SHAPING PROCESSES FOR PLASTICS

- Properties of Polymer Melts
- Extrusion and Related Processes
- Molding Processes
- Casting
- Polymer Foam Processing and Forming
- Product Design Considerations

Plastic Products

- Plastics can be shaped into a wide variety of products:
  - Molded parts
  - Extruded sections
  - Films
  - Sheets
  - Insulation coatings on electrical wires
  - Fibers for textiles

More Plastic Products

- In addition, plastics are often the principal ingredient in other materials, such as
  - Paints and varnishes
  - Adhesives
  - Various polymer matrix composites
- Many plastic shaping processes can be adapted to produce items made of rubbers and polymer matrix composites

Trends in Polymer Processing

- Applications of plastics have increased at a much faster rate than either metals or ceramics during the last 50 years
  - Many parts previously made of metals are now being made of plastics
  - Plastic containers have been largely substituted for glass bottles and jars
- Total volume of polymers (plastics and rubbers) now exceeds that of metals (tonnage is still less because density of metals is greater)

Why Plastic Shaping Processes are Important

- Almost unlimited variety of part geometries
- Plastic molding is a *net shape* process; further shaping is not needed
- Less energy is required than for metals because processing temperatures are much lower
  - Handling of product is simplified during production because of lower temperatures
- Painting or plating is usually not required

Two Types of Plastics

1. Thermoplastics
   - Chemical structure remains unchanged during heating and shaping
   - More important commercially, comprising more than 70% of total plastics tonnage
2. Thermosets
   - Undergo a curing process during heating and shaping, causing a permanent change (called *cross-linking*) in molecular structure
   - Once cured, they cannot be remelted

Classification of Plastics Shaping Processes by Product Geometry

- Extruded products with constant cross-section
- Continuous sheets and films
- Continuous filaments (fibers)
- Molded parts which are mostly solid
- Hollow molded parts with relatively thin walls
- Discrete parts made of formed sheets and films
- Castings
- Foamed products

Polymer Melts

- To shape a thermoplastic polymer it must be heated so that it softens to the consistency of a liquid
- In this form, it is called a *polymer melt*
- Important properties:
  - Viscosity
  - Viscoelasticity

Viscosity of Polymer Melts

Fluid property that relates shear stress to shear rate during flow

- Due to its high molecular weight, a polymer melt is a thick fluid with high viscosity
- Important because most polymer shaping processes involve flow through small channels or die openings
- Flow rates are often large, leading to high shear rates and shear stresses, so significant pressures are required to accomplish the processes

Viscosity of a polymer melt decreases with shear rate, thus the fluid becomes thinner at higher shear rates

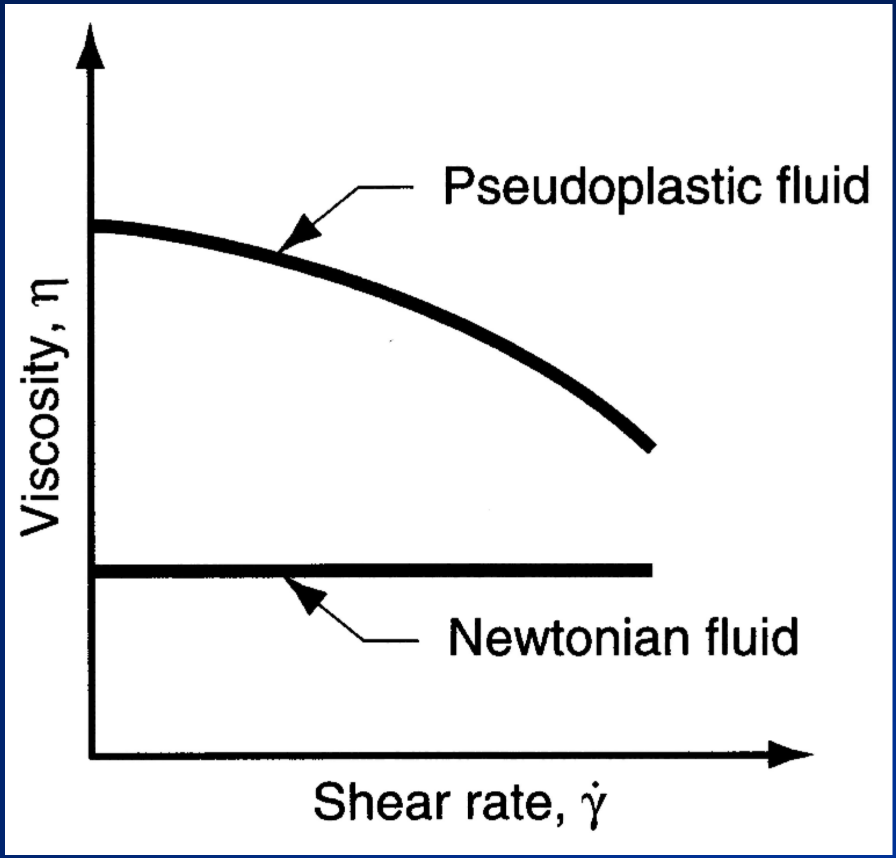


Figure 13.1 ‑ Viscosity relationships for Newtonian fluid and typical polymer melt

Viscosity of a polymer melt decreases with temperature, thus the fluid becomes thinner at higher temperatures

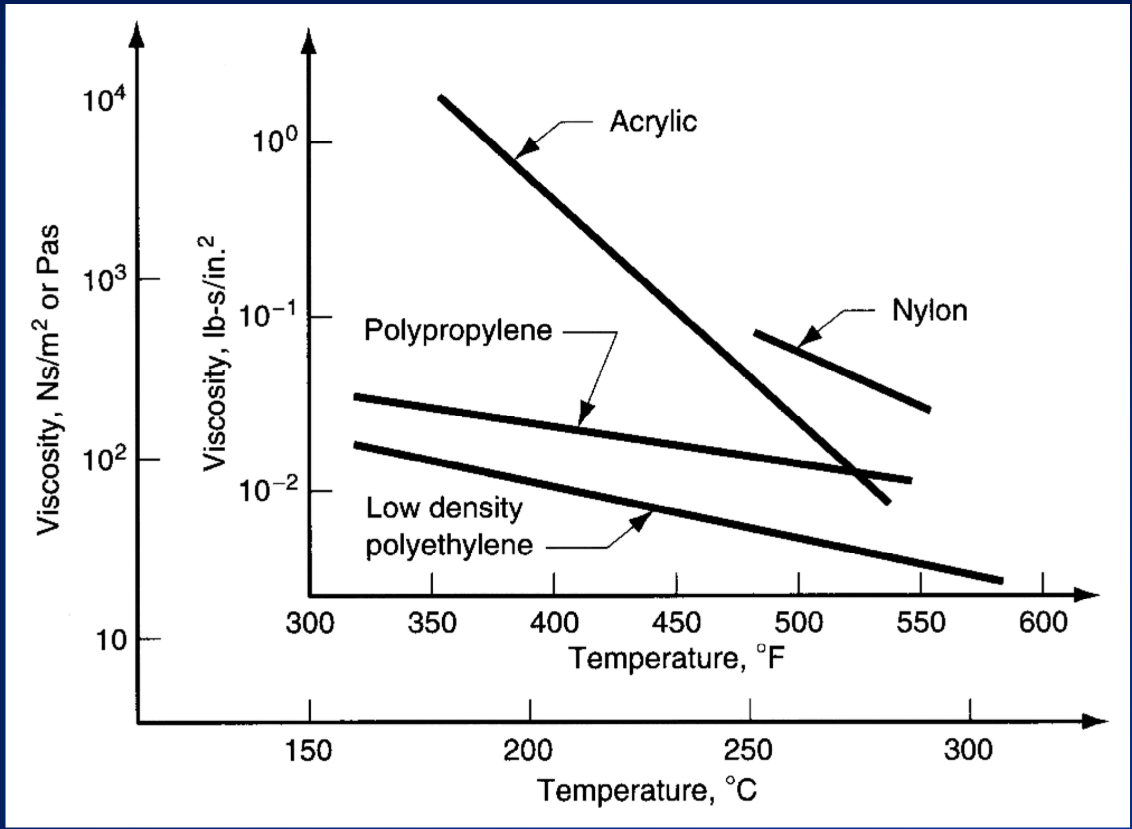


Figure 13.2 - Viscosity as a function of temperature for selected polymers at a shear rate of $10^3\ s^{-1}$

Viscoelasticity

Combination of viscosity and elasticity

- Possessed by both polymer solids and polymer melts
- Example: die swell in extrusion, in which the hot plastic expands when exiting the die opening

Die Swell

Extruded material "remembers" its former shape when in the larger cross-section of the extruder and attempts to return to it after leaving the die orifice

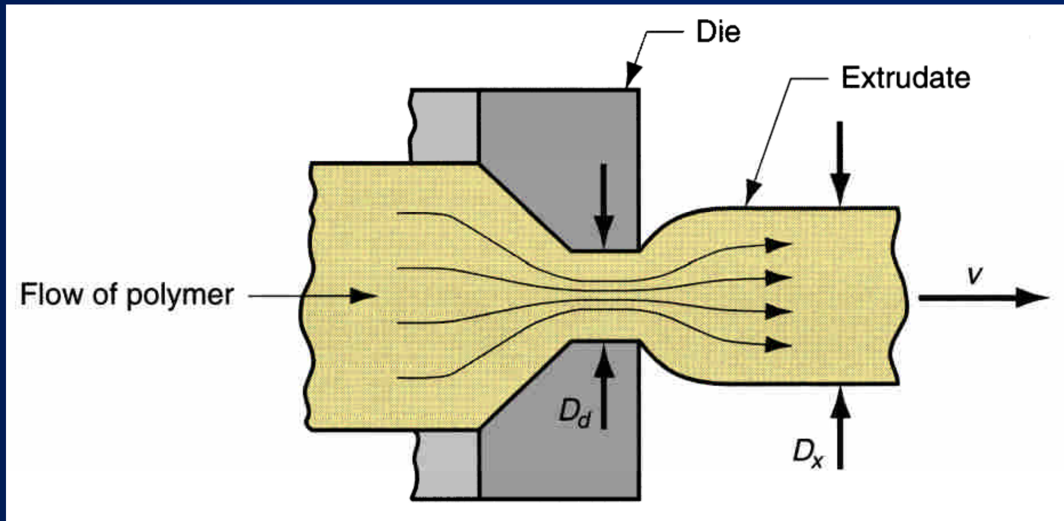


Figure 13.3 - Die swell, a manifestation of viscoelasticity in polymer melts, as depicted here on exiting an extrusion die

Extrusion

Compression process in which material is forced to flow through a die orifice to provide long continuous product whose cross-sectional shape is determined by the shape of the orifice

- Widely used for thermoplastics and elastomers to mass produce items such as tubing, pipes, hose, structural shapes, sheet and film, continuous filaments, and coated electrical wire
- Carried out as a continuous process; *extrudate* is then cut into desired lengths

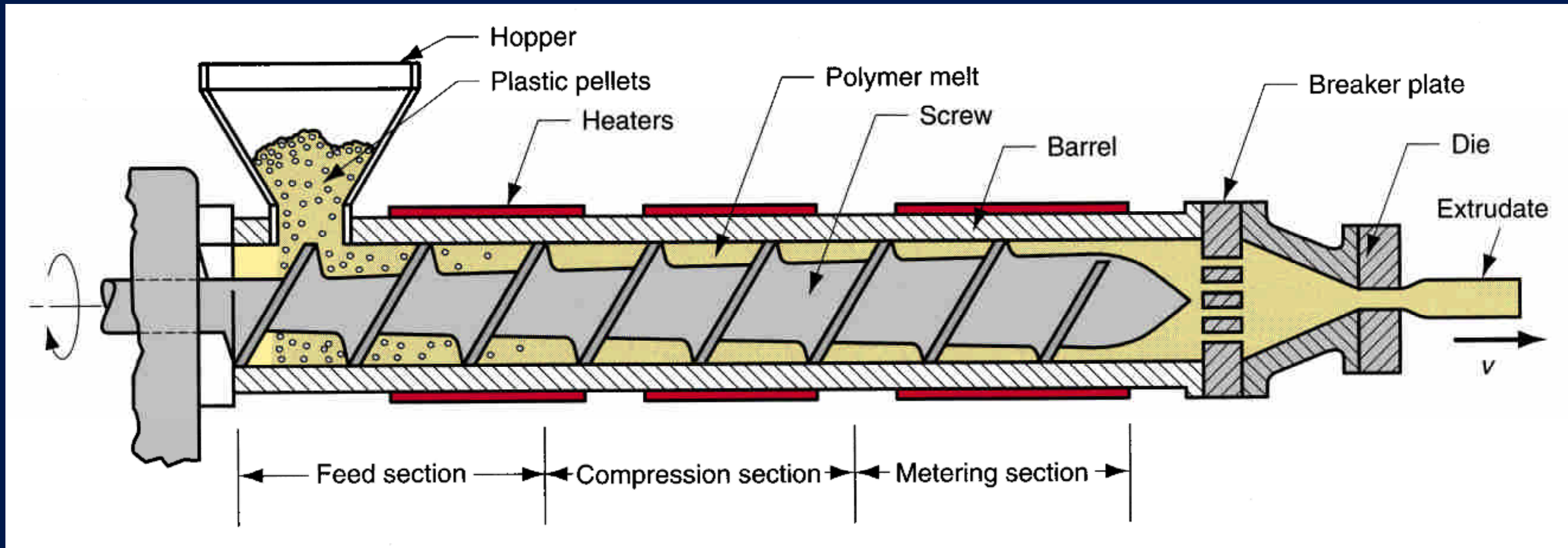


Figure 13.4 ‑ Components and features of a (single‑screw) extruder for plastics and elastomers

Two Main Components of an Extruder

1. Barrel
2. Screw

- *Die* - not an extruder component
  - It is a special tool that must be fabricated for particular profile to be produced

Extruder Barrel

- Internal diameter typically ranges from 25 to 150 mm (1.0 to 6.0 in.)
- *L*/*D* ratios usually between 10 and 30: higher ratios for thermoplastic, lower ratios for elastomers
- Feedstock fed by gravity onto screw whose rotation moves material through barrel
- Electric heaters melt feedstock; subsequent mixing and mechanical working adds heat which maintains the melt

Extruder Screw

- Divided into sections to serve several functions:
  - *Feed section* - feedstock is moved from hopper and preheated
  - *Compression section* - polymer is transformed into fluid, air mixed with pellets is extracted from melt, and material is compressed
  - *Metering section* - melt is homogenized and sufficient pressure developed to pump it through die opening

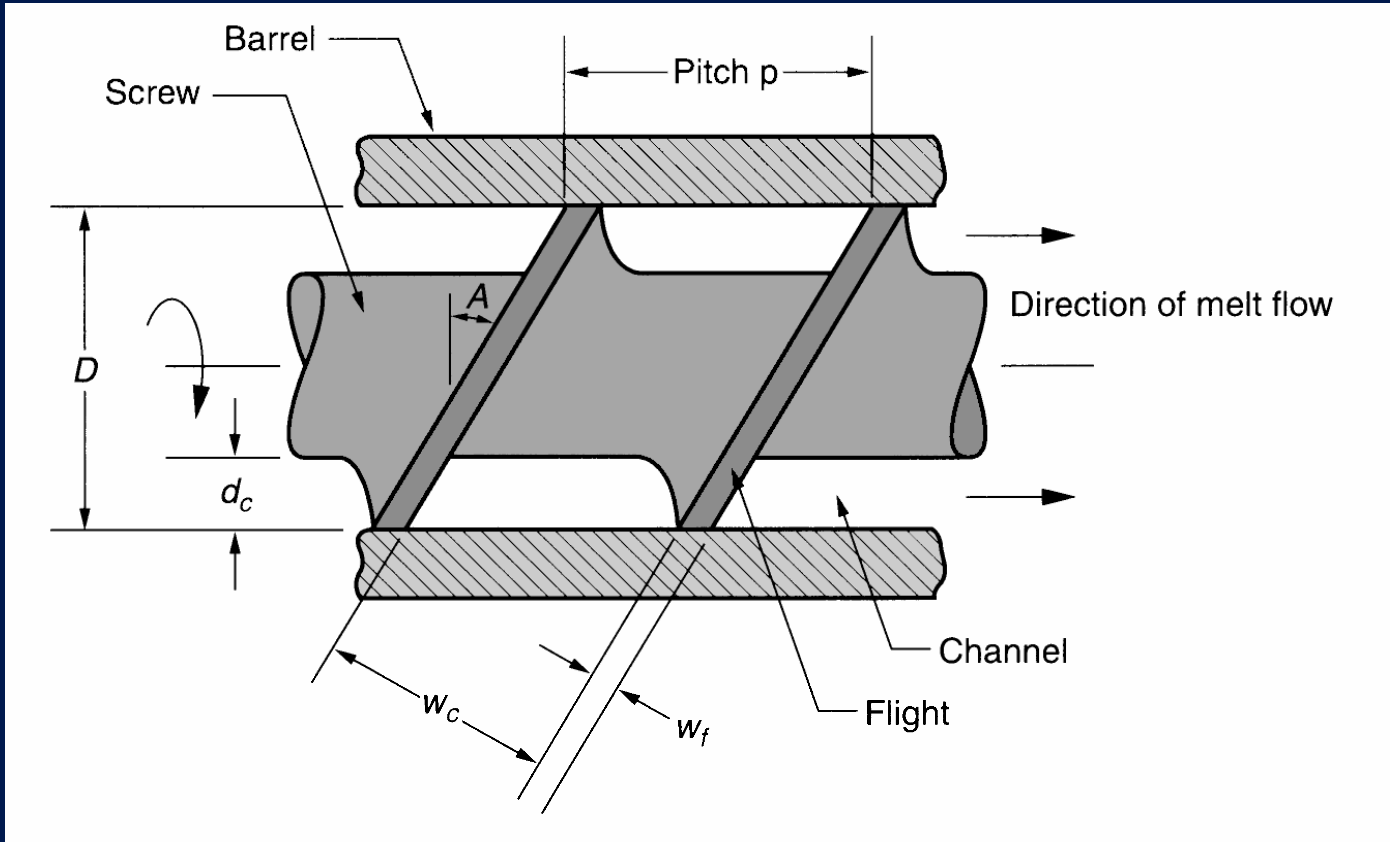


Figure 13.5 - Details of an extruder screw inside the barrel

Die End of Extruder

- Progress of polymer melt through barrel leads ultimately to the die zone
- Before reaching die, the melt passes through a *screen pack* - series of wire meshes supported by a stiff plate containing small axial holes
- Functions of screen pack:
  - Filter contaminants and hard lumps from melt
  - Build pressure in metering section
  - Straighten flow of polymer melt and remove its "memory" of circular motion imposed by screw

Melt Flow in Extruder

- As screw rotates inside barrel, polymer melt is forced to move forward toward die; as in an Archimedian screw
- Principal transport mechanism is *drag flow*, Q_d, resulting from friction between the viscous liquid and the rotating screw
- Compressing the polymer melt through the die creates a *back pressure* that reduces drag flow transport (called *back pressure flow*, Q_b)
- Resulting flow in extruder is $Q_x = Q_d - Q_b$

Die Configurations and Extruded Products

- The shape of the die orifice determines the cross-sectional shape of the extrudate
- Common die profiles and corresponding extruded shapes:
  - Solid profiles
  - Hollow profiles, such as tubes
  - Wire and cable coating
  - Sheet and film
  - Filaments

Extrusion of Solid Profiles

- Regular shapes such as
  - Rounds
  - Squares
- Irregular cross-sections such as
  - Structural shapes
  - Door and window moldings
  - Automobile trim
  - House siding

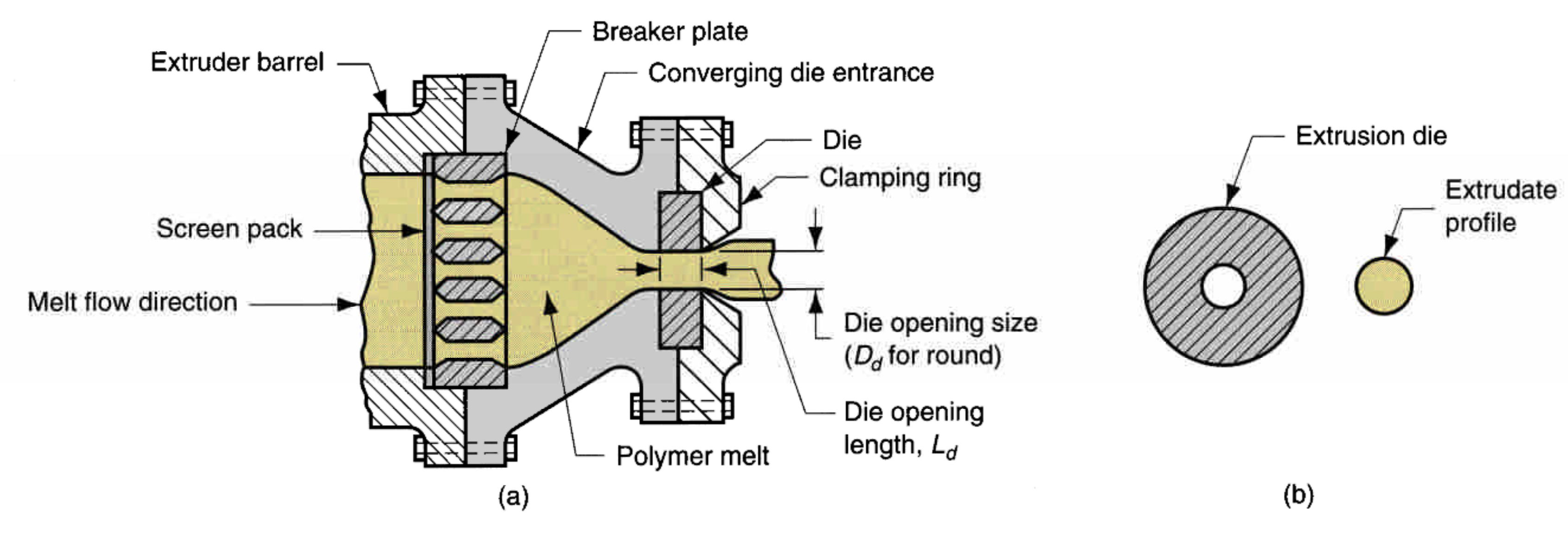


Figure 13.8 ‑ (a) Side view cross‑section of an extrusion die for solid regular shapes, such as round stock; (b) front view of die, with profile of extrudate Die swell is evident in both views

(Some die construction details are simplified or omitted for clarity.)

Hollow Profiles

- Examples: tubes, pipes, hoses, and other cross-sections containing holes
- Hollow profiles require mandrel to form the shape
- Mandrel held in place using a spider
  - Polymer melt flows around legs supporting the mandrel to reunite into a monolithic tube wall
- Mandrel often includes an air channel through which air is blown to maintain hollow form of extrudate during hardening

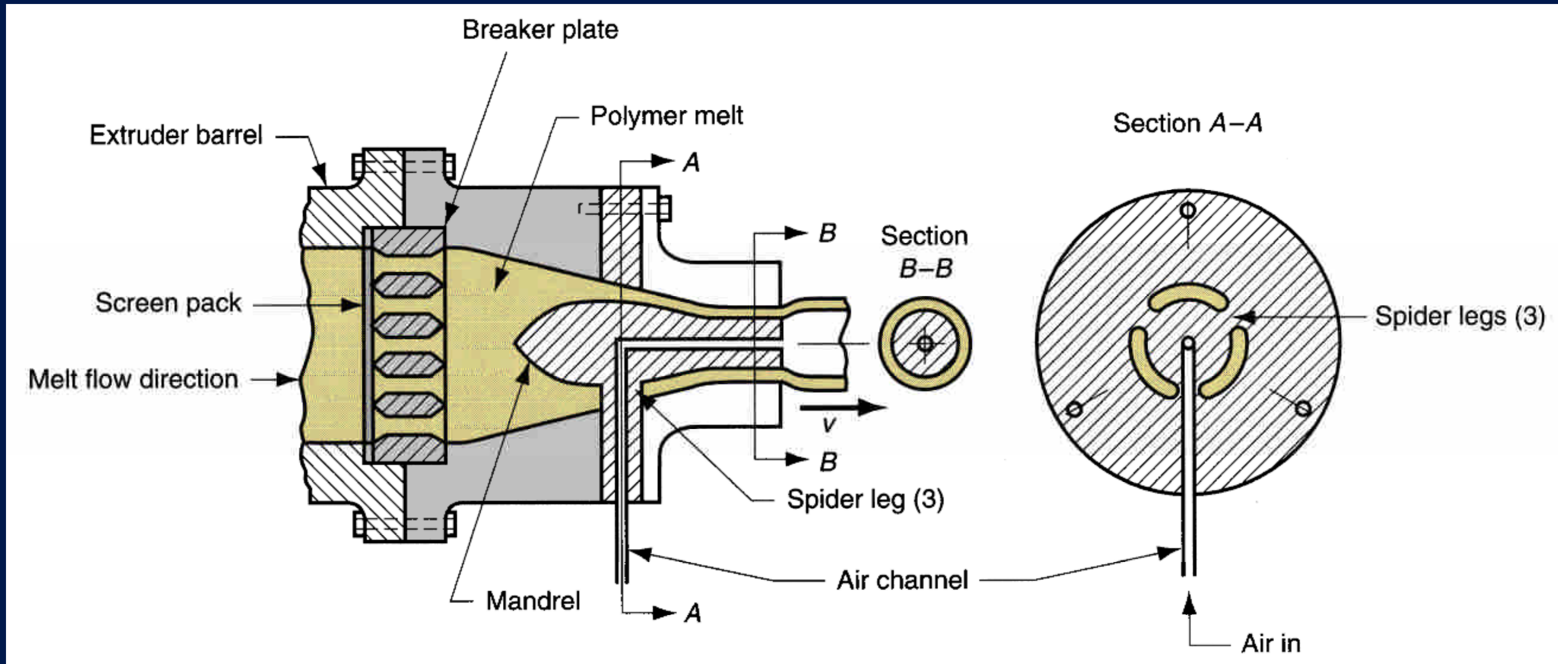


Figure 13.10 ‑ Side view cross‑section of extrusion die for shaping hollow cross‑sections such as tubes and pipes; Section A‑A is a front view cross‑section showing how the mandrel is held in place; Section B‑B shows the tubular cross‑section just prior to exiting the die; die swell causes an enlargement of the diameter

Wire and Cable Coating

- Polymer melt is applied to bare wire as it is pulled at high speed through a die
  - A slight vacuum is drawn between wire and polymer to promote adhesion of coating
- Wire provides rigidity during cooling - usually aided by passing coated wire through a water trough
- Product is wound onto large spools at speeds up to 50 m/s (10,000 ft/min)

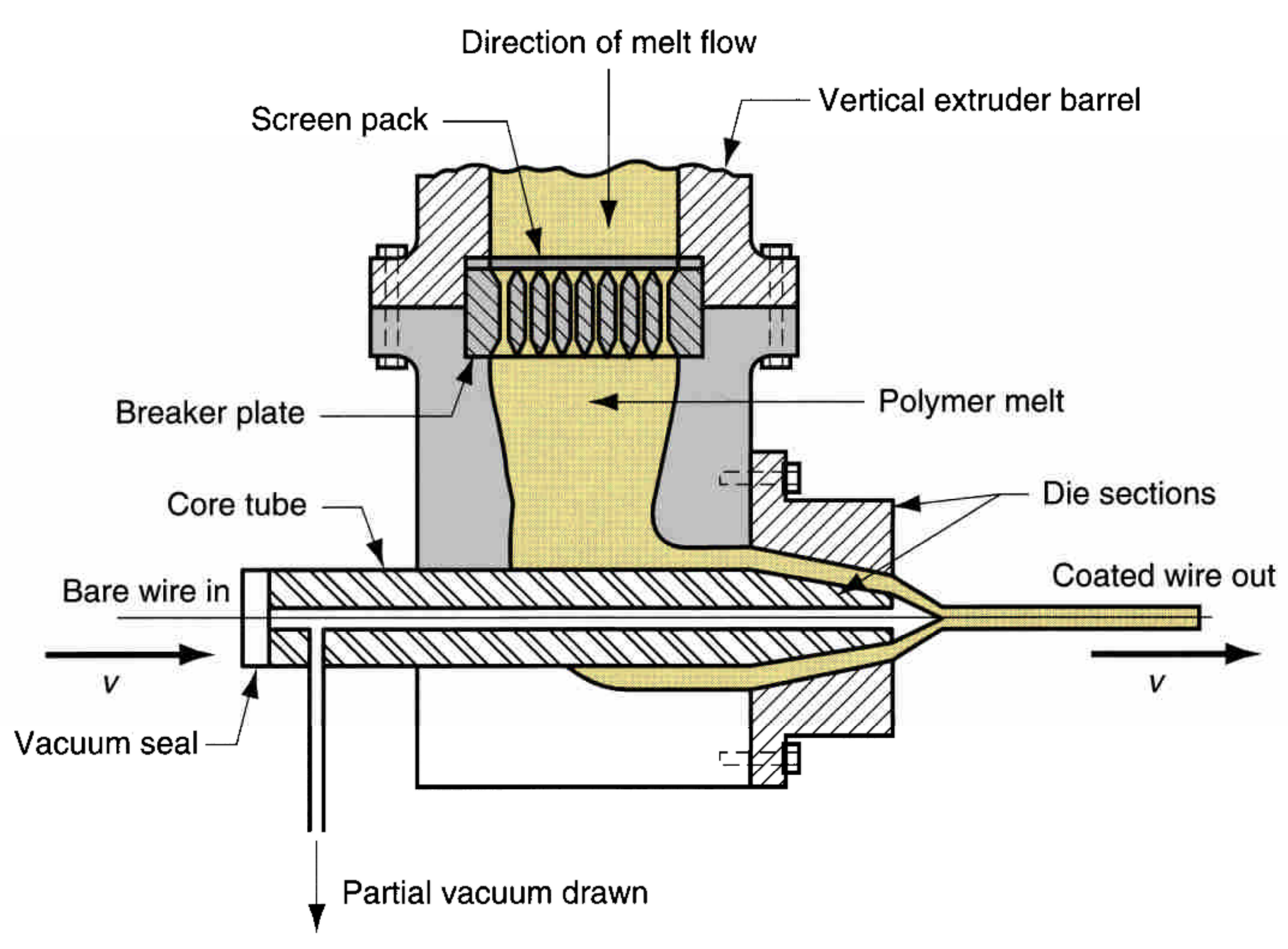


Figure 13.11 ‑ Side view cross‑section of die for coating of electrical wire by extrusion

Polymer Sheet and Film

- Sheet
  - Thickness from 0.5 mm (0.020 in.) to about 12.5 mm (0.5 in.)
  - Used for products such as flat window glazing and stock for thermoforming
- Film
  - Thickness below 0.5 mm (0.020 in.)
  - Used for packaging (product wrapping material, grocery bags, and garbage bags)
  - Thicker film applications include pool covers and liners for irrigation ditches

Materials for Polymer Sheet and Film

- All thermoplastic polymers
  - Polyethylene, mostly low density PE
  - Polypropylene
  - Polyvinylchloride
  - Cellophane

Sheet and Film Production Processes

- Most widely used processes are continuous, high production operations
- Processes include:
  - Slit-Die Extrusion of Sheet and Film
  - Blown-Film Extrusion Process
  - Calendering

Slit-Die Extrusion of Sheet and Film

Production of sheet and film by conventional extrusion, using a narrow slit as the die opening

- Slit may be up to 3 m (10 ft) wide and as narrow as around 0.4 mm (0.015 in)
- A problem in this method is uniformity of thickness throughout width of stock, due to drastic shape change of polymer melt during its flow through die
- Edges of film usually must be trimmed because of thickening at edges

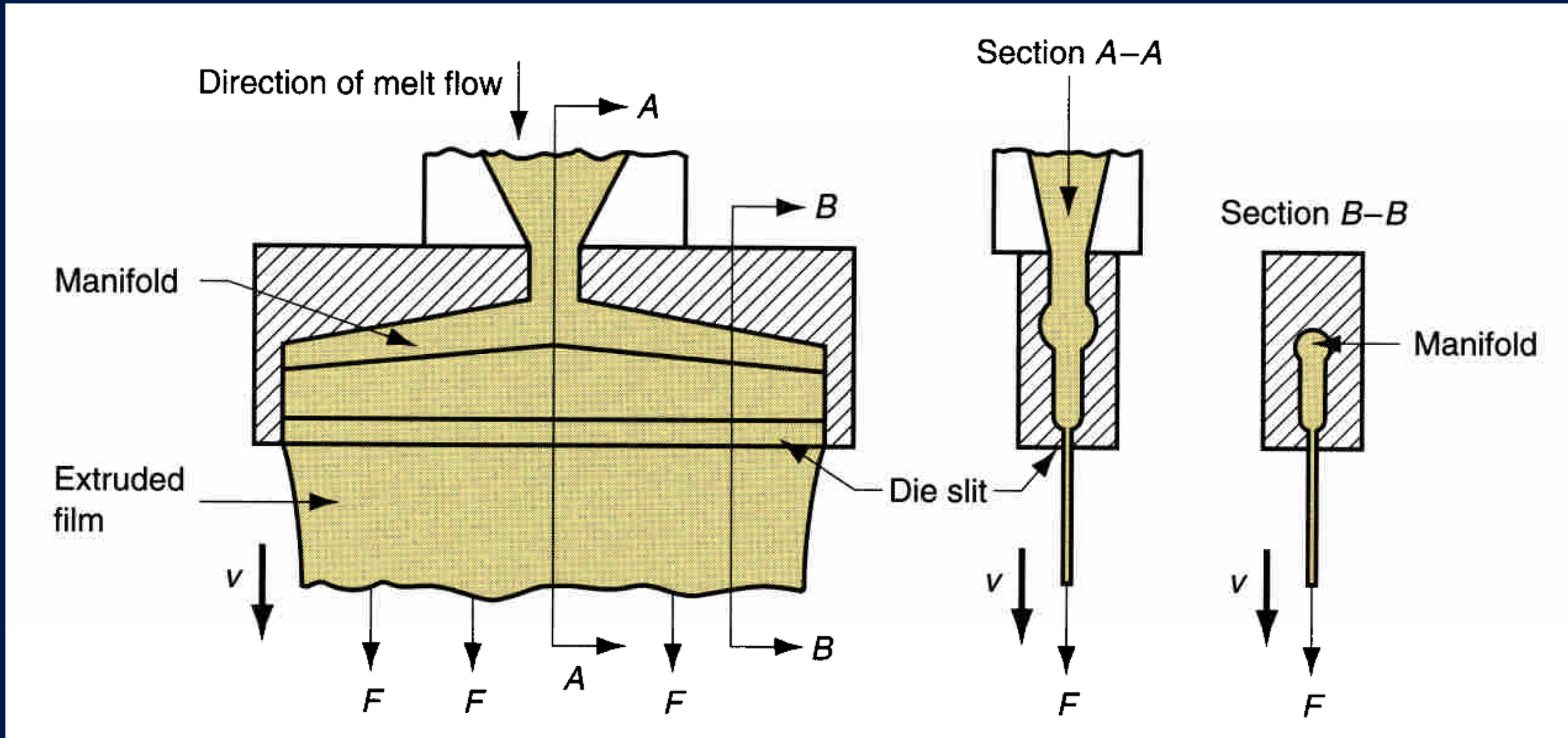


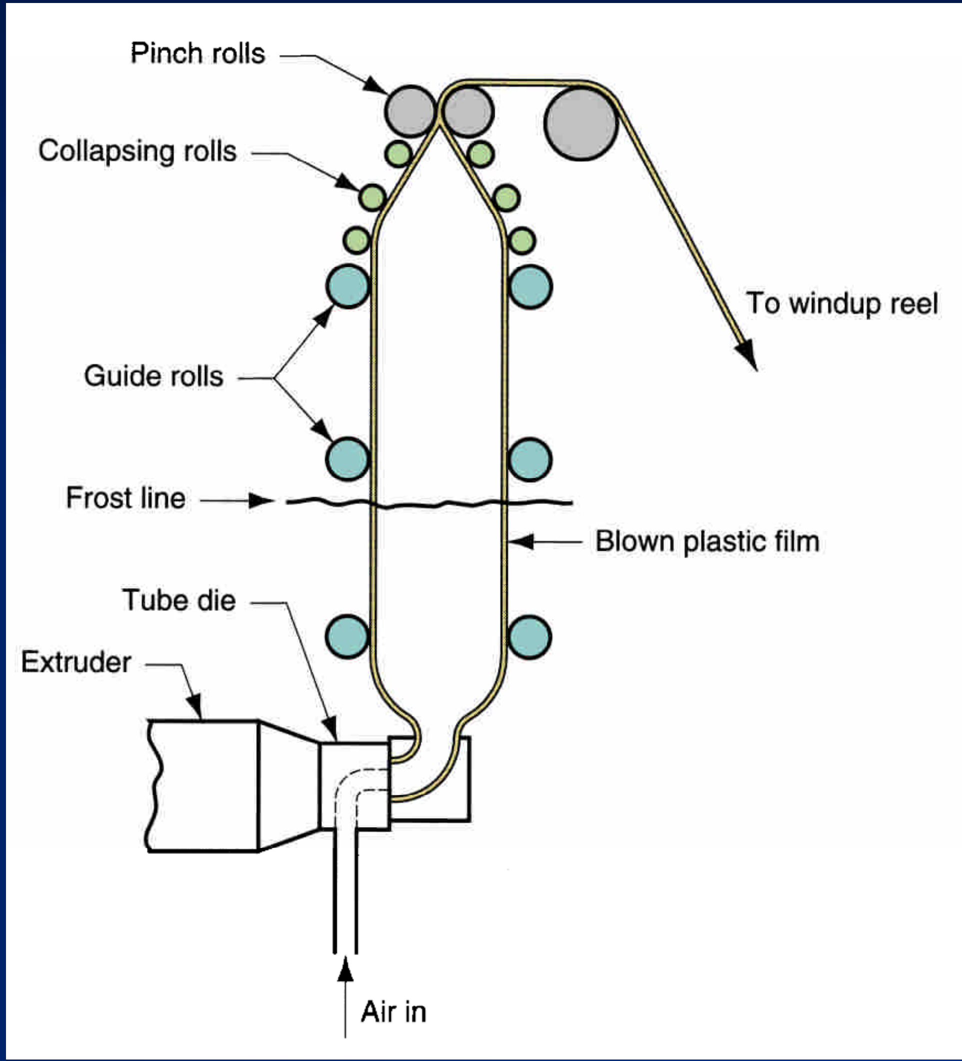
Figure 13.14 - One of several die configurations for extruding sheet and film

Blown-Film Extrusion Process

Combines extrusion and blowing to produce a tube of thin film

- Process begins with extrusion of tube that is drawn upward while still molten and simultaneously expanded by air inflated into it through die mandrel
- Air is blown into tube to maintain uniform film thickness and tube diameter

Figure 13.16 - Blown-film process for high production of thin tubular film



Calendering

Feedstock is passed through a series of rolls to reduce thickness to desired gage

- Equipment is expensive, but production rate is high
- Process is noted for good surface finish and high gage accuracy
- Typical materials: rubber or rubbery thermoplastics such as plasticized PVC
- Products: PVC floor covering, shower curtains, vinyl table cloths, pool liners, and inflatable boats and toys

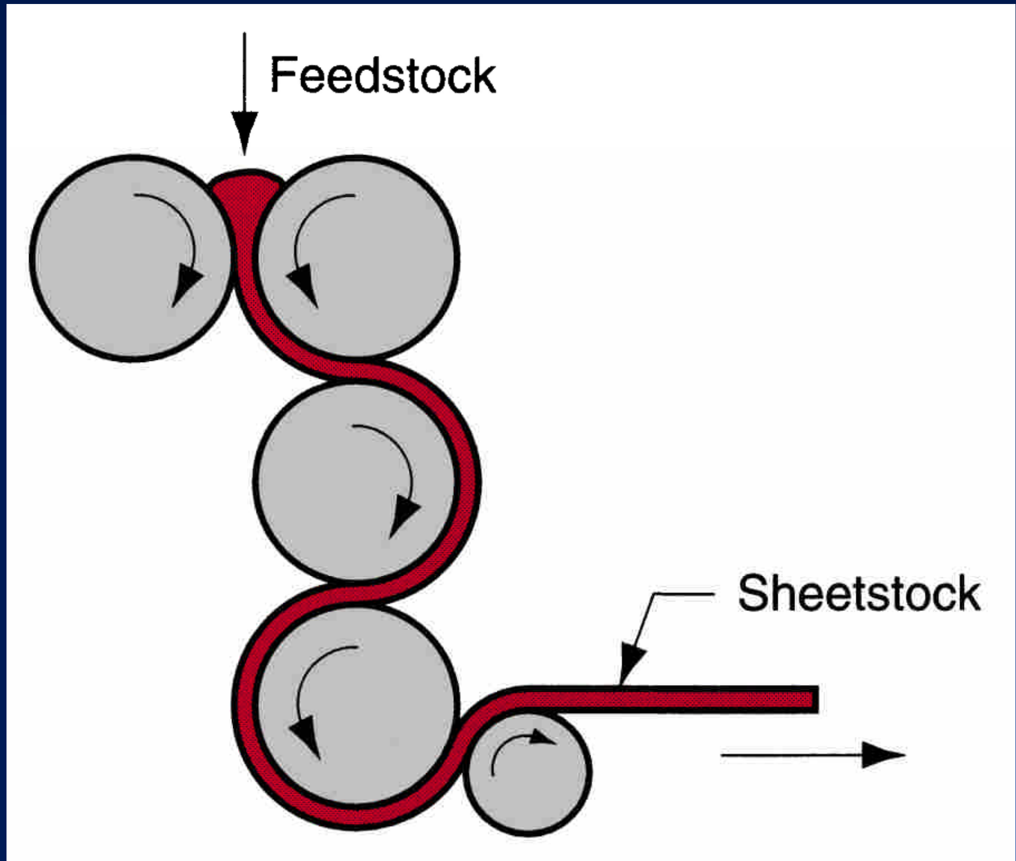


Figure 13.17 - A typical roll configuration in calendering

Fiber and Filament Products

- Most important application of fibers and filaments is in textiles
- Their use as reinforcing materials in plastics (composites) is growing, but still small compared to textiles
- Definitions:
  - *Fiber* - a long, thin strand whose length is at least 100 times its cross-section
  - *Filament* - a fiber of continuous length

Materials for Fibers and Filaments

- Fibers can be natural or synthetic
- Synthetic fibers constitute about 75% of total fiber market today:
  - Polyester is the most important
  - Others: nylon, acrylics, and rayon
- Natural fibers are about 25% of total:
  - Cotton is by far the most important staple
  - Wool production is significantly less than cotton

Fiber and Filament Production - Spinning

- The term *spinning* is a holdover from methods used to draw and twist natural fibers into yarn or thread

For synthetic fibers, *spinning* = extruding a polymer melt or solution through a *spinneret* (a die with multiple small holes), then drawing and winding the product onto a *bobbin*

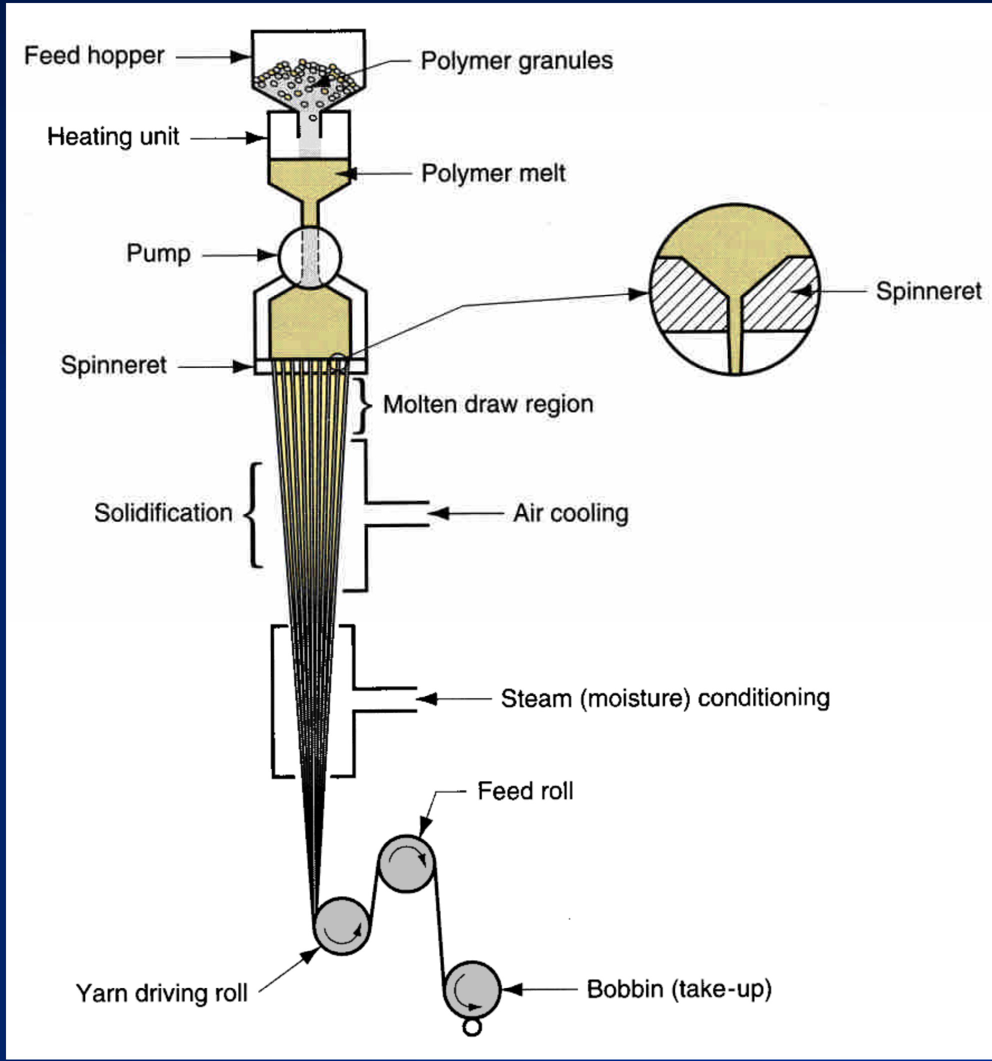
- Three variations, depending on polymer processed:
  1. Melt spinning
  2. Dry spinning
  3. Wet spinning

Melt Spinning

Starting polymer is heated to molten state and pumped through spinneret, similar to conventional extrusion

- Typical spinneret is 6 mm (0.25 in) thick and contains approximately 50 holes of diameter 0.25 mm (0.010 in)
- Filaments are drawn and air cooled before being spooled onto bobbin
- Significant extension and thinning of filaments occur while polymer is still molten, so final diameter wound onto bobbin may be only 1/10 of extruded size
- Used to produce filaments of polyesters and nylons

Figure 13.18 - Melt spinning of continuous filaments



Dry Spinning

Similar to melt spinning, but starting polymer is in solution and solvent can be separated by evaporation

- First step is extrusion through spinneret
- Extrudate is pulled through a heated chamber which removes the solvent, leaving the polymer
- Used to produce filaments of cellulose acetates and acrylics

Wet Spinning

- Polymer is also in solution, only solvent is non-volatile
- To separate polymer, extrudate is passed through a liquid chemical that coagulates or precipitates the polymer into coherent strands which are then collected onto bobbins
- Used to produce filaments of rayon (regenerated cellulose)

Subsequent Processing of Filaments

- Filaments produced by any of the three processes are usually subjected to further cold drawing to align crystal structure along direction of filament axis
  - Extensions of 2 to 8 are typical
  - Effect is to significantly increase tensile strength
  - Drawing is accomplished by pulling filament between two spools, where winding spool is driven at a faster speed than unwinding spool

Injection Molding

Polymer is heated to a highly plastic state and forced to flow under high pressure into a mold cavity where it solidifies; molded part is then removed from cavity

- Produces discrete components almost always to net shape
- Typical cycle time ~10 to 30 sec., but cycles of one minute or more are not uncommon
- Mold may contain multiple cavities, so multiple moldings are produced each cycle

Injection Molded Parts (*Moldings*)

- Complex and intricate shapes are possible
- Shape limitations:
  - Capability to fabricate a mold whose cavity is the same geometry as part
  - Shape must allow for part removal from mold
- Part size from ~ 50 g (2 oz) up to ~ 25 kg (more than 50 lb), e.g., automobile bumpers
- Injection molding is economical only for large production quantities due to high cost of mold

Polymers for Injection Molding

- Injection molding is the most widely used molding process for *thermoplastics*
- Some *thermosets* and *elastomers* are injection molded
  - Modifications in equipment and operating parameters must be made to avoid premature cross-linking of these materials

Injection Molding Machine

- Two principal components:
  - *Injection unit* – melts and delivers polymer melt, operates much like an extruder
  - *Clamping unit* – opens and closes mold each injection cycle

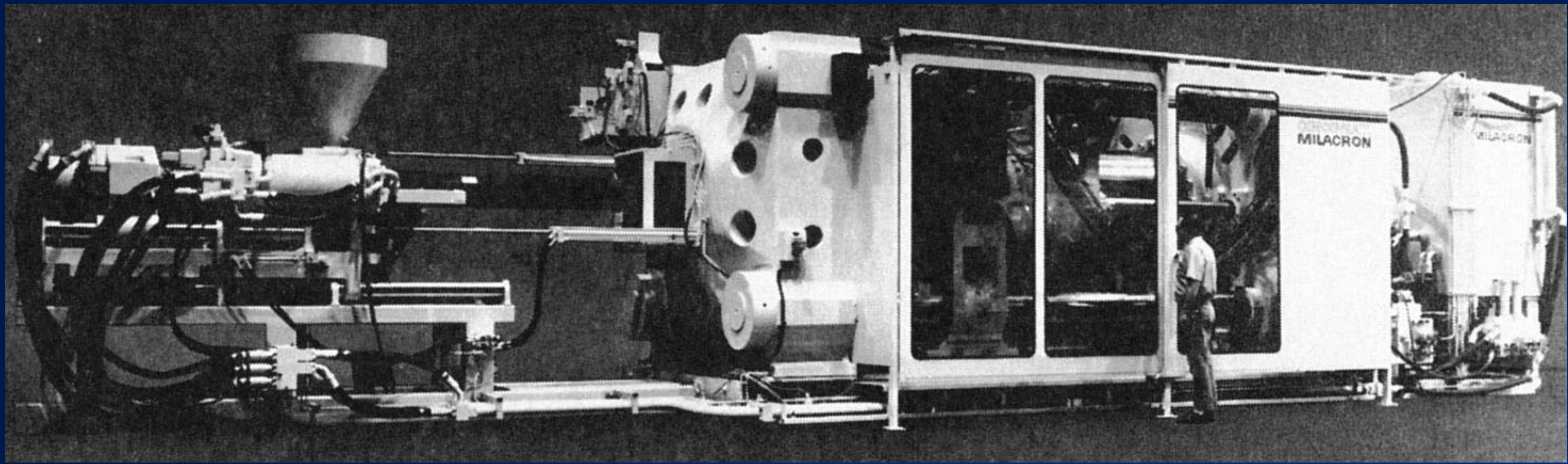


Figure 13.20 - A large (3000 ton capacity) injection molding machine (courtesy Cincinnati Milacron)

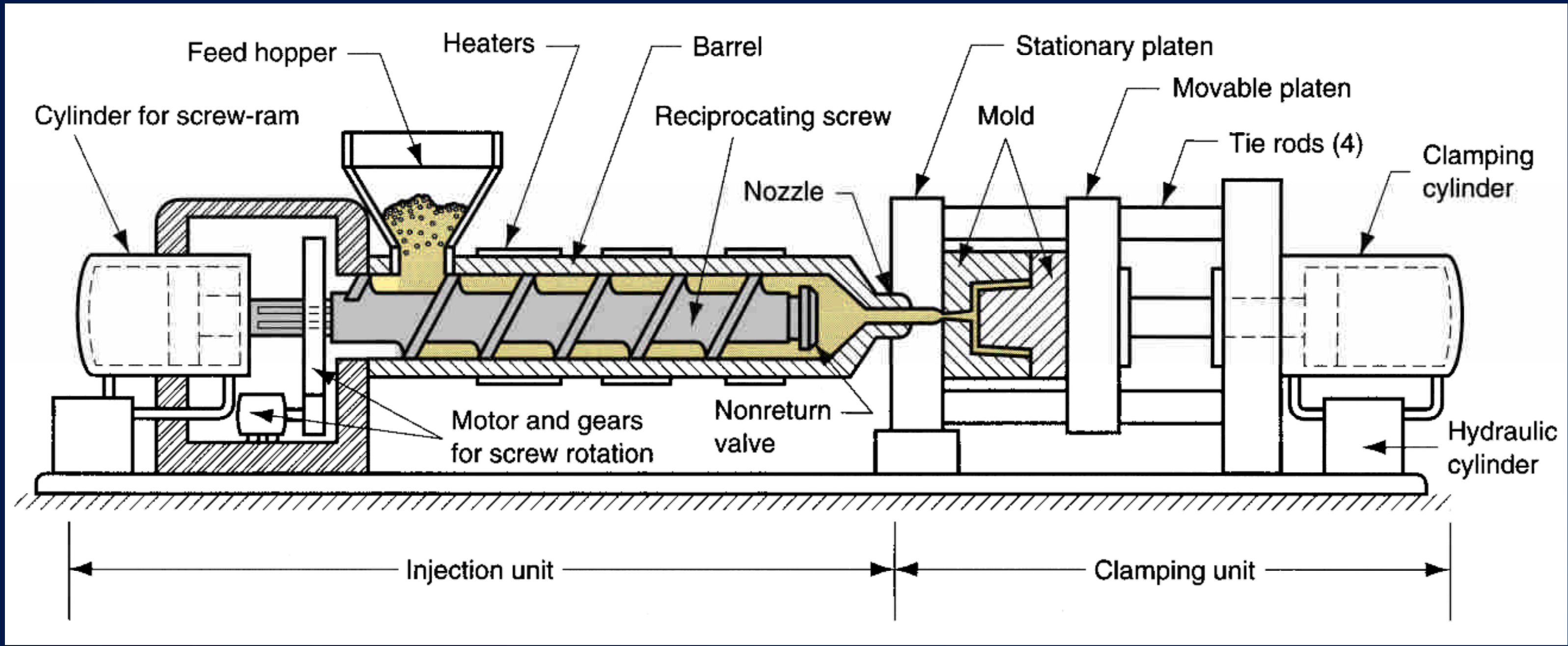


Figure 13.21 - Diagram of an injection molding machine, reciprocating screw type (some mechanical details are simplified)

Injection Unit of Molding Machine

- Consists of *barrel* fed from one end by a hopper containing supply of plastic pellets
- Inside the barrel is a *screw* which has two functions:

1. Rotates for mixing and heating the polymer
2. Acts as a ram to inject molten plastic into mold
   - Non-return valve near tip of screw prevents melt flowing backward along screw threads
   - Later in molding cycle ram retracts to its former position

Clamping Unit of Molding Machine

- Functions:
  1. Holds two halves of mold in proper alignment with each other
  2. Keeps mold closed during injection by applying a clamping force sufficient to resist injection force
  3. Opens and closes the mold at the appropriate times in molding cycle

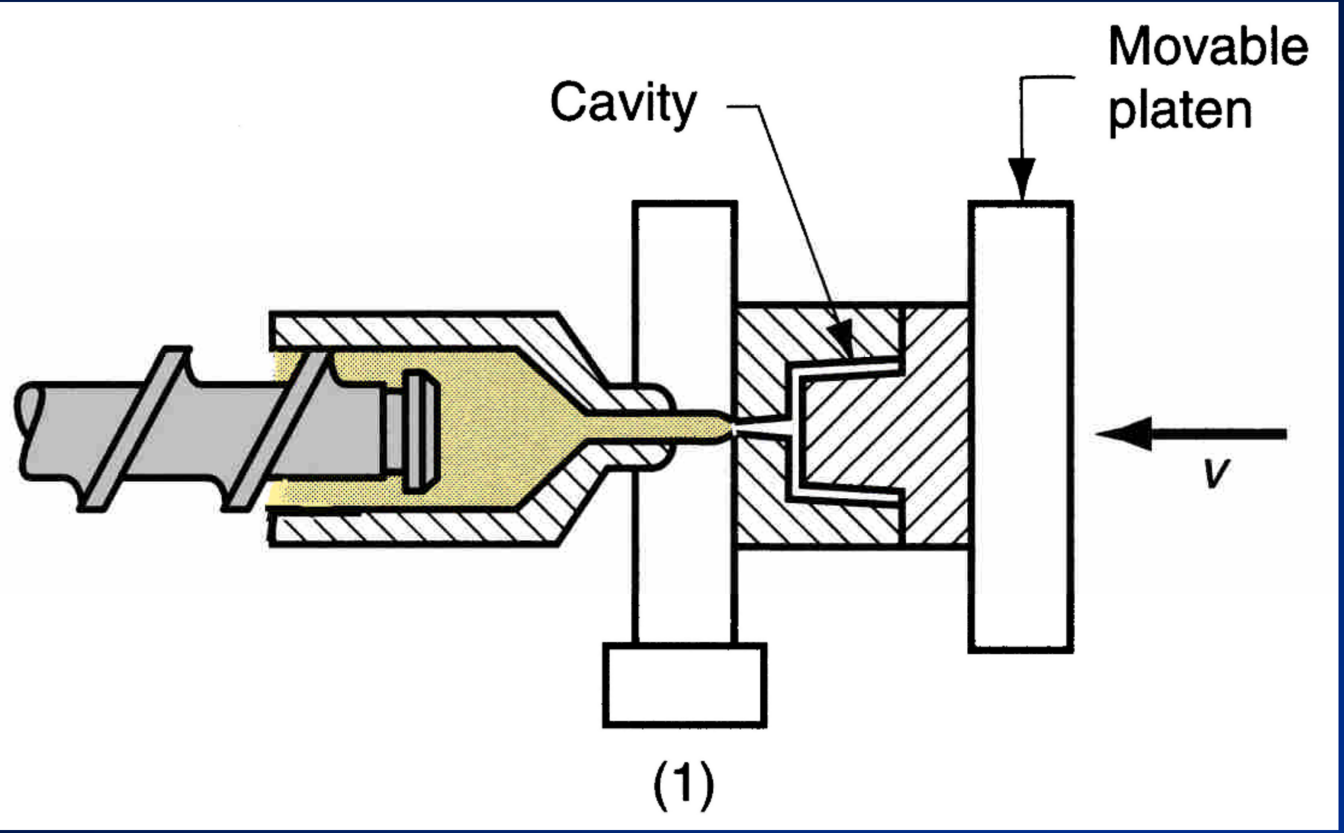


Figure 13.22 - Typical molding cycle:
(1) mold is closed

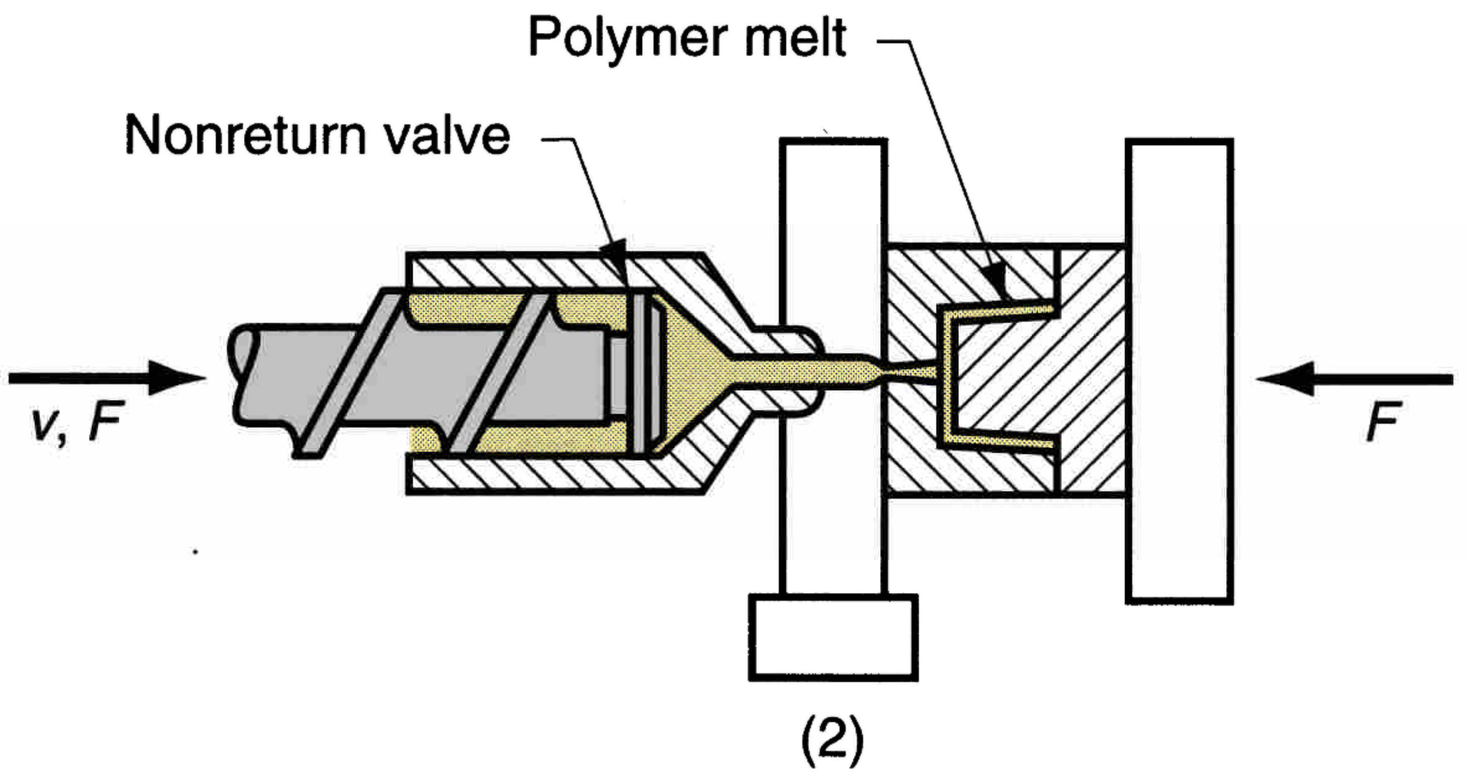


Figure 13.22 - Typical molding cycle:
(2) melt is injected into cavity

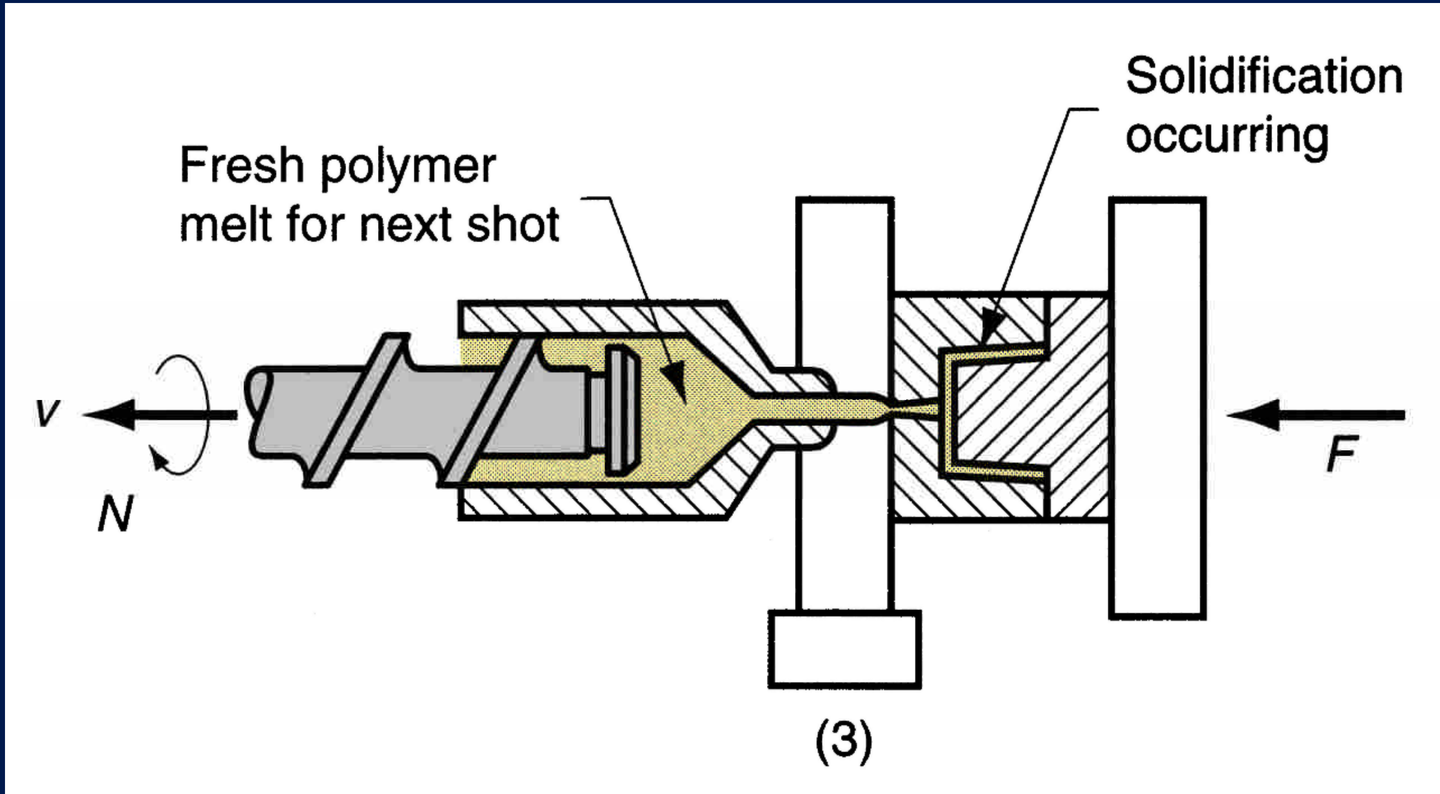


Figure 13.22 - Typical molding cycle:

(3) screw is retracted

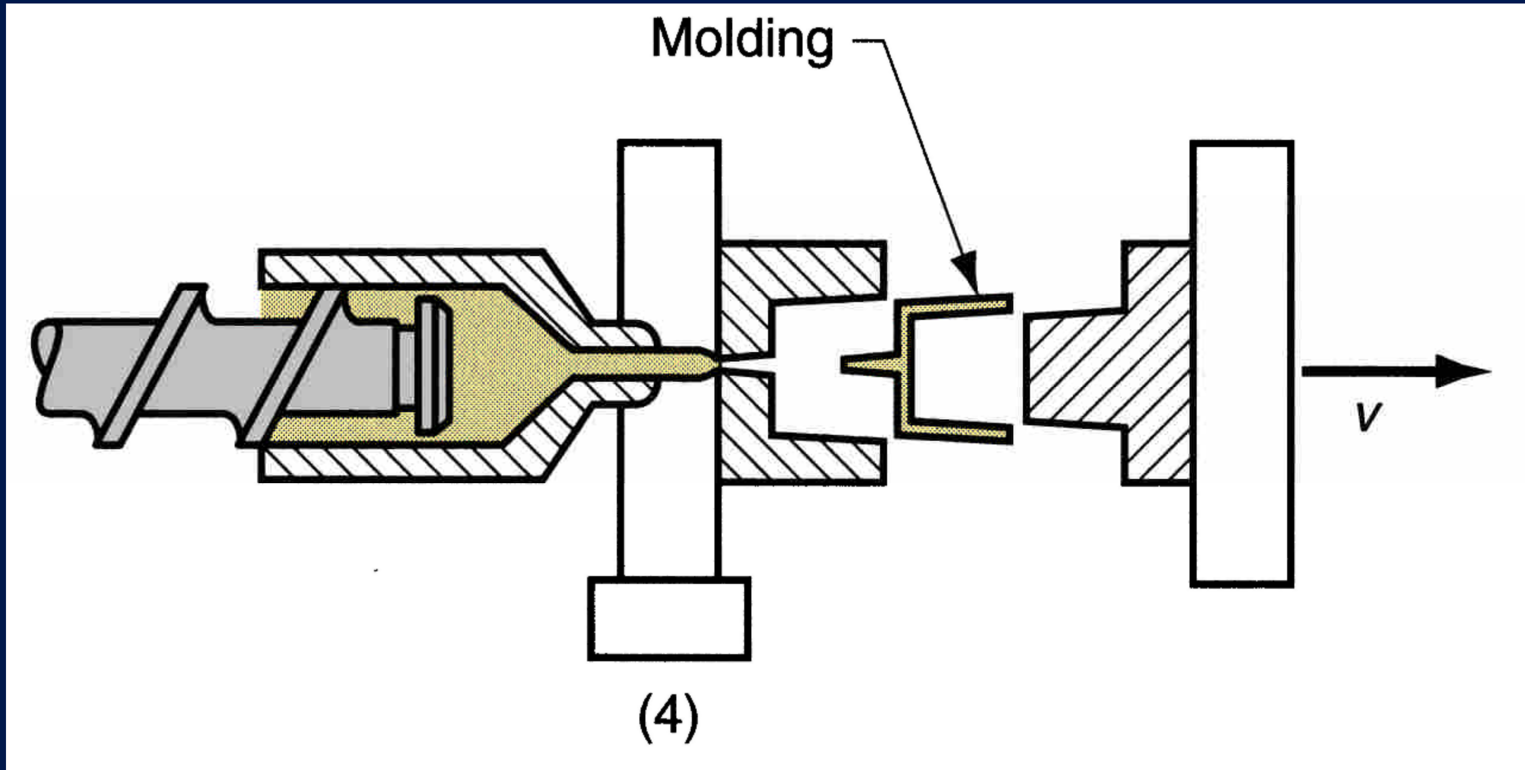


Figure 13.22 - Typical molding cycle:
(4) mold opens and part is ejected

The Mold

- The special tool in injection molding
- Custom-designed and fabricated for the part to be produced
- When production run is finished, the mold is replaced with a new mold for the next part
- Various types of mold for injection molding:
  - Two-plate mold
  - Three-plate mold
  - Hot-runner mold

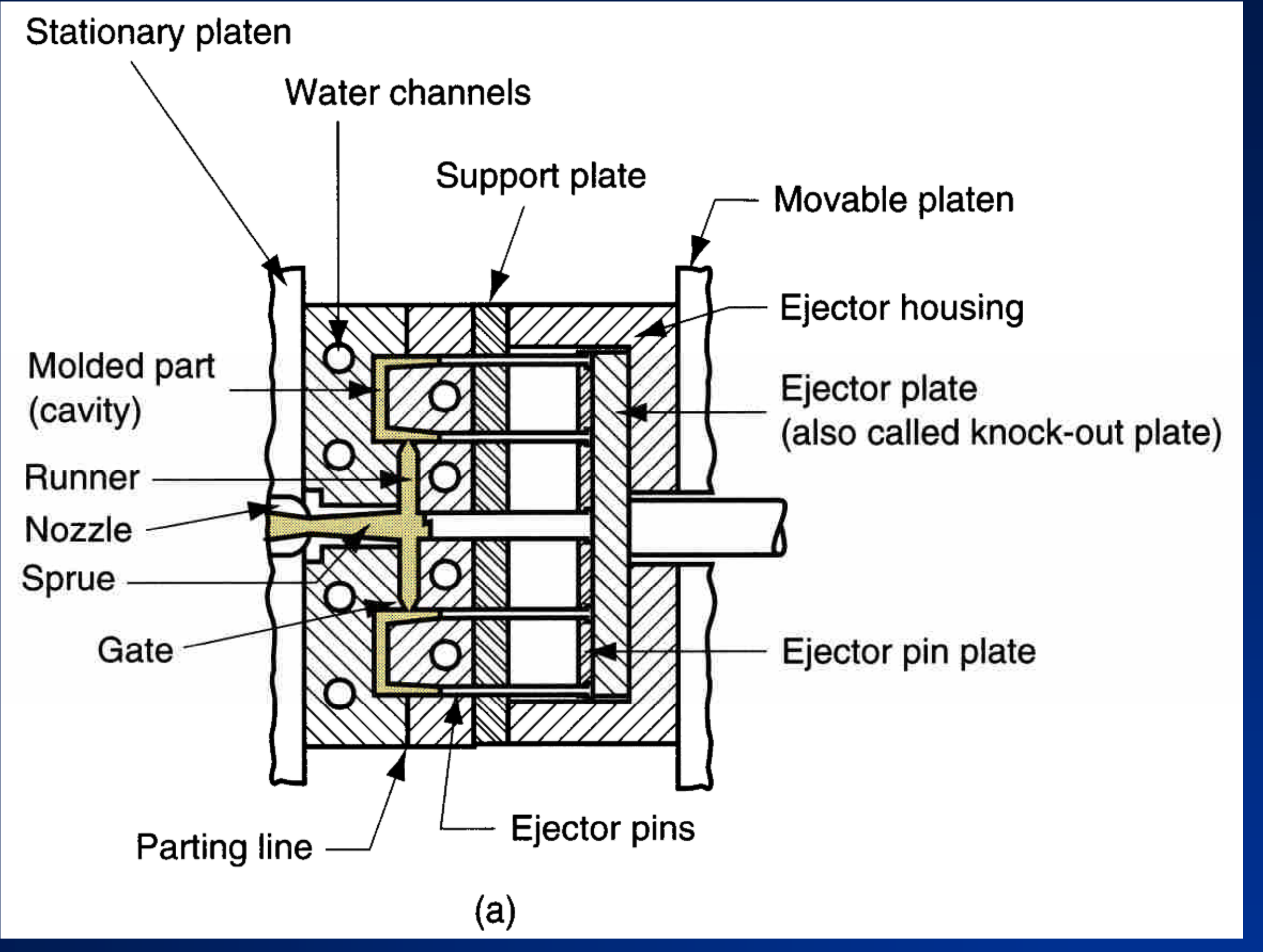


Figure 13.23 - Details of a two-plate mold for thermoplastic injection molding: (a) closed. Mold has two cavities to produce two cup-shaped parts with each injection shot

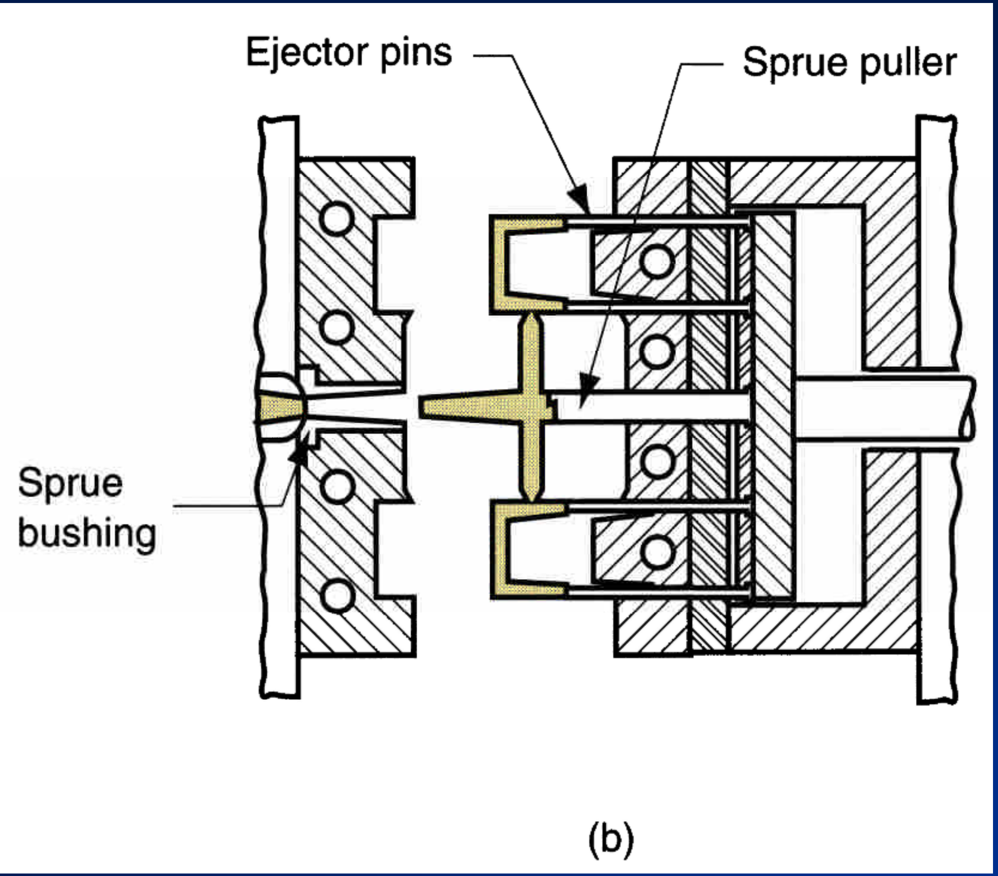


Figure 13.23 - Details of a two-plate mold for thermoplastic injection molding: (b) open

Two-Plate Mold Features

- *Cavity* – has geometry of part but slightly oversized to allow for shrinkage
  - Created by machining of the mating surfaces of two mold halves
- *Distribution channel* through which polymer melt flows from nozzle into mold cavity
  - *Sprue* - leads from nozzle into mold
  - *Runners* - lead from sprue to cavity (or cavities)
  - *Gates* - constrict flow of plastic into cavity

More Two-Plate Mold Features

- *Ejection system* – function is to eject molded part from cavity at end of molding cycle
  - *Ejector pins* built into moving half of mold usually accomplish this function
- *Cooling system* - consists of external pump connected to passageways in mold, through which water is circulated to remove heat from hot plastic
- *Air vents* – to permit evacuation of air from cavity as polymer melt rushes in

Three-Plate Mold

Uses three plates to separate parts from sprue and runner when mold opens

- Advantages over two-plate mold:
  - Allows automatic operation of molding machine
    - As mold opens, runner and parts disconnect & drop by gravity into two containers under mold
  - Flow of molten plastic is through a gate at the base of part rather than side, allowing more even distribution of plastic melt into sides of cup

Hot-Runner Mold

- Eliminates solidification of sprue and runner by locating heaters around the corresponding runner channels
- While plastic in mold cavity solidifies, material in sprue and runner channels remains molten, ready to be injected into cavity in next cycle
  - This saves material that otherwise would be scrap in the unit operation

Injection Molding Machines

- Injection molding machines differ in both injection unit and clamping unit
- The name of the injection molding machine is generally based on the type of injection unit used
  - Example: Reciprocating-screw machine
- Several clamping designs
  - Examples: mechanical (toggle) vs. hydraulic

Shrinkage

Reduction in linear size during cooling from molding to room temperature

- Polymers have high thermal expansion coefficients, so significant shrinkage occurs during cooling in mold
- Typical shrinkage values for selected polymers:

Plastic	Shrinkage, mm/mm (in/in)
Nylon-6,6	0.020
Polyethylene	0.025
Polystyrene	0.004
PVC	0.005

Compensation for Shrinkage

- Dimensions of mold cavity must be larger than specified part dimensions:

$$D_c = D_p + D_pS + D_pS^2$$

where D_c = dimension of cavity; D_p = molded part dimension, and S = shrinkage value

- Third term on right hand side corrects for shrinkage in the shrinkage

Shrinkage Factors

- *Fillers* in the plastic tend to reduce shrinkage
- *Injection pressure* – as pressure is increased, forcing more material into mold cavity, shrinkage is reduced
- *Compaction time* - similar effect - forces more material into cavity during shrinkage
- *Molding temperature* - higher temperatures lower polymer melt viscosity, allowing more material to be packed into mold and reducing shrinkage

Thermoplastic Foam Injection Molding

Molding of thermoplastic parts that possess dense outer skin surrounding lightweight foam center

- Part has high stiffness-to-weight ratio suited to structural applications
- Produced either by introducing a gas into molten plastic in injection unit or by mixing a gas-producing ingredient with starting pellets
- During injection, a small amount of melt is forced into mold cavity, where it expands to fill cavity
- Foam in contact with cold mold surface collapses to form dense skin, while core retains cellular structure

Injection Molding of Thermosets

- Equipment and operating procedure must be modified to avoid premature cross-linking of TS polymer
  - Reciprocating-screw injection unit with shorter barrel length
- Temperatures in barrel are relatively low
- Melt is injected into a heated mold, where cross-linking occurs to harden plastic
- Mold is then opened and part is removed
- Curing is the most time-consuming step in the cycle

Reaction Injection Molding

Two highly reactive liquid ingredients are mixed and immediately injected into a mold cavity where chemical reactions leading to solidification occur

- RIM was developed with polyurethane to produce large automotive parts such as bumpers and fenders
  - RIM polyurethane parts possess a foam internal structure surrounded by a dense outer skin
- Other materials used in RIM: epoxies, and urea-formaldehyde

Compression Molding

- An old and widely used molding process for thermosetting plastics
- Applications also include rubber tires and polymer matrix composite parts
- Molding compound available in several forms: powders or pellets, liquid, or preform
- Amount of *charge* must be precisely controlled to obtain repeatable consistency in the molded product

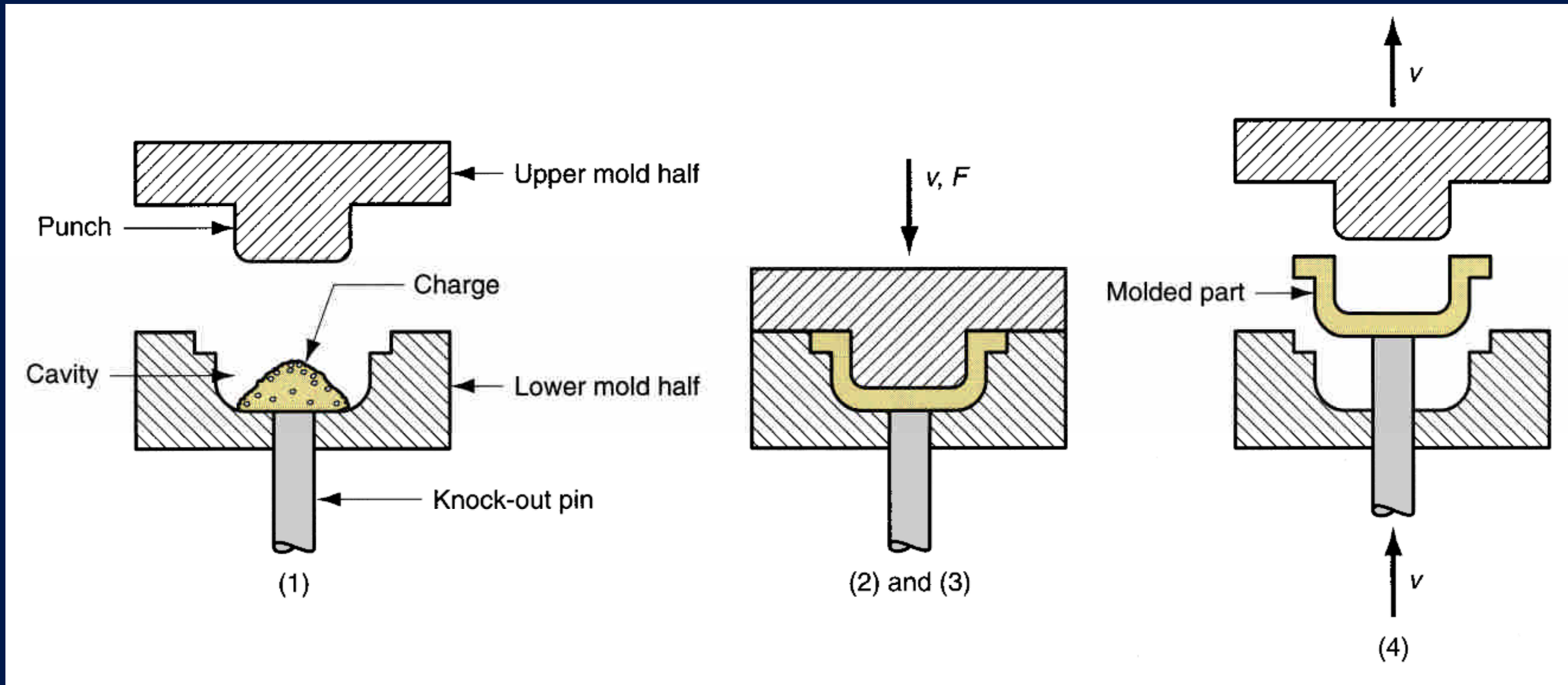


Figure 13.28 - Compression molding for thermosetting plastics: (1) charge is loaded, (2) and (3) charge is compressed and cured, and (4) part is ejected and removed (some details omitted)

Compression Molding Presses

- Oriented vertically
- Contain two platens to which mold halves are fastened
- Presses have either of two types of actuation:
  1. Upstroke of bottom platen
  2. Downstroke of top platen

Molds for Compression Molding

- Simpler than injection molds
- No sprue and runner system in a compression mold
- Process itself generally limited to simpler part geometries due to lower flow capabilities of TS materials
- Mold must be heated, usually by electric resistance, steam, or hot oil circulation

Materials and Products in Compression Molding

- Materials: phenolics, melamine, urea-formaldehyde, epoxies, urethanes, and elastomers
- Typical TS moldings: electric plugs, sockets, and housings; pot handles, and dinnerware plates

Transfer Molding

TS charge is loaded into a chamber immediately ahead of mold cavity, where it is heated; pressure is then applied to force soft polymer to flow into heated mold where it cures

- Two variants:
  - *Pot transfer molding* - charge is injected from a "pot" through a vertical sprue channel into cavity
  - *Plunger transfer molding* – plunger injects charge from a heated well through channels into cavity

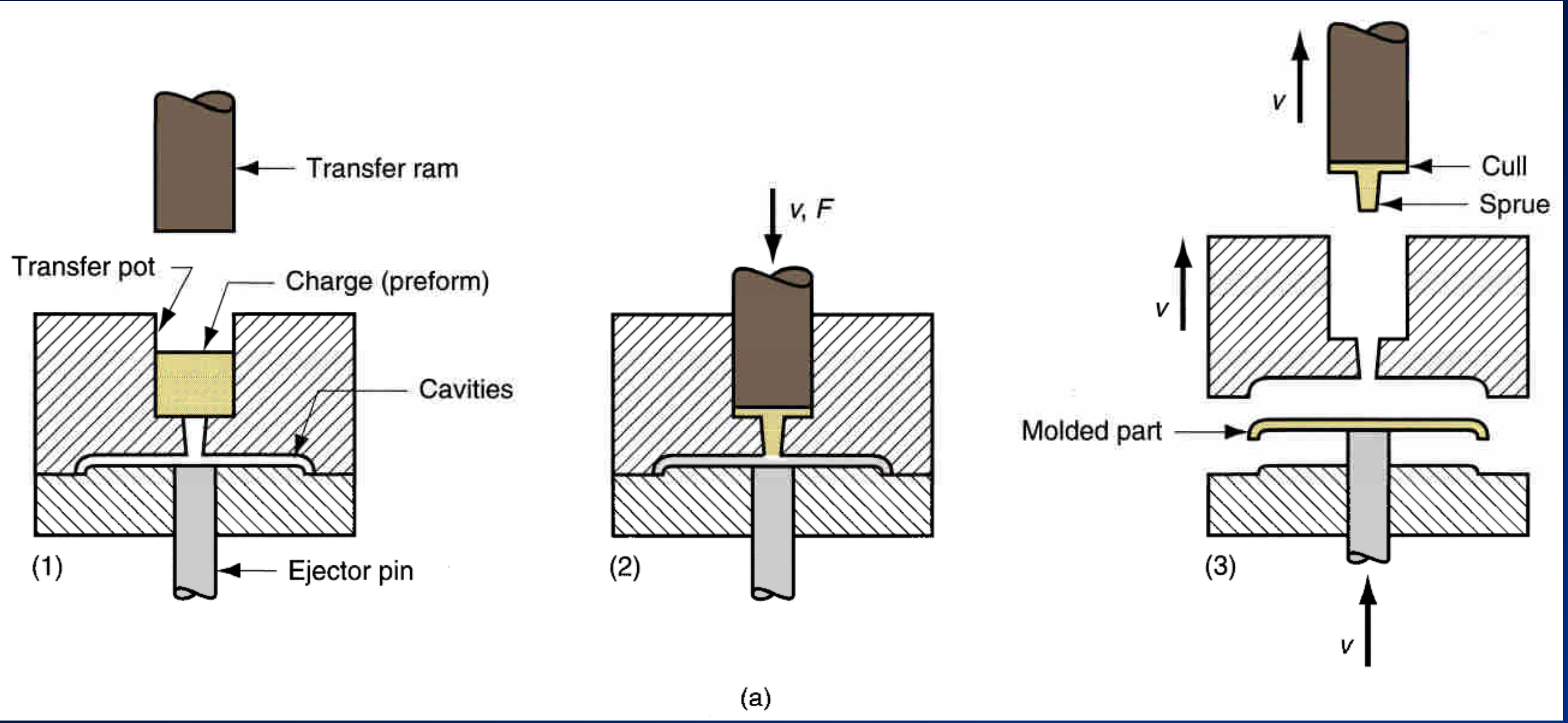


Figure 13.29 - (a) Pot transfer molding

(1) charge is loaded into pot,

(2) softened polymer is pressed into mold cavity and cured, and

(3) part is ejected

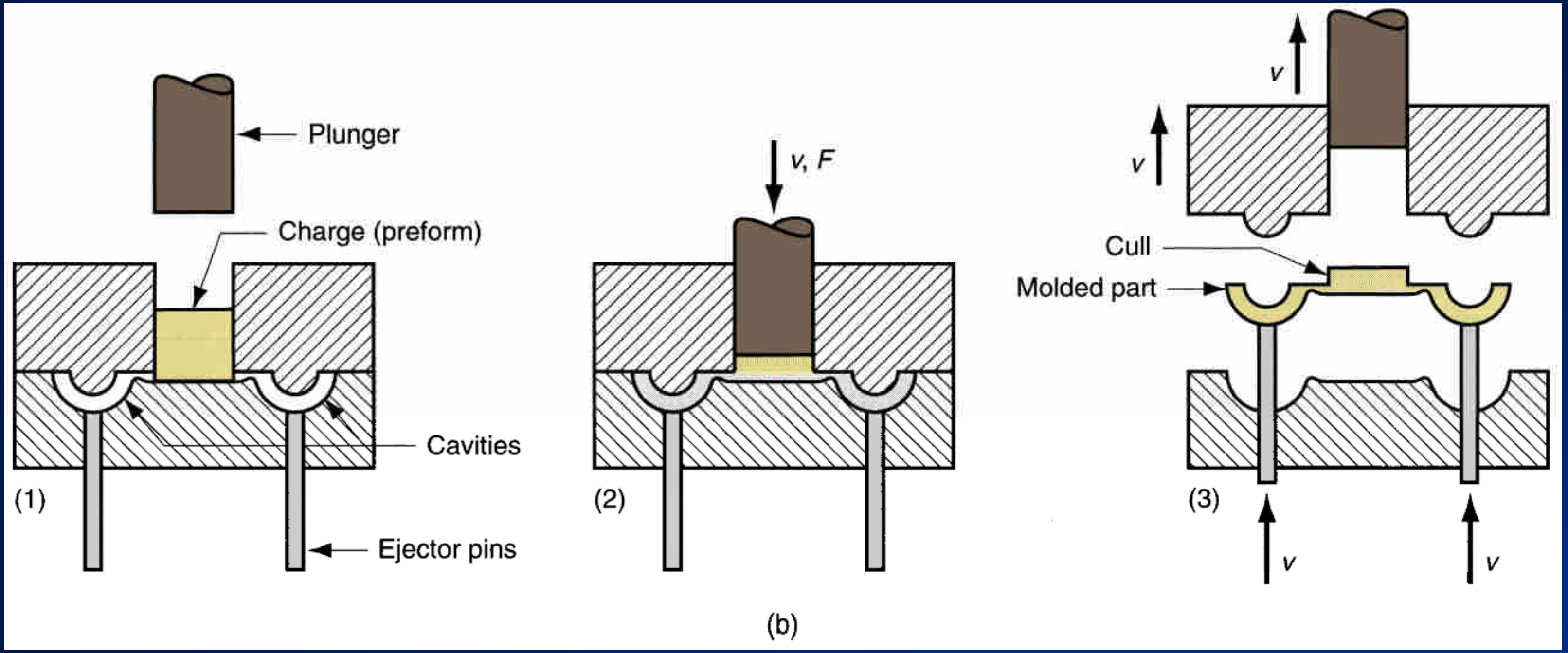


Figure 13.29 - (b) plunger transfer molding

(1) charge is loaded into pot,

(2) softened polymer is pressed into mold cavity and cured, and

(3) part is ejected

Compression and Transfer Molding Compared

- In both processes, scrap is produced each cycle as leftover material, called the *cull*
- The TS scrap cannot be recovered
- Transfer molding is capable of molding more intricate part shapes than compression molding but not as intricate as injection molding
- Transfer molding lends itself to molding with inserts, in which a metal or ceramic insert is placed into cavity prior to injection, and the plastic bonds to insert during molding

Blow Molding

Molding process in which air pressure is used to inflate soft plastic into a mold cavity

- Important for making one-piece hollow plastic parts with thin walls, such as bottles
- Since these items are used for consumer beverages in mass markets, production is typically organized for very high quantities

Blow Molding Process

- Accomplished in two steps:
  1. Fabrication of a starting tube, called a *parison*
  2. Inflation of the tube to desired final shape
- Forming the parison is accomplished by either
  - Extrusion or
  - Injection molding

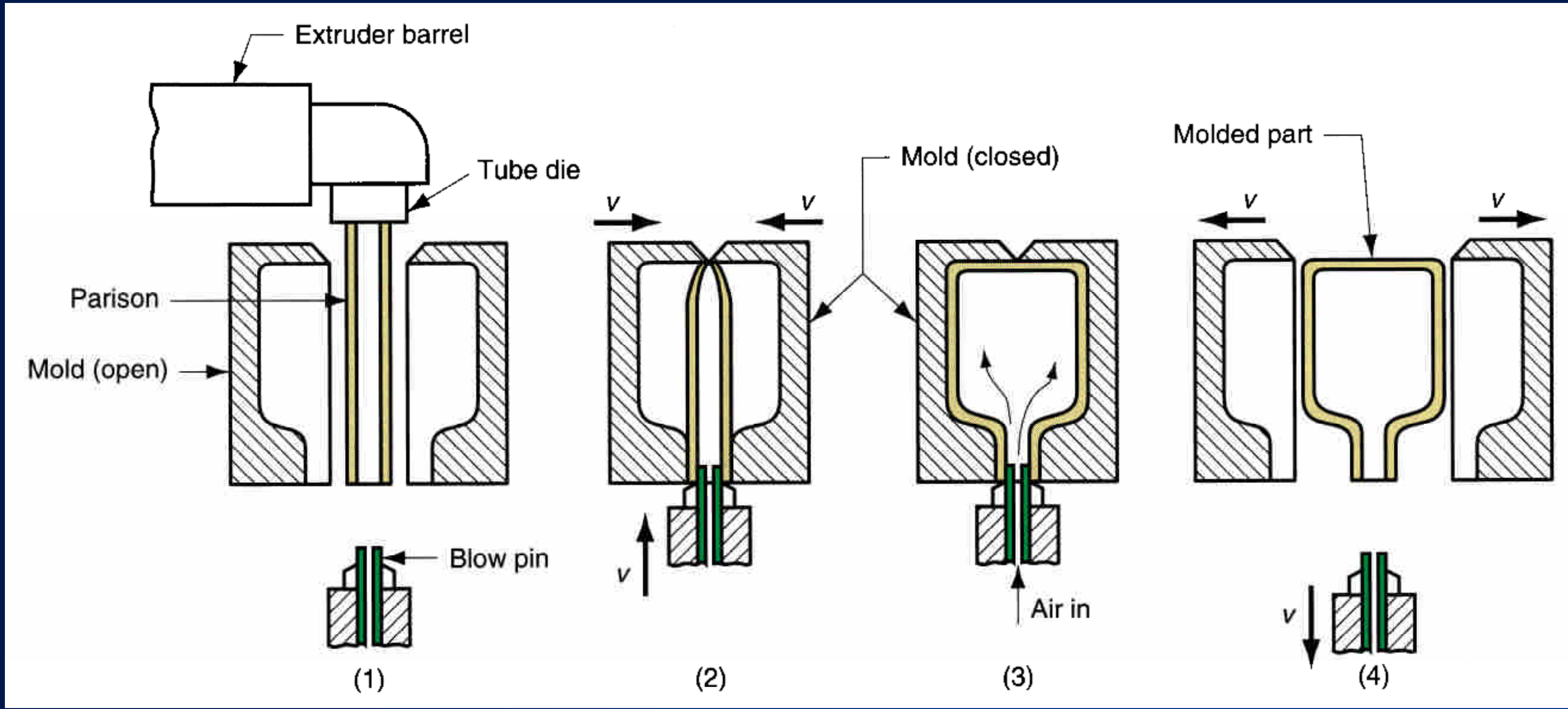


Figure 13.30 - Extrusion blow molding: (1) extrusion of parison; (2) parison is pinched at the top and sealed at the bottom around a metal blow pin as the two halves of the mold come together; (3) the tube is inflated so that it takes the shape of the mold cavity; and (4) mold is opened to remove the solidified part

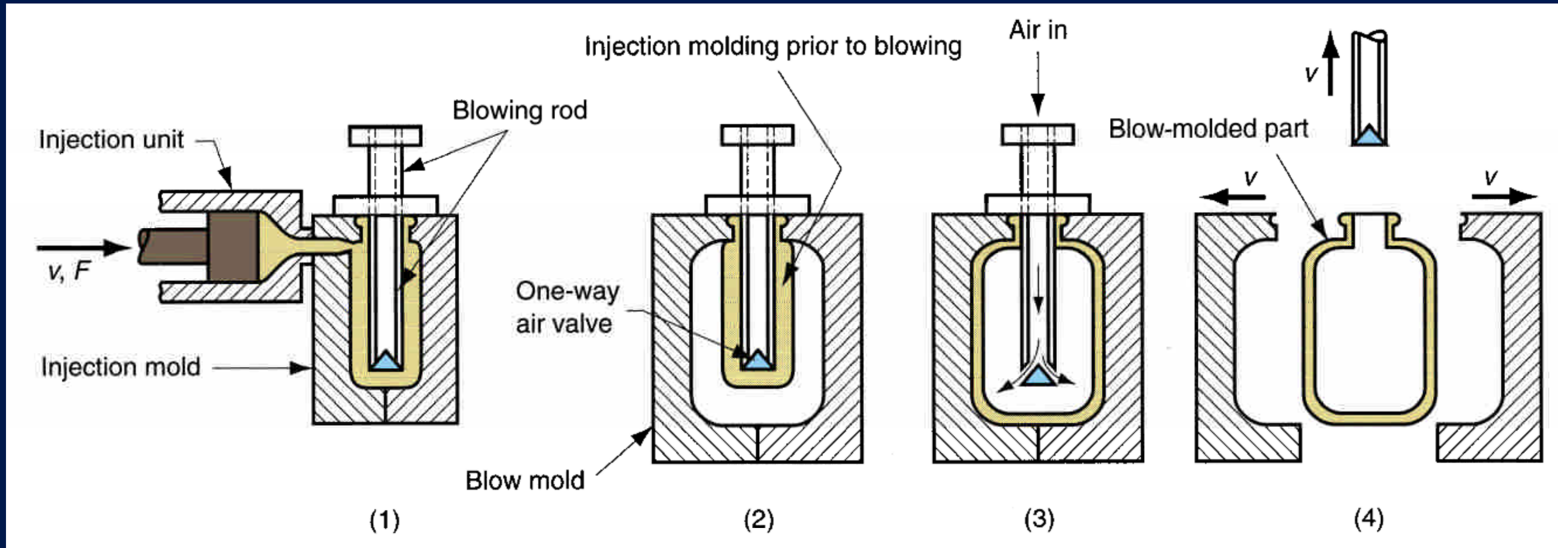


Figure 13.32 - Injection blow molding: (1) parison is injected molded around a blowing rod; (2) injection mold is opened and parison is transferred to a blow mold; (3) soft polymer is inflated to conform to the blow mold; and (4) blow mold is opened and blown product is removed

Stretch Blow Molding

Variation of injection blow molding in which blowing rod extends downward into parison in step 2, stretching the soft plastic for a more favorable stressing of polymer than conventional blow molding

- Resulting structure is more rigid, with higher transparency and better impact resistance
- Most widely used material is polyethylene terephthalate (PET) which has very low permeability and is strengthened by stretch blow molding
- Combination of properties makes it ideal as container for carbonated beverages

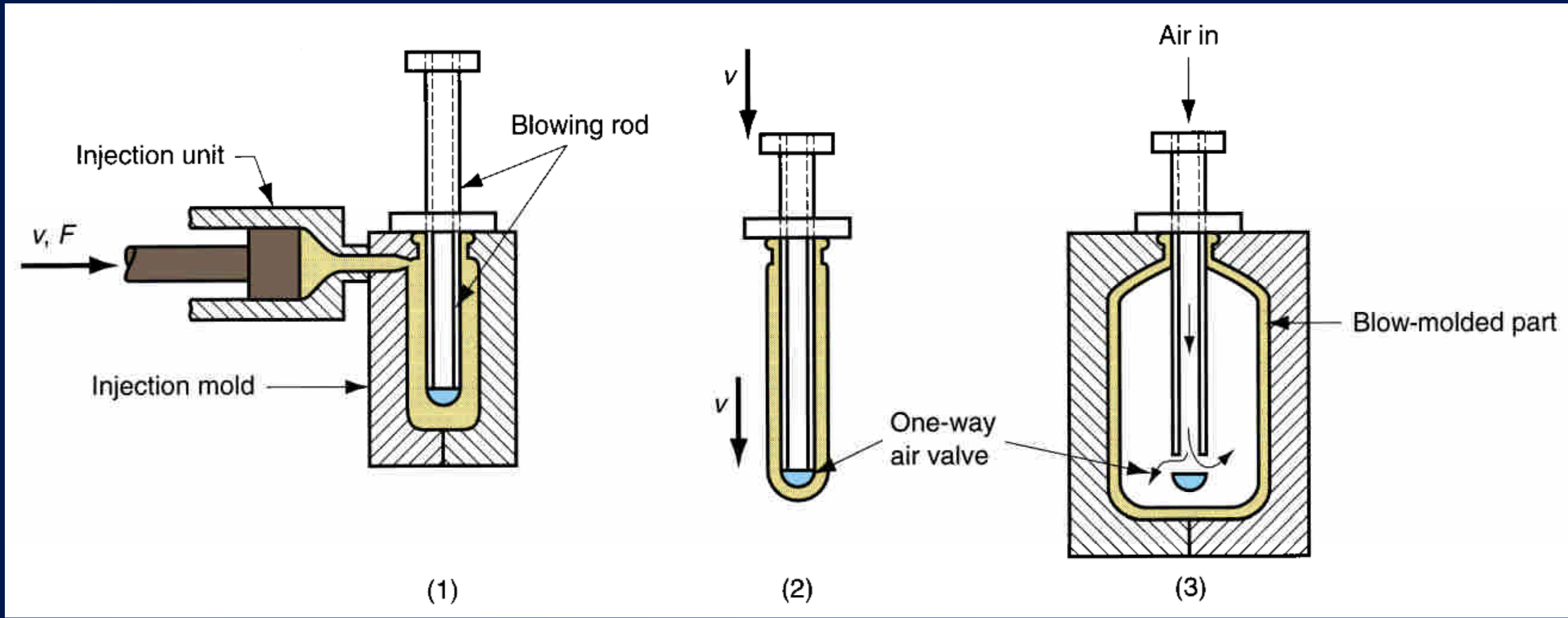


Figure 13.33 - Stretch blow molding:
(1) injection molding of parison; (2) stretching; and (3) blowing

Materials and Products in Blow Molding

- Blow molding is limited to thermoplastics
- Materials: high density polyethylene, polypropylene (PP), polyvinylchloride (PVC), and polyethylene terephthalate
- Products: disposable containers for liquid consumer goods, large shipping drums (55 gallon) for liquids and powders, large storage tanks (2000 gallon), gasoline tanks, toys, and hulls for sail boards and small boats

Thermoforming

Flat thermoplastic sheet or film is heated and deformed into desired shape using a mold

- Heating usually accomplished by radiant electric heaters located on one or both sides of starting plastic sheet or film
- Widely used in packaging of products and to fabricate large items such as bathtubs, contoured skylights, and internal door liners for refrigerators

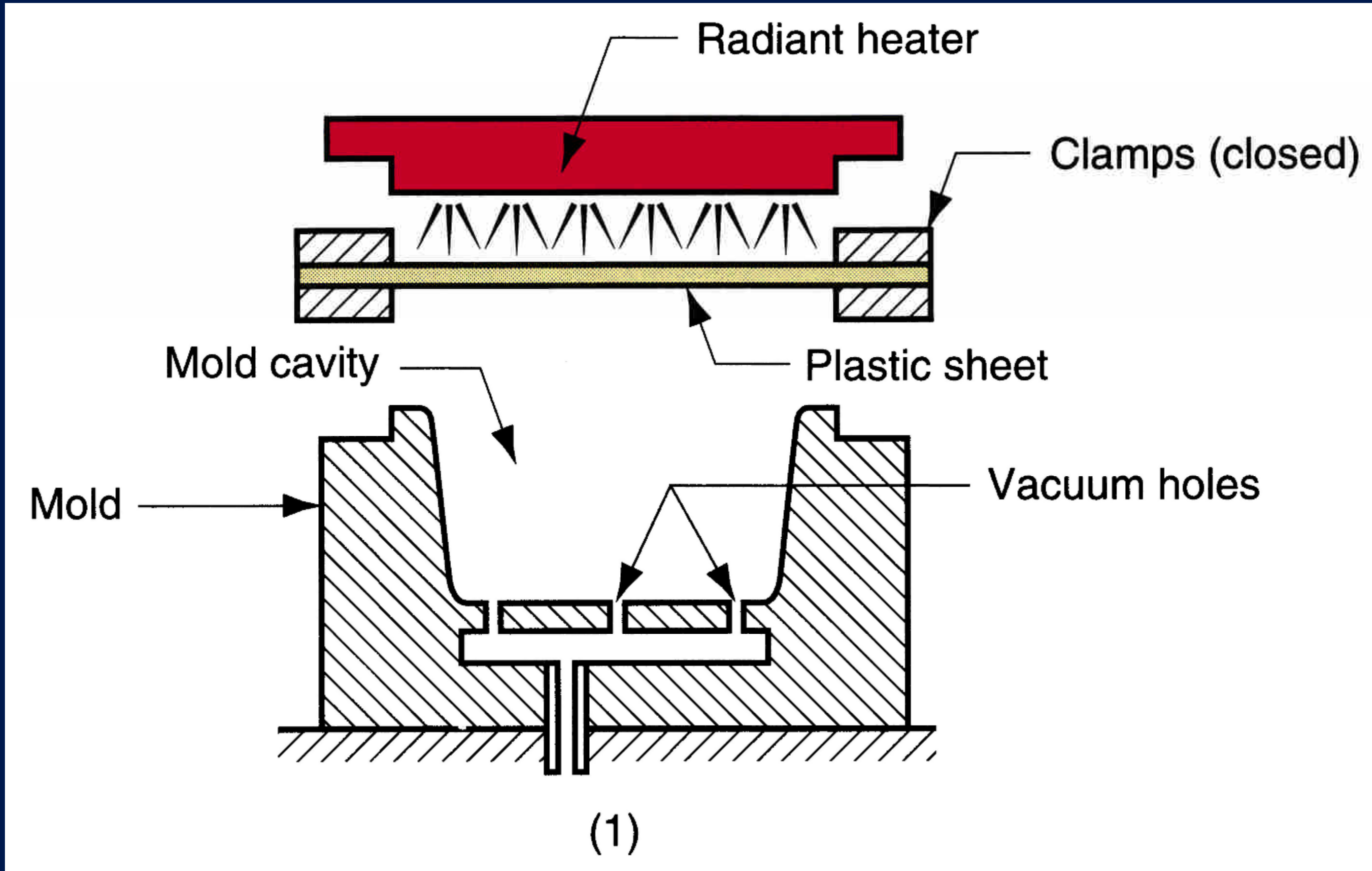


Figure 13.35 - Vacuum thermoforming:

(1) a flat plastic sheet is softened by heating

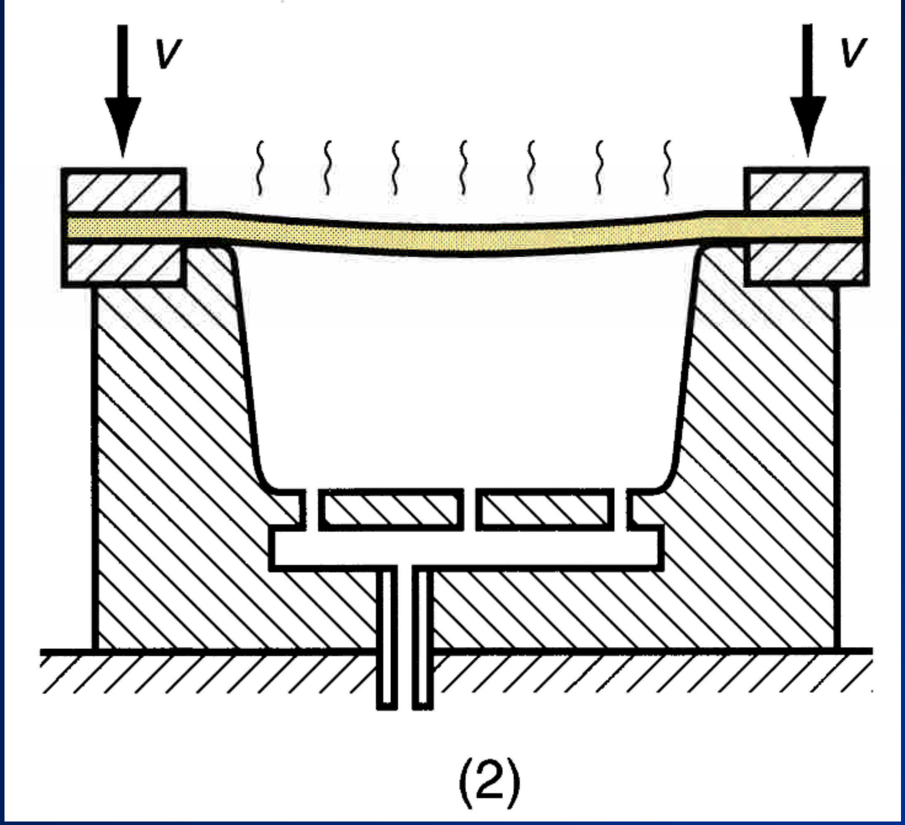


Figure 13.35 - Vacuum thermoforming:

(2) the softened sheet is placed over a concave mold cavity

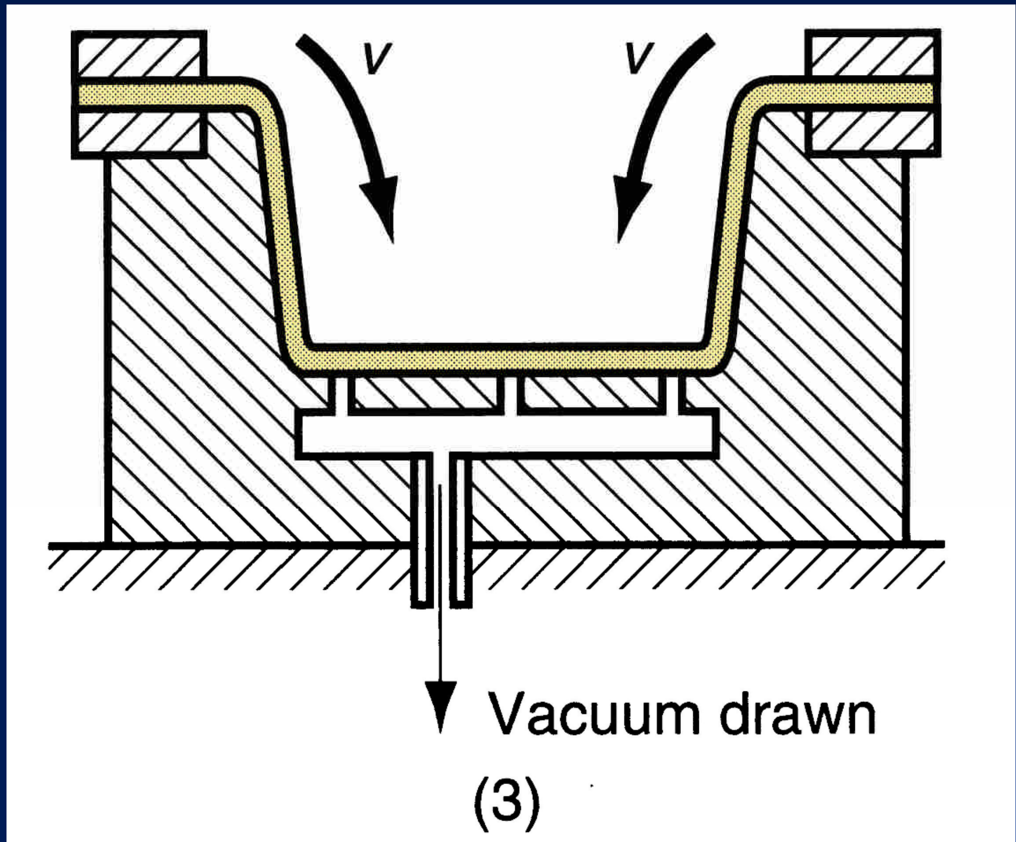
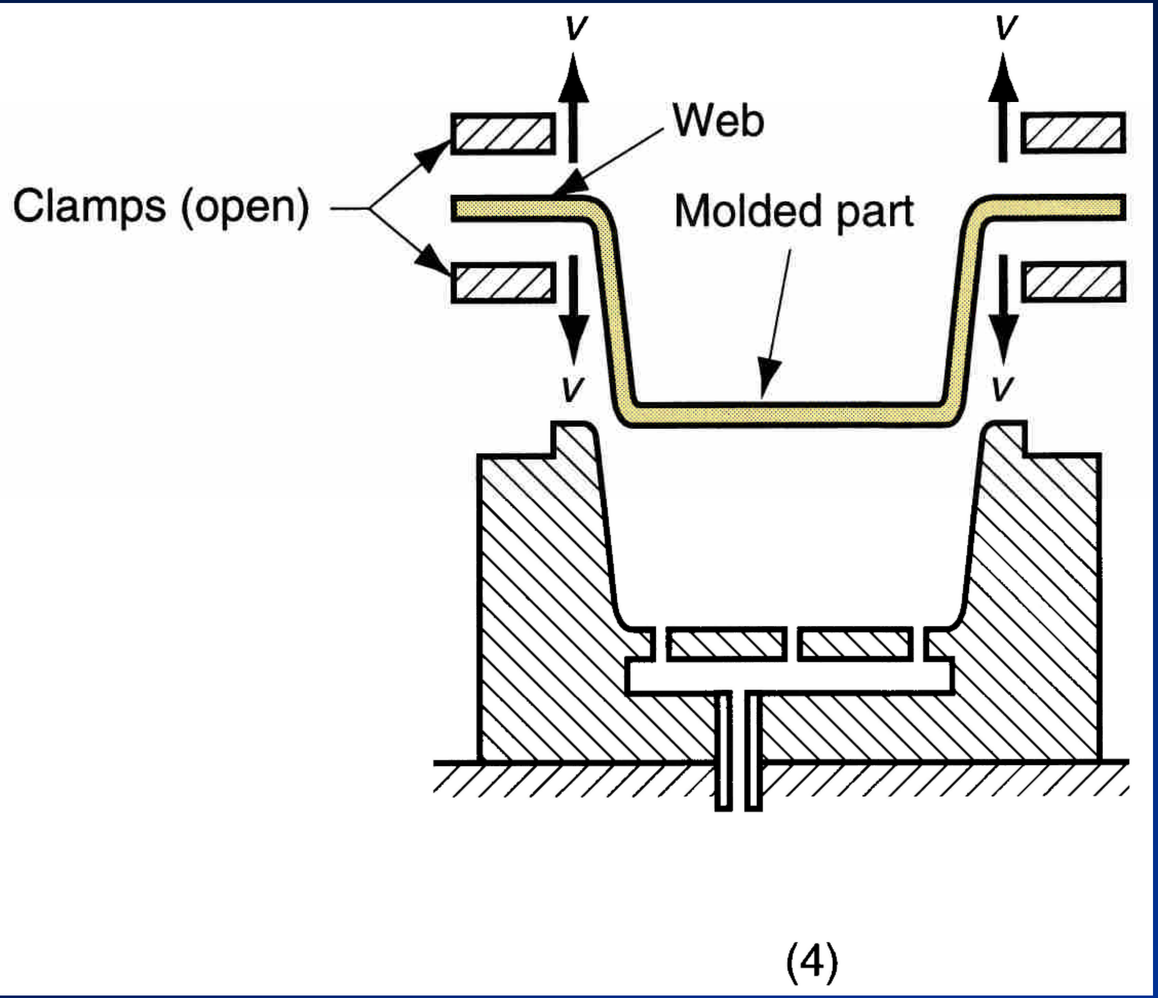


Figure 13.35 ‑ Vacuum thermoforming:
(3) a vacuum draws the sheet into the cavity

Figure 13.35 -

(4) the plastic hardens on contact with the cold mold surface, and the part is removed and subsequently trimmed from the web



Negative Molds vs. Positive Molds

Negative mold – concave cavity

Positive mold - convex shape

- Both types are used in thermoforming
- For positive mold, heated sheet is draped over convex form and negative or positive pressure forces plastic against mold surface

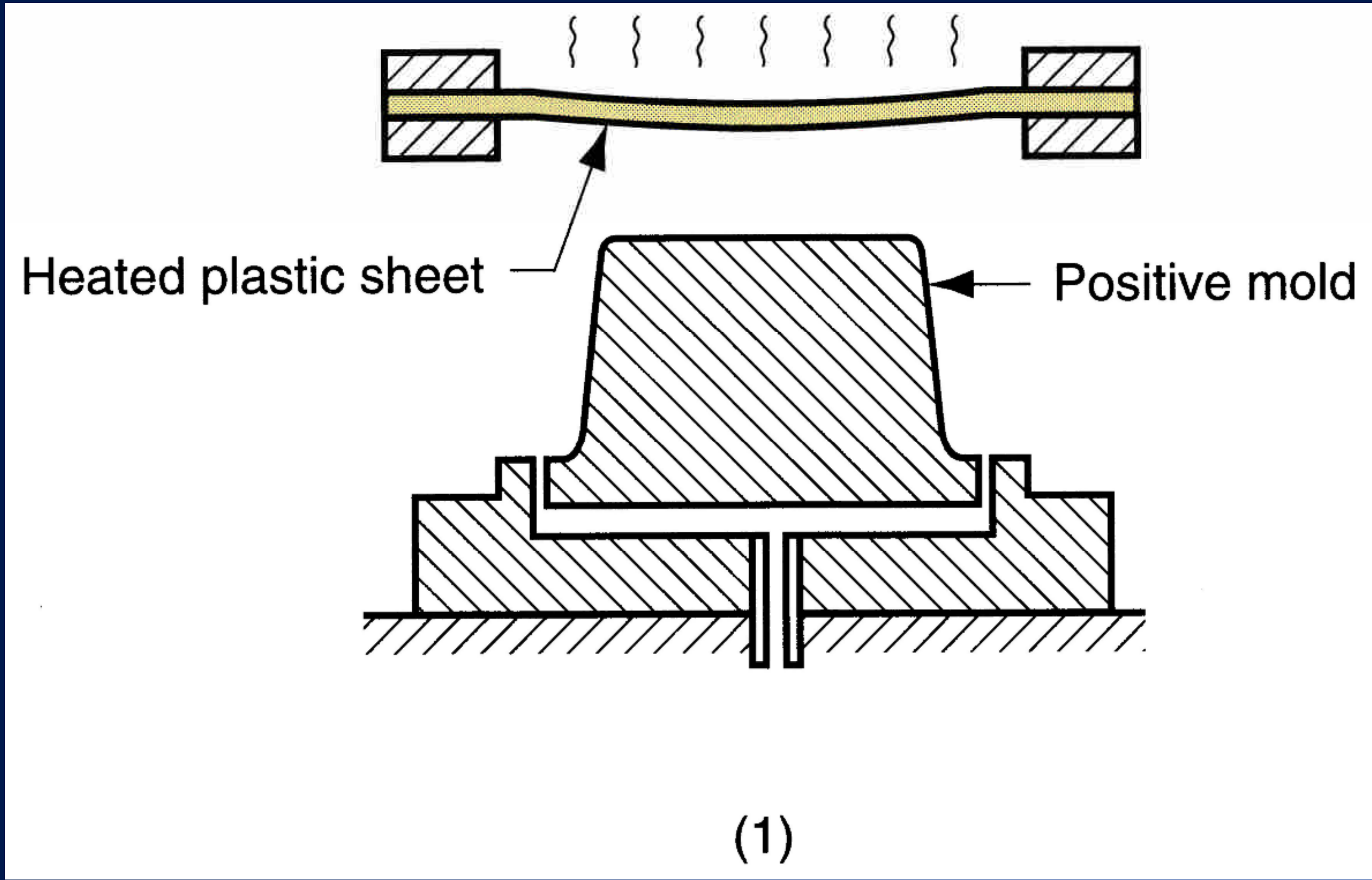


Figure 13.37 ‑ Use of a positive mold in vacuum thermoforming: (1) the heated plastic sheet is positioned above the convex mold

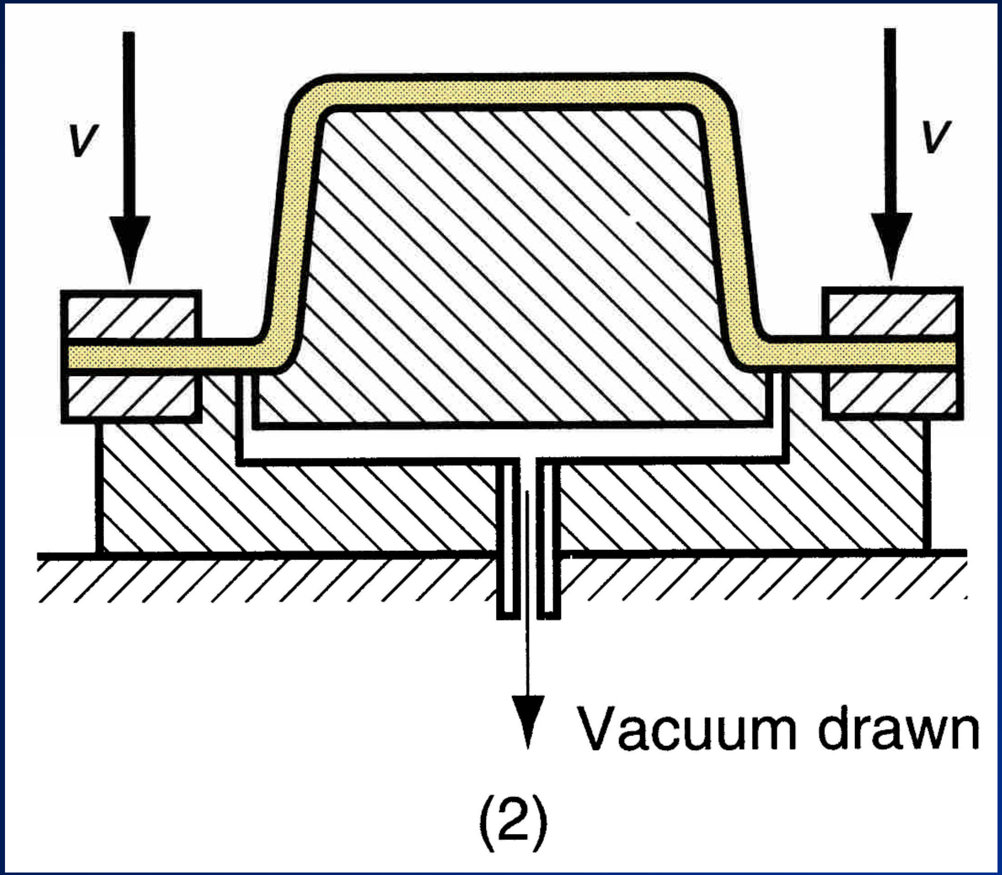


Figure 13.37 - Use of a positive mold in vacuum thermoforming:

(2) the clamp is lowered into position, draping the sheet over the mold as a vacuum forces the sheet against the mold surface

Materials for Thermoforming

- Only thermoplastics can be thermoformed, since extruded sheets of thermosetting or elastomeric polymers have already been cross-linked and cannot be softened by reheating
- Common TP polymers: polystyrene, cellulose acetate, cellulose acetate butyrate, ABS, PVC, acrylic (polymethylmethacrylate), polyethylene, and polypropylene

Applications of Thermoforming

- *Thin films*: blister packs and skin packs for packaging commodity products such as cosmetics, toiletries, small tools, and fasteners (nails, screws, etc.)
  - For best efficiency, filling process to containerize item(s) is placed immediately downstream from thermoforming
- *Thicker sheet stock*: boat hulls, shower stalls, advertising displays and signs, bathtubs, certain toys, contoured skylights, internal door liners for refrigerators

Casting

Pouring liquid resin into a mold, using gravity to fill cavity, where polymer hardens

- Both thermoplastics and thermosets are cast
  - Thermoplastics: acrylics, polystyrene, polyamides (nylons) and PVC
  - Thermosetting polymers: polyurethane, unsaturated polyesters, phenolics, and epoxies
- Simpler mold
- Suited to low quantities

Polymer Foam

A polymer-and-gas mixture that gives the material a porous or cellular structure

- Most common polymer foams: polystyrene (Styrofoam, a trademark), polyurethane
- Other polymers: natural rubber ("foamed rubber") and polyvinylchloride (PVC)

Characteristic Properties of a Foamed Polymer

- Low density
- High strength per unit weight
- Good thermal insulation
- Good energy absorbing qualities

Classification of Polymer Foams

- *Elastomeric* - matrix polymer is a rubber, capable of large elastic deformation
- *Flexible* - matrix is a highly plasticized polymer such as soft PVC
- *Rigid* - polymer is a stiff thermoplastic such as polystyrene or a thermoset such as a phenolic
- Depending on chemical formulation and degree of cross-linking, polyurethanes can range over all three categories

Applications of Polymer Foams

- Characteristic properties of polymer foams, and the ability to control elastic behavior by selection of base polymer, make these materials suitable for certain applications
- Applications: hot beverage cups, heat insulating structural materials, cores for structural panels, packaging materials, cushion materials for furniture and bedding, padding for automobile dashboards, and products requiring buoyancy

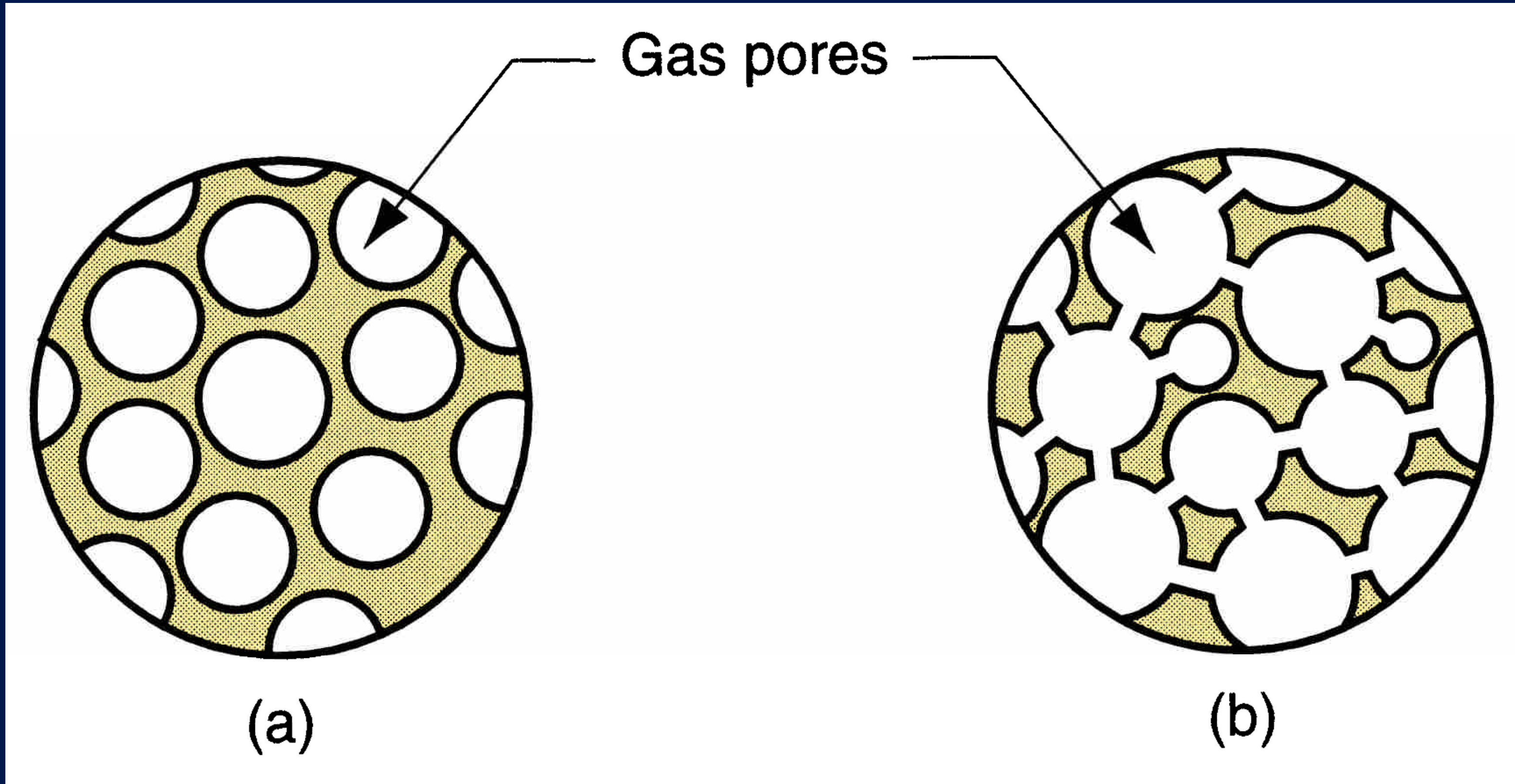


Figure 13.40 - Two polymer foam structures:
(a) closed cell and (b) open cell

Extrusion of Polystyrene Foams

- Polystyrene is a thermoplastic polymer
- A physical or chemical blowing agent is fed into polymer melt near die end of extruder barrel; thus, extrudate consists of expanded polymer
- Products: large sheets and boards that are subsequently cut to size for heat insulation panels and sections

Molding Processes for Polystyrene Foams

- *Expandable foam molding* - molding material usually consists of prefoamed polystyrene beads
- Prefoamed beads are fed into mold cavity where they are further expanded and fused together to form molded product
- Products: hot beverage cups of polystyrene foam are produced in this way

Shaping Processes for Polyurethane Foams

- Polyurethane can be thermosetting, elastomer or thermoplastic (less common)
- Polyurethane foam products are made in a one-step process in which the two liquid ingredients are mixed and immediately fed into a mold or other form
  - Polymer is synthesized and part geometry is created at the same time
- Shaping processes for polyurethane foam:
  - Spraying
  - Pouring

Product Design Guidelines for Plastics – General - I

- Strength and stiffness
  - Plastics are not as strong or stiff as metals
  - Avoid applications where high stresses will be encountered
  - Creep resistance is also a limitation
  - Strength-to-weight ratios for some plastics are competitive with metals in certain applications

Product Design Guidelines for Plastics – General - II

- Impact Resistance
  - Capacity of plastics to absorb impact is generally good; plastics compare favorably with most metals
- Service temperatures
  - Plastics are limited relative to engineering metals and ceramics
- Thermal expansion
  - Dimensional changes due to temperature changes much more significant than for metals

Product Design Guidelines for Plastics – General - III

- Many plastics are subject to *degradation* from sunlight and other forms of radiation
- Some plastics degrade in oxygen and ozone atmospheres
- Plastics are soluble in many common solvents
- Plastics are resistant to conventional corrosion mechanisms that afflict many metals

Product Design Guidelines – Extruded Plastics - I

- Wall thickness
  - Uniform wall thickness is desirable in an extruded cross-section
  - Variations in wall thickness result in nonuniform plastic flow and uneven cooling which tend to warp extrudate

Product Design Guidelines – Extruded Plastics - II

- Hollow sections
  - Hollow sections complicate die design and plastic flow
  - Desirable to use extruded cross-sections that are not hollow yet satisfy functional requirements

Product Design Guidelines – Extruded Plastics III

- Corners
  - Sharp corners, inside and outside, should be avoided in extruded cross-sections, since they result in uneven flow during processing and stress concentrations in the final product

Product Design Guidelines – Molded Parts - I

- Economic production quantities
  - Each part requires a unique mold, and the mold for any molding process can be costly, particularly for injection molding
  - Minimum production quantities for injection molding are usually around 10,000 pieces
  - For compression molding, minimum quantities are ~1000 parts, due to simpler mold designs
  - Transfer molding lies between other two

Product Design Guidelines – Molded Parts - II

- Part complexity
  - Although more complex part geometries mean more costly molds, it may nevertheless be economical to design a complex molding if the alternative involves many individual components that must be assembled
  - An advantage of plastic molding is that it allows multiple functional features to be combined into one part

Product Design Guidelines – Molded Parts - III

- Wall thickness
  - Thick cross-sections are wasteful of material, more likely to cause warping due to shrinkage, and take longer to harden
- Reinforcing ribs
  - Achieves increased stiffness without excessive wall thickness
  - Ribs should be made thinner than the walls they reinforce to minimize sink marks on outside wall

Product Design Guidelines – Molded Parts - IV

- Corner radii and fillets
  - Sharp corners, both external and internal, are undesirable in molded parts; they interrupt smooth flow of the melt, tend to create surface defects, and cause stress concentrations in the part
- Holes
  - Holes are quite feasible in plastic moldings, but they complicate mold design and part removal

Product Design Guidelines – Molded Parts - V

- Draft
  - A molded part should be designed with a draft on its sides to facilitate removal from mold
  - Especially important on inside wall of a cup-shaped part because plastic contracts against positive mold shape
  - Recommended draft:
    - For thermosets, around 1/2° to 1°
    - For thermoplastics, between 1/8° and 1/2°

Product Design Guidelines – Molded Parts - VI

- Tolerances
  - Although shrinkage is predictable under closely controlled conditions, generous tolerances are desirable for injection moldings because of
    - Variations in process parameters that affect shrinkage
    - Diversity of part geometries encountered