high, uniform elongation, else it will neck and tear
- Molds for thermoforming are made of aluminum because high strength is not required, thus tooling is inexpensive

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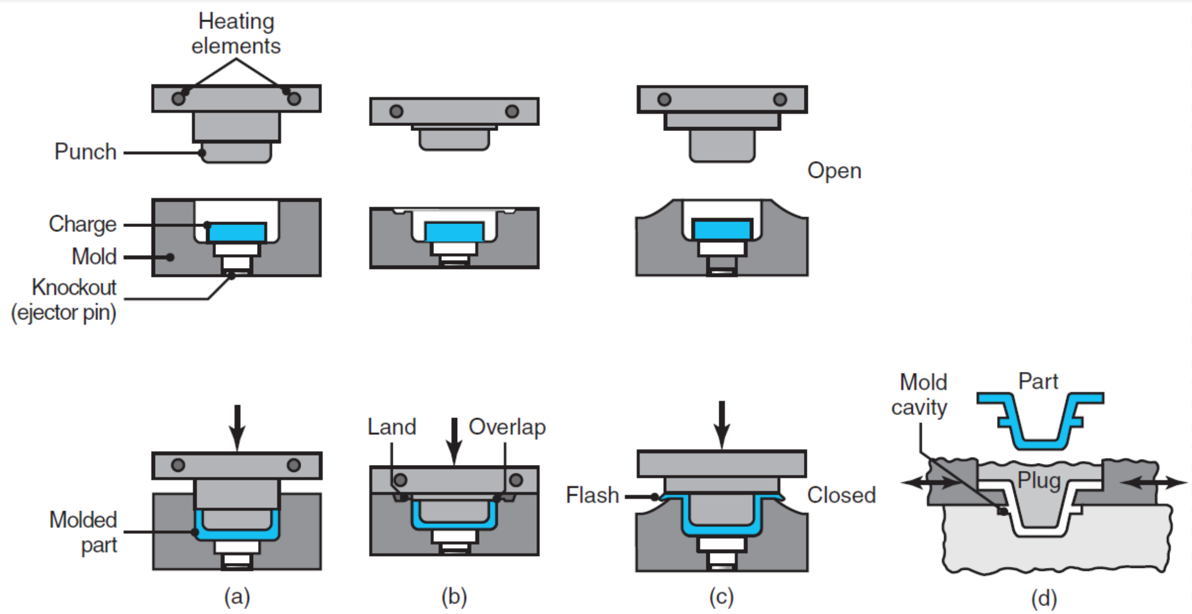
Compression Molding

- In *compression molding*, a viscous mixture of liquid-resin and filler material is placed into a heated mold cavity
- Forming is done under pressure from a plug or upper half of the die



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Compression Molding

Process Capabilities

- 3 types of compression molds are available:

1. *Flash type*: for shallow or flat parts
2. *Positive type*: for high-density parts
3. *Semipositive type*: for quality production

- Complexity of parts produced is less than that from injection molding
- Dimensional control is better

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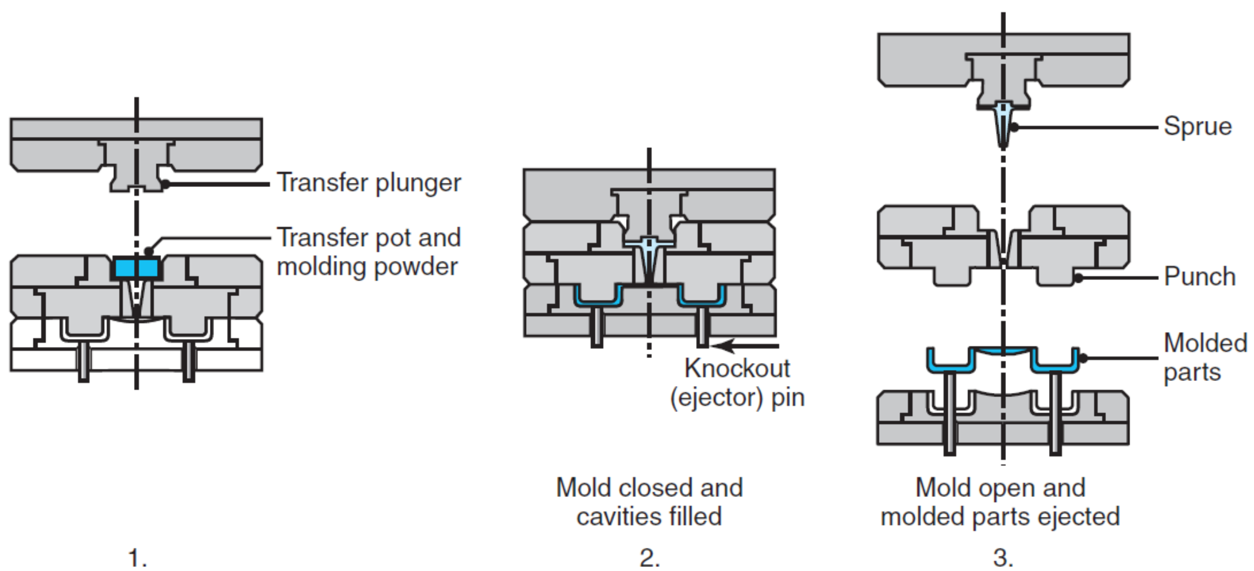
Transfer Molding

- *Transfer molding* is a further development of compression molding
- The uncured thermosetting resin is placed in a heated transfer pot or chamber and after the material is heated, it is injected into heated closed molds



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Transfer Molding

Process Capabilities

- Suitable for intricate shapes with varying wall thicknesses
- Molds are more expensive
- Some excess material will be left in the channels of the mold during filling

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Casting

- Thermoplastics and thermosetting plastics can be *cast* into shapes using rigid or flexible molds
- Casting is a slow but simple and inexpensive process
- Polymer must have low viscosity in order to flow easily into the mold

Centrifugal Casting

- Similar to centrifugal metal casting
- Used with thermoplastics, thermosets and reinforced plastics with short fibers

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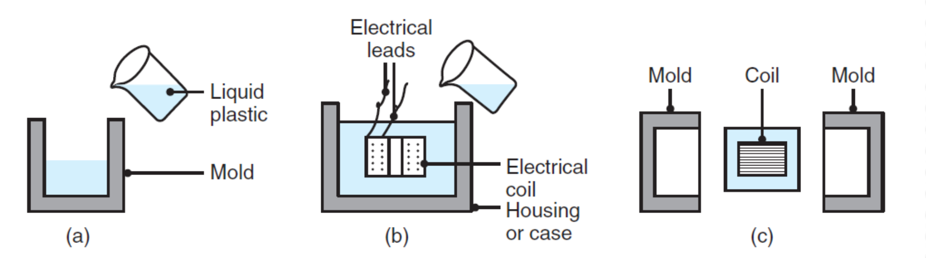
Casting

Potting and Encapsulation

- *Potting* and *encapsulation* involve casting the plastic material around an electrical component to embed it in the plastic
- *Potting* is carried out in a housing or case, which becomes an integral part of the component and fixes it in position
- In *encapsulation* the component is coated with a layer of the plastic, surrounding it completely and solidifying



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Foam Molding

- Products are styrofoam cups, food containers, insulating blocks and shaped packaging materials
- In *foam molding,* raw material is expandable **polystyrene beads** where products have a **cellular structure**
- Structure may have *open and interconnected porosity* or have *closed cells*
- Amount of expansion can be controlled by varying the temperature and time
- A common method of foam molding is to use *preexpanded polystyrene beads*

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Foam Molding

Structural Foam Molding

- Molding process used to make plastic products with a *solid outer skin* and a *cellular core structure*
- Thermoplastics are mixed with a blowing agent and injection molded into cold molds of desired shapes

Polyurethane Foam Processing

- Furniture cushions and insulating blocks are made by this process
- Starts with the mixing of two or more components and allowing chemical reactions to take place

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Cold Forming and Solid-phase Forming

- Used in the cold working of metals and form thermoplastics at room temperature (*cold forming*)
- Considerations for this process are the polymer must be ductile at room temperature and its deformation must be non-recoverable
- Advantages of the cold forming of plastics are:

1. Strength, toughness and uniform elongation are increased
2. Superior properties using high molecular weights plastics
3. Forming speeds are not affected by part thickness

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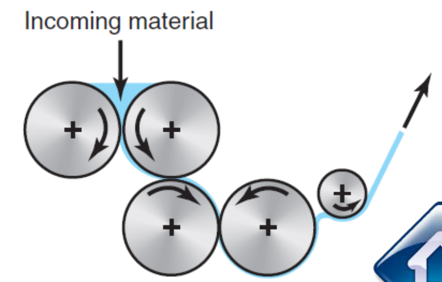
Processing Elastomers

- In terms of its processing characteristic, thermoplastic *elastomer* is a polymer
- In terms of its function and performance, it is a *rubber*
- Additives can enhances properties such as tensile and fatigue strength, abrasion and tear resistance, ultraviolet protection and resistance to chemicals
- Elastomers can be shaped by a variety of processes that are used for shaping thermoplastics
- Thermoplastic polyurethane can be shaped by all conventional methods
- Rubber and thermoplastic sheets are formed by the **calendering** process



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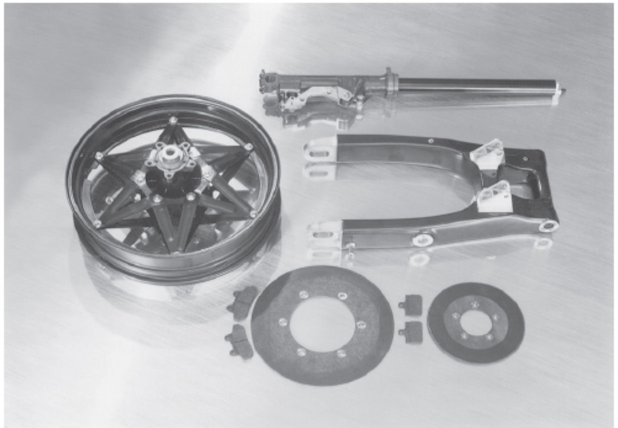
Processing Polymer-matrix Composites

- Polymer-matrix composites (PMCs) are *engineered materials* with unique mechanical properties, especially high strength-to-weight ratio, stiffness-to-weight ratio, fatigue strength, creep resistance, and directional properties
- Polymer-matrix composites can be fabricated to ensure reliable properties in composite parts and structures



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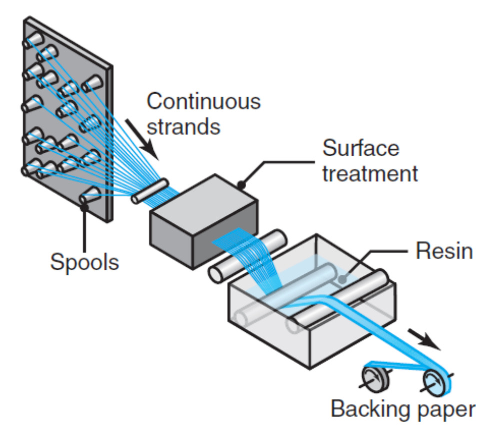
Processing Polymer-matrix Composites: Fiber Impregnation

- To obtain good bonding and protect during handling, fibers are surface treated by impregnation (*sizing*)

Prepregs

- To produce fiber-reinforced plastic *prepregs,* the continuous fibers are aligned and subjected to a surface treatment to enhance the adhesion to the polymer matrix



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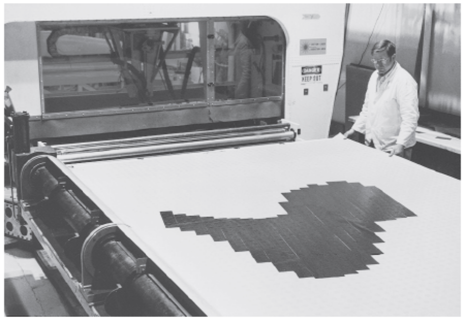
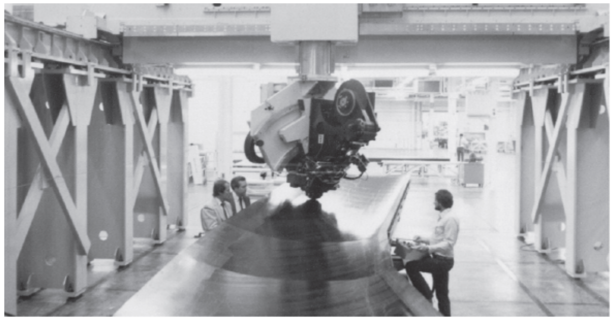
Processing Polymer-matrix Composites: Fiber Impregnation

Prepregs

- They are then coated by dipping them in a resin bath and are made into a *tape*
- Individual segments of prepreg tape are then cut and assembled into *laminated structures*
- Automated *computer-controlled tape-laying machines* have been built for laying prepreg tapes

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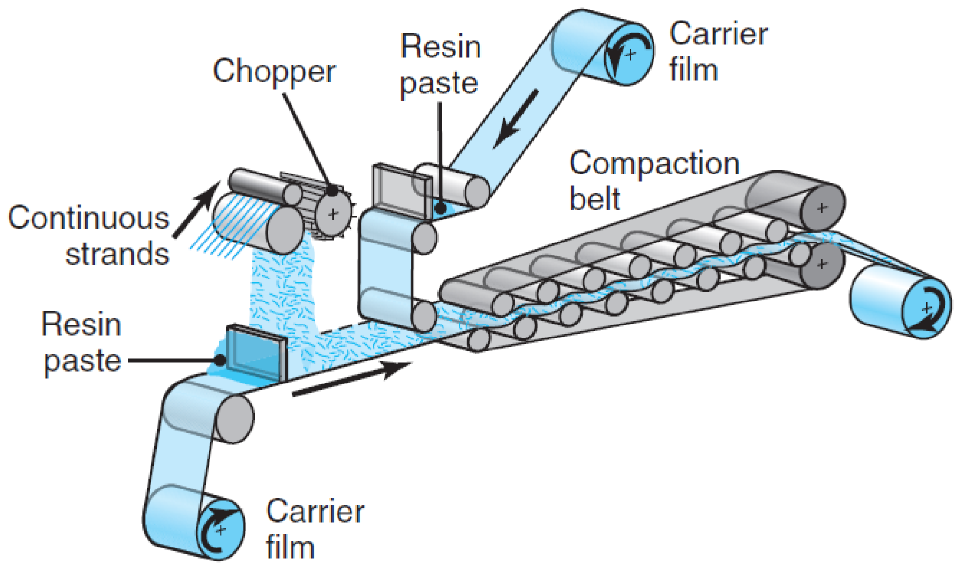
Processing Polymer-matrix Composites: Fiber Impregnation

Sheet-molding Compound

- In making *sheet-molding compound* (SMC), continuous strands of reinforcing fiber are chopped and deposited in random orientations over a layer of resin paste



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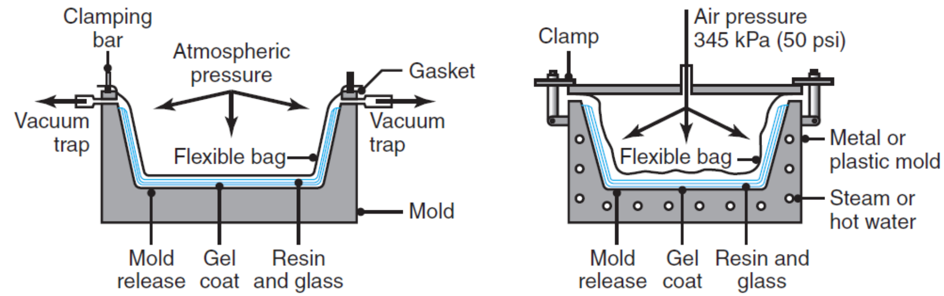
Processing Polymer-matrix Composites: Molding of Reinforced Plastics

Compression Molding

- Material is placed between 2 molds and pressure applied
- Sheet-molding compounds also can be processed

Vacuum-bag Molding

- Prepregs are laid in a mold to form the desired shape
- **Pressure-bag molding** is placed over the resin and reinforcing fiber mixture and pressure is applied



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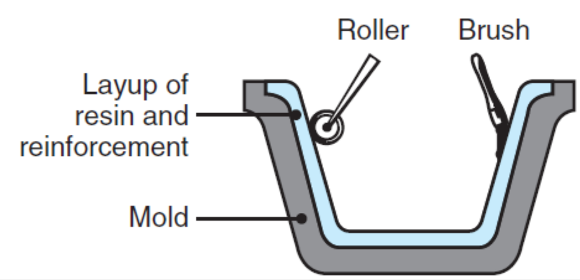
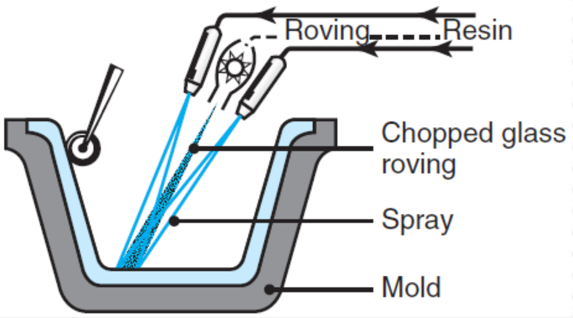
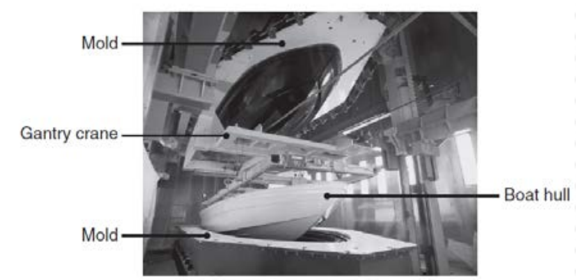
Processing Polymer-matrix Composites: Molding of Reinforced Plastics

Contact Molding

- Also referred to as *open-mold processing*
- Use a single male or female mold made of reinforced plastics, wood, metal, or plaster
- Contact molding is used in making *laminated products* with high surface area–to-thickness ratios
- 2 types: **hand layup** and **spray layup**







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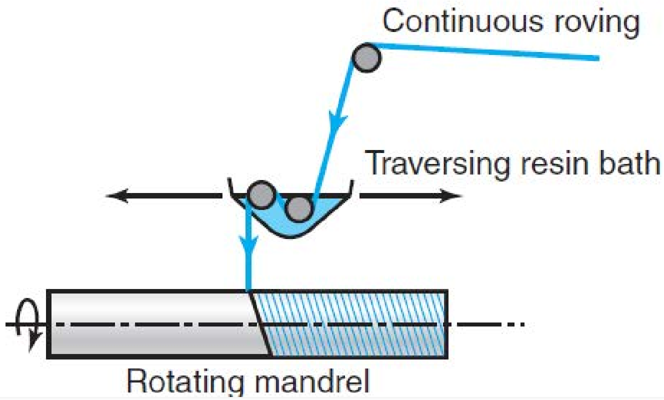
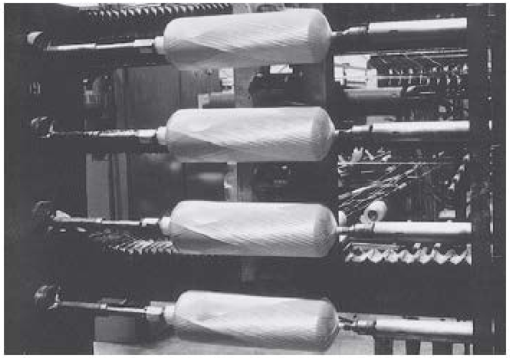
Processing Polymer-matrix Composites: Filament Winding, Pultrusion, and Pulforming

Filament Winding

- A process where resin and fibers are combined at the time of curing in order to develop a composite structure
- Products made by filament winding are very strong because of their highly reinforced structure





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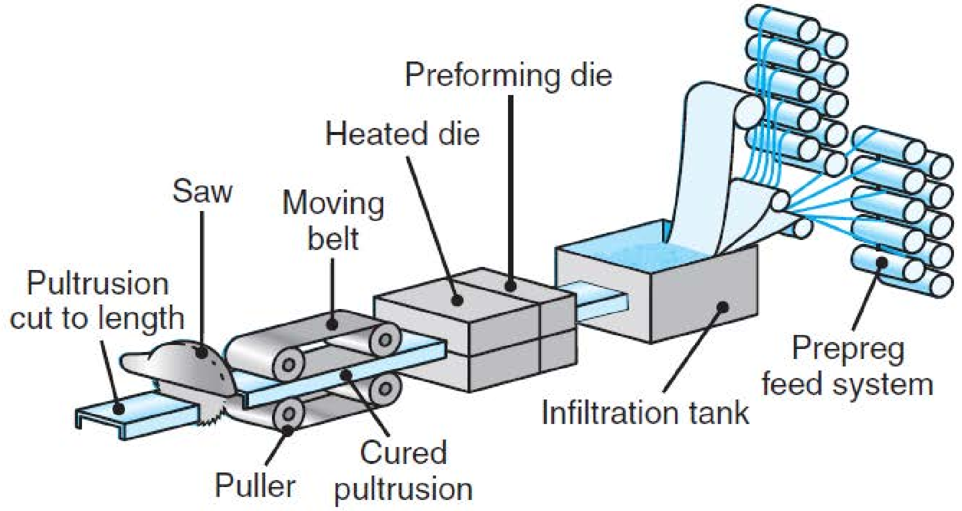
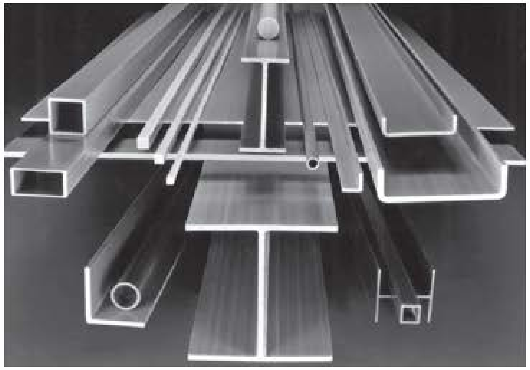
Processing Polymer-matrix Composites: Filament Winding, Pultrusion, and Pulforming

Pultrusion

- Long parts with various uniform cross sections made continuously by the *pultrusion* process
- Continuous reinforcement, glass roving, or fabric is supplied through several bobbins





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Processing Polymer-matrix Composites: Filament Winding, Pultrusion, and Pulforming

EXAMPLE 19.3

Polymer Automotive-body Panels Shaped by Various Processes

- Polymeric materials are used for automobile bodies
- Materials are selected for design flexibility, impact strength and toughness, corrosion resistance, high durability, and low mass

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Processing Polymer-matrix Composites: Quality Considerations in Processing Reinforced Plastics

- Gases must be allowed to escape from the layup through the vacuum bag in order to avoid porosity due to trapped gases
- Microcracks may develop during improper curing or during the transportation and handling of parts

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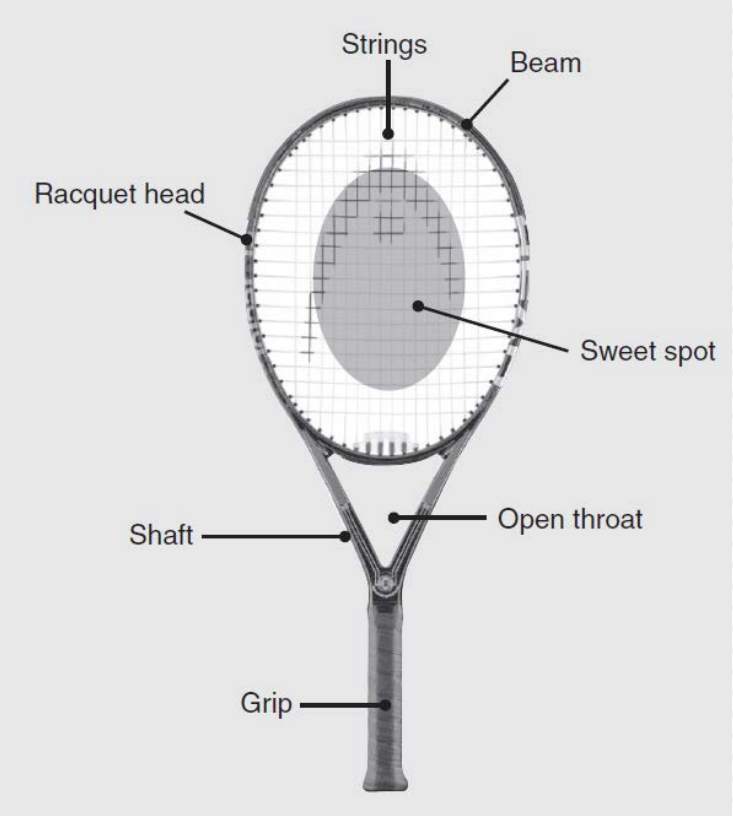
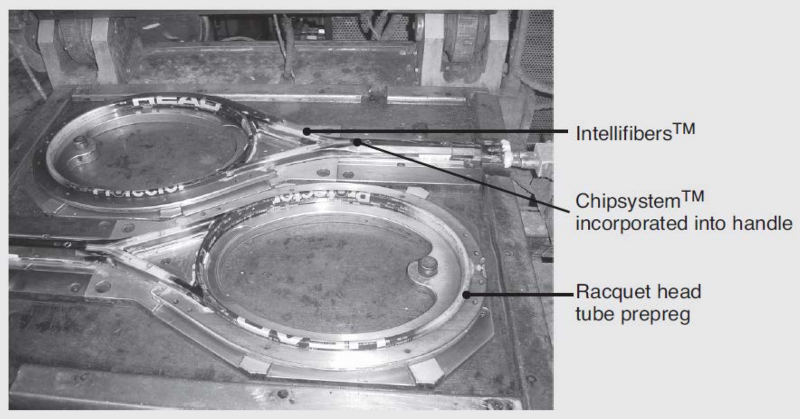
Processing Polymer-matrix Composites: Quality Considerations in Processing Reinforced Plastics

CASE STUDY 19.1

Manufacture of Head Protector™ Tennis Racquets





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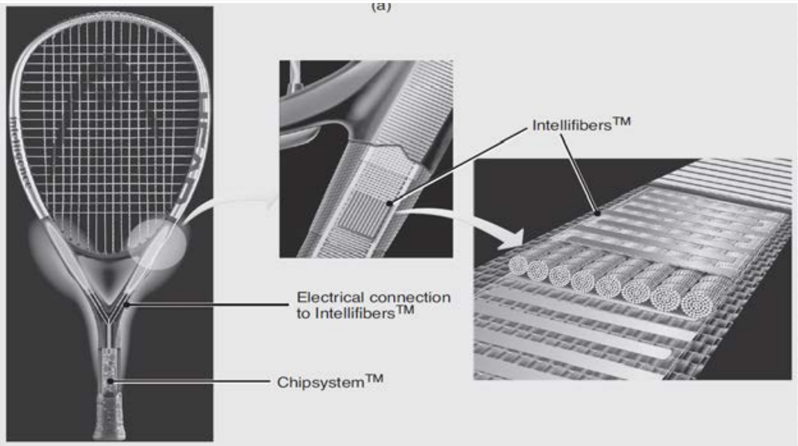

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Processing Metal-matrix and Ceramic-matrix Composites

- Metal-matrix composites (MMCs) can be made into near-net shaped parts by:

1. **Liquid-phase processing**
2. **Solid-phase processing**
3. **Two-phase (liquid–solid) processing**

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Processing Metal-matrix and Ceramic-matrix Composites

EXAMPLE 19.4

Metal-matrix Composite Brake Rotors and Cylinder Liners

- Brake rotors are made of composites consisting of an aluminum-based matrix reinforced with 20% silicon-carbide particles
- To improve the wear- and heat resistance of cast iron cylinder liners in aluminum engine blocks, aluminum-matrix liners also are being developed

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Processing Metal-matrix and Ceramic-matrix Composites: Processing Ceramic-matrix Composites

- Other process used to make ceramic-matrix composites (CMCs):

1. **Slurry infiltration**
2. **Chemical-synthesis**
3. **chemical-vapor infiltration**

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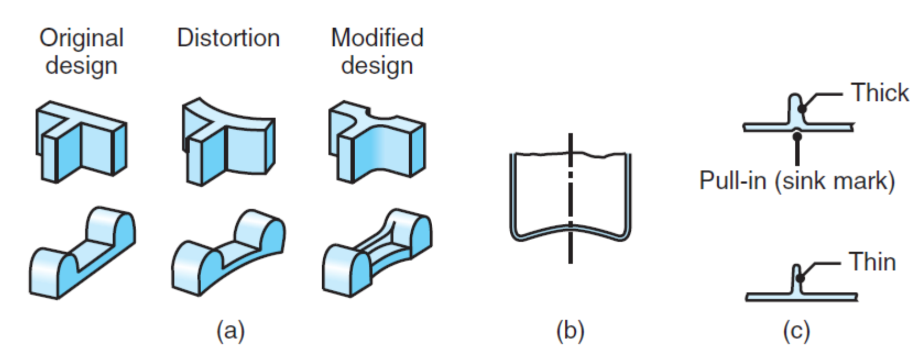
Design Considerations

- General design guidelines for the production of plastic and composite-material parts:

1. Complex parts with internal and external features can be produced with relative ease and at high production rates
2. Plastics have much lower stiffness and strength, section sizes and shapes should be selected accordingly
3. Overall part shape and thickness determine the shaping or molding process to be selected



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Design Considerations

4. Large variations in cross-sectional areas, section thicknesses, and abrupt changes in geometry, should be avoided to achieve the desired shape
5. Low elastic moduli of plastics requires that shapes be selected properly for improved stiffness of the component
6. Improper part design or assembly can lead to distortion and uneven shrinking
7. Properties of the final product depend on the original material and its processing history
8. Reinforced plastics has directional nature of the strength of the composite

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Economics of Processing Plastics and Composite Materials

- Design and manufacturing decisions are based on performance and cost
- Final selection of a process depends greatly on production volume

Comparative Production Characteristics of Various Molding Methods

Molding method	Equipment and tooling cost	Production rate	Economical production quantity
Extrusion	M–L	VH–H	VH
Injection molding	VH	VH	VH
Rotational molding	M	M–L	M
Blow molding	M	H–M	H
Compression molding	H–M	M	H–M
Transfer molding	H	M	VH
Thermoforming	M–L	M–L	H–M
Casting	M–L	M–L	L
Centrifugal casting	H–M	M–L	M–L
Pultrusion	H–M	H	H
Filament winding	H–M	L	L
Spray layup and hand layup	L–VL	L–VL	L

VH = very high; H = high; M = medium; L = low; VL = very low.

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MACHINING FROM STOCK

During machining of plastics the followings should be considered:

Low modulus of elasticity
High elastic recovery
Poor conduction of heat
Higher thermal expansion

Guidelines in specifying tool geometry:

1) Provide polished surfaces on those tool areas coming in contact with the work so as to minimise frictional drag and resulting heat generation

2) Design tools so that continuous type chips are produced. This involves the precaution of large rake angles The rake angle will be dependent on the depth of cut, cutting speed, and the type of plastic material.

3) In drill design, the packaging of chips should be avoided by providing wide polished fluites and low helix angle.

4) In turning and milling, diamond tools provide the best accuracy, surface finish and uniformity. Surface speeds of 150-200 m/min with feeds of 0,05-0.10 mm are typical.