SHAPING PROCESSES FOR PLASTICS

Outline

- Introduction
- Extrusion
  - *The extruder*
  - *Extrusion Die*
  - *Melt flow in extruder*
- Wire and Cable Coating
- Polymer Sheet and Film
- Fiber and Filament

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*
- 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**

Why Plastic Shaping Processes are Important

- 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*
  - *For example: plastic containers have been largely substituted for glass bottles and jars*
- Total volume of polymers (plastics and rubbers) now ………. that of metals (*tonnage is still less because density of metals is greater*)
- Almost unlimited variety of part geometries
- Plastic molding is a ………… 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*

✓ 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*

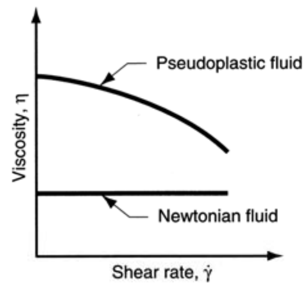
✓ Important properties:
- Viscosity
- Viscoelasticity

Viscosity of Polymer Melts

Fluid property that relates shear stress to shear rate during flow

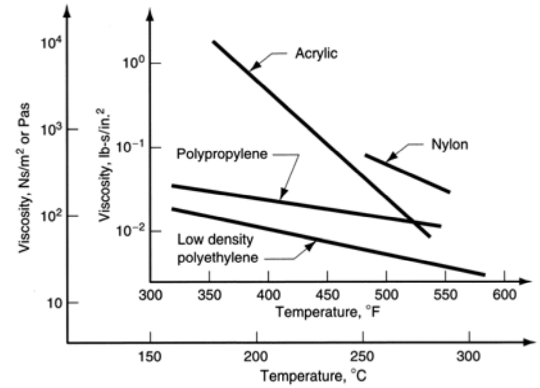
- Due to its high molecular weight, a polymer melt is a thick fluid with high viscosity
- Important because most polymer shaping processes involve flow through small **channels** or **die openings**
- Flow rates are often ……, leading to high shear rates and shear stresses, so significant pressures are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

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



Viscosity of Polymer Melts

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

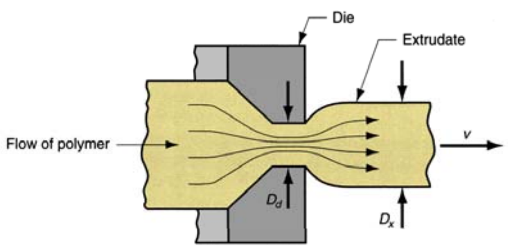


Viscoelasticity

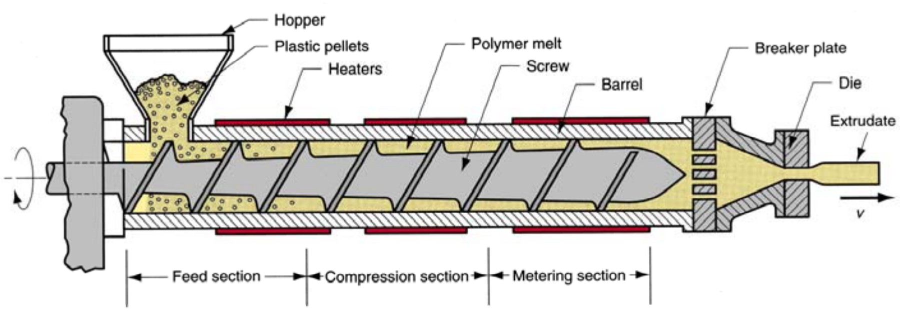
Combination of viscosity and elasticity

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

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



Extrusion

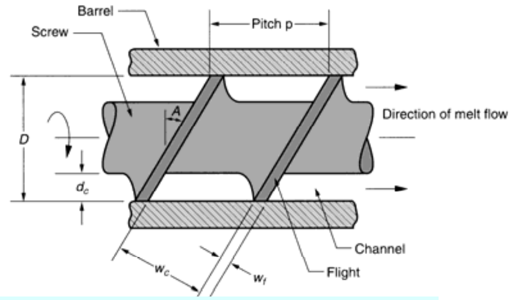


- Compression process in which material is forced to flow through a die orifice to provide long continuous product whose cross-sectional shape is determined by the shape of the orifice
- Widely used for thermoplastics and elastomers to mass produce items such as tubing, *pipes, hose, structural shapes, sheet and film, continuous filaments, and coated electrical wires*
- Carried out as a continuous process; *extrudate* is then cut into desired lengths

Two Main Components of an Extruder

1- Barrel

- Internal diameter typically ranges from 25 to 150 mm
- *L/D* ratios usually between 10 and 30: ……. ratios for thermoplastic, …….. ratios for elastomers
- Electric heaters melt feedstock; subsequent mixing and mechanical working adds heat which maintains the melt



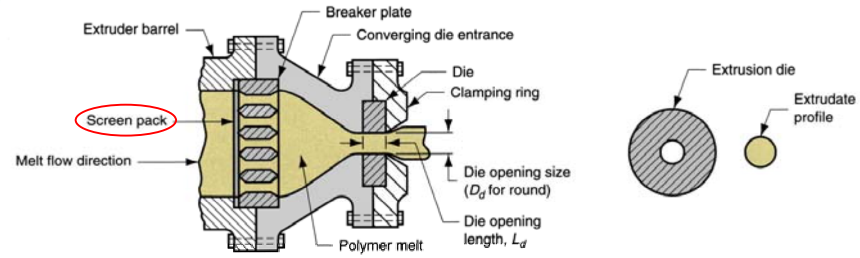
2- Screw

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

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

Polymer Extrusion Die

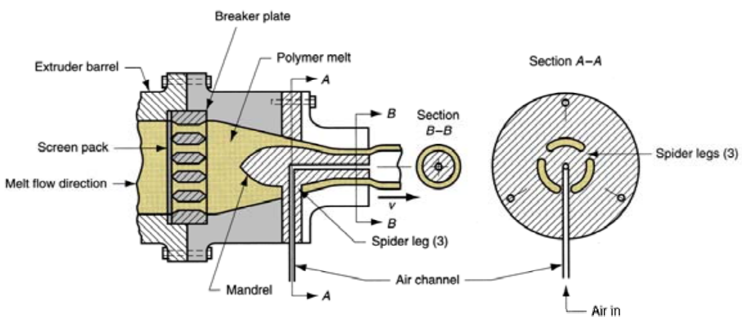


- Before reaching die, the melt passes through a *screen pack* - series of wire meshes supported by a stiff plate containing small axial holes
- Functions of screen pack:
  - ***Filter*** *contaminants and hard lumps from melt*
  - *Build* ***pressure*** *in metering section*
  - *Straighten flow of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

Common die profiles and corresponding extruded shapes:

- *Solid profiles*
- *Hollow profiles, such as tubes*
- *Wire and cable coating*
- *Sheet and film*
- *Filaments*

Extruding Hollow Profiles



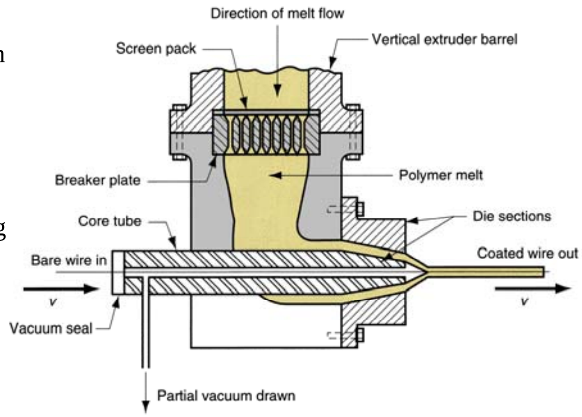
- Examples: tubes, pipes, hoses, and other cross-sections containing holes
- Hollow profiles require mandrel to form the shape
- Mandrel held in place using a spider
  - *Polymer melt flows around legs supporting the mandrel to reunite into a monolithic tube wall*
- Mandrel often includes an air channel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

Melt Flow in Extruder

- As screw rotates inside barrel, polymer melt is forced to move forward toward die; as in an ……………. 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 $Q_x = Q_d - Q_b$

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



Polymer Sheet and Film

Sheet:

- Thickness from 0.5 mm to ~12.5 mm
- Used for products such as flat window glazing and *stock for **thermoforming***

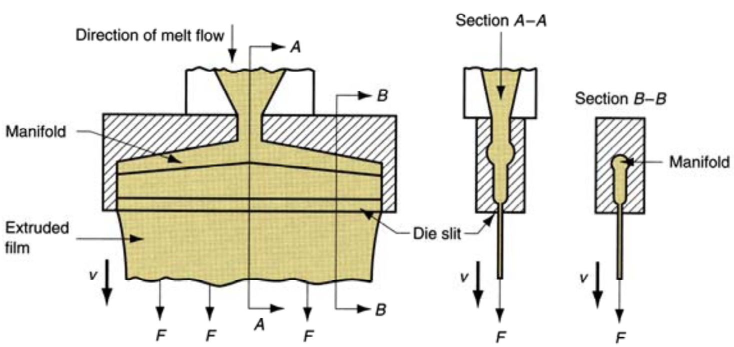
Film:

- Thickness below 0.5 mm
- 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

Processes include:
- Slit-Die Extrusion of Sheet and Film
- Blown-Film Extrusion Process
- Calendering

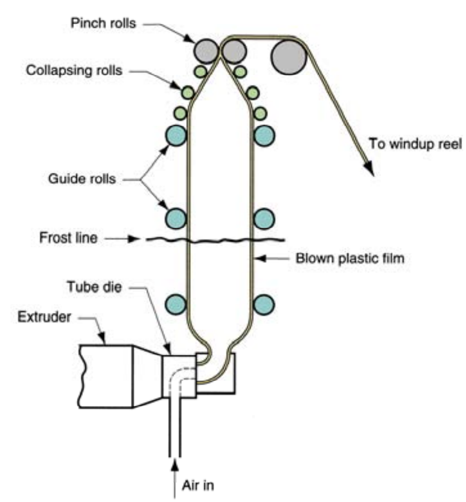
Slit-Die Extrusion of Sheet and Film



- Slit may be up to 3 m wide and as narrow as around 0.4 mm
- A problem in this method is ………… 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

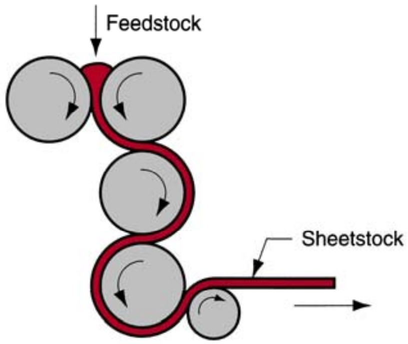
Blown-Film Extrusion Process

- 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



Calendering

- Feedstock is passed through a series of rolls to reduce thickness to desired gage
- Equipment is …………, but production rate is high
- Process is noted for …….. 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

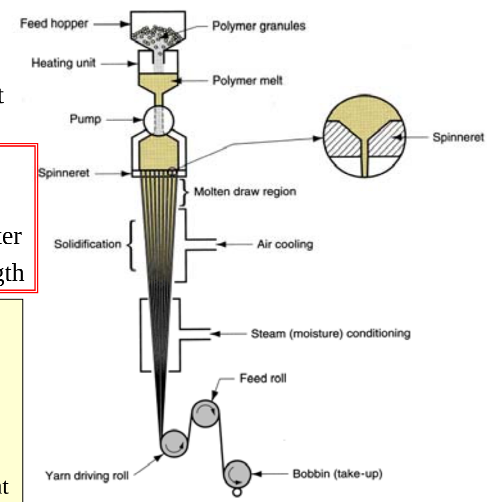


Fiber and Filament Products

- 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

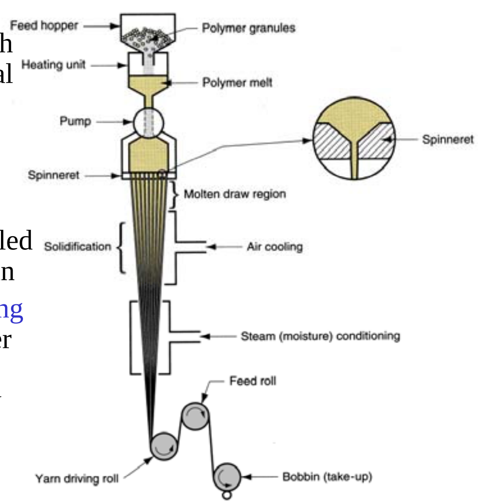
- Definitions:
- *Fiber* - a long, thin strand whose length is at least **100 times** its diameter
- *Filament* - a fiber of **continuous** length

- 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
  - Wool production is less than cotton



Melt Spinning

- Starting polymer is heated to molten state and pumped through spinneret, similar to conventional extrusion
- Typical spinneret is 6 mm thick and contains approximately 50 holes of diameter 0.25 mm
- 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



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

Next time:

Injection Molding