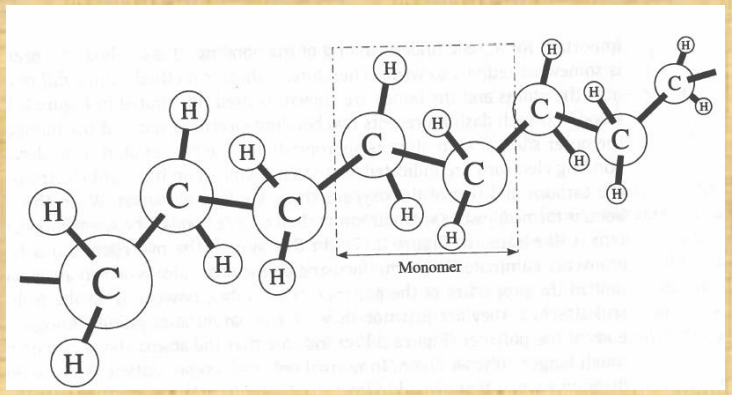
Structure and Properties of Engineering Polymers

Lecture: **Polymer Processing**

Nikolai V. Priezjev



Textbook: *Plastics: Materials and Processing* (Third Edition), by A. Brent Young (Pearson, NJ, 2006).

Polymer Processing

- Plastic manufacturing processes are used to convert plastic materials in the form of pellets, powders, sheets etc.
- Different types of plastic manufacturing processes are:

a. Compression molding
b. Transfer molding
c. Injection molding
d. Extrusion molding
e. Blow molding
f. Calendaring
g. Thermoforming
h. Thin Films
i. Fibers

Reading: Chapters 11-18 of *Plastics: Materials and Processing* by A. Brent Strong

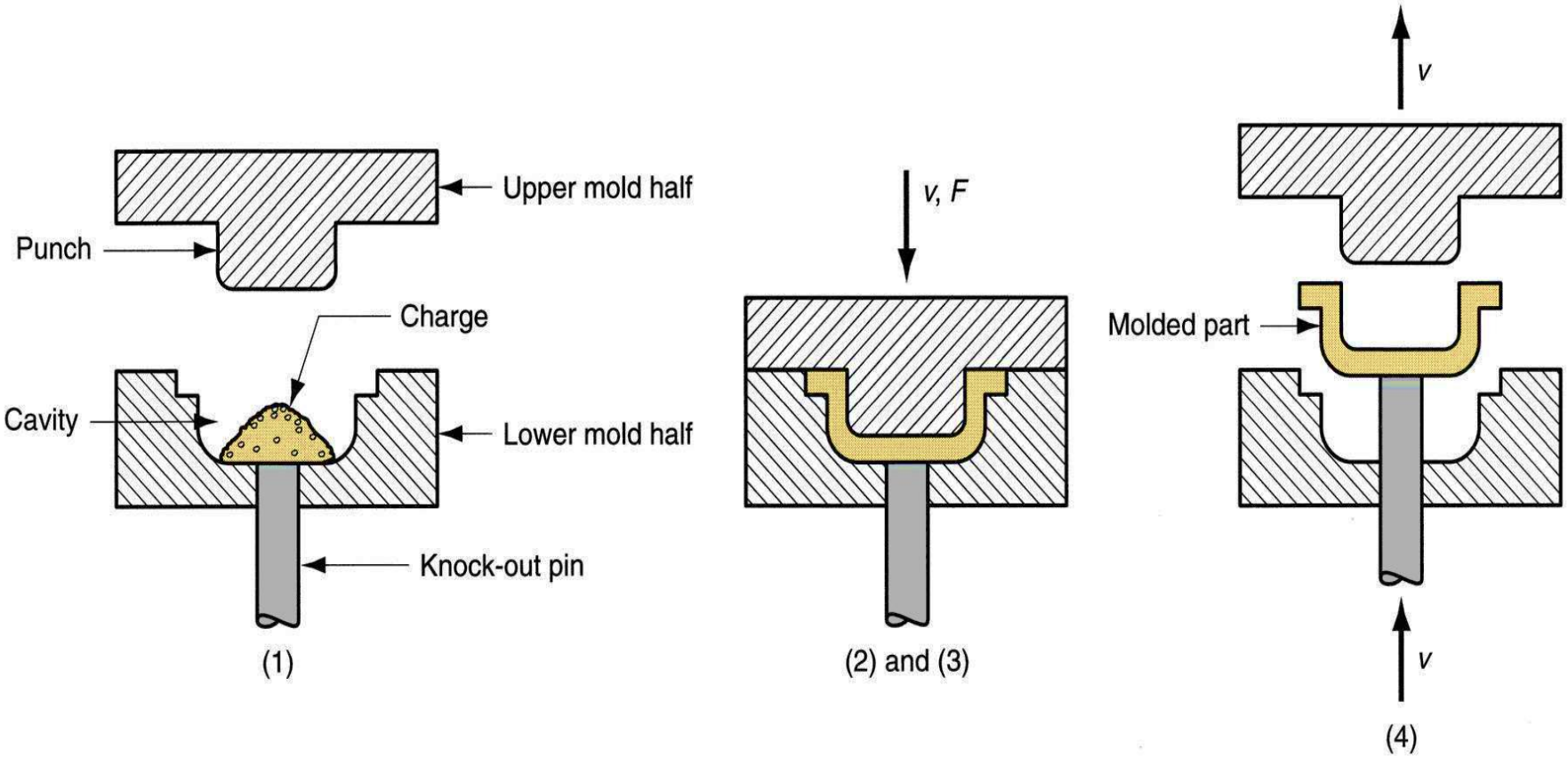
Polymer Processing

- Thermoplastic –
  - can be reversibly cooled & reheated, i.e. recycled
  - heat till soft, shape as desired, then cool
  - ex: polyethylene, polypropylene, polystyrene, etc.
- Thermoset –
  - when heated forms a network
  - degrades (not melts) when heated
  - mold the prepolymer then allow further reaction
  - ex: urethane, epoxy

Reading: Chapters 11-18 of *Plastics: Materials and Processing* by A. Brent Strong

Compression Molding

- The charge (thermosets) is heated by means of the hot mold to polymerize and cure (Xlink) it into a solidified desired shaped molded plastic component. (Waffle making).



Compression Molding

- First, the charge is loaded into the lower half of mold which is preheated to maintain the temperature of charge during the process.
- The placed charge is compressed by bringing both halves of mold close together.
- The charge is heated by means of the hot mold to polymerize and cure it into a solidified desired shaped molded plastic component.
- Then, the halves are opened & molded plastic part is removed by pressing knockout pins towards inside.

Compression Molding

Advantages

- Low initial setup costs and fast setup time
- Heavy plastic parts can be molded
- Complex intricate parts can be made
- Good surface finish of the molded parts
- Wastes relatively little material as compared with other methods
- The molding process is cheaper as compared to injection molding

Disadvantages

- Low production rate
- Limited largely to flat or moderately curved parts with no undercuts
- Reject part cannot be reprocessed

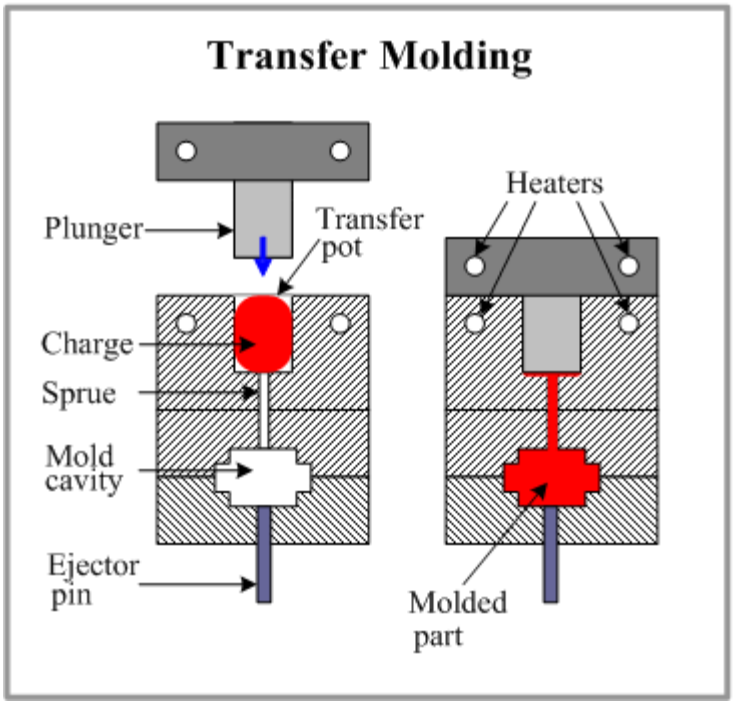
Compression Molding

Applications

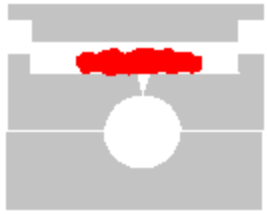
- Electrical and electronic equipments, brush and mirror handles, trays, cookware knobs, aircraft main power terminal housing, pot handles, dinnerware plates, automotive parts.

Compression molded rubber boots before the flashes are removed.

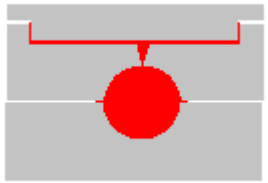
Transfer Molding



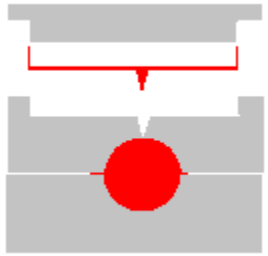
Transfer molding is a process where the amount of material is measured and inserted before the molding process takes place. The material is then preheated and loaded into a *pot* and a plunger is then used to force the material from the pot through the runner system into the mold cavities. The mold remains closed as the material is inserted and is opened to release the part from the runner. The mold walls are heated to a temperature above the melting point of the mold material; this allows a faster flow of material through the cavities.



Step #1 - A piece of uncured rubber is placed into a portion of the mold called the "pot." The plunger (on the top-most part of the mold) fits snugly into the "pot."



Step #2 - The mold is closed up and under hydraulic pressure the rubber is forced through the small hole (the "gate") into the cavity. The mold is held closed while the rubber cures.



Step #3 - The plunger is raised up and the "transfer pad" material may be removed and thrown away.

Step #4 - Mold is opened and the part can be removed. The flash and the gate may need to be trimmed.

Transfer Molding

Advantages

- Fast setup time and lower setup costs
- Low maintenance cost
- Plastic parts with metal inserts can be made
- Design flexibility
- Dimensionally stable
- Uniform thickness of parts
- Large production rate

Disadvantages

- Wastage of material
- Production rate lower than injection molding
- Air can be trapped in the mold

Applications Integrated circuits, plugs, connectors, pins, coils, studs, radio, television cabinets and car body shells.

Injection Molding

– thermoplastic & some thermosets

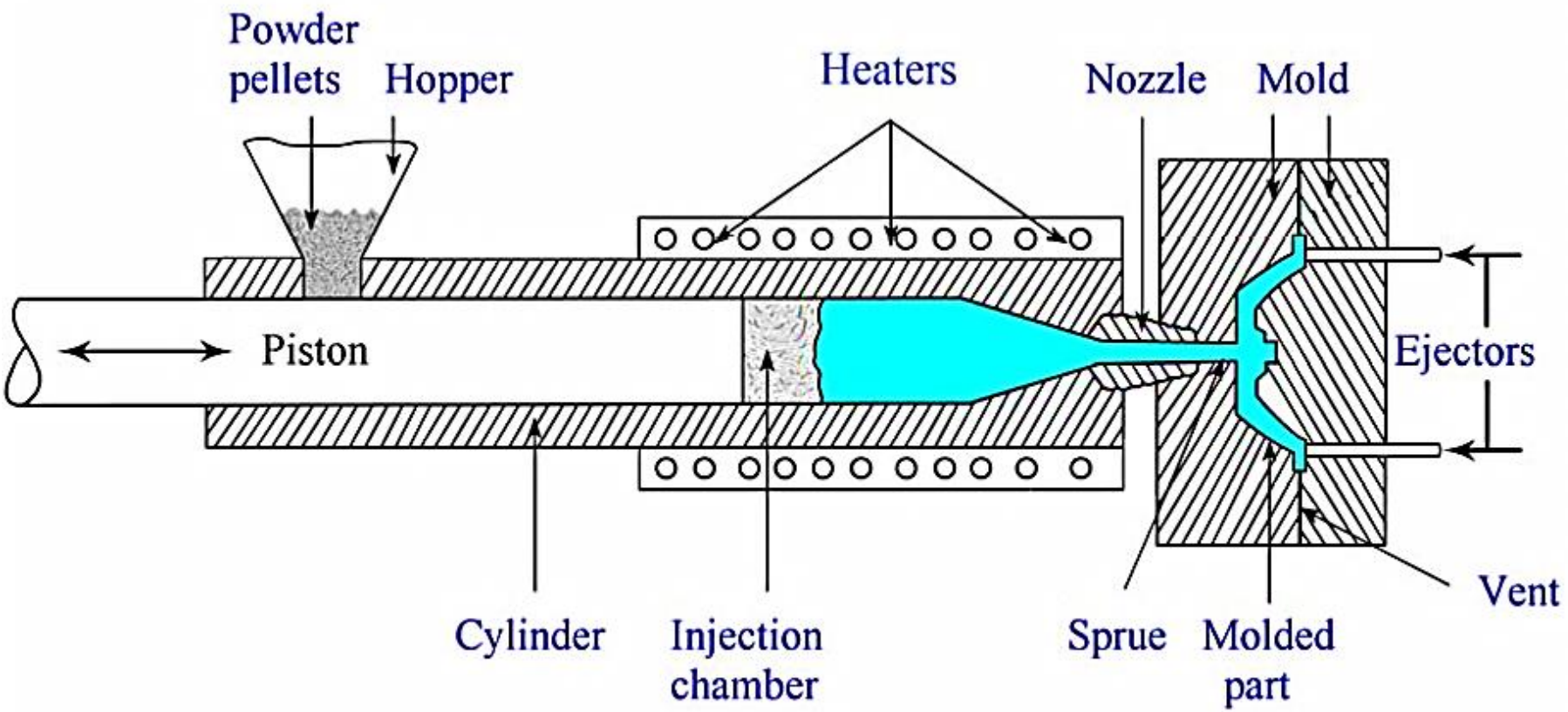
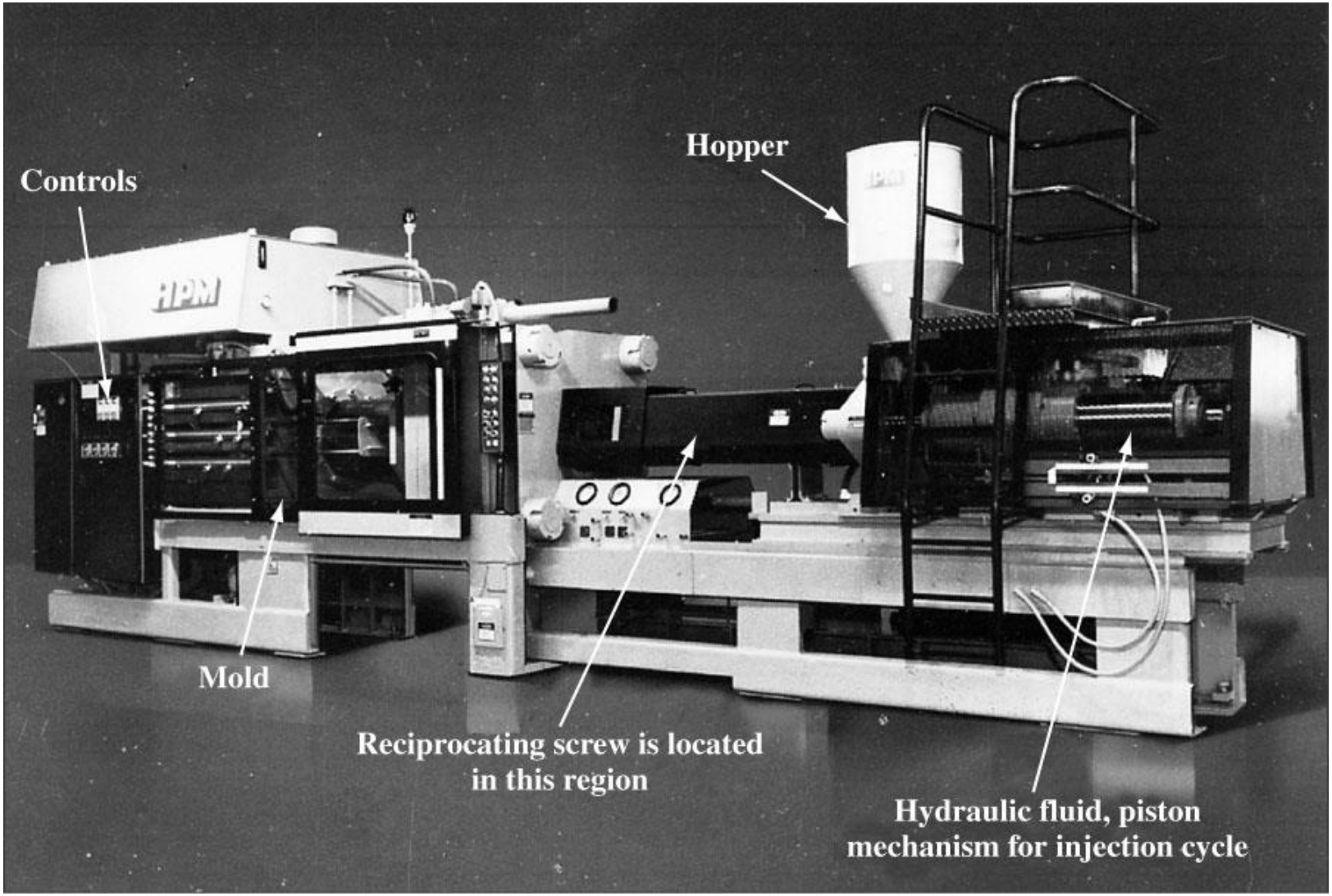


Figure 1 Injection molding setup

Injection Molding



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Injection Molding

- Palletized material is fed with use of hopper into a cylinder where material melts due to heating coils.
- Molten material (thermoplastic) is impelled through nozzle into the enclosed cavity.
- Outstanding characteristic of this molding process is cycle time is short (10 – 30 sec), i.e. rate of production is very high. (longer cycle times for thermosets).
- The complete injection molding process is divided into four stages: clamping, injection, cooling and ejection.

Injection Molding

Advantages

- Higher production rate
- Close tolerances on small intricate parts
- Minimum wastage of material
- Complex geometry can be easily produced

Disadvantages

- Tooling cost higher
- High setup cost
- Large undercuts can't be formed

Applications

- household appliances, electronics, and automotive dashboards, buckets, etc…

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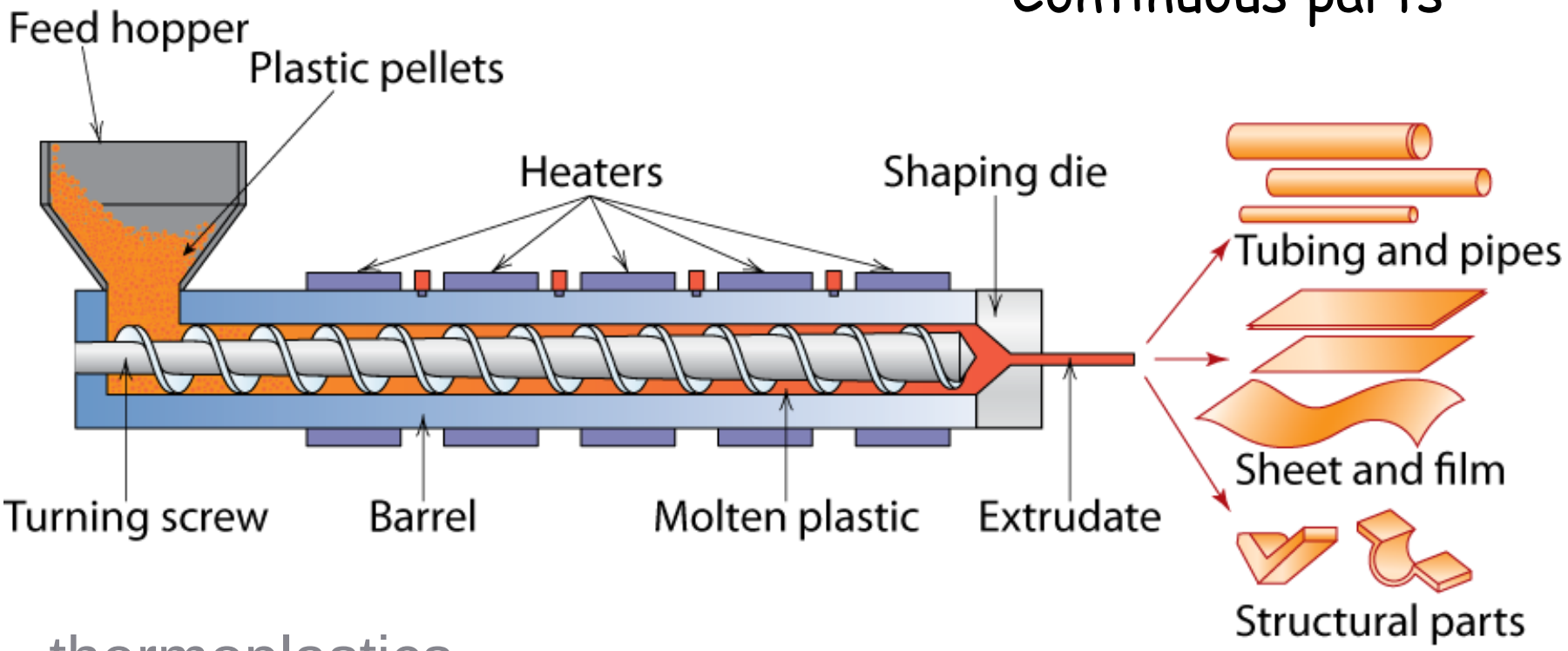
Extrusion Molding

Continuous parts



thermoplastics

- plastic pellets drop from hopper onto the turning screw
- plastic pellets melt as the turning screw pushes them forward by the heaters
- molten polymer is forced under pressure through the shaping die to form the final product

Extrusion Molding

- Similar to injection molding except long uniform sections are produced.
- The material which is fed through hopper, is conveyed forward by a feeding screw & forced through a die, converting to continuous polymer product.
- Heating is done in order to soften or melt the polymer. The temp is controlled by thermocouples.
- The product going out of the die is cooled by blown air or in water bath.

Extrusion Molding

Advantages

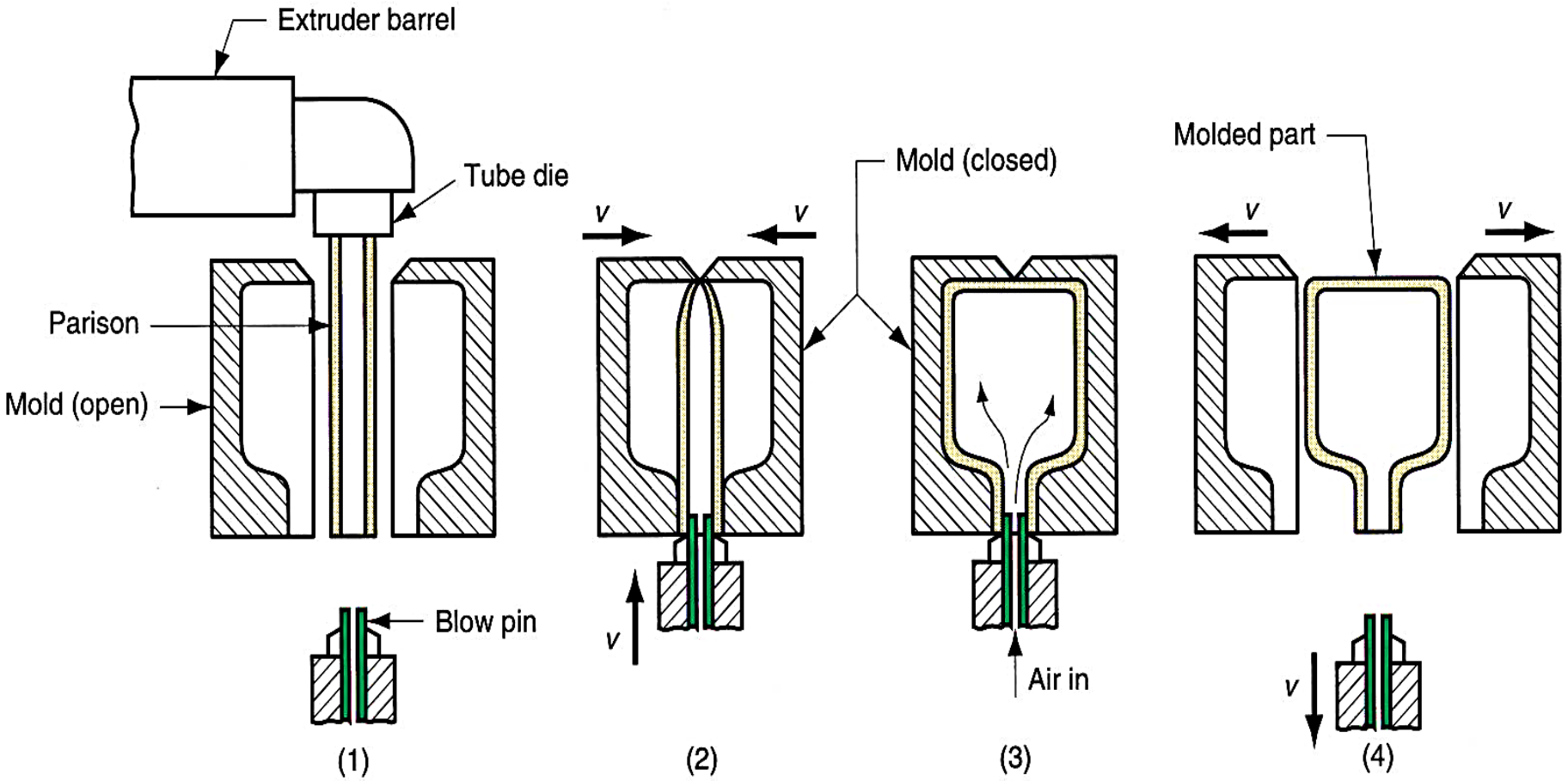
- High production volumes
- Relatively low cost as compared with other molding process
- Design flexibility
- Short lead times
- Coating of wire can be done to achieves desired properties
- Continuous part can be produced

Disadvantages

- Limited complexity of parts
- Uniform cross section can only be produced

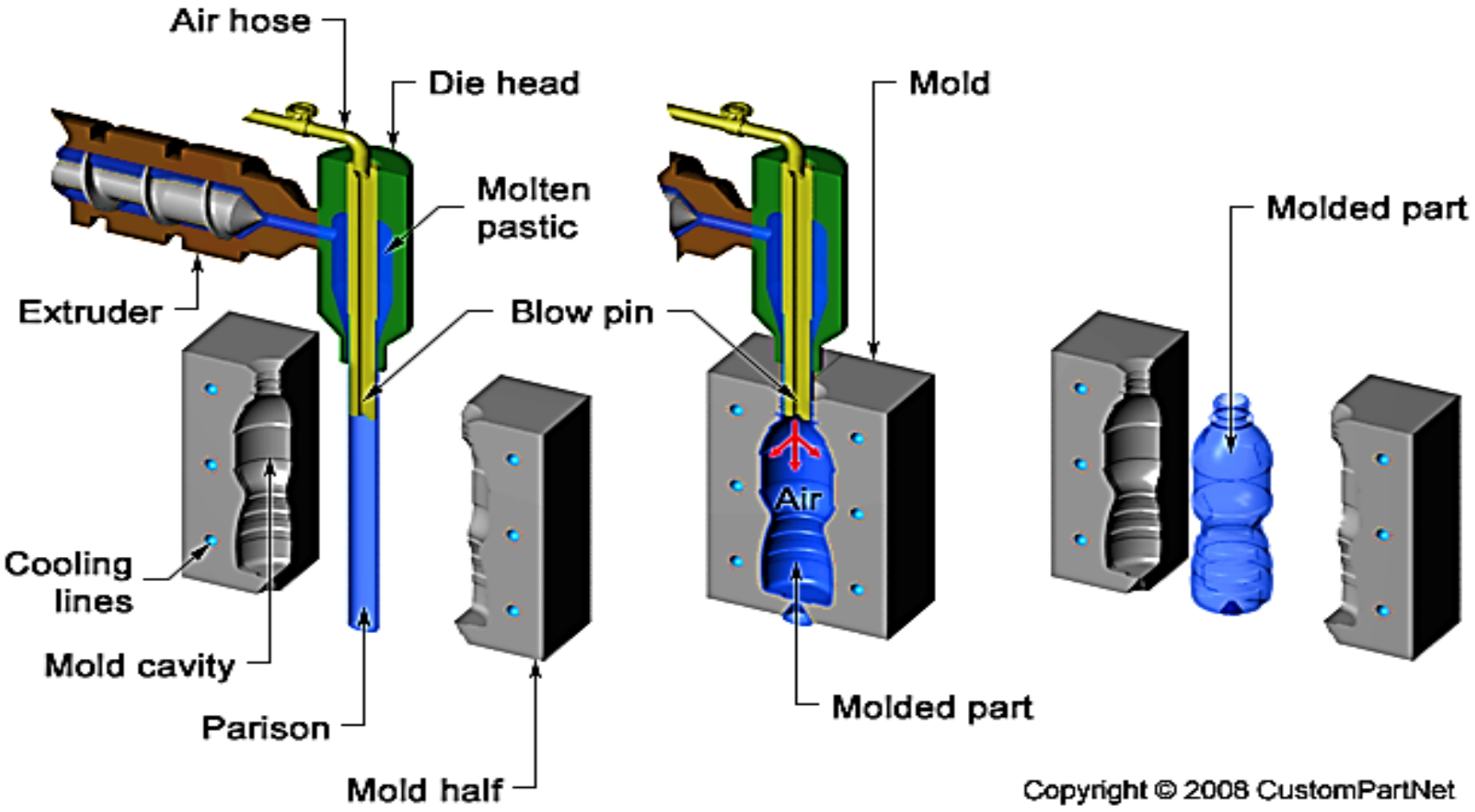
Applications The extrusion process is used for manufacturing rods, plates and tubes, wire and cable coating, hose liners, hose mandrels, filaments, sheet, multilayer film, medical packaging and food packaging, etc. (continuous shape)

Blow Molding



hollow parts with uniform thickness: plastic bottles

Blow Molding



Blow Molding

- Using this manufacturing process hollow parts are made like bottle or sphere etc.
- Air is blown into a thin walled plastic cylinder called the parison. The parison is formed by melted plastic material being pushed through an extruder.
- When the parison reaches a certain length, the two halves of the mould close around the parison sealing it at the bottom.
- Compressed air is then used to inflate the parison to form the shape of the cavity inside the mould.

Blow Molding

Advantages

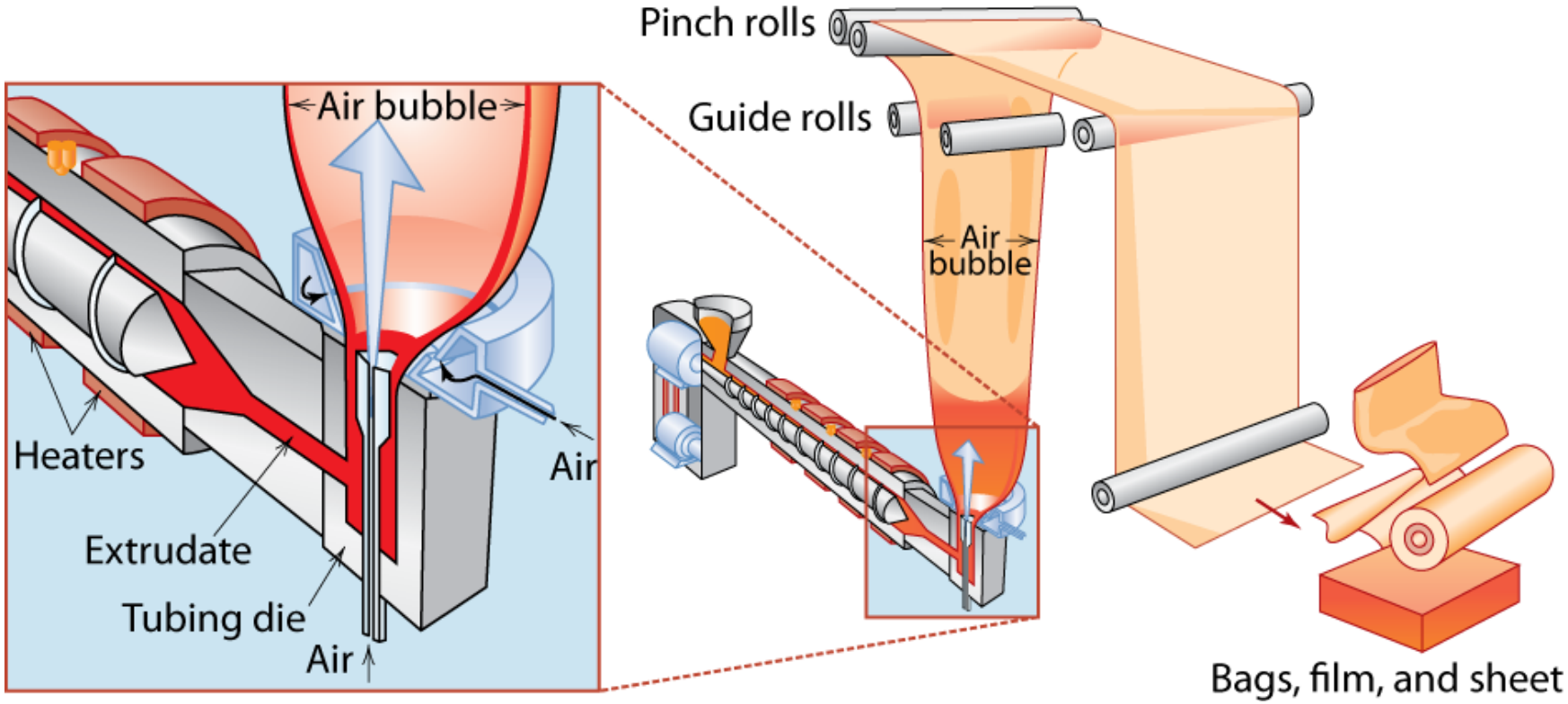
- Low tooling cost
- Fast production rates
- Ability to mold complex part with uniform thickness
- Little scrap generated
- Large hollow shape can be produced
- Produced parts can be recycled

Disadvantages

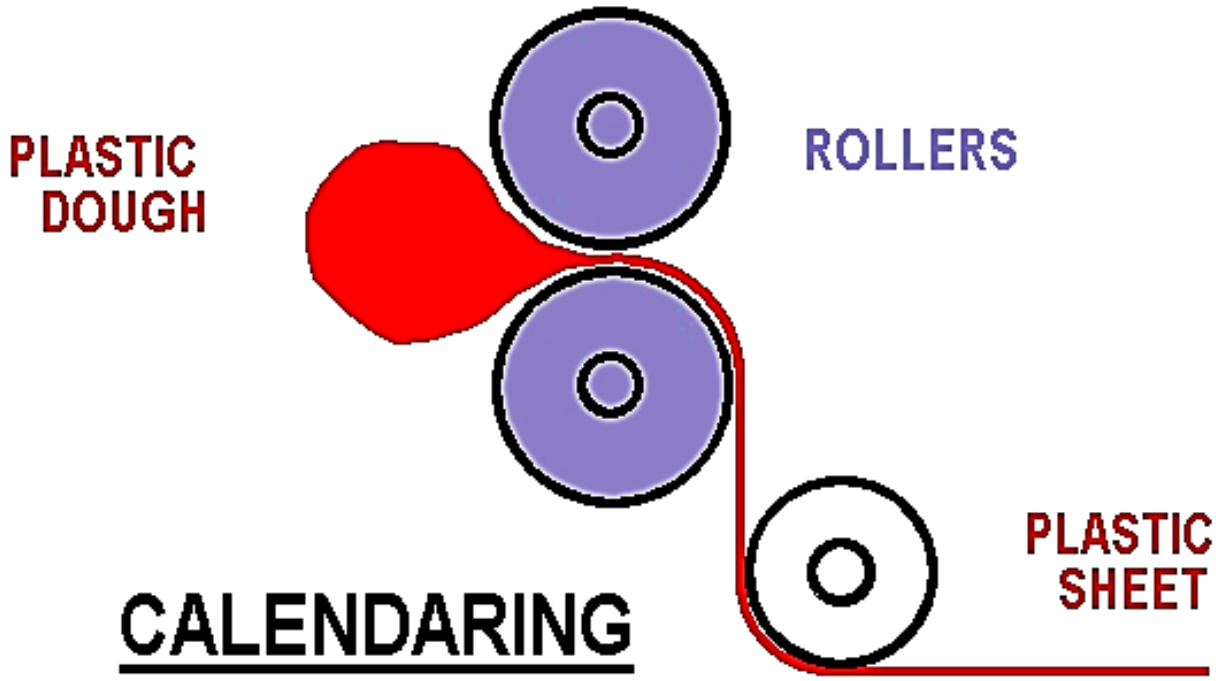
- Limited to hollow parts
- Thick parts can't be manufactured

Applications bottles in different shape and size, jars, and containers, ducting, fluid oil tanks, mugs, and toys, etc.

Blown-Film Extrusion

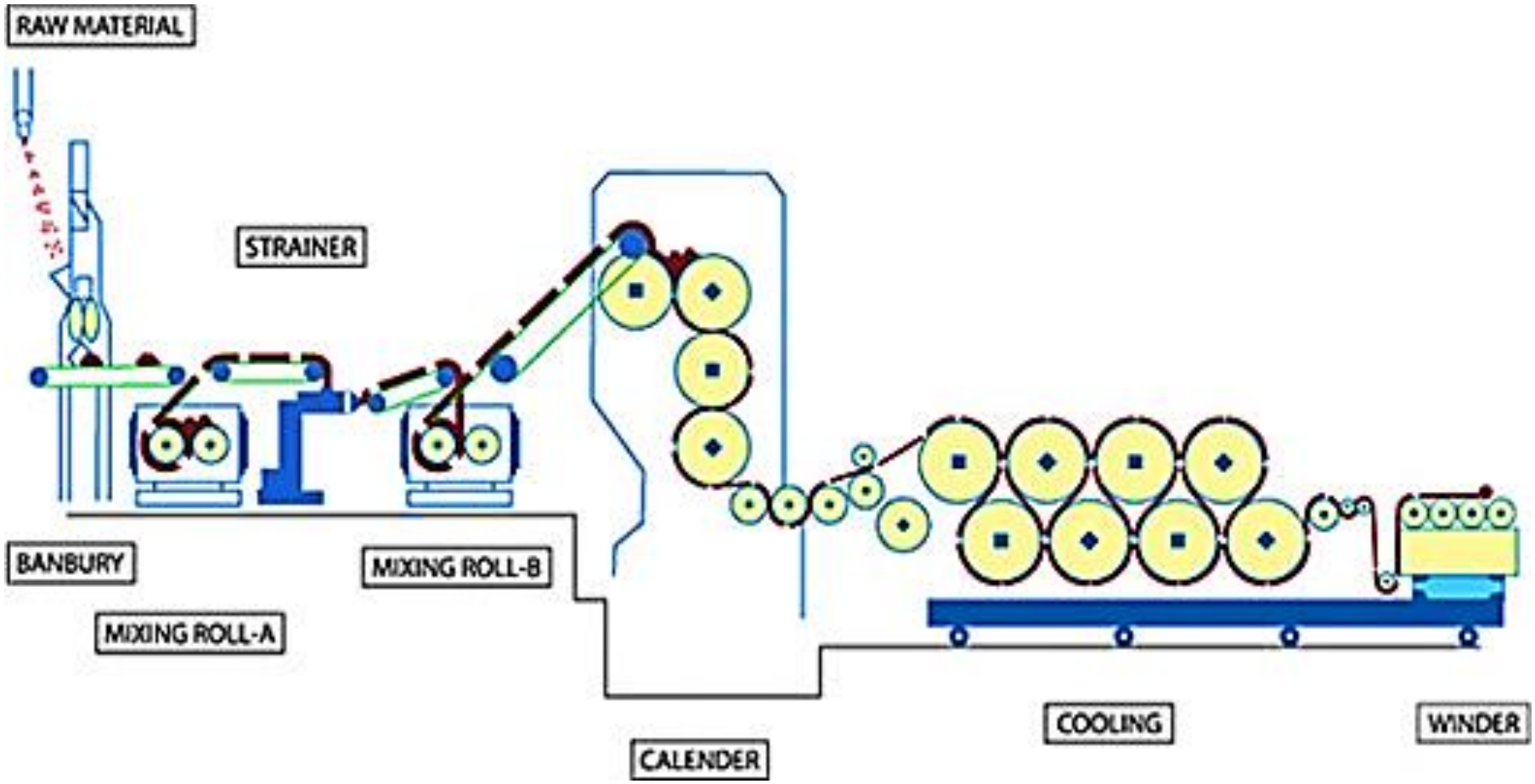


Calendaring



- In this process the plastic material is allowed to pass between the cylindrical rollers.
- The process is used to prepare plain flat sheets of plastics.

Calendaring



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Polymer Types: Fibers

Fibers - length/diameter >100

- Textiles are main use
  - Must have high tensile strength
  - Usually highly crystalline & highly polar

- Formed by spinning
  - ex: extrude polymer through a spinneret
- Pt plate with 1000's of holes for nylon
- ex: rayon (artificial silk) – dissolved in solvent then pumped through die head to make fibers
  - the spun fibers are drawn under tension
  - leads to highly aligned chains- fibrillar structure

Thermoforming

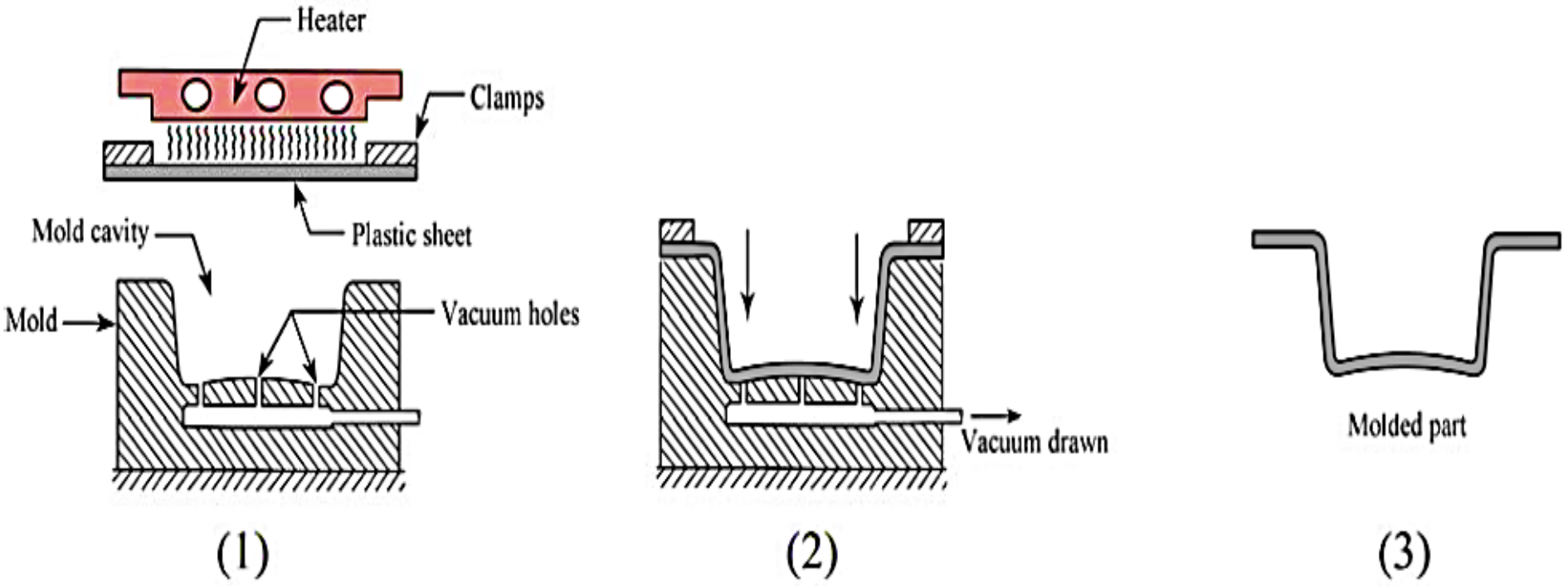
- Thermoforming is a plastic manufacturing process in which the thermoplastic sheets are formed with the application of heat and pressure in a mold.
- The thermoplastic sheet is held horizontally over a mold surface and clamped with a holding device. The sheet is heated up to predetermined temperature using a heating element (heater).
- The thermoplastic sheet softens with the application of heat and is pressed into or stretched over the mold surface by application of air pressure or by any other means.

Thermoforming

- The softened sheet conforms to the mold shape and it is held in place until it cools.
- The mold cavity is opened and the thermoformed part is released.
- The excess material is then trimmed out from the formed part. Excess material can be reground, mixed with unused plastic, and again reformed into thermoplastic sheets.
- There are mainly three different types of thermoforming process depending upon the pressure required i.e., vacuum thermoforming, pressure thermoforming and mechanical thermoforming.

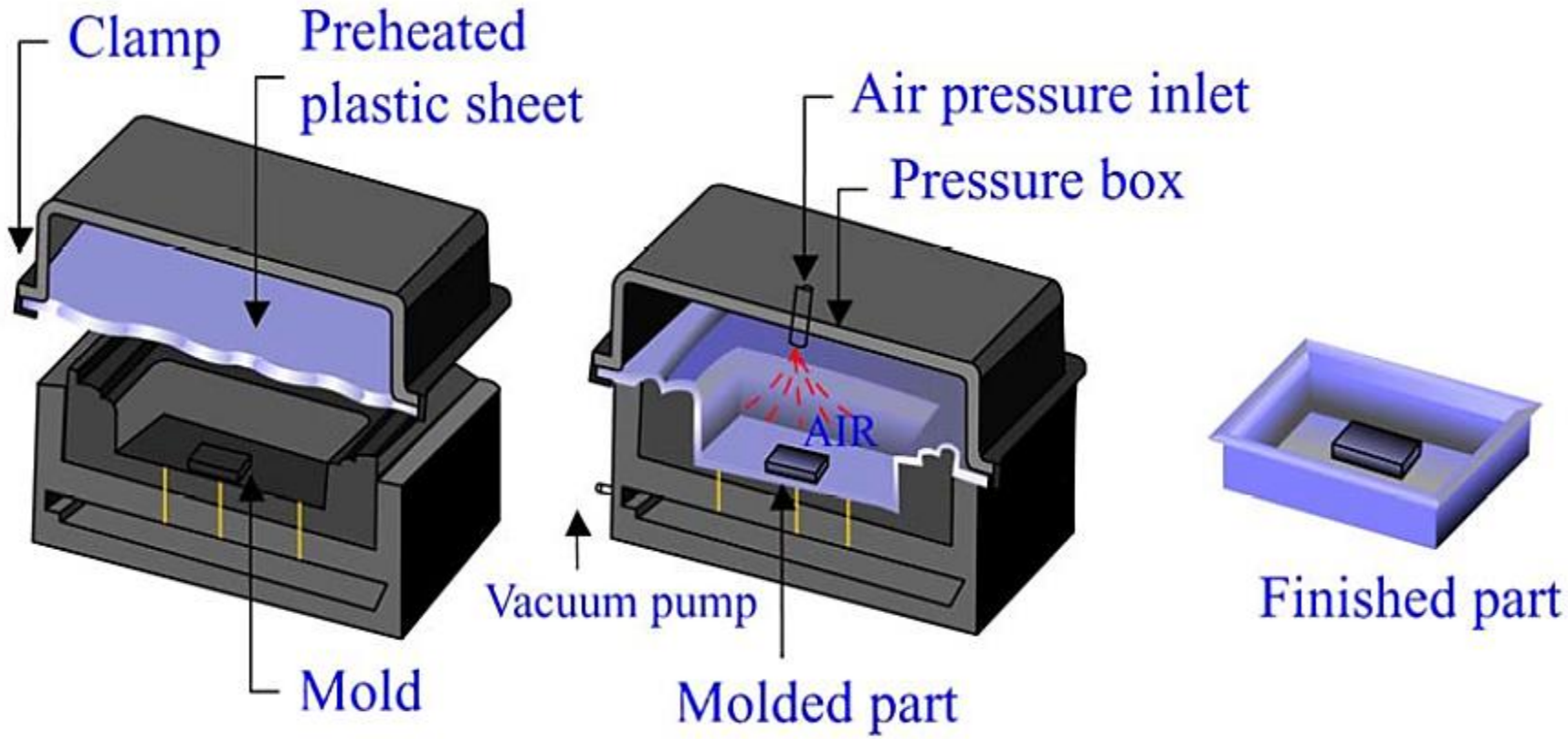
Thermoforming

a. vacuum thermoforming



Thermoforming

b. pressure thermoforming



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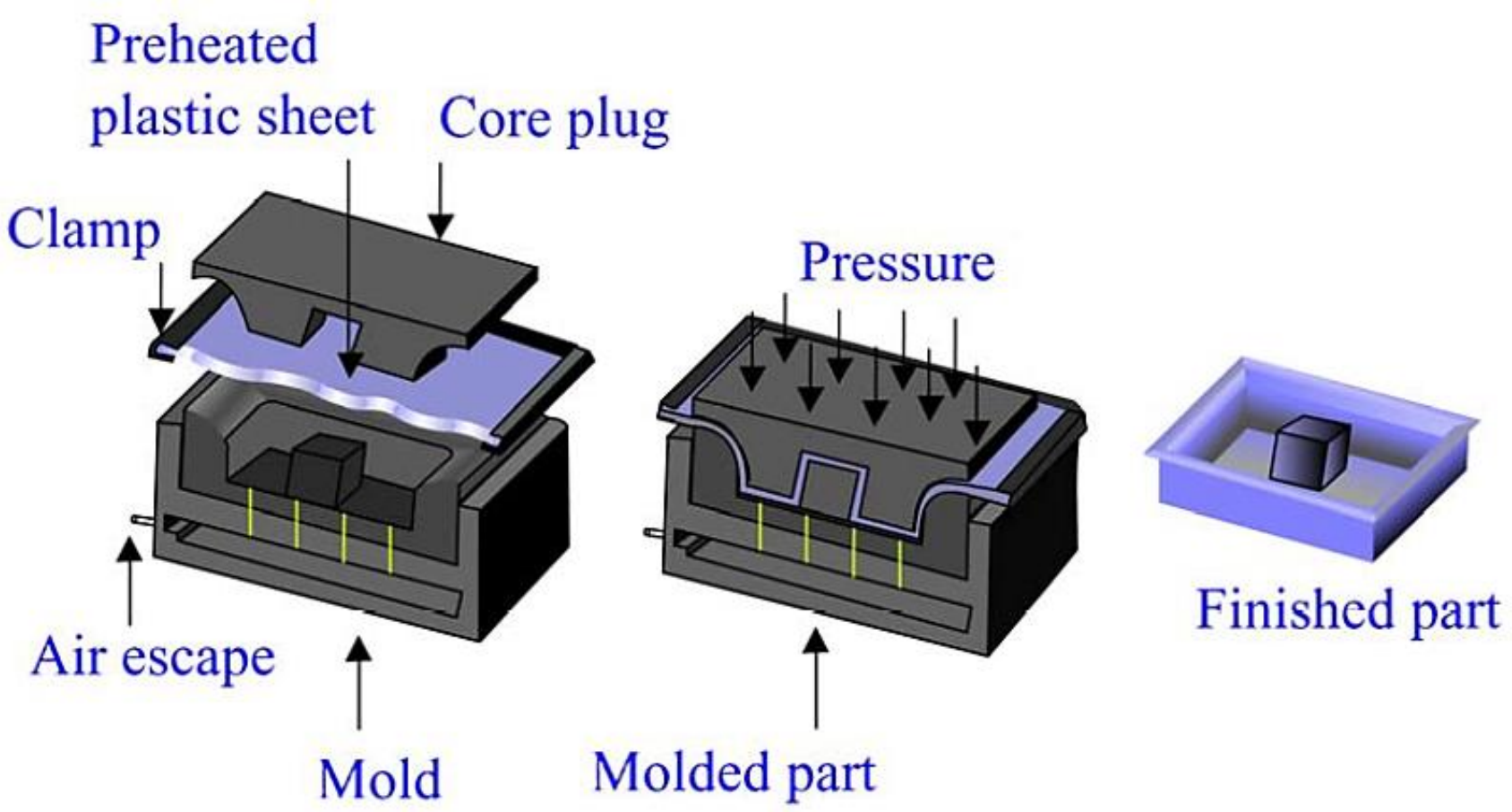
Thermoforming

c. mechanical thermoforming



Thermoforming

Advantages

- Extremely adaptive to design requirement
- Rapid prototype development
- Low initial setup costs
- Low production costs
- Smaller thermal stresses than injection molding and compression molding
- Good dimensional stability

Disadvantages

- Poor surface finish
- Parts may have non-uniform wall thickness.
- All parts need to be trimmed
- Ribs and bosses cannot be molded easily
- Very thick plastic sheets can't be formed

Thermoforming

Applications

- food packaging, automotive parts, trays, building products, aircraft windscreens, medical equipment, material handling equipment, electrical and electronic equipment, spas and shower enclosures etc.

Polymer Foaming

Foaming processes are characterized by techniques that cause tiny bubbles to form within plastic material such that when plastic solidifies the bubbles remain. Foams or *cellular plastics*.

Foams have been widely used in a variety of applications: Insulation, cushion, absorbents, etc.

Various polymers have been used for foam applications: **Polyurethane** (PU), **polystyrene** (PS), polyethylene (PE), polypropylene (PP), poly(vinyl chloride) (PVC), polycarbonate (PC), etc.

1- Mechanical Foaming

2- Foaming with Hollow Glass Beads

3- Chemical Foaming

4- Physical Foaming

Classification of Polymer Foams

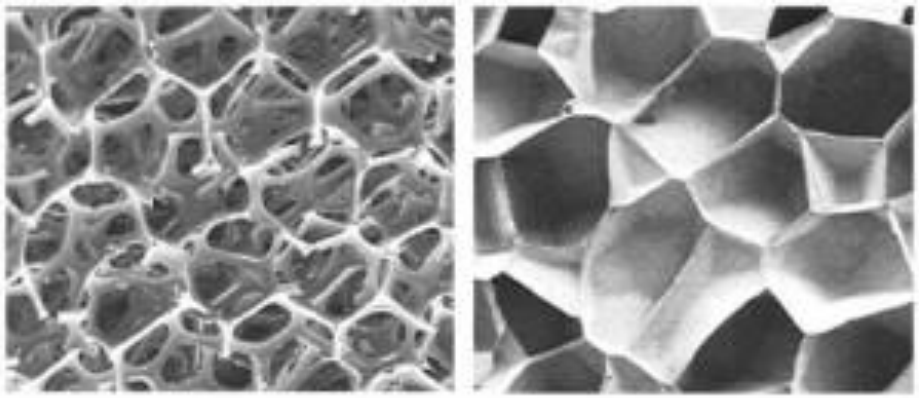
Polymer foams can also be defined as either ***closed cell or open cell foams***.

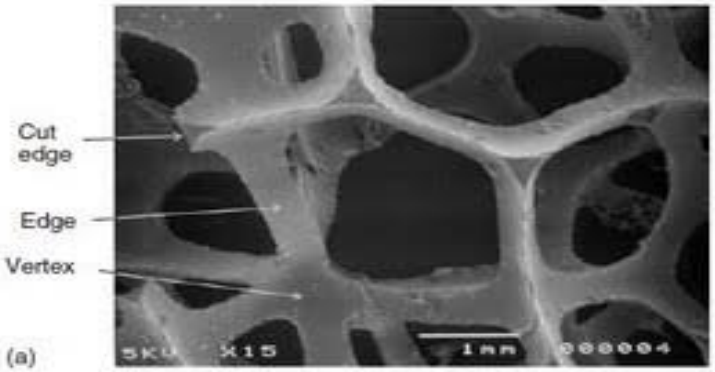
In ***closed cell foams***, the foam cells are isolated from each other and cavities are surrounded by complete cell walls. Generally, closed cell foams have lower permeability, leading to better insulation properties. Absorb sound, especially bass tones. Closed cell foams are usually characterized by their *rigidity* and *strength*, in addition to the *high R-value* (Resistance to heat flow).
Closed cell polyurethane spray foam has among the highest R-values of any commercially available insulation.

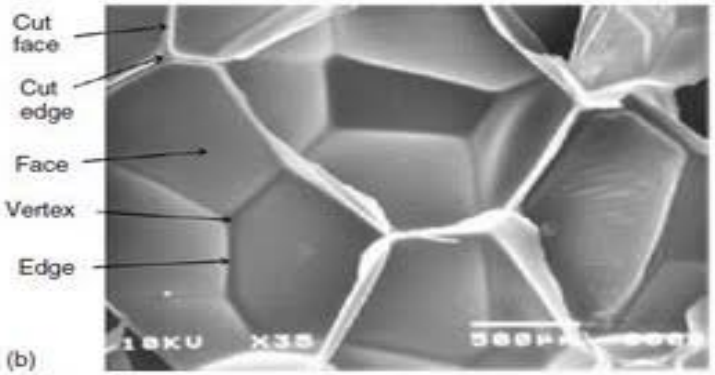
In ***open cell foams***, cells are connected with each other. They have *softer* and spongier appearance. Open cell foams are incredibly effective as a *sound barrier* in normal noise frequency ranges and provide *better absorptive capability*.

The advantages of closed-cell foam compared to open-cell foam include its strength, higher R-value, and its greater resistance to the leakage of air or water vapor. The disadvantage of the closed-cell foam is that it is denser, requires more material, and therefore, is more expensive.

Polymer Foaming







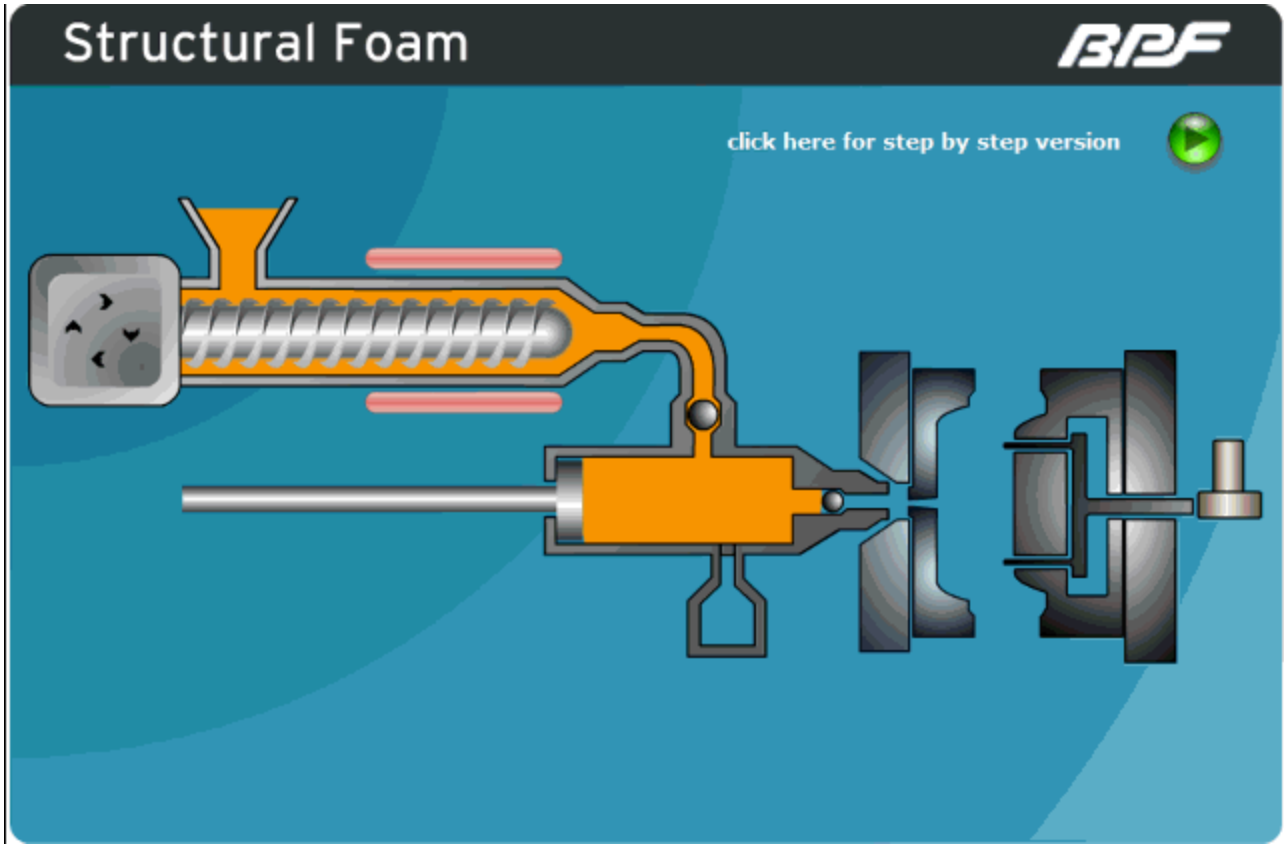
SEM photograph of (a) PU open-cell foam of density 28 kg m^{-3}; and (b) closed-cell low density polyethylene (LDPE) foam of density 24 kg m^{-3}.

Fig. 1 Examples of cellular solids:
a) open-cell polyurethane foam,
b) closed-cell polyethylene foam.

Polymer Foaming

Injection moulding of foams is achieved in two steps

1. An inert gas is dispersed through the molten region directly before moulding by
• direct gas injection (usually N_2) or
• pre-blending of the resin with a chemical blowing agent.



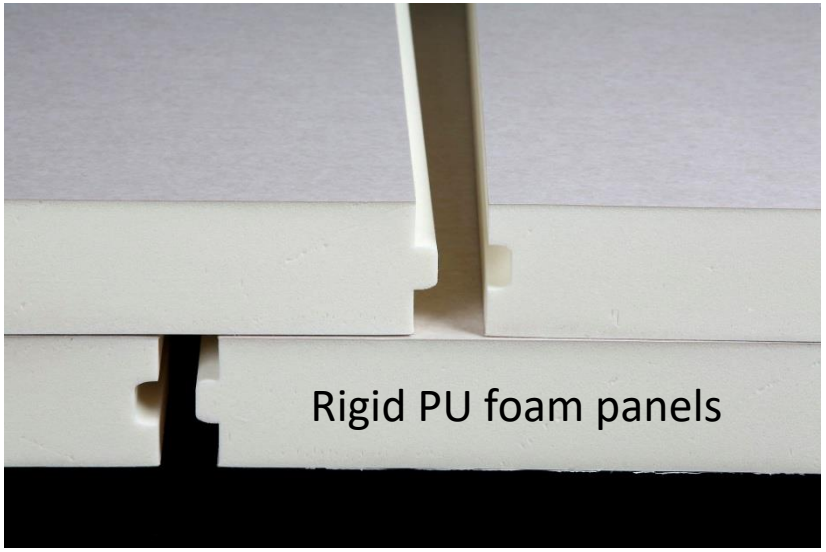
2. Rapid injection of gas/resin mixture into the mould cavity causes the gas to expand "explosively". The material is thus forced in all parts of the mould. The resulting properties of the foam are :
• Very high rigidity/weight ratio,
• Almost no orientation effect (uniform shrinkage),
• Moulding of thick sections without sink marks.

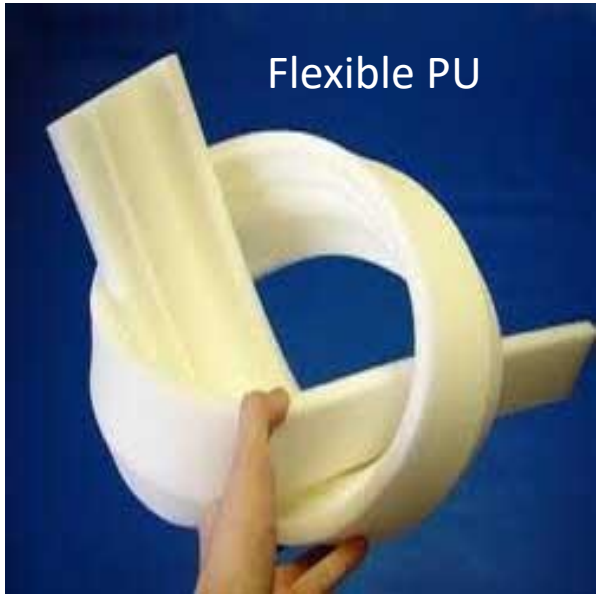
Foamed articles are used for insulating containers and for packaging. The process above may be used with thermoplastics or thermosets.

Classification of Polymer Foams

Polymer foams can be classified as ***rigid or flexible foams***

Rigid foams are widely used in applications such as building insulation, appliances, transportation, packaging, furniture, food and drink containers.





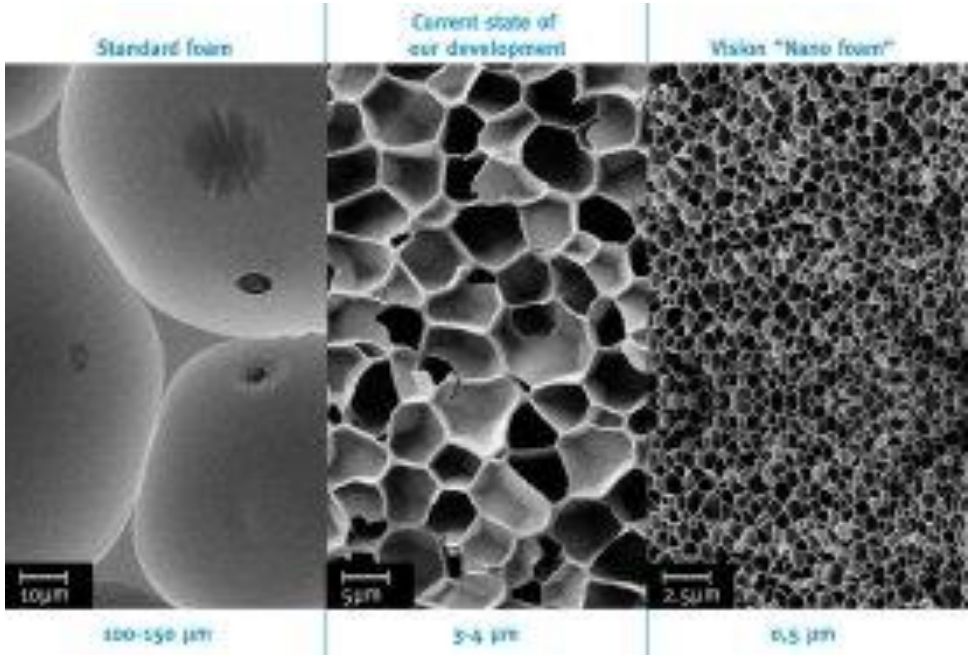
Flexible foams are used as furniture, transportation, bedding, carpet underlay, textile, sports applications, shock and sound attenuation.

Classification of Polymer Foams

According to the size of the foam cells, polymer foams can be classified as:

- Macrocellular (>100 µm),
- Microcellular (1–100 µm),
- Ultramicrocellular (0.1–1 µm)
- Nanocellular (0.1–100 nm).

Polyurethane foams. The thermal insulation performance of a polyurethane rigid foam depends chiefly on the size of the foam pores. *The smaller the diameter, the lower the thermal conductivity and the better the insulating effect.* Today's polyurethane rigid foams typically have pore sizes of roughly 150 micrometers, which exceeds the pore size of nanofoams planned for the future by a factor of approximately 1,000.



Polymer Foaming

Advantageous

- They have low density so they are light weight materials.
- Some polymer foams have low heat or sound transfer, making them optimal insulators.
- Many are flexible and soft, meaning they provide more comfort as cushion.

Disadvantageous

- Inferior mechanical strength
- Low thermal and dimensional stability
- The most widely used chloroflorocarbon (CFC) blowing agents have been found to cause ozone depletion in the upper atmosphere and banned by 2010 according to Montreal Protocol.

Advanced Polymers

- Ultrahigh molecular weight polyethylene (UHMWPE)
  - Molecular weight ca. 4×10^6 g/mol
  - Outstanding properties
    - high impact strength
    - resistance to wear/abrasion
    - low coefficient of friction
    - self-lubricating surface
  - Excellent properties for variety of applications
    - bullet-proof vest, golf ball covers, hip joints, etc.

Adapted from chapter-opening photograph, Chapter 22, *Callister 7e.*

Advanced Polymers

The Stem, femoral head, and the AC socket are made from Cobalt-chrome metal alloy or ceramic, AC cup made from polyethylene

ABS – A Polymerized "Alloy"

ABS, Acrylonitrile-Butadiene-Styrene

Made up of the 3 materials: acrylonitrile, butadiene and styrene. The material is located under the group styrene plastic. Styrene plastics are in volume one of the most used plastics.

Properties

The mechanical properties for ABS are good for impact resistance even in low temperatures. The material is stiff, and the properties are kept over a wide temperature range. The hardness and stiffness for ABS is lower than for PS and PVC.

Weather and chemical resistance

The weather resistance for ABS is restricted, but can be drastically improved by additives as black pigments. The chemical resistance for ABS is relatively good and it is not affected by water, non organic salts, acids and basic. The material will dissolve in aldehyde, ketone, ester and some chlorinated hydrocarbons.

Processing

ABS can be processed by standard mechanical tools as used for machining of metals and wood. The cutting speed need to be high and the cutting tools has to be sharp. Cooling is recommended to avoid melting of the material. If the surface finish is of importance for the product, the ABS can be treated with varnish, chromium plated or doubled by a layer of acrylic or polyester. ABS can be glued to it self by use of a glue containing dissolvent. Polyurethane based or epoxy based glue can be used for gluing to other materials.

Summary

- Plastic manufacturing processes are used to convert plastic materials in the form of pellets, powders, sheets etc.
- Different types of plastic manufacturing processes are:

a. Compression molding
b. Transfer molding
c. Injection molding
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e. Blow molding
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