GLASSWORKING

- Raw Materials Preparation and Melting
- Shaping Processes in Glassworking
- Heat Treatment and Finishing
- Product Design Considerations
Glass: Overview of the Material

• Glass is one of three basic types of ceramics
  – The others are traditional ceramics and new ceramics
• Glass is distinguished by its noncrystalline (vitreous) structure
  – The other ceramic materials have a crystalline structure
Glass Products

- Glass products are commercially produced in an almost unlimited variety of shapes
- Most products are made in very large quantities:
  - Light bulbs, beverage bottles, jars, light bulbs
  - Window glass
  - Glass tubing (e.g., for fluorescent lighting)
  - Glass fibers
- Other products are made individually:
  - Giant telescope lenses
Shaping Methods for Glass

- Methods for shaping glass are quite different from those used for traditional and new ceramics.
- In glassworking, the principal starting material is silica.
  - Usually combined with other oxide ceramics that form glasses.
- The starting material is heated to transform it from a hard solid into a viscous liquid; it is then shaped into the desired geometry while in this fluid condition.
- When cooled and hard, the material remains in the glassy state rather than crystallizing.
Figure 12.1 - The typical process sequence in glassworking:
(1) preparation of raw materials and melting,
(2) shaping, and
(3) heat treatment
Raw Materials Preparation and Melting

• The principal component in nearly all glasses is silica (SiO₂)
  – Primary source is natural quartz in sand
• Other components, such as soda ash (source of Na₂O), limestone (source of CaO), aluminum oxide (Al₂O₃), and potash (source of K₂O), are added in proportions to achieve the desired composition
• Recycled glass is usually added to the mixture too
  – In addition to preserving the environment, recycled glass facilitates melting
Glass Melting

• The batch of starting materials to be melted is called a *charge*, and loading it into the furnace is called *charging* the furnace
  – Melting temperatures for glass are around 1500°C to 1600°C (2700°F to 2900°F)
  – Melting cycle for a typical charge is 24 to 48 hours
• The viscosity of molten glass is inversely related to temperature
  – Since shaping immediately follows melting, the temperature at which the glass is tapped depends on the viscosity required for the shaping process
Shaping Processes in Glassworking

- Shaping processes to fabricate these products can be grouped into three categories:
  1. Discrete processes for piece ware (bottles, jars, plates, light bulbs)
  2. Continuous processes for making flat glass (sheet and plate glass) and tubing (laboratory ware, fluorescent lights)
  3. Fiber-making processes to produce fibers (for insulation and fiber optics)
Shaping of Piece Ware

- Ancient methods of hand-working glass included glass blowing
- Handicraft methods are still used today for making glassware items of high value in small quantities
- However, most modern glass shaping processes are highly mechanized technologies for producing discrete pieces such as jars, bottles, and light bulbs in high quantities
Piece Ware Shaping Processes

- **Spinning** – similar to centrifugal casting of metals
- **Pressing** – for mass production of flat products such as dishes, bake ware, and TV tube faceplates
- **Press-and-blow** – for production of wide-mouth containers such as jars
- **Blow-and-blow** - for production of smaller-mouth containers such as beverage bottles and incandescent light bulbs
- **Casting** – for large items such as large astronomical lenses that must cool very slowly to avoid cracking
Figure 12.2 - Spinning of funnel-shaped glass parts such as back sections of cathode ray tubes for TVs and computer monitors:
(1) gob of glass dropped into mold; and
(2) rotation of mold to cause spreading of molten glass on mold surface
Figure 12.3 - Pressing of flat glass pieces: (1) glass gob is fed into mold from furnace; (2) pressing into shape by plunger; and (3) plunger is retracted and finished product is removed (symbols \(v\) and \(F\) indicate motion (velocity) and applied force)
Figure 12.4 - Press-and-blow forming sequence: (1) molten gob is fed into mold cavity; (2) pressing to form a parison; (3) the partially formed parison, held in a neck ring, is transferred to the blow mold, and (4) blown into final shape
Figure 12.5 - Blow-and-blow forming sequence: (1) gob is fed into inverted mold cavity; (2) mold is covered; (3) first blowing step; (4) partially formed piece is reoriented and transferred to second blow mold, and (5) blown to final shape.
Casting

- If molten glass is sufficiently fluid, it can be poured into a mold
- Relatively massive objects, such as astronomical lenses and mirrors, are made by this method
- After cooling and solidifying, the piece must be finished by lapping and polishing
- Casting of glass is not often used except for special jobs
- Smaller lenses are usually made by pressing
Shaping of Flat and Tubular Glass

• Processes for producing flat glass such as sheet and plate glass:
  – Rolling of flat plate
  – Float process

• Process for producing glass tubes
  – Danner process
Rolling of Flat Plate

Starting glass from melting furnace is squeezed through opposing rolls whose gap determines sheet thickness, followed by grinding and polishing for parallelism and smoothness.

Figure 12.6 - Rolling of flat glass
Float Process

Molten glass flows onto the surface of a molten tin bath, where it spreads evenly across the surface, achieving a uniform thickness and smoothness - no grinding or polishing is needed.

Figure 12.7 - The float process for producing sheet glass
Danner Process

Molten glass flows around a rotating hollow mandrel through which air is blown while the glass is drawn.

Figure 12.8 - Drawing of glass tubes by the Danner process
Forming of Glass Fibers

Glass fiber products can be divided into two categories, with different production methods for each:

1. Fibrous glass for thermal insulation, acoustical insulation, and air filtration, in which the fibers are in a random, wool-like condition
   - Produced by centrifugal spraying

2. Long continuous filaments suitable for fiber reinforced plastics, yarns, fabrics, and fiber optics
   - Produced by drawing
Centrifugal Spraying

• In a typical process for making glass wool, molten glass flows into a rotating bowl with many small orifices around its periphery
• Centrifugal force causes the glass to flow through the holes to become a fibrous mass suitable for thermal and acoustical insulation
Drawing of Glass

Continuous glass fibers of small diameter (lower limit is about 0.0025 mm) are produced by drawing (pulling) strands of molten glass through small orifices in a heated plate made of a platinum alloy.

Figure 12.9 - Drawing of continuous glass fibers
Heat Treatment: Annealing of Glass

Heating to elevated temperature and holding for a time to eliminate stresses and temperature gradients; then slow cooling to suppress stress formation, followed by more rapid cooling to room temperature

- Annealing temperatures are around 500°C (900°F)
- Annealing has the same function in glassworking as in metalworking – to relieve stresses
- Annealing is performed in tunnel-like furnaces, called lehrs, in which the products flow slowly through the hot chamber on conveyors
Tempering of Glass

Heating to a temperature somewhat above annealing temperature into the plastic range, followed by quenching of surfaces, usually by air jets

- When the surfaces cool, they contract and harden while interior is still plastic
- As the internal glass cools, it contracts, putting the hard surfaces in compression
- *Tempered glass* is more resistant to scratching and breaking due to compressive stresses on its surfaces
- Products: windows for tall buildings, all-glass doors, safety glasses, and other products requiring toughened glass
A Case Study: Automobile Windshields

• When tempered glass fails, it shatters into many small fragments which are less likely to cut someone than conventional (annealed) window glass
• Automobile windshields are not made of tempered glass, due to the danger posed to the driver by this fragmentation
• Instead, conventional glass is used; it is fabricated by sandwiching two pieces of glass on either side of a tough polymer sheet
• Should this laminated glass fracture, the glass splinters are retained by the polymer sheet and the windshield remains relatively transparent
Finishing Operations on Glass

- Operations include grinding, polishing, and cutting.
- Glass sheets often must be ground and polished to remove surface defects and scratch marks and to make opposite sides parallel.
- In pressing and blowing with split dies, polishing is often used to remove seam marks from the product.
- Cutting of continuous sections of tube and plate into smaller pieces is done by first scoring the glass with a glass-cutting wheel or cutting diamond and then breaking the section along the score line.
Other Finishing Operations

- Decorative and surface processes performed on certain glassware products include:
  - Mechanical cutting and polishing operations; and sandblasting
  - Chemical etching (with hydrofluoric acid, often in combination with other chemicals)
  - Coating (e.g., coating of plate glass with aluminum or silver to produce mirrors)
Product Design Considerations - I

• Glass is transparent and has optical properties that are unusual if not unique among engineering materials
  – For applications requiring transparency, light transmittance, magnification, and similar optical properties, glass is likely to be the material of choice
  – Certain polymers are transparent and may be competitive, depending on design requirements
Product Design Considerations - II

- Glass is much stronger in compression than tension
  - Components should be designed to be subjected to compressive stresses, not tensile stresses
- Glass is brittle
  - Glass parts should not be used in applications that involve impact loading or high stresses that might cause fracture
Product Design Considerations - III

- Certain glass compositions have very low thermal expansion coefficients and can tolerate thermal shock
  - These glasses should be selected for applications where this characteristic is important
- Design outside edges and corners with large radii and inside corners with large radii, to avoid points of stress concentration
- Threads may be included in glass parts
  - However, the threads should be coarse