Extrusion Processing

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Presentation overview

- Introduction
- Extrusion process
- Compounding of plastics
- Extrusion machines and comparison of different extruder systems
- Processing section of the extruder
- Profile of material state in extruder
- Extruder Wear
- Pelletizer system
- Extrusion layout
- Installation in the field
- Sources of finishing variability
- How Extruder derives benefits?
Introduction

Extrusion process:
• A high volume manufacturing process in which plastic material is melted and moves towards a screw mechanism
  — may be mixed with colorants before the process begins
  — may be compounded with other materials, ultraviolet (UV) inhibitors, additives,…
• The screw rotates, forcing the plastic material to advance through the extruder cavity and is pushed through the die
• After exiting the die it is cooled, solidifies and cut to pallets
Extrusion process

Applications

- Use of extruded items very common in our life

Extruded Products:
- Compounded plastics
- Pipe/tubing
- Fence, deck railing
- Window frames
- Adhesive tapes
- Wire insulation

Plastic extrusion can refer to both
- Final product
- Manufacturing process

Plastics used in extrusion process
- High impact styrene (HIPS)
  - has a uniform matte finish, perfect for indoor applications
  - cost effective, easy to be colored
  - has good resistance to impact
- Rigid vinyl (R/PVC)
  - a tough plastic, moderately priced, used in both indoor and outdoor applications
  - available in transparent to opaque colors
- Flexible vinyl (F/PVC)
- Polyethylene (PE)
- Polypropylene (PP)
- PET

PET
Vacuum pump
Atm.Vent
Die Head
Extrusion process: types

- Wire and cable coating
- Sheet/film extrusion
  - Slit die extrusion
  - Blown film extrusion
- Tubing extrusion
- Co-extrusion
- Extrusion coating
- Compounding of plastics

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 extrusion process

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 LDPE
- Polypropylene – PP
- Polyvinyl Chloride – PVC

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

Slit Die Extrusion of Sheet and Film

- Slit may be up to 3 m wide and as narrow as around 0.4 mm
- 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 through die mandrel
- Air is blown into tube to *maintain uniform film thickness* and *tube diameter*
Compounding of plastics

- **A process that mixes** one or more polymers with additives to give plastic compounds
- **The feeds** may be pellets, powder and/or liquids, but the product is usually in pellet form, to be used in other plastic-forming processes such as extrusion and injection molding
- **Machine size varies** from tiny lab machines to the biggest extruders in the industry, running as much as 100 tons per hour, as used by the chemical companies that make the base resins
- **Usually twin-screw extruders** are preferred because they give better mixing at lower melt temperatures. Most of these have screws and barrels made up of smaller segments (mixing, conveying, venting and additive feeding) so that the design can be changed to meet the production and product needs
- **Single-screw extruders** can be used for compounding as well, especially with appropriate screw design and static mixers after the screw
- **Selection of the components** to be mixed (viscosities, additive carriers) is as important as the equipment
Extrusion machines

Single Screw Extruder

Twin Screw Extruder

- **90% of PVC pipes** are produced on twin screw extruders
- Twin screw extrusion is used extensively for *mixing, compounding, or reacting* polymeric materials
- Flexibility of screws operation
  - Co-rotating or counter-rotating
  - Intermeshing or non-intermeshing
- Flexibility of screw configurations
  - forward conveying elements
  - reverse conveying elements,
  - kneading blocks

Advantages

- Positive transport of material with little backflow
- Less dependence of the polymer residence time in screw upon the back pressure
- Easier control of heat input by oil heating of screws and heater bands on the barrel
- Greater homogenization due to shearing b/w flights on the screws and calendaring effect of one screw against the other

Co-rotation of intermeshing twin screws
Co-rotating vs counter-rotating
twin screw extruders

Co-rotating extruders:
• Relatively uniform shear rate distribution in the regular screw sections
• High screw speeds possible with corresponding high throughput rates
• Fair conveying efficiency

Counter-rotating extruders:
• High shear in the intermeshing region, which result in effective dispersive mixing
• Lower screw speeds than co-rotating extruders
• More positive conveying characteristics than co-rotating extruders because of the better sealing between the two screws

Design Principal

\[ \frac{D_o}{D_i} = \text{Diameter ratio} \]
\[ \text{Determines shear, degassing and powder intake} \]

\[ \frac{Md}{a^3} = \text{Specific torque} \]
\[ \text{Determines power density and filling degree} \]

\[ n = \text{Screw speed} \]
\[ \text{Determines shear and mixing} \]

\[ D_o = \text{Outer diameter} \]
\[ D_i = \text{Inner diameter} \]
\[ a = \text{Centerline distance} \]
Functions of a Good Twin-Screw Design

1. To take in a maximum amount of powder per screw revolution
2. To transport, melt, and meter material into the die without hang-up
3. To mix the material without creating too much friction by too small or too large a gap between the outer diameter of one screw and core of the other
4. To homogenize and melt material by shearing it between flights
5. To vent material when it is agglomerate, not when it is still powder or already melt
6. To compress material before venting so that flights are full and so that a vacuum cannot act toward the hopper
7. To create frictional heat to plasticize efficiently by heating and cooling of screws and barrel

Extruder sections with different flights and thread designs

1. The feeding section: has open flights to ensure maximum material intake
2. The melting section: has large surface area. Multiple-thread design to ensure good heat convection
3. The mixing section: should mix materials and create no overheating
4. Degassing section: should have to be a decompression zone with open flights to prevent material form getting into the venting holes and should ensure effective degassing
5. The metering zone: should have an appropriate pressure buildup and balanced energy to ensure good homogenization without overheating to make high out put possible
Mixing mechanisms in twin screw compounders

Dispersive Mixing
= Break up of agglomerates and aggregates

Distributive Mixing
= Distribution of primary particles

Screw elements for dispersive mixing
Kneading blocs and kneading discs

Screw elements for distributive mixing
Mixing elements for the incorporation of fibers, fillers or for blending polymers
Profile of material state in extruder
Extruder wear

**Abrasive Wear:**
- Erosion of metal surfaces due to harder materials (i.e. TiO2) rubbing against softer materials
- Melting and mixing sections are regions where abrasive materials are present

**Adhesive Wear:**
- Rubbing of metal surfaces against each other
- It has been seen where mechanical stresses exist:
  - Inadequate screw support/centering
  - Shaft deflection
  - Incorrect screw assembly

**Corrosive Wear:**
- Erosion of metal surfaces due to chemical attack
Extruder wear

- As the flights of conveying elements are worn, conveying efficiency is reduced. Diagnosing a worn in conveying section is; feed limitation and backup into main feed port.

- When the tips of kneading elements are worn, melting and mixing efficiency are reduced. Diagnosing a worn is; melting of resins and mixing of additives moves to downstream kneading elements which impact physical properties of products. Un-melted resin appears at side feeder and additives appears in vacuum vent or on screen.

- As the flights of conveying elements in the metering section are worn, efficiency is reduced.

- Increasing screw speed will compensate efficiency reduction but it also accelerate wear rate.
Processing section of the extruder: screen changer
# Processing section of the extruder: Die plate

## Die plate design

<table>
<thead>
<tr>
<th>Without distributor</th>
<th>With distributor</th>
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<tbody>
<tr>
<td><img src="image1.png" alt="Without distributor diagram" /></td>
<td><img src="image2.png" alt="With distributor diagram" /></td>
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</table>

- **Without distributor**: 
  - Die plate

- **With distributor**:
  - Distributor
  - Die plate
  - Housing
  - Optimized form for the same flow velocity
  - Spider plate (distributor)
  - Die plate

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**UG 1000: Cleaning of Die Face prior to Start-up**

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- ![Image 1](image1.png)
- ![Image 2](image2.png)
- ![Image 3](image3.png)
Types of pelletizing systems

- **Strand Water Bath**
  - **Cold face cutter** (Pelletizing of the polymer in solid form)

- **Strand Water Slide**
- **Die Face Underwater**
  - **Hot face cutter** (Cutting of the polymer melt directly at the die plate. The polymer freezes in pellet form)

- **Die Face Air cooled**
- **Die Face Water Ring**
- **Drop Pelletizing**
Design and function of strand pelletizer:

Components:
1. Guide roll
2. Infeed Chute
3. Under infeed roll
4. Upper feeding roll
5. Bed knife holder
6. Cutter rotor
Strand Water Bath

**Strengths:**
- Low cost
- Simple to use
- Easy to clean and changeover
- Almost all materials

**Weaknesses:**
- Very little automation
- Limited pellet size
- Higher cutter wear / maintenance
- Sensitive to process variations
- Max throughput is limited by the handling of the strands
Strand Water Slide Pelletizer

**Strengths:**
- Higher level of automation
- Self stranding
- Variable cooling
- More compact
- High strand speed and throughput rates up to 22,000 kg/hr

**Weaknesses:**
- High cost
- Higher cutter wear and maintenance but less than water bath
- Difficult to setup
Strand Water Slide Pelletizer

**Horizontal Water Slide Pelletizer**

Applications:
- ABS, PP, PC, PA, PET
- Throughputs up to 12000 Kg/hr
- 250 m/min strand speed

**Vertical Water Slide Pelletizer**

Applications:
- GPPS, HIPS, PMMA, SAN
- Throughputs up to 7500 Kg/hr
- Brittle plastics, requiring short cooling sections
Underwater Pelletizer

**Strengths:**

- Highest automation
- Can process sticky products
- High blade life
- Production of micro pellets
- High throughput up to 70,000 Kg/hr

**Weaknesses:**

- Relatively high system cost
- Complicated auxiliary and water/drying systems
- Die freeze issues on high heat products
Installation in the field
Sources of finishing variability

- MFI (Melt Flow Index)

**Operator Errors**
- formulation
- setup
- QC errors

**Raw Material Variation**
- Resin MW
- Resin color
- Resin morphology
- SPD pellet

**Process Faults**
- clogged feeders, die screen
- poor barrel temp regulation
- vent, die port blockage

**Equipment Faults**
- feeder drive, motor control
- dust pellet cutter
- screw shaft breakage
- screw wear

**Product Variability**
- MV
- Composition
- Color
- mechanical strength

**Diagram**
- MFR: g/10 mins
- Bi-modal resins (HDPE)
  - Good processability
  - High strength
- Molecular weight
- Viscosity
- Low viscosity
- High viscosity
- Very low viscosity
- Very high viscosity

- Weight e.g. 2.16kg
- Piston
- Heated barrel
- Piston head
- Test sample
- Dio (8 mm long)
How extruder derives benefits?
Questions