Fabrication of Plastics, Ceramics, and Composites

14.1 Introduction

- Plastics, ceramics, and composites have **different structure** and **properties** than metals
- Principles of **material selection** and **manufacturing** are **different**
- Provide required **properties** and **fabrication** processes to produce **desired shape** in an **economical way**
- **Large, complex shapes** can be formed as a single unit
- Processes can produce a **near perfect shape** and **surface product**

14.1 Introduction

- Many of fabrication processes convert raw materials into a finished product in **a single operation**
- **Properties** of these materials are affected by **processes** used to produce shapes.
- Fabrication of an acceptable product involves selections:
  - **Appropriate material**, and
  - **Companion method** of processing, such that the resulting combination provides the desired shape, properties, precision, and finish surface.

14.2 Fabrication of Plastics

- A successful plastic product is manufactured so that it satisfies the various **mechanical** and **physical property** requirements
- The preferred **manufacturing method** is determined by the **desired size, shape,** and **quantity** and **type of polymers.**
- There are three main different types of polymers: **thermoplastics, thermosets**, and **elastomers**

14.2 Fabrication of Plastics

- **Thermoplastics** can be heated to produce either a soft, formable solid, or liquid. It can be cast, injected into a mold, or forced into or through dies to produce a desired shape.
- **Thermosets** can’t be further deformed once polymerization has occurred.
- **Elastomers** are sufficiently unique.

14.2 Fabrication of Plastics

- Fabrication Processes of Plastics
  - Casting
  - Blow Molding
  - Compression Molding
  - Transfer Molding
  - Cold Molding
  - Injection Molding
  - Reaction Injection Molding
  - Extrusion
  - Thermoforming
  - Rotational Molding
  - Form Molding
  - Other Plastic-Forming Processes

Casting

- **Simplest** of the **shape-forming processes**
- No fillers and no pressure is required
- **Thermoplastics** are the main type of polymer that can be casted
  - Acrylics, nylons, urethanes, and PVC plastisols
- Some thermosets can also be cast

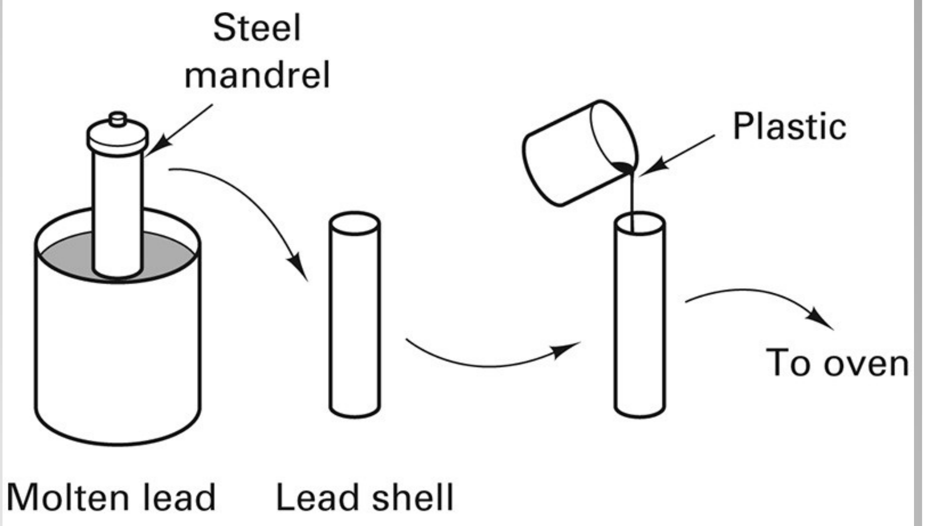


Figure 14-1 Steps in the casting of plastic parts using a lead shell mold.

Blow Molding

- **Thermoplastics** can be converted to hollow-shape containers such as bottles
- The preform is heated and placed between the two mold halves
- The mold closes and the preform is expanded from air or gas pressure
- The mold is then cooled, halves separated, and the product is removed
- Flash, extra material, is trimmed from the part and recycled

Blow Molding

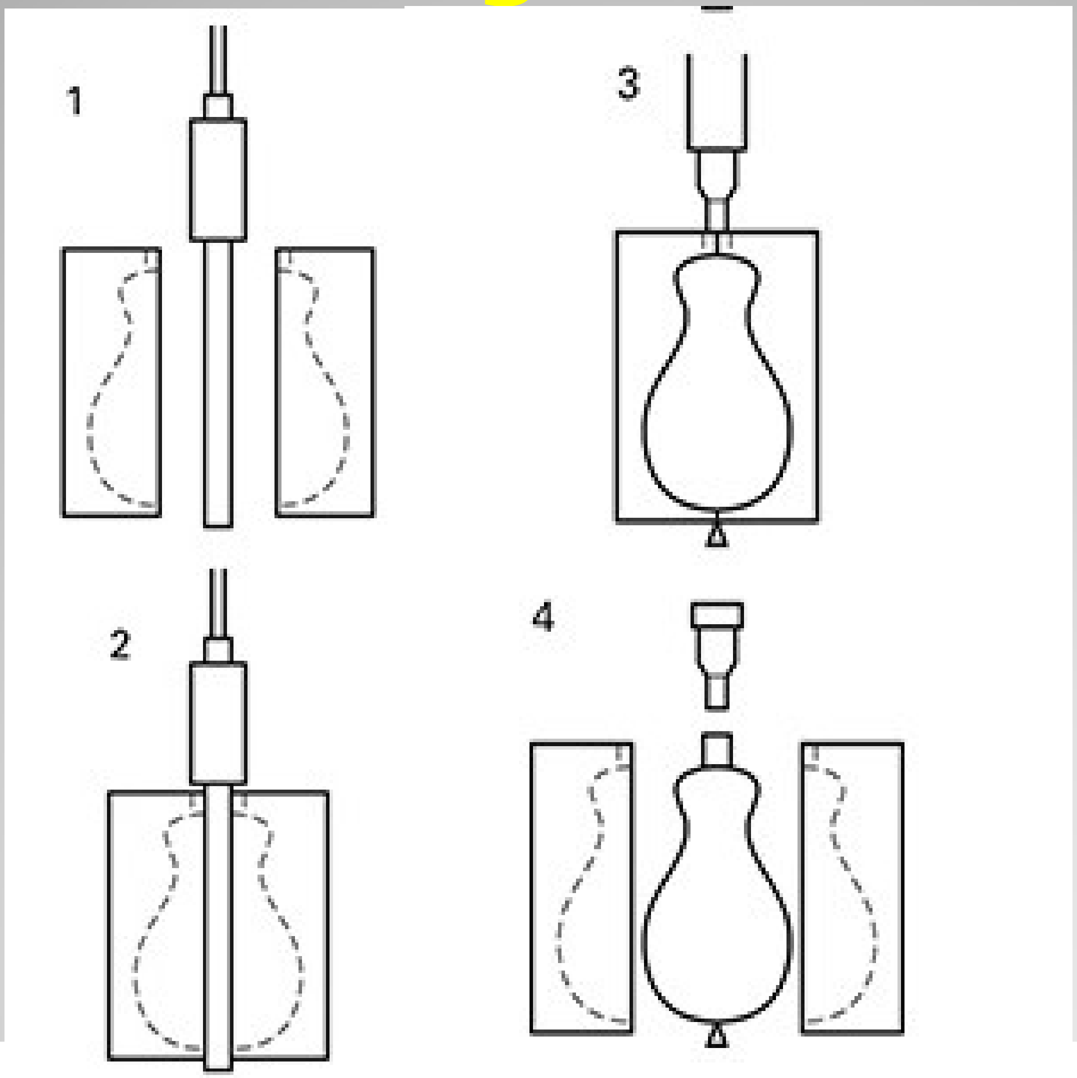
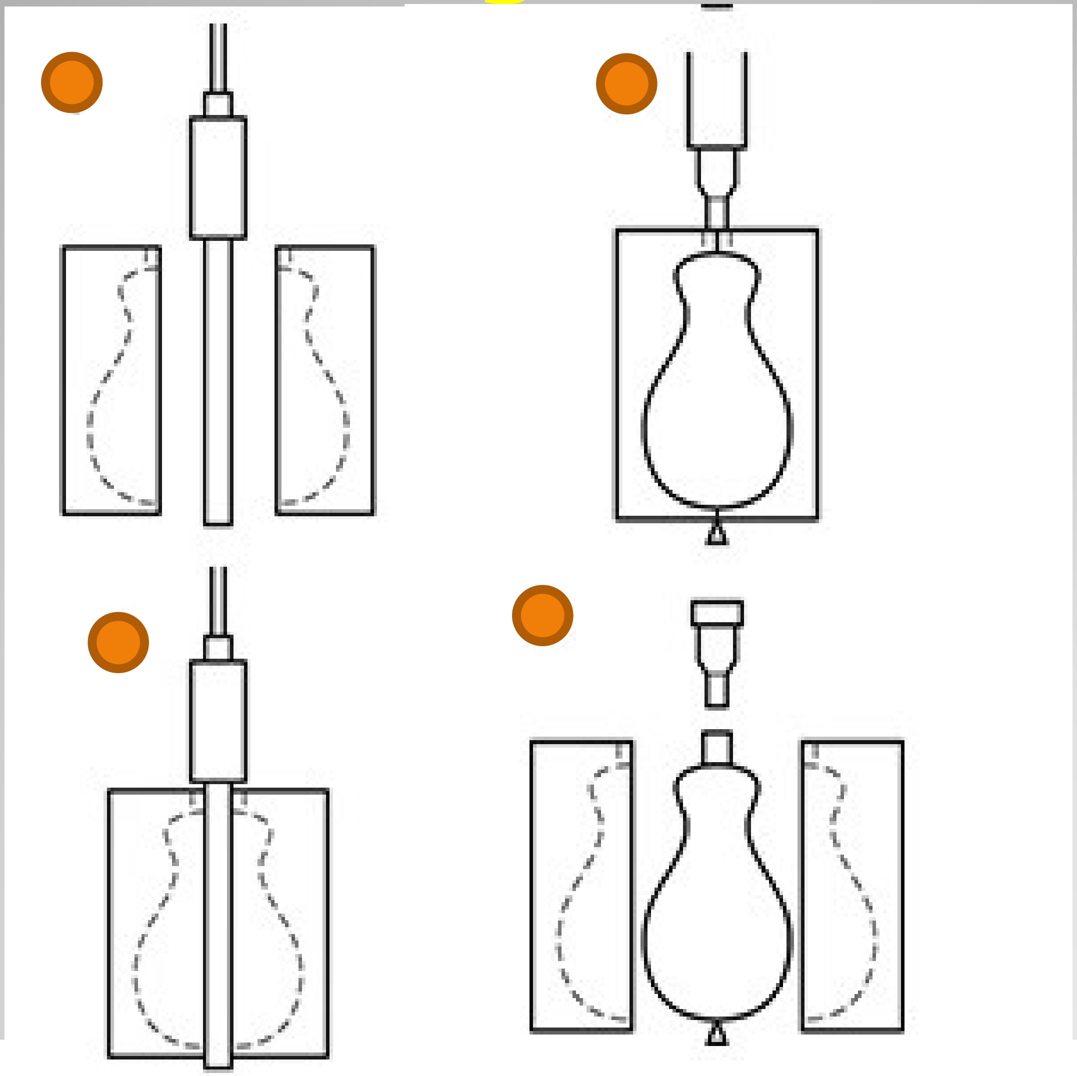


Figure 14-2 Steps in blow molding plastic parts: (1) a tube of heated plastic is placed in the open mold; (2) the mold closes over the tube, simultaneously sealing the bottom; (3) air expands the tube against the sides of the mold; and (4) after sufficient cooling, the mold opens to release the product.

Blow Molding



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Compression Molding or Hot-Compression Molding

- Solid granules or preformed tablets of **unpolymerized plastic** are placed into an open, **heated** cavity
- A heated plunger applies pressure to the plastics, melting it and making it turn into a fluid
- The pressure in the cavity is maintained until the material is set

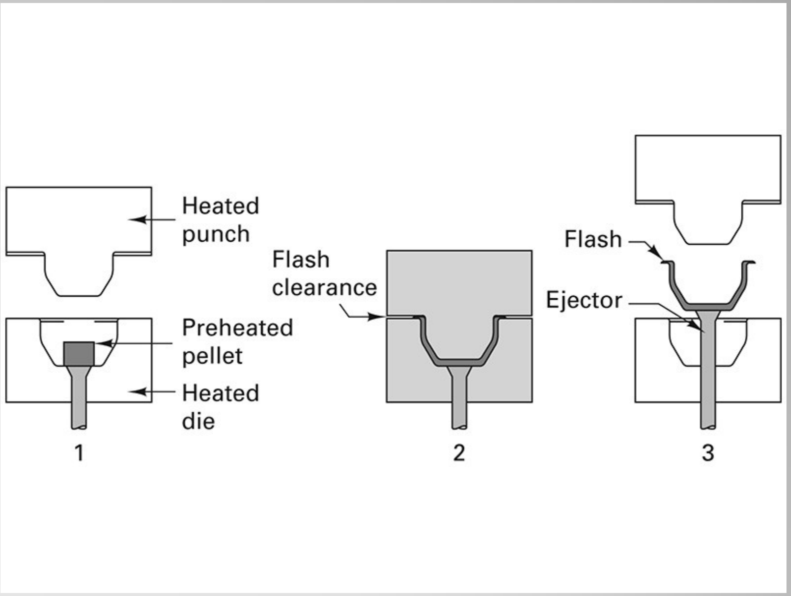


Figure 14-3 The hot-compression molding process: (1) solid granules or a preform pellet is placed in a heated die; (2) a heated punch descends and applies pressure; and (3) after **curing (thermosets)** or **cooling (thermoplastics),** the mold is opened and the part is removed.

Compression Molding or Hot-Compression Molding

- **Costs for compression molding are much lower** than complete processing
- **High dimensional precision** and **high surface finishing**
- Typical parts are gaskets, seals, exterior automotive panels, and aircraft fairings
- Manufacturing equipment typically consists of a hydraulic or pneumatic press
- Primarily used with thermosetting polymers, but recently it is also used for shaping thermoplastics and composites.

Transfer Molding

- **Reduces turbulence** and **uneven flow** that occurs often in high pressure, hot-compression molding
- The material is first heated until molten and then is forced into the cavity by a plunger
- The temperature and pressure are maintained until the **thermosetting** resin has cured

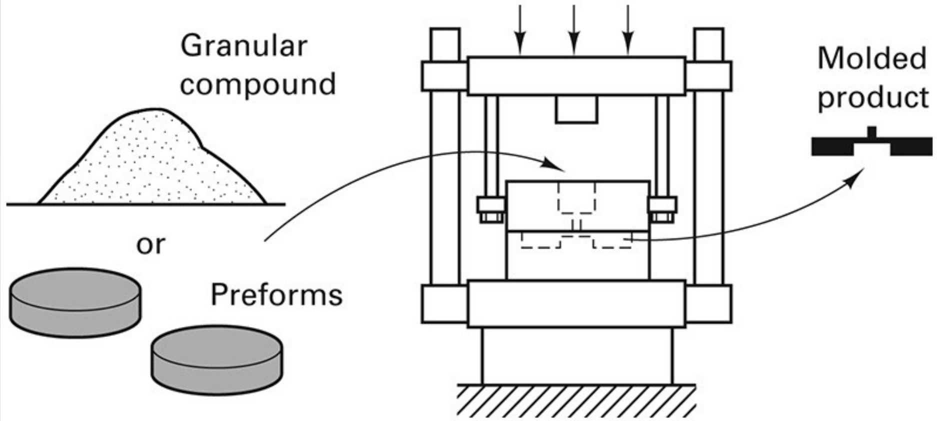


Figure 14-4 Diagram of the transfer molding process. Molten or softened material is first formed in the upper heated cavity. A plunger then drives the material into an adjacent die.

Cold Molding

- In cold molding, **uncured thermosetting** material is **pressed to shape** while **cold**
- The material is then removed from mold and cured in a separate oven.
- Advantages:
  - Faster
  - More economical
- Disadvantages
  - Not good surface finish
  - Not good dimensional precision

Injection Molding

- **Used for high-volume production** of **complex thermoplastic parts**
- Granules of a raw material are fed through a hopper into a cavity that is ahead of a plunger
- The plunger moves forward and the material is heated
- In the torpedo section, the material is mixed, melted, and superheated
- The fluid then flows through a nozzle that is against the mold
- Sprues and runners are used in the same way as in metal casting

Injection Molding

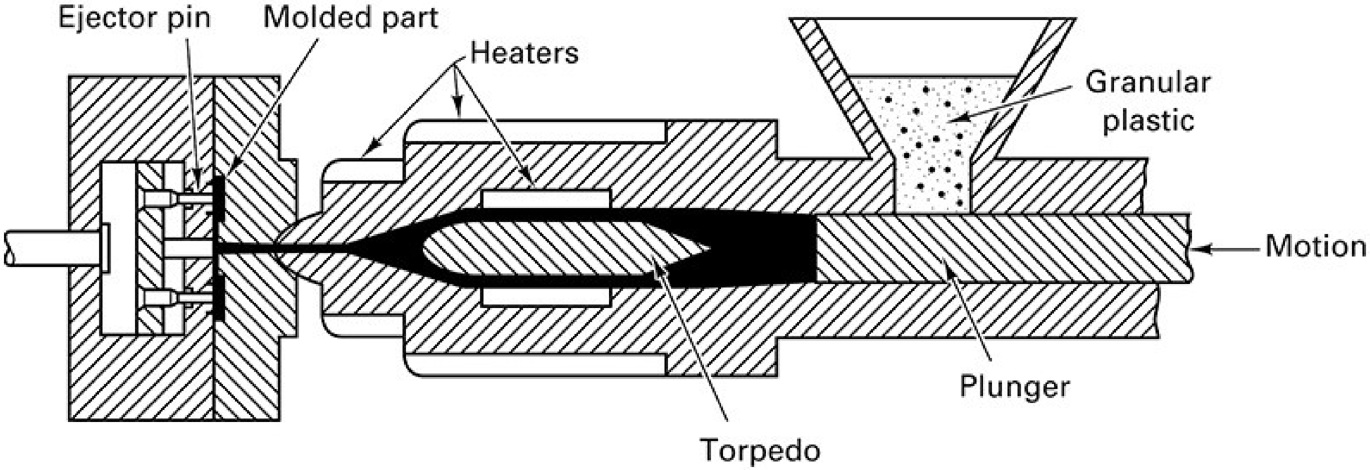


Figure 14-5 Schematic diagram of the injection molding process. A moving plunger advances material through a heating region (in this case, through a heated manifold and over a heated torpedo) and further through runners into a mold where the molten thermoplastic cools and solidifies.

Reaction Injection Molding

- **Two or more liquid reactants** are **mixed under pressure**
- The mixture then flows through a pressure-reducing chamber and into a mold
- **Exothermic reaction** causes the **thermosets** to polymerize
- Curing times are typically **less than a minute**
- **Low processing temperatures** and **low injection pressures**
    - Typical for casting **large parts**

Reaction Injection Molding

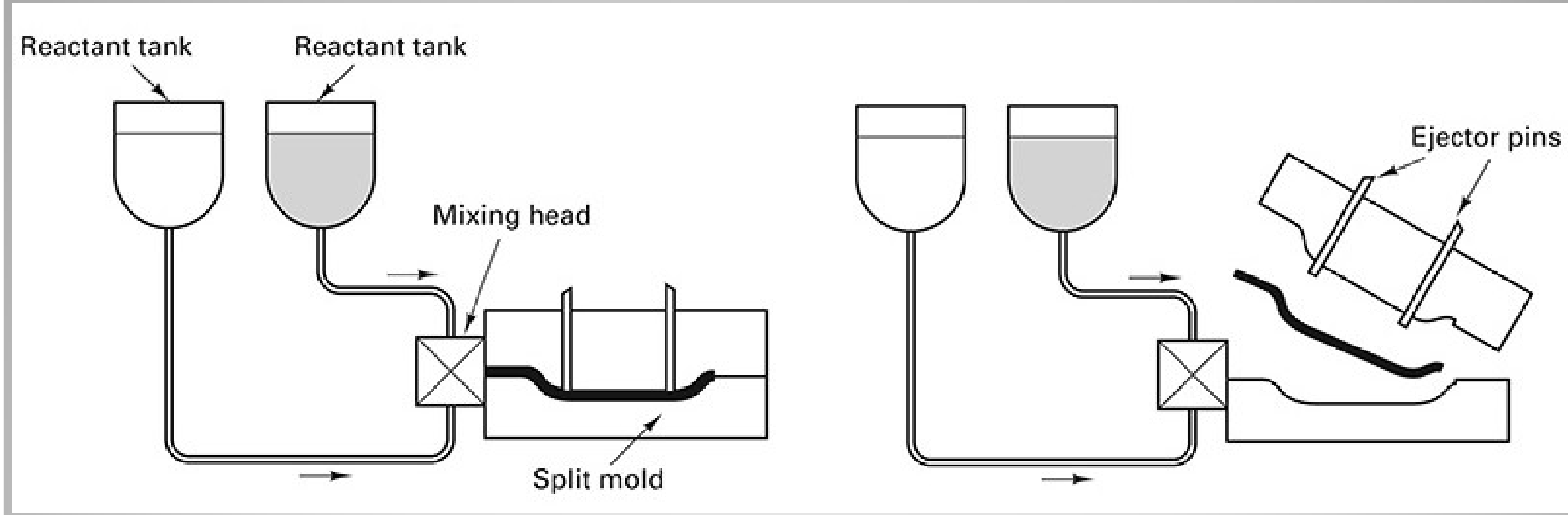


Figure 14-6 The reaction injection molding process. (Left) Measured amounts of reactants are combined in the mixing head and injected into the split mold. (Right) After sufficient curing, the mold is opened and the component is ejected.

Extrusion

- Used for **long plastic products with a uniform cross-section**
- Pellets or powders are fed through a hopper and then into a chamber with a large screw
- The screw rotates and propels the material through a preheating section where it is heated, homogenized, and compressed
- To preserve its shape, the material is cooled by jets of air or water spraying

Extrusion

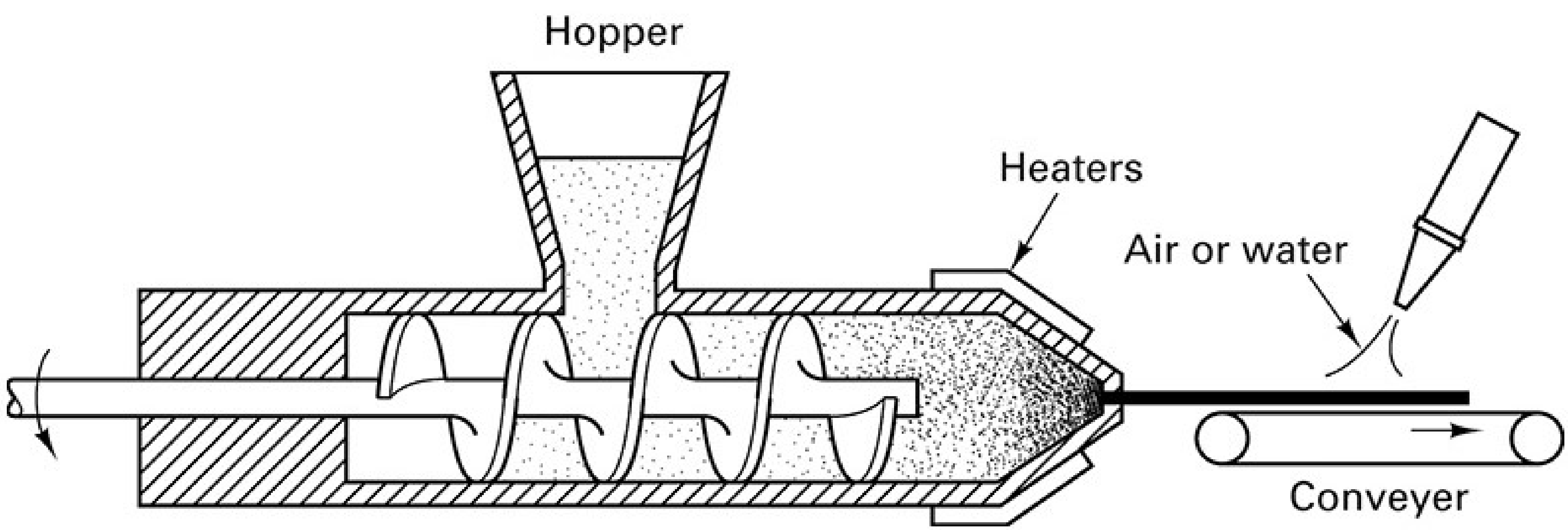


Figure 14-7 A screw extruder producing thermoplastic product. Some units may have a changeable die at the exit to permit production of different-shaped parts.

Thermoforming

- **Thermoplastic sheet** material is heated and then placed over a mold
- A **vacuum, pressure, or mechanical tool** is applied **to draw the material into the mold**
- The die can impart the dimensions and finish or texture on the final product
- Typical products are thin-walled parts, plastic luggage, plastic trays, and panels for light fixtures

Thermoforming

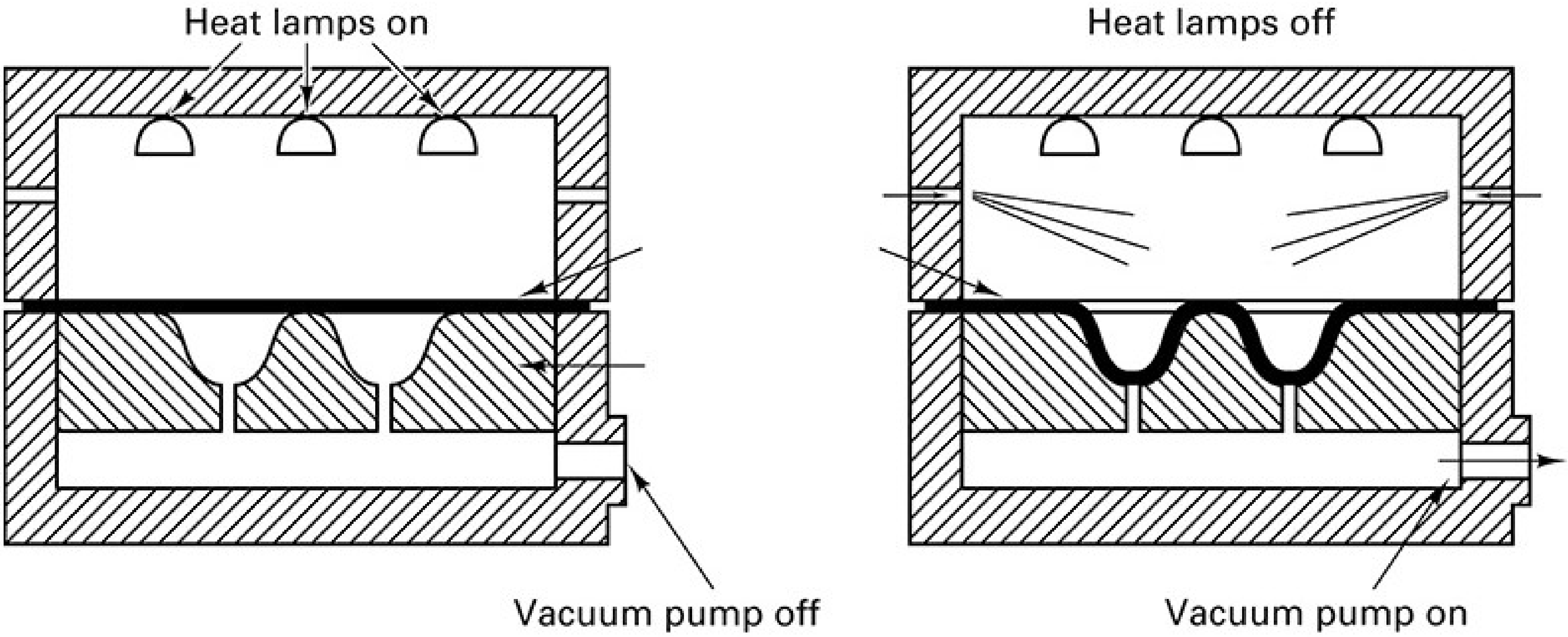


Figure 14-8 A type of thermoforming where **thermoplastic** sheets are shaped using a combination of heat and vacuum.

Rotational Molding

- **Produces hollow, seamless products**
- Typical products are tanks, bins, refuse containers, doll parts, footballs, helmets, and boat hulls
- A mold or cavity is filled with a specific amount of **thermoplastic powder** or **liquid**
- The molds are then placed in an oven and rotated simultaneously about two perpendicular axes
- The resin is evenly distributed across the mold walls
- All of starting material is used in the product, no scrap is generated.

Foam Molding

- **A foaming agent** is mixed with a **plastic resin** and releases **gas** when the material is heated during molding
- The materials expand to **2 to 50 times** their original size
- Produces **low density products**
- Both rigid and flexible foams can be produced
  - Rigid type is used for structural applications such as computer housings, packaging, and shipping containers
  - Flexible foams are used for cushioning

Other Plastic-Forming Processes

- Calendering process
  - A mass of **thermoplastic** is forced between and over two or more counter-rotating rolls to produce thin sheet or films of polymer.
- Drawing
- Rolling
- Spinning
- Many of these processes can be combined with other processes to produce a final part

Machining of Plastics

- Plastics can undergo many of the same processes of metals
  - **Milling, sawing, drilling, and threading**
- General characteristics of plastics that affect machining
  - **Poor thermal conductors**
  - **Soft** and may **clog tooling**
  - Softening may **reduce the precision** of the final dimensions of **thermoplastics**
  - **Thermosets** can have **more precise dimensions** because of its rigidity

Tooling Considerations for Machining Plastics

- **High temperatures** may develop at the cutting point and cause **the tools to be hot**
- **Carbide tools may be preferred** over high-speed tool steels **if high-speed cutting is performed**
- **Coolants can be used** to keep temperatures down
  - Water, soluble oil and water, weak solutions of sodium silicate
- **Lasers** may be used for cutting operations

Finishing and Assembly Operations

- Printing, hot stamping, vacuum metallizing, electrolapping, and painting can be used on plastics
- **Thermoplastic polymers** can be **joined** by heating relevant surfaces
  - The heat can be applied by a stream of hot gases, applied through a soldering iron, or generated by ultrasonic vibrations
- **Snap-fits** may be used to assemble plastic components
- Self-tapping screws can also be used

Designing for Fabrication

- Materials should be selected with the manufacturing processes in mind
- The designer should be aware that polymers can soften or burn at elevated temperatures, have **poor dimensional stability**, and **properties deteriorate with age**
- Many property evaluation tests are conducted under specific test conditions
  - Materials should be selected that take these conditions into account

Designing for Fabrication

- Each process has limitations and design considerations
  - **Shrinkage** in casting
  - **Solidification** issues
  - **Part removal** and **ejection**
  - **Surface finish**
  - **Section thickness**
  - **Thick corners**

Inserts

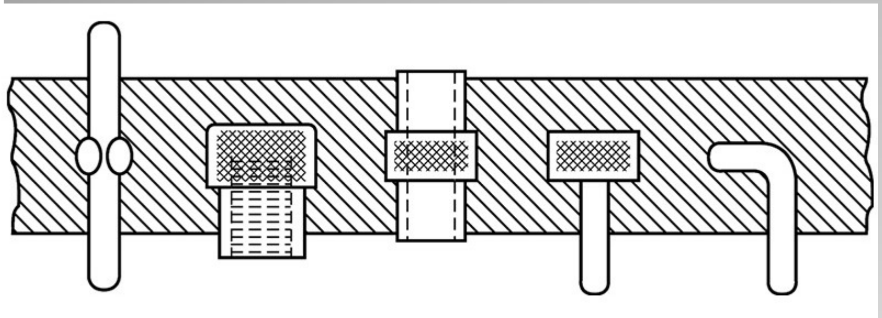
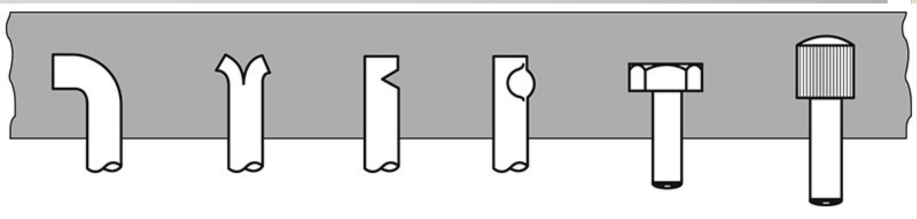


Figure 14-11 Typical metal inserts used to provide threaded cavities, holes, and alignment pins in plastic parts.

Figure 14-12 Various ways of anchoring metal inserts in plastic parts (left to right): bending, splitting, notching, swaging, noncircular head, and grooves and shoulders. Knurling is depicted in Figure 14-11.



- Metal (brass or steel) may be incorporated into plastic products to enhance performance
  - Threaded inserts
- May serve as mounting surfaces
- Often used for electrical terminals

Design Factors Related to Finishing

- Finish and appearance of plastics is important to consumers
- **Decorations or letters** can be produced on the **surface of the plastic**, but may increase cost
- Processes should be chosen so that **secondary machining is minimized**
- If parting lines will result in flash, the parting lines should be placed in geometrically easy locations (i.e. corners and edges) if possible

Design Factors Related to Finishing

- **Plastics have a low modulus of elasticity**, so flat areas should be avoided
- Flow marks may be apparent, so dimples or textured surfaces can be used
- Holes should be countersunk

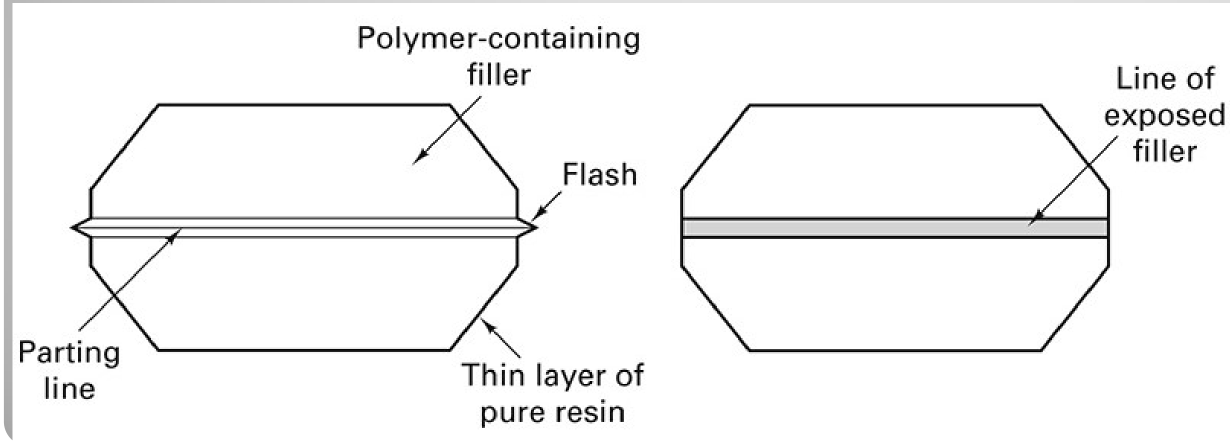


Figure 14-13 Trimming the flash from a plastic part ruptures the thin layer of pure resin along the parting line and creates a line of exposed filler.

14.3 Processing of Rubber and Elastomers

- Dipping
  - **A master form** is produced from **some type of metal**
  - This **master form** is then **dipped into a liquid or compound**, then removed and allowed to dry
  - Additional dips are done to achieve a desired thickness
  - Electrostatic charges may be used to accelerate the process

Rubber and Elastomer Compounds

- Elastomeric resin, vulcanizers, fillers, antioxidants, accelerators, and pigments may be added to the compounds
  - Typically done in a mixer
  - **Injection, compression, and transfer molding may be used**
  - **Some compounds can be directly cast to shape**
- Rubber compounds can be made into sheets using calenders
- Inner tubes, tubing, etc. can be produced by extrusion
- Rubber or artificial elastomers can be bonded to metals using adhesives

Processing of Elastomers and Rubbers

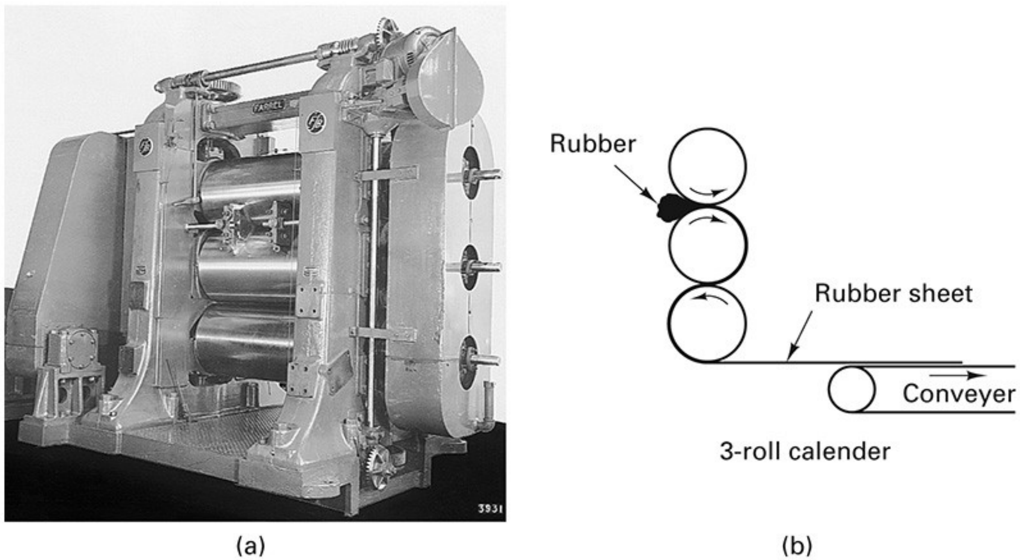


Figure 14-15 (Left) (a) Three-roll calender used for producing rubber or plastic sheet. (b) Schematic diagram showing the method of making sheets of rubber with a three-roll calender. [(a) (Courtesy of Farrel-Birmingham Company, Inc. Ansonia, CT.)]

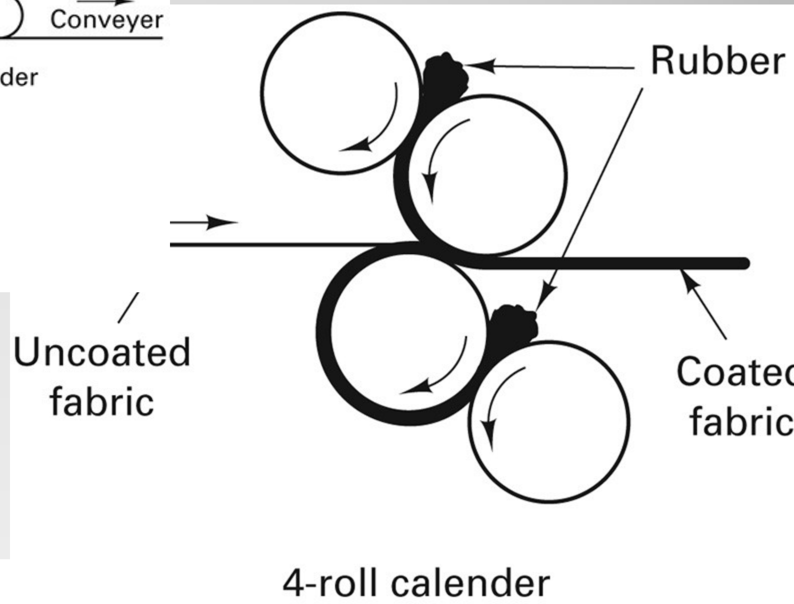


Figure 14-16 (Right) Arrangement of the rolls, fabric, and coating material for coating both sides of a fabric in a four-roll calender.

14.4 Processing of Ceramics

- **Two distinct classes** of **processing ceramics**
  - **Glasses** are manufactured by means of **molten material via viscous flow**
  - **Crystalline ceramics** are manufactured by **pressing moist aggregates** or **powder into shape**
  - The material is then bonded together using one of several mechanisms
    - **Chemical reaction**
    - **Vitrification**
    - **Sintering**

Fabrication Techniques for Glasses

- **Shaped at elevated temperatures**
- Sheet and plate glass is formed by **extrusion** through a **narrow slit and rolling** it through **water-cooled rolls**
- Glass shapes can be made by pouring molten material into a mold
  - Cooling rates may be controlled
- **Constant cross section** products can be made through **extrusion**
  - Glass fibers are made through an extrusion process

Fabrication Techniques for Glasses

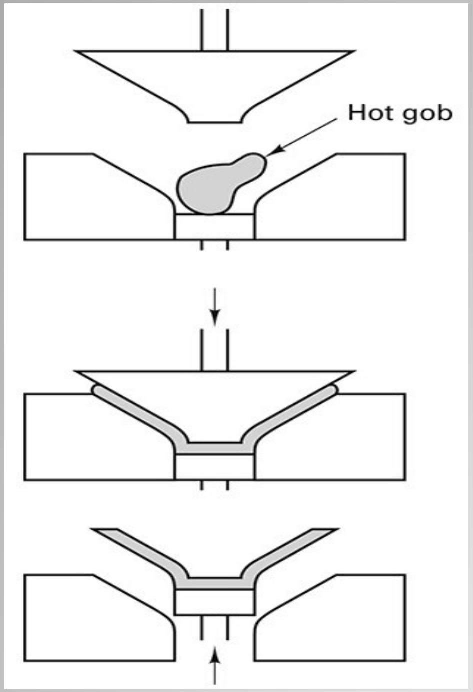


Figure 14-17 Viscous glass can be easily shaped by mating male and female die members.

- Viscous masses may be used instead of molten glass
  - Female and male die members are typically used
  - Processes similar to blow molding are used to make bottles and containers

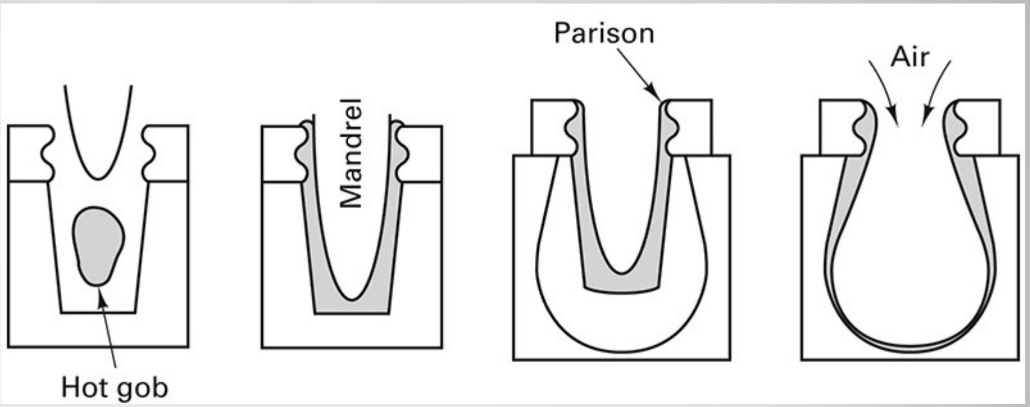


Figure 14-18 Thin-walled glass shapes can be produced by a combination of pressing and blow molding.

Fabrication Techniques for Glasses

- **Heat treatments**
  - **Forced cooling** produces **surface compression** and this glass is known as tempered glass and is **stronger** and more **fracture resistant**.
  - **Annealing operation** can be used to relieve **unfavorable residual stresses** when they exist

Fabrication Techniques for Glasses

- **Glass Ceramics**
  - A unique class of material with **part crystalline** and **part glass**
  - Glass material is subjected to **a special heat treatment** (devitrification)
    - Controls nucleation and growth of crystalline component
    - Dual structure with **good strength, toughness, and low thermal expansion**.
    - Typical products such as cookware and ceramic stove tops

Fabrication of Crystalline Ceramics

- Crystalline ceramics are **hard, brittle** materials that have **high melting points**
- **Cannot be formed by techniques** that **require plasticity** or **melting**
- Processed **in the solid state**
  - Dry pressing
  - Isostatic pressing
- Clay products are ceramics blended with water and additives

Fabrication of Crystalline Ceramics

TABLE 14-1 Processes Used to Form Products from Crystalline Ceramics

Process	Starting material	Advantages	Limitations
Dry axial pressing	Dry powder	Low cost; can be automated	Limited cross sections; density gradients
Isostatic processing	Dry powder	Uniform density; variable cross sections; can be automated	Long cycle times; small number of products per cycle
Slip casting	Slurry	Large sizes; complex shapes; low tooling cost	Long cycle times; labor-intensive
Injection molding	Ceramic–plastic blend	Complex cross sections; fast; can be automated; high volume	Binder must be removed; high tool cost
Forming processes (e.g., extrusion)	Ceramic–binder blend	Low cost; variable shapes (such as long lengths)	Binder must be removed; particles oriented by flow
Clay products	Clay, water, and additives	Easily shaped by forming methods; wide range of size and shape	Requires controlled drying

Machining of Ceramics

- Most ceramics are **hard and brittle**, so **machining is difficult**
- **Machining before firing** is called **green machining**
- **Machining after firing are typically nonconventional machining processes**
  - Grinding, lapping, polishing, drilling, cutting, ultrasonic, laser, electron beam, water-jet, and chemical

Design Considerations

- Joining of Ceramics
  - **Adhesive bonding**
  - **Brazing**
  - **Diffusion bonding**
  - **Threaded assemblies**
- Most ceramics are designed to be one piece structures
- **Bending and tensile loading should be minimized** during manufacture
- **Sharp corners and edges** should be **avoided**
- It is costly to achieve precise dimensions and surface finishing