Polymer Processing

There are many processes for plastics. Selection of a process depends on many factors including:

- Quantity and production rate
- Dimensional accuracy and surface finish
- Form and detail of the product
- Nature of material
- Size of final product

In general, plastics processes have three phases:

1. Heating - To soften or melt the plastic
2. Shaping / Forming - Under constraint of some kind
3. Cooling - So that it retains its shape
Thermoplastics start as regular pellets or granules and can be remelted.

Thermosetting materials start as liquids/syrups, often called "resins", as powders or partially cured products ("preforms") which need heat for the shaping phase. The shaping is accompanied by a chemical reaction, which means that the material does not soften on reheating. The reaction may be exothermic (giving heat out), in which case cooling is required.
Processes

1. Thermoforming
2. Compression and transfer molding
3. Rotational molding and sintering
4. Extrusion
5. Extrusion-based processes
6. Injection molding
7. Blow molding
8. Plastic foam molding
1. Thermoforming

Gift packaging

Communication packaging

AUTOMOBILE INNER DECORATION PACKAGING

SPECIDIFFERENCE PACKAGING
- Air pressure and plug assisted forming of the softened sheet.
- Invariably automated and faster cycle times
- Only thermoplastics sheet can be processed by this method.
- The largest application is for Food Packaging.
- Other industries include Toiletries, Pharmaceuticals and Electronics
Food related applications such as Meat Trays, Microwave & Deep Freeze Containers, Ice Cream and Margarine Tubs, Snack Tubs, Bakery and Patisserie packaging, Sandwich Packs and Vending Drink Cups.

Manufacturing Collation trays, Blister packaging and Point of Sale display trays.
2. Compression and transfer molding

Thermoset Compression/Transfer Molding

1. Measured Charge is placed between two matched metal molds
2. Molds Closed Heat & Pressure
3. Cured Part is ejected and trimmed
-place a pre-weighed amount of material in a matched metal mold and closing the mold.
-heat and pressure cause the material to liquify and flow into the voids in the tool where it chemically reacts and hardens into the final shape.
-very large shapes can be molded in compression presses.
Advantages of compression molding (compared with injection molding)

- Low scrap arisings
- Low orientation in the moldings
  - well distributed fibrous fillers
  - low residual stress product
  - retained mechanical and electrical properties
- Low mold maintenance
- Low capital and tooling costs
- พัฒนามาจาก compression คือจะมีที่ใส่สารแล้วก็ยกดัดผ่าน runners ไปสู่ cavities ซึ่งเกิดขึ้นภายในแพร์พิมพ์
- ต้องการให้ได้ส่วนที่เล็ก ๆ ของแบบได้ง่ายขึ้น
- ลดการสูญเสียหรือแตกหักจากส่วนของแพร์พิมพ์ที่บางหรือซับซ้อน
- เรียกว่า compression เพราะ heat transfer ไม่ช่วงที่ผ่าน runner
Disadvantages when compared with compression
-Give unwelcome orientation in the product
-Increase wear and maintenance costs
-Tooling is more complex and more expensive
-Runners owe scrap
3. Rotational molding and sintering

**Thermoplastic - Rotational Molding**

- Plastic powder is added to aluminum mold
- Mold is clamped shut
- Mold is rotated while heat is applied
- Mold is air or water cooled to allow part to solidify
- Tool is opened, part is removed
-cast hollow plastic parts with few restrictions regarding size or complexity

Very stable parts - no molded in stresses
Low tooling cost for large parts
Suited for low volume production
Can produce complex part geometries
Can mold in metal inserts and graphics
Rotational Molding uses relatively low cost molds and processes polymer at very low shear rates. The material experiences higher temperatures for longer times than other process methods.
Thermoplastic - Rotational Molding

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4. Extrusion

-the forcing of a plastic or molten material through a shaped die by means of pressure.
-screw has one or two ‘flights’ spiraling along its length.

-φ to outside of the flight is constant along the length to allow the close fit in the barrel.

-core is of varying φ and so the spiraling channel varies in depth.

-in general, the channel depth ↓ from feed end to die end → pressure ↑
The zones in an extruder

1. *Feed zone*
   - preheat polymer and convey it to the subsequent zones.
   - screw depth is constant

2. *Compression zone*
   - channel depth ↓
   - expel air trapped between original granules
   - heat transfer from the heated barrel walls is improved ‘coz material thickness ↓
   - density change during melting is accommodated
     melt sharply → very short compression zone
     melt gradually → very long compression zone
3. *Metering zone*
   - constant screw depth
   - homogenize the melt
   - supply to the die region material which is of homogeneous quality at constant T & P

4. *Die zone*
   - breaker plate - screen pack (perforated steel plate)
     a) sieve out extraneous material, e.g. ungeled polymer, dirt and foreign bodies
     b) allow head P to develop by providing a resistance for the pumping action of the metering zone
     c) remove ‘turning memory’ from the melt
Flow mechanisms: Conveying

- **Drag flow**
  - dragging along by the screw of the melt as the result of the frictional forces
  - equivalent to viscous drag between stationary and moving plates separated by a viscous medium.
  - constitute output component for the extruder.

- **Pressure flow**
  - P gradient along the extruder (high P at the output end, low at the feed end

- **Leak flow**
  - finite space between screw and barrel through which material can leak backwards.

**Total flow = drag flow – pressure flow – leak flow**
The extrusion die

1. Basic flow patterns
   Maintain laminar flow

2. Die entry effects
   Tensile stress exceed the tensile strength of the melt
   → extrudate will be of irregular shape
   → called *melt fracture*
The die entrance is tapered:

1. Eliminate the dead spots in the corners, maintaining a steady heat and shear history

2. Minimize the development of tensile stresses, and minimize distortion of the streamlines

Long die land → extend the process time which helps to eliminate memory of earlier processing, e.g. screw turning memory

Deborah Number, $N_{deb}$
Relaxation time – the characteristic timescale for which a melt has memory -describe as its viscous and elastic responses to an applied stress

\[ \text{relaxation time} = \frac{\text{viscosity}}{\text{modulus}} = \frac{Ns \times m^2}{m^2 \times N} = s \]

\[ N_{\text{deb}} = \frac{\text{relaxation time of material, in process}}{\text{timescale of process}} \]

If \( N_{\text{deb}} > 1 \), process is dominantly elastic.

If \( N_{\text{deb}} < 1 \), process is predominantly viscous.
3. Die exit instabilities

*sharkskin*
- roughening of the surface of the extrudate
- caused by tensile stresses:
  the melt, with max velocity at the center and zero at the wall, leaves the die lips
  ➔ material at the wall accelerate to the velocity at which the extrudate is leaving the die
  ➔ generate tensile stress.. If tensile stress exceeds tensile strength, surface ruptures.

*orange peel*
- when conditions become more intense, e.g. P at the extruder becomes excessive, or the die T drops
- coarser-grained appearance
**bambooing**

-the whole extrudate ‘snaps back’

Extra heating of the die will often help to remedy these defects, by thermally relaxing the stresses and lowering viscosity
4. Die swell
- Effect in which the polymer swells as it leaves the die.
- Extrudate differs in its dimensions from those of the die orifice.
- Extruded rod has larger diameter and pipe has thicker walls, e.g. o.d. ↑, i.d. ↓

Result of the elastic component in the overall response of the polymer melt to stress. → recovery of the elastic deformation as the extrudate leaves the constraint of the die channel and before it freezes.
Die swell
Part Cost - low
Tool Cost - low
Production Capability - high
Short lead times to production
Uniform cross section of parts
Multiple materials are possible in the same part.
5. Extrusion-based processes

Profile extrusion: pipe, sheet

Tubular blown film extrusion: ถุงร้อย

Cross-head extrusion: สายเคเบิล

Synthetic fibers: เส้นใยสังเคราะห์ เช่น เส้นใยโพลีเอสเตอร์

Netting: ถุงใสผัก ผลไม้

Co-extrusion
Pipe extrusion

Fig. 5.3 Pipe extrusion: internal sizing mandrel.

Fig. 5.4 Pipe extrusion—external sizing: (a) pressure sizing; (b) vacuum sizing.
Sheet extrusion

Film thickness: 0.5 – 20 mil (1 mil = 0.001 inch)
Tubular blown film extrusion
Netting

-Garden uses, fruit packaging

-Made with annular dies but with outer die and the central mandrel counter-rotating and close fitting

-Both parts have slots so that concentric sets of filaments extrude

-When counter-rotation starts the filaments cross one another to form welded junctions and a net pattern.
Co-extrusion

- Extrusion of more than one type of polymer at once to give a laminate product.

- Require a separate extruder for each polymer

- Multilayer product forming at a die

- ‘tie-layers’: bond the functional layers together
Multi-Layer … Mono Material

For non-demanding applications, a mono material sheet is usually specified. This is a sheet in which there is only one material. With a more demanding application, a multi-layer sheet is used. Multi head extruders feed into the extrusion die with the differing materials.

Multi layer sheeting, with a heat compliant top layer, can be used to make heat-sealed applications. PVC / PE for Meat Trays, and CPET / APET for Meat Trays and Ready Meals.
6. Injection molding

Injection molding is accomplished by forcing molten plastic under pressure into a cavity formed between two matched metal mold halves. Once the plastic cools, the molds are opened and the part is removed.
- Part cost - low
- Tooling cost - high
- Production Rate - high
- Can produce intricate parts
- Large variety of polymers gives wide range of properties.
- Can produce a wide range of part sizes with different press sizes.
mold
Functions:

1. Allow rapid freezing of polymer: isolate the cavity and permits withdrawal of the screw

2. Narrow and thin solid section: be sheared off easily after demolding

3. Increase shear rates as melt flows through: lower viscosity to ease rapid and complete filling of complex shapes
Cycle of operations for the production of injection mouldings.
Problems:

- sink marks and voids
- weld lines
Weld line: formed where polymer flows meet

Can be moved to a position on the molding where unimportant
7. Blow molding

Extrusion blow molding

‘parison’
Extrusion blow molding

Typical products
- Bottles and containers
- Automotive fuel tanks
- Venting ducts
- Watering cans
- Part cost - moderate
- Tooling Cost - moderate
- Production rate - moderate to high
- Blow molding produces parts with the highest strength to weight ratio of any plastic process. Complex, hollow parts are formed with no internal stresses. Parts as large as 12 ft. x 4 ft. x 4 ft. can be formed
Stages

1. The hot plastic extruded into the mold in pipe form.

2. While still hot, the plastic is trapped in the mold, a hot knife cuts it off at the top and it is also pinched at the bottom.

3. The mold then moves to the right. An air hose is inserted into the top.

4. The plastic in the mold expands to fill the mold.

5. The mold then separates, which releases the plastic (bottle).
Injection blow molding

Carbonated drinks → using PET

The tube → ‘preform’ made by injection molding to a very cold mold to quench it in its amorphous state

Is reheated to blowing T (just about its $T_g$) and stretch blown

Develop biaxial orientation in the product

Alternate name for this process is ‘stretch-blow’
Injection blow molding
8. Plastic foam molding

-low-pressure injection molding process that is capable of producing very large structural parts.

-The molten plastic material is injected into a mold after being mixed with a blowing agent or high-pressure gas.

-This produces bubbles in the plastic causing it to foam. The foam retains the properties of the plastic but weighs less because of reduced density.