RUBBER PROCESSING TECHNOLOGY

- Rubber Processing and Shaping
- Manufacture of Tires and Other Rubber Products
- Product Design Considerations

Overview of Rubber Processing and Products

- Many of the production methods used for plastics are also applicable to rubbers
- However, rubber processing technology is different in certain respects, and the rubber industry is largely separate from the plastics industry
- The rubber industry and goods made of rubber are dominated by one product: *tires*
  - Tires are used in large numbers on automobiles, trucks, aircraft, and bicycles

Rubber Processing and Shaping

- Production of rubber goods consists of two basic steps:
  1. Production of the rubber itself
     - Natural rubber is an agricultural crop
     - Synthetic rubbers are made from petroleum
  2. Processing into finished goods, consisting of:
     (a) Compounding
     (b) Mixing
     (c) Shaping
     (d) Vulcanizing

The Rubber Industries

- Production of raw NR might be classified as an agricultural industry because *latex*, the starting ingredient, is grown on plantations in tropical climates
- By contrast, synthetic rubbers are produced by the petrochemical industry
- Finally, processing into tires and other products occurs at processor (fabricator) plants, commonly known as the rubber industry
  - The company names include Goodyear, B. F. Goodrich, and Michelin, all reflecting the importance of the tire

Production of Natural Rubber

- Natural rubber is tapped from rubber trees (*Hevea brasiliensis*) as latex
  - The trees are grown on plantations in Southeast Asia and other parts of the world
- Latex is a colloidal dispersion of solid particles of the polymer *polyisoprene* in water
  - Polyisoprene $(C_5H_8)_n$ is the chemical substance that comprises rubber, and its content in the emulsion is about 30%
- The latex is collected in large tanks, thus blending the yield of many trees together

Recovering the Rubber

- The preferred method of recovering rubber from latex involves coagulation - adding an acid such as formic acid (HCOOH); coagulation takes about 12 hours
- The coagulum, now soft solid slabs, is then squeezed through a series of rolls which drive out most of the water and reduce thickness to about 3 mm (1/8 in)
- The sheets are then draped over wooden frames and dried in smokehouses
  - Several days are normally required to complete the drying process

Grades of Natural Rubber

- The resulting rubber, now in a form called *ribbed smoked sheet*, is folded into large bales for shipment to the processor
  - It has a characteristic dark brown color
- In some cases, the sheets are dried in hot air rather than smokehouses, and the term *air-dried sheet* is used; this is considered to be a better grade of rubber
- A still better grade, called *pale crepe* rubber, involves two coagulation steps, followed by warm air drying
  - Its color is light tan

Synthetic Rubber

- Most synthetic rubbers are produced from petroleum by the same polymerization techniques used to synthesize other polymers
- Unlike thermoplastic and thermosetting polymers, which are normally supplied to the fabricator as pellets or liquid resins, synthetic rubbers are supplied to rubber processors in the form of large bales
  - The rubber industry has a long tradition of handling NR in these unit loads

Compounding

- Rubber is always compounded with additives
  - Compounding adds chemicals for vulcanization, such as sulfur
  - Additives include fillers which act either to enhance the rubber's mechanical properties (reinforcing fillers) or to extend the rubber to reduce cost (non-reinforcing fillers)
  - It is through compounding that the specific rubber is designed to satisfy a given application in terms of properties, cost, and processability

Carbon Black in Rubber

- The single most important reinforcing filler in rubber is *carbon black*, a colloidal form of carbon, obtained by thermal decomposition of hydrocarbons (soot)
  - Its effect is to increase tensile strength and resistance to abrasion and tearing of the final rubber product
  - Carbon black also provides protection from ultraviolet radiation
  - Most rubber parts are black in color because of their carbon black content

Other Fillers and Additives in Rubber

- China clays - hydrous aluminum silicates ($Al_2Si_2O_5(OH)_4$) provide less reinforcing than carbon black but are used when black is not acceptable
- Other polymers, such as styrene, PVC, and phenolics
- Recycled rubber added in some rubber products, but usually 10% or less
- Antioxidants; fatigue- and ozone-protective chemicals; coloring pigments; plasticizers and softening oils; blowing agents in the production of foamed rubber; and mold release compounds

Mixing

- The additives must be thoroughly mixed with the base rubber to achieve uniform dispersion of ingredients
- Uncured rubbers have high viscosity so mechanical working of the rubber can increase its temperature up to 150°C (300°F)
- If vulcanizing agents were present from the start of mixing, premature vulcanization would result - the “rubber processor's nightmare”

Two-Stage Mixing

- To avoid premature vulcanization, a two-stage mixing process is usually employed

  Stage 1 - carbon black and other non-vulcanizing additives are combined with the raw rubber

  - The term masterbatch is used for this first-stage mixture

  Stage 2 - after stage 1 mixing has been completed, and time for cooling has been allowed, stage 2 mixing is carried out in which vulcanizing agents are added

Filament Reinforcement in Rubber Products

- Many products require filament reinforcement to reduce extensibility but retain the other desirable properties of rubber
  - Examples: tires, conveyor belts
  - Filaments used for this purpose include cellulose, nylon, and polyester
  - Fiber-glass and steel are also used (e.g., steel-belted radial tires)
  - Continuous fiber materials must be added during shaping; they are not mixed like the other additives

Shaping and Related Processes

- Shaping processes for rubber products can be divided into four basic categories:
  1. Extrusion
  2. Calendering
  3. Coating
  4. Molding and casting
- Some products require several basic processes plus assembly work
  - Example: tires

Extrusion

- Screw extruders are generally used for extrusion of rubber
- The L/D ratio of the extruder barrel is less than for thermoplastics, typically in the range 10 to 15, to reduce the risk of premature cross-linking
- Die swell occurs in rubber extrudates, since the polymer is in a highly plastic condition and exhibits the “memory” property
- The rubber has not yet been vulcanized

Calendering

Stock is passed through a series of gaps of decreasing size made by a stand of rotating rolls.

- Rubber sheet thickness determined by final roll gap

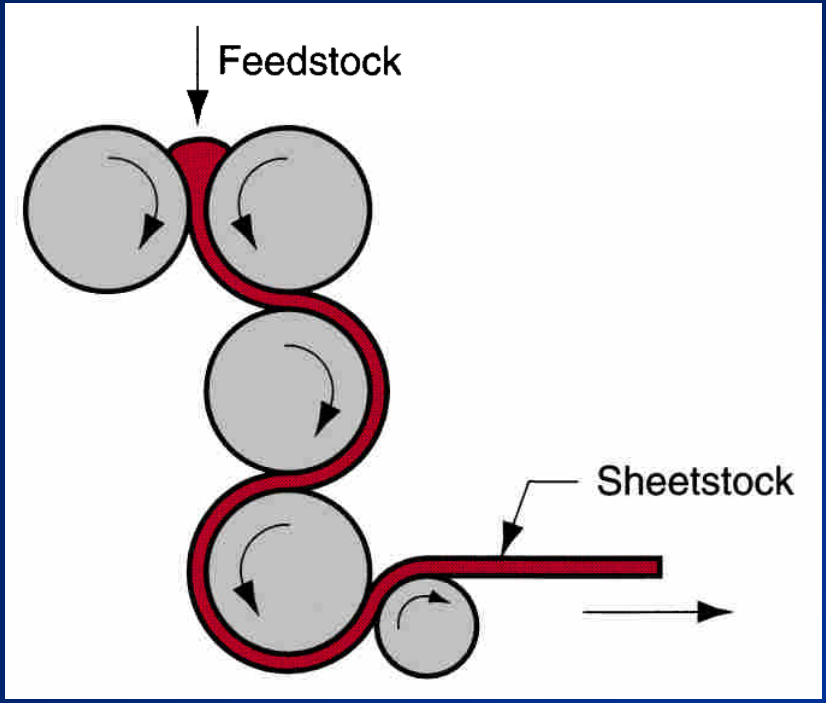

Figure 13.17 – Calendering

Roller Die Process

Combination of extrusion and calendering that results in better quality product than either extrusion or calendering alone

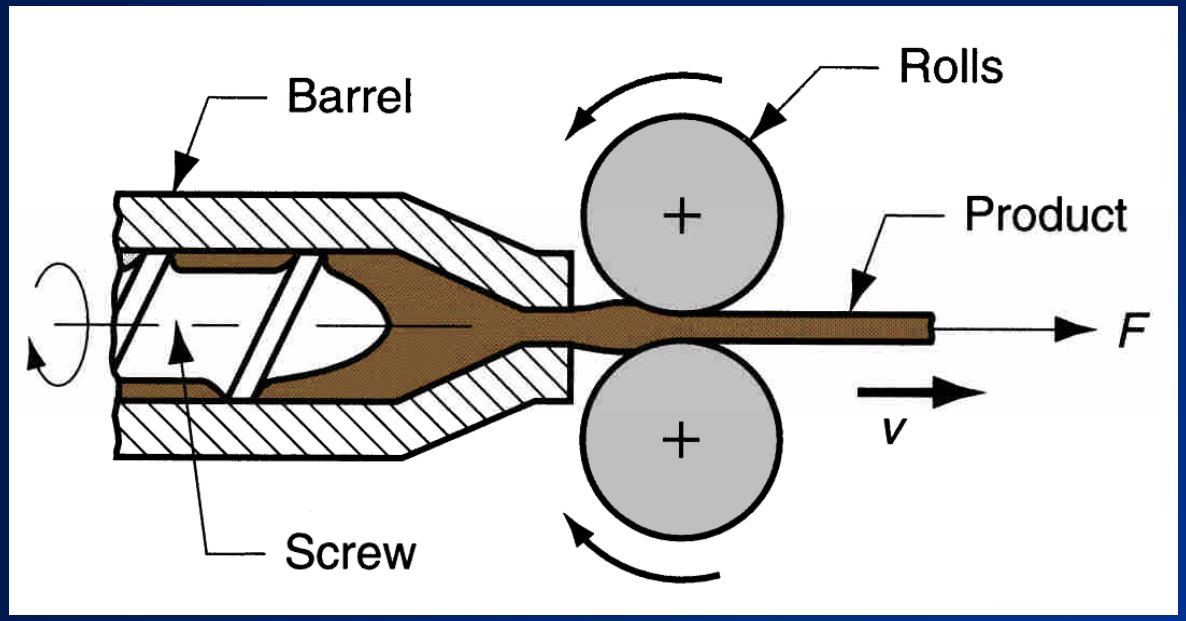

Figure 14.2 - Roller die process - rubber extrusion followed by rolling

Coating or Impregnating Fabrics with Rubber

- An important industrial process for producing automobile tires, conveyor belts, inflatable rafts, and waterproof cloth tents and rain coats

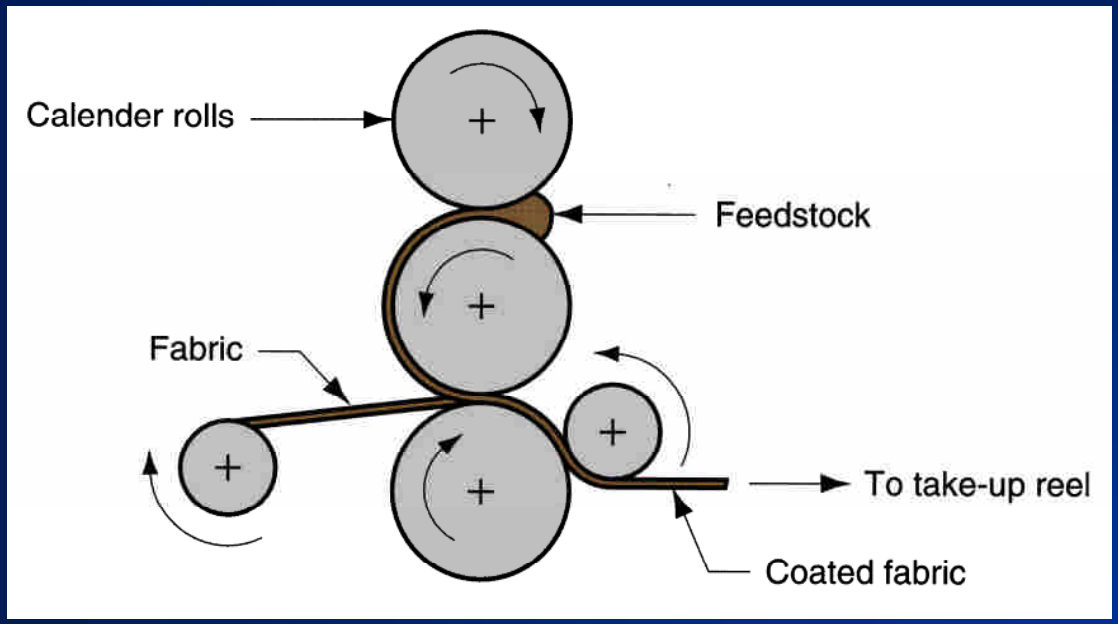

Figure 14.3 - Coating of fabric with rubber using a calendering process

Molded Rubber Products

- Molded rubber products include shoe soles and heals, gaskets and seals, suction cups, and bottle stops
- Also, many foamed rubber parts are produced by molding
- In addition, molding is an important process in tire production

Molding Processes for Rubber

- Principal molding processes for rubber are: (1) compression molding, (2) transfer molding, and (3) injection molding
  - Compression molding is the most important technique because of its use in tire manufacture
- Curing (vulcanizing) is accomplished in the mold in all three processes, this representing a departure from the previous shaping methods, all of which use a separate vulcanizing step

Vulcanization

The treatment that accomplishes cross-linking of elastomer molecules, so that the rubber becomes stiffer and stronger but retains extensibility

- On a submicroscopic scale, the long-chain molecules of rubber become joined at certain tie points, the effect of which is to reduce the ability of the elastomer to flow
  - A typical soft rubber has 1 or 2 cross-links per 1000 units (mers)
  - As the number of cross-links increases, the polymer becomes stiffer and behaves more and more like a thermosetting plastic (hard rubber)

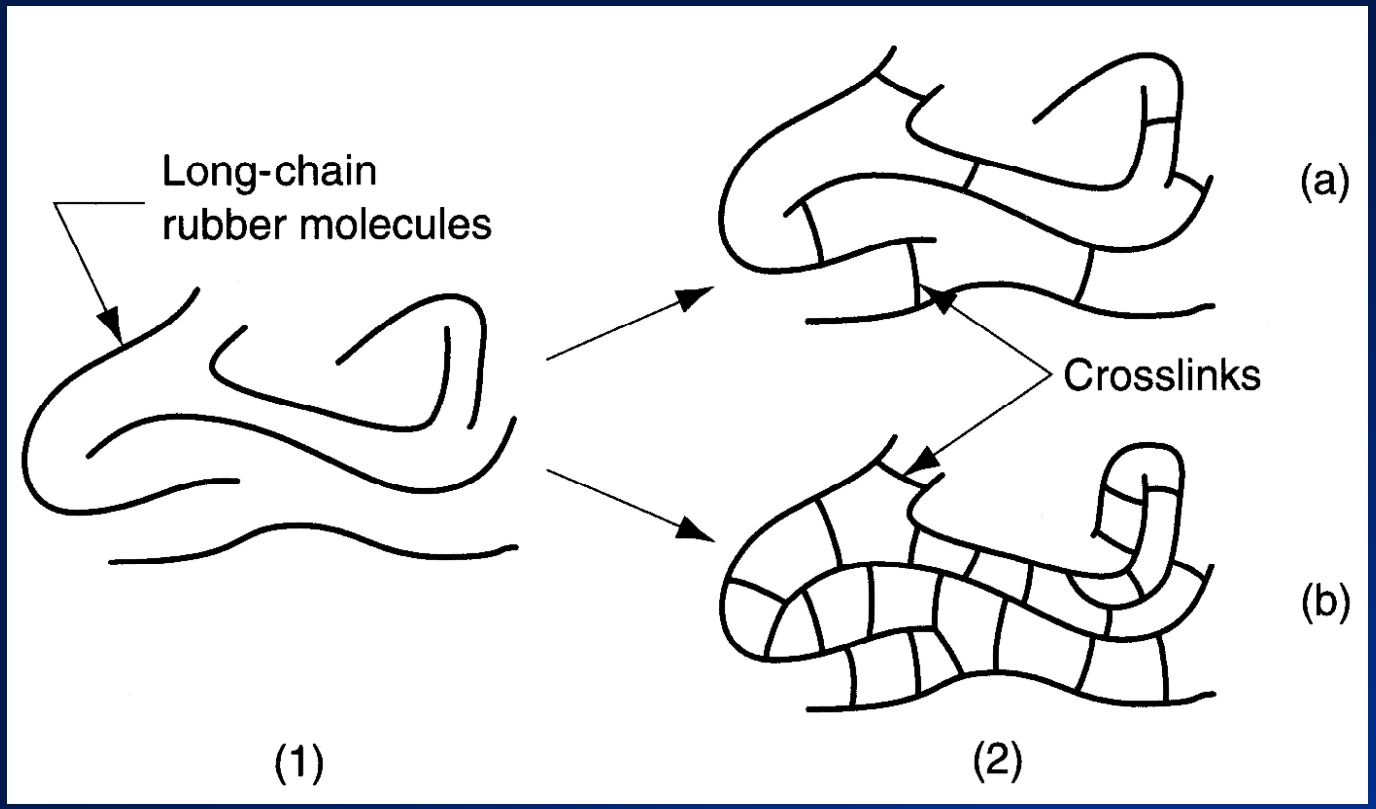

Figure 14.4 - Effect of vulcanization on rubber molecules: (1) raw rubber, and (2) vulcanized (cross-linked) rubber. Variations of (2) include: (a) soft rubber, low degree of cross- linking; and (b) hard rubber, high degree of cross-linking

Vulcanization Chemicals and Times

- As it was first invented by Goodyear in 1839, vulcanization used sulfur (about 8 parts by weight of S mixed with 100 parts of NR) at 140°C (280°F) for about 5 hours
  - Vulcanization with sulfur alone is no longer used today, due to the long curing times
- Various other chemicals are combined with smaller doses of sulfur to accelerate and strengthen the treatment
  - The resulting cure time is 15-20 minutes
- A variety of non-sulfur vulcanizing treatments have also been developed

Tires and Other Rubber Products

- Tires are the principal product of the rubber industry
  - Tires are about 75% of total rubber tonnage
- Other important products:
  - Footwear
  - Seals
  - Shock-absorbing parts
  - Conveyor belts
  - Hose
  - Foamed rubber products
  - Sports equipment

Tires

- Pneumatic tires are critical components of the vehicles on which they are used
- Functions of vehicle tires:
  - Support the weight of the vehicle, passengers, and cargo
  - Transmit the motor torque to propel the vehicle
  - Absorb road vibrations and shock to provide a comfortable ride
- Tires are used on automobiles, trucks, buses, farm tractors, earth moving equipment, military vehicles, bicycles, motorcycles, and aircraft

Tire Construction

- A tire is an assembly of many parts - a passenger car tire has about 50 individual components; a large earthmover tire may have as many as 175
  - The internal structure of the tire, known as the *carcass*, consists of multiple layers of rubber coated cords, called *plies*
  - The cords are strands of nylon, polyester, fiber glass, or steel, which provide inextensibility to reinforce the rubber in the carcass
- Three basic tire constructions: (a) diagonal ply, (b) belted bias, and (c) radial ply

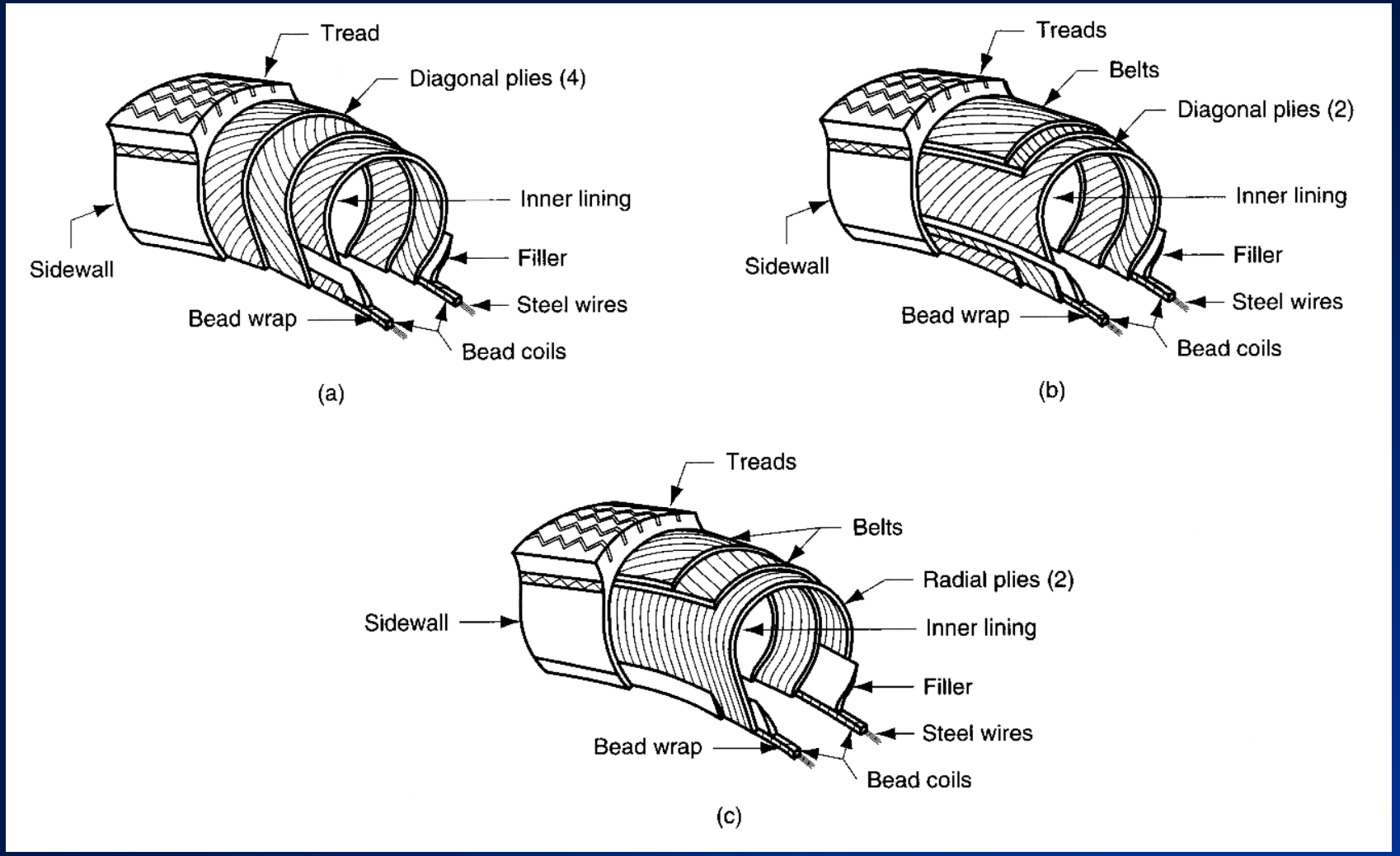

Figure 14.5 Three tire constructions: (a) diagonal ply, (b) belted bias, and (c) radial ply.

Tire Production Sequence

- Tire production can be summarized in three steps:
  1. Preforming of components
  2. Building the carcass and adding rubber strips to form the sidewalls and treads
  3. Molding and curing the components into one integral piece
- The following descriptions of these steps are typical; there are variations in processing depending on construction, tire size, and type of vehicle on which the tire will be used

Preforming of Components

- The carcass consists of a number of components, most of which are rubber or reinforced rubber
- These, as well as the sidewall and tread rubber, are produced by continuous processes and then pre-cut to size and shape for subsequent assembly
- The components include: bead coil, plies, inner lining, belts, tread, and sidewall

Building the Carcass

- The carcass is traditionally assembled using a machine known as a *building drum*, whose main element is a cylindrical arbor that rotates

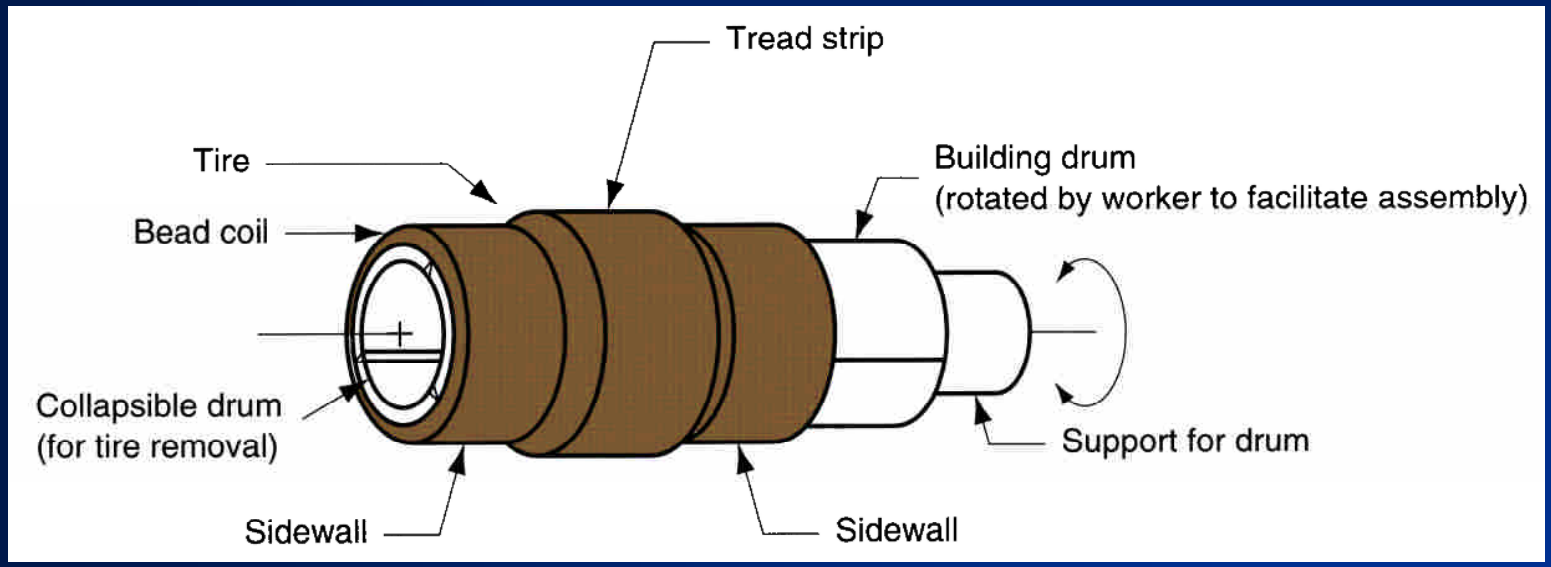

Figure 14.6 - Tire just before removal from building drum, but prior to molding and curing

Molding and Curing

- Tire molds are usually split molds and contain the tread pattern to be impressed on the tire

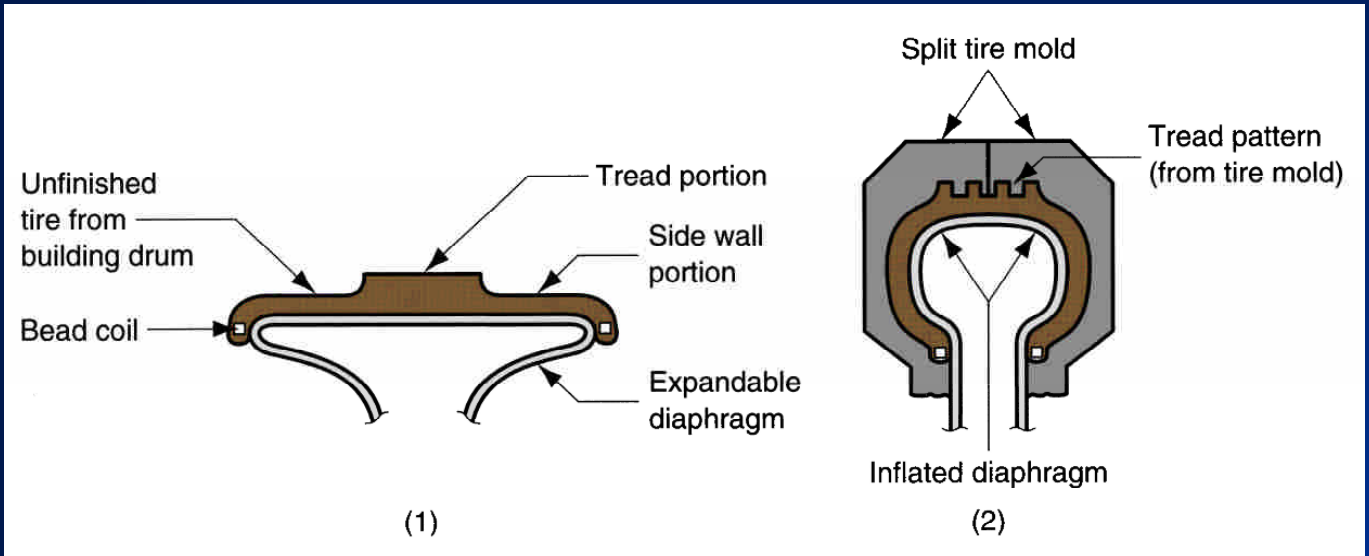

Figure 14.7 - Tire molding: (1) uncured tire is placed over expandable diaphragm; (2) mold is closed and diaphragm is expanded to force uncured rubber against mold cavity, impressing tread pattern into rubber; mold & diaphragm are heated to cure rubber

Other Rubber Products - Rubber Belts for Conveyors and Pulleys

- Widely used in conveyors and mechanical power transmission systems
- As in tires, rubber is an ideal material for these products but the belt must have little or no extensibility in order to function
  - Accordingly, it is reinforced with fibers, commonly polyester or nylon
- Fabrics of these polymers are usually coated by calendering, assembled together to obtain required number of plies and thickness, and subsequently vulcanized by continuous or batch heating processes

Other Rubber Products – Hose

- Two basic types:
  1. Plain hose (no reinforcement) is extruded tubing
  2. Reinforced tube consists of:
     - Inner tube - extruded of a rubber compounded for particular liquid that will flow through it
     - Reinforcement layer - applied to the inner tube as a fabric, or by spiraling, knitting, braiding
     - Outer layer – compounded for environmental conditions and applied by extrusion

Other Rubber Products – Footwear

- Rubber components in footwear include soles, heels, rubber overshoes, and certain upper parts
- Molded parts are produced by injection molding, compression molding, and certain special molding techniques developed by the shoe industry
- The rubbers include both solid and foamed
- For low volume production, manual methods are sometimes used to cut rubber from flat stock

Processing of Thermoplastic Elastomers

A *thermoplastic elastomer* (TPE) is a thermoplastic polymer that possesses the properties of a rubber

- TPEs are processed like thermoplastics, but their applications are those of an elastomer
- Most common shaping processes are injection molding and extrusion, which are generally more economical and faster than the traditional processes used for rubbers that must be vulcanized

TPE Products

- Molded products include shoe soles, athletic footwear, and automotive components such as fender extensions and corner panels
- Extruded items include insulation coating for electrical wire, tubing for medical applications, conveyor belts, sheet and film stock
- No tires of TPE

Product Design Considerations - Economic Production Quantities

- Rubber parts produced by compression molding (the traditional process) can often be produced in quantities of 1000 or less
  - The mold cost is relatively low compared to other molding methods
- Injection molding, as with plastic parts, requires higher production quantities to justify the more expensive mold

Product Design Considerations - Draft

- Draft is usually unnecessary for molded parts of rubber, because its flexibility allows it to deform for removal from the mold
- Shallow undercuts, although undesirable, are possible with rubber molded parts for the same reason
- The low stiffness and high elasticity of the material permits removal from the mold