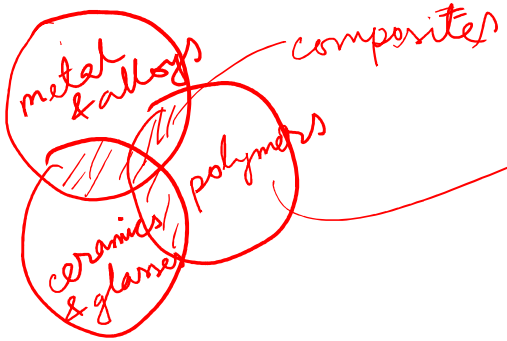
ME222: Manufacturing Technology I

Module 5: Polymer Fabrication Methods

Department of Mechanical Engineering

Indian Institute of Technology Guwahati



Polymeric materials

Plastics

Elastomers

(e.g. rubber)

Thermoplastics

Thermosetting

Commodity plastics

(Polyethylene, polypropylene, polystyrene, PVC etc.)

Engineering plastics

(Polyamide, nylons polycarbonate, polyacetals, cellulosics etc.)

Commodity plastics

(phenolics, unsaturated polyesters, ureas etc.)

Engineering plastics

(silicones, urethanes, melamines etc.)

[Courtesy: Manufacturing Technology-I, P N Rao]

Polymers

why lightweight, lower stiffness, strength?

- **Polymers** are always composed of atoms of **carbon** in combination with other elements. Mainly 8 elements are used to create different plastics
  - hydrogen, carbon, nitrogen, oxygen, fluorine, silicon, sulphur and chlorine
- Different families of plastics are in commercial use
- Plastic parts are usually produced by **moulding processes** (metals → mould/mold not moulding)
- However, for **extremely complex** shapes - **machining** and **additive manufacturing** can be used
- For particular application, **joining** of different shapes is required
- Processing of plastics depend primarily on their mechanical, thermal and rheological properties
- **Properties** – light weight, corrosion resistance, electrical resistance, formability, surface finish

Polymers

- Polymers are formed when small organic molecules **joined** together to form a long chain of molecules
- The process is called **polymerisation** and the organic molecules used in polymerisation are called **monomers**
- Polymerisation is generally of two types: addition polymerisation and condensation polymerisation
- **Addition polymerisation:** involves breaking of double carbon bond (C=C) in bifunctional polymers to form long chains. E.g., styrene, vinyl chloride, propylene, ethylene.
- **Condensation polymerisation:** involves two different organic molecules react to form plastic molecule and it generally results in the separation of a small molecule such as H_2O as by-product. These polymers can **degrade when exposed to water and high temperature** due to depolymerisation, which involves breaking polymer chains. E.g., epoxy (araldite), phenol-formaldehyde (bakelite), polyamide (nylon). (**epoxy** is result of condensation polymerisation of epichlorohydrin + bisphenol A. **polyamide** results from hexamethylene diamine + adipic acid)

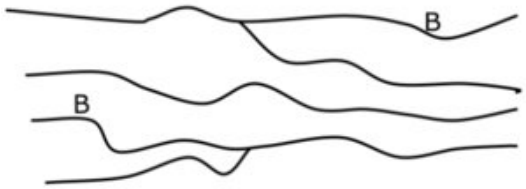
- **Resin** is uncompounded monomers that are mixed but not yet polymerised. E.g, thermosetting resin, thermoplastic resin
- Amorphous polymers are less dense than crystalline polymers
- Crystallinity in polymers increases strength and toughness

(semi-crystalline) → short-range crystallinity

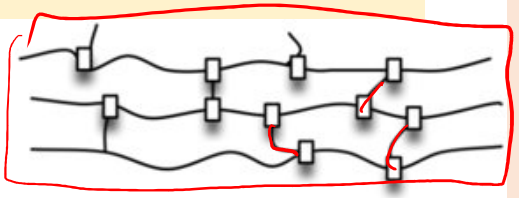
Thermoplastics vs Thermosetting Polymers

Thermoplastics

- Can be softened and melted by heat and then can be formed into required shape when it is hot
- Long thin polymer chains similar to 2D structure
- Recycling (remelting) possible though frequent remelting is avoided in industry due to probable chemical degradation
- The manufacturing processes used for thermoplastics (such as blow moulding and injection moulding) are less expensive compared to those used of thermosetting plastics



Thermoplastic
B: Branch



Thermosettings
□: Crosslinking point

Biomedical Polyurethane-Based Materials, August 2012
In book: Polyurethane: Properties, Structure and ApplicationsPublisher: Nova Publishers, New York

Thermosetting

- Cannot be melted once they are solidified
- They degrade rather than soften when exposed to high temperature
- They burn and char when heated
- 3D network molecules
- Could not be recycled (until recently)
- Resins (raw materials used) are mixed and placed in the mould, heated and compressed
- Polymerisation by strong network bonds (cross-linking) with the help of heat, pressure and/or time
- Cross-links between neighbouring polymer molecules limit chain movement.
- Manufacturing processes used for thermosetting polymers are relatively expensive

Additives in plastics

To impart **colour, moldability, improved properties, cost reduction**

Additives: fillers, plasticizers, lubricants, coloring agents, stabilizers, antioxidants, and flame retardants

Fillers – enhance mechanical properties, reduce shrinkage, reduce weight

Plasticizer – increase flexibility and flowability

Lubricant – improve moldability and extraction from mould

Coloring agent – impart colour

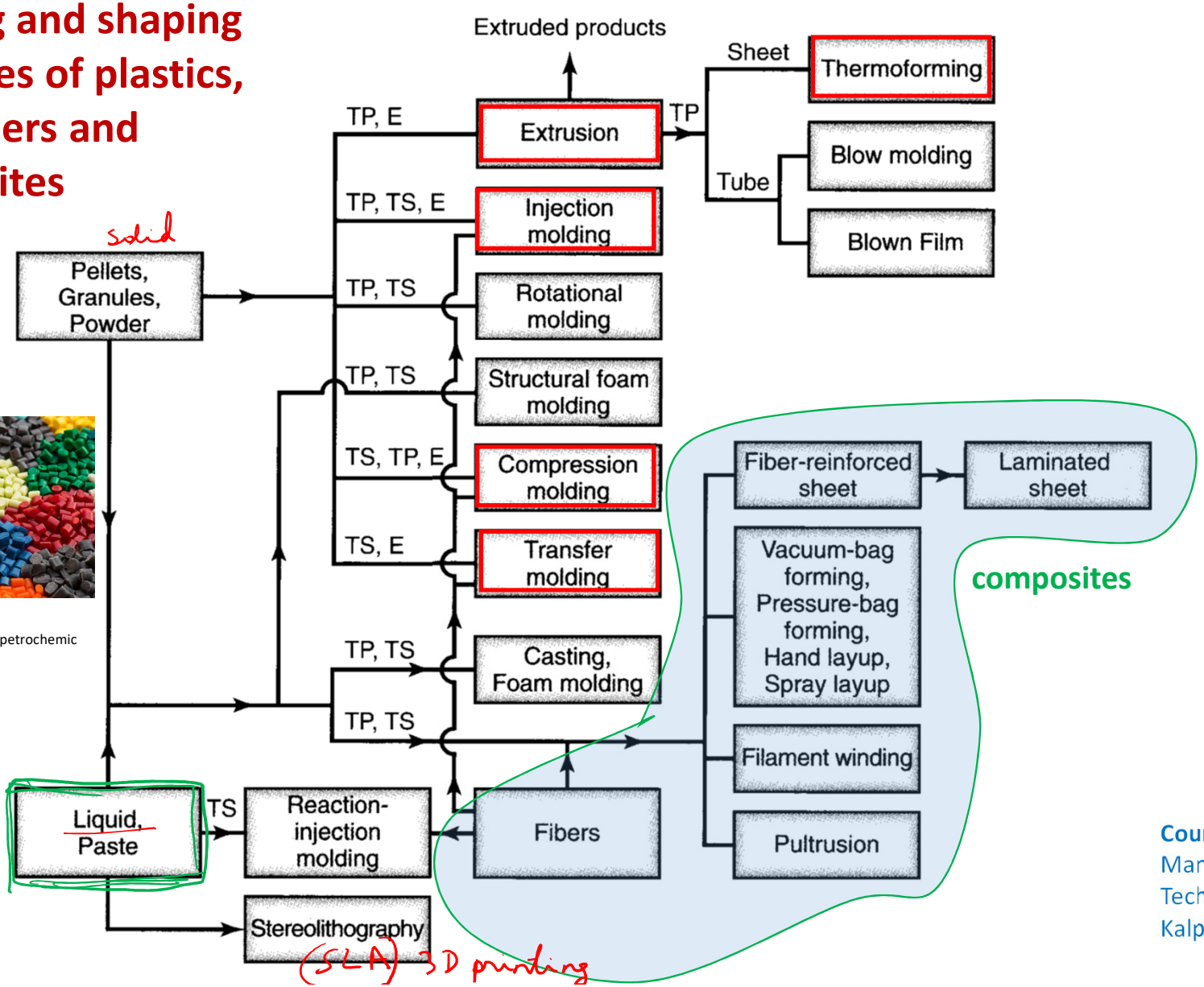
Stabilizers – retard degradation due to light or heat

Antioxidants – retard degradation due to oxidation

Flame retardants – reduce flammability

Forming and shaping processes of plastics, elastomers and composites

https://www.statec-binder.com/en/industries/petrochemical



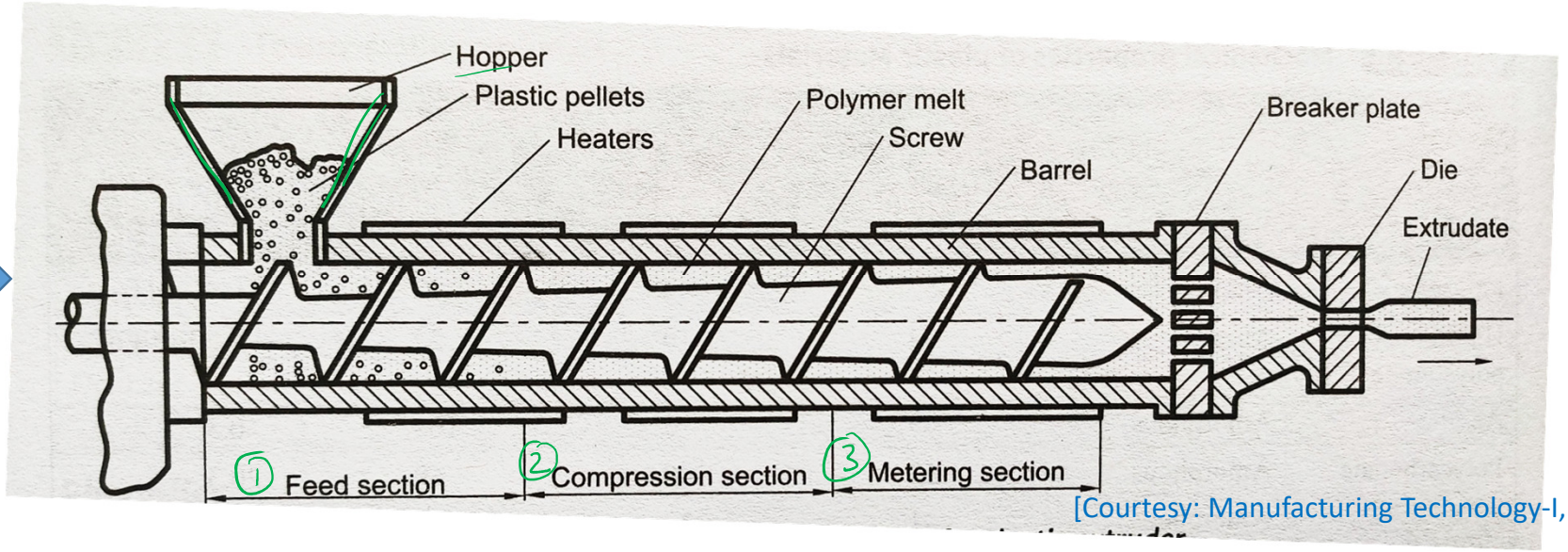
TP: thermoplastic
TS: Thermoset
E: Elastomer

Red-highlighted processes will be discussed

Courtesy:
Manufacturing Engineering and Technology,
Kalpakjian and Schmid

Extrusion of Plastics

Plastic extruder



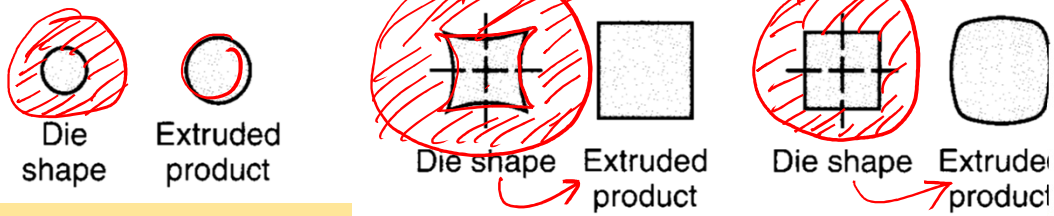
[Courtesy: Manufacturing Technology-I, P N Rao]

- Can be used for **most thermoplastics**, e.g., polyethylene, polypropylene, polyurethane, polystyrene, polyamide, polyester, flexible polyvinyl chloride
- Extruded plastics generally have a **higher melt viscosity** (compared to injection-moulded plastics) that allows the plastic to retain the shape created by the die while the material is in cooling stages
- Plastic in the form of pellets or granules is fed into the **plastic extruder** through a hopper
- The pellets move to barrel, which is heated using electric heaters, and then moved towards the die using the screw rotation
- Electrical heating along with the mechanical work and friction of screw movement heat up the plastic to soften the pellets

Extrusion of Plastics

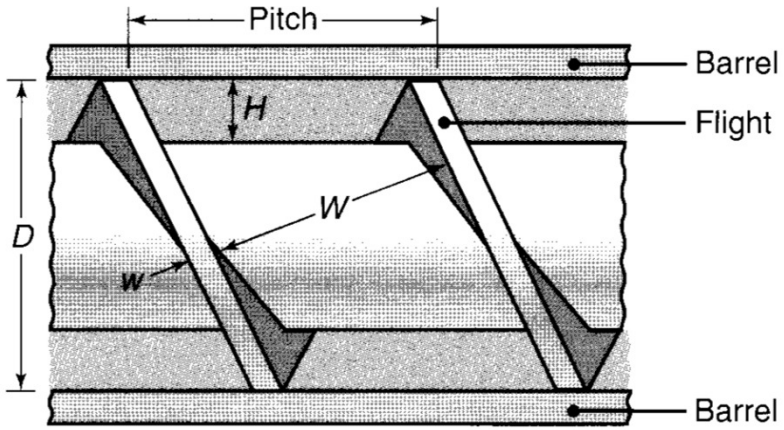
Courtesy:
Manufacturing Engineering and Technology, Kalpakjian and Schmid

- Three different sections of rotating screw:
  - **Feed section**: pellets moved from hopper and preheated
  - **Compression section**: plastic softened to flow smoothly like liquid
  - **Metering section**: the plastic is homogenised and sufficient pressure is developed so that it is forced through the die
- Breaker plate with small holes improves the mixing of the plastic before it enters the die
- The extrudate (extruded material) is cooled using air or water



Round die for producing rod

Non-uniform recovery of the part after it exits the die



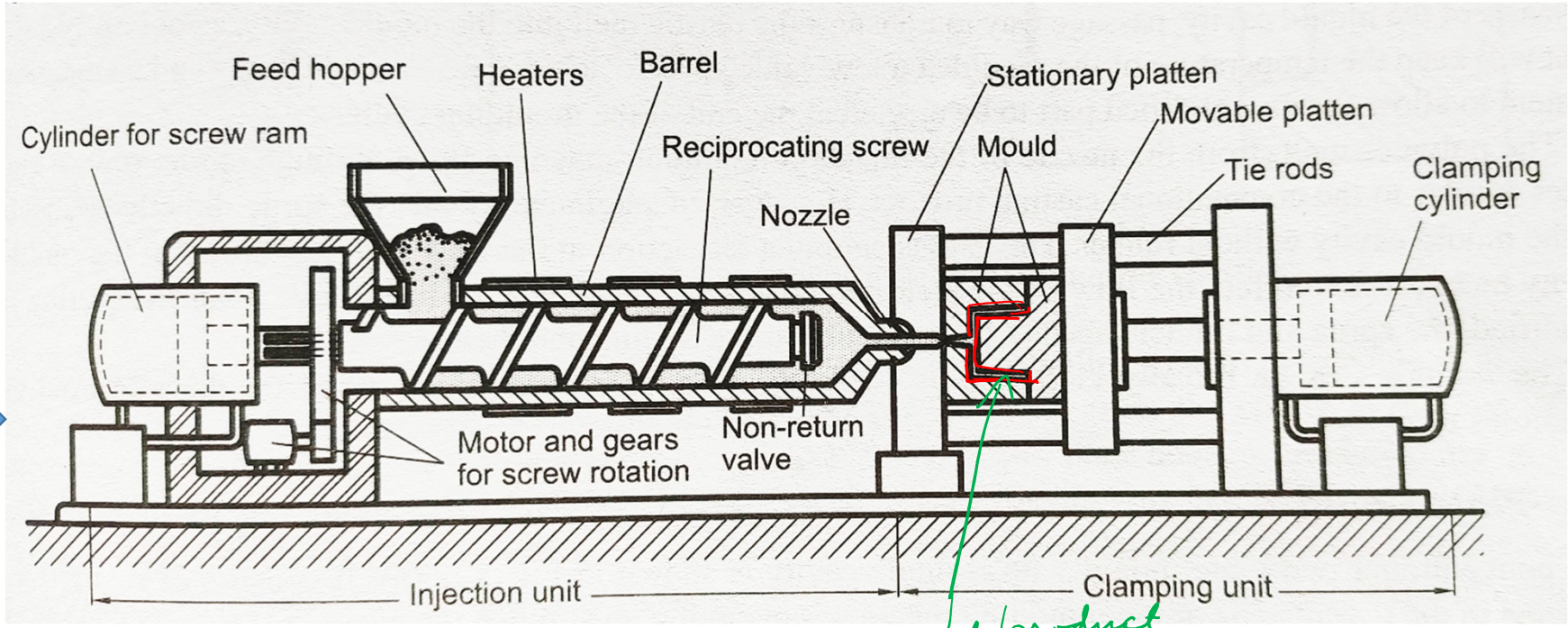
Geometry of an extruder screw

Advantages of extrusion:

- Equipment is simple and relatively inexpensive
- Complex cross-section can be extruded
- Relatively low tooling cost
- Overall cost of parts produced is low

Injection Moulding

Injection moulding machine



[Courtesy: Manufacturing Technology-I, P N Rao]

- Most widely used plastic manufacturing process
- Similar to pressure die casting of metal but plastic melts have high viscosity and require high pressure to flow
- The plastic is made highly softened and forced to flow under high pressure through a nozzle to the mould cavity
- The plastic solidifies in the die and the produced part is removed by opening the die
- Reciprocating and rotating screw that pressurized the soften plastic

Injection Moulding

- Machine has two parts: (1) injection unit and (2) clamping unit

Injection unit

- It is similar to extruder machine; the screw soften the plastic and pressurize the melt
- Plastic granules or pellets are fed to the barrel through the hopper
- At the end of the barrel, the screw acts like a ram and pushes the softened plastic through the nozzle
- After the injection, the screw returns to the original position

Clamping unit

- It holds the two halves of the mould securely during injection process
- It opens the mould after cooling and ejects the product from the mould

Injection Moulding

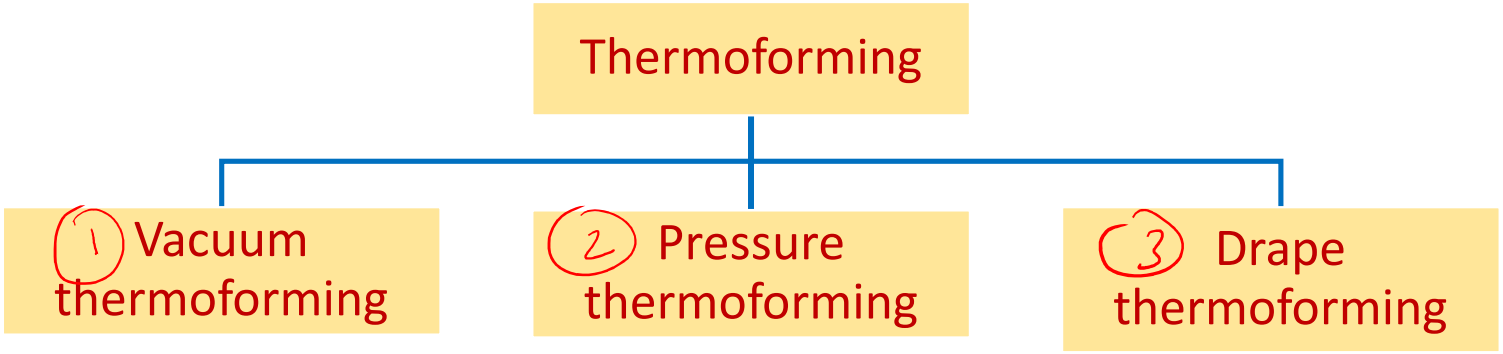
Advantages of injection moulding:

- The shape of the component is almost in final form
- Extremely fast rate (typical cycle time is 10 to 30 seconds)
- Very complex shapes can be made
- Wide range of product sizes (e.g., 50g to 25kg) with excellent control of tolerances
- Most polymers can be injection-moulded: thermoplastics, thermosetting plastics, elastomers and fibre-reinforced thermoplastics

composites

Thermoforming

- Thermoplastic sheets can be formed into 3D shape by application of heat and differential pressures
- **Step 1:** the sheet is clamped to a frame and uniformly heated to produce a soft and flowable material
- **Step 2:** differential pressure (either vacuum or pressure, or both) is applied to impart the required shape
- Used for making parts for covers, displays, trays, drinking cups, food packaging
- Different thermoforming processes

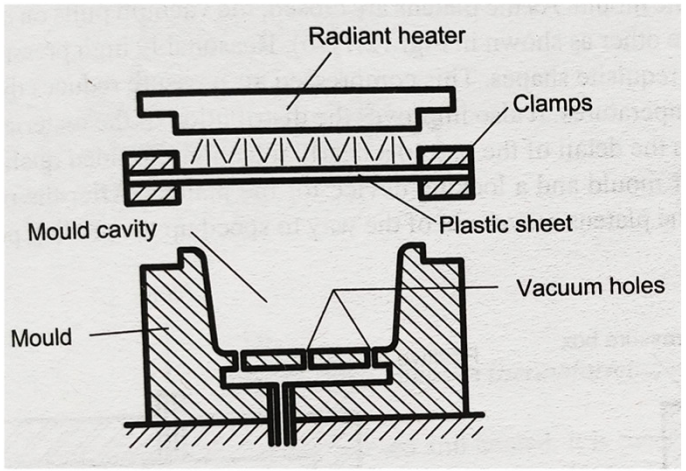


Advantages of thermoforming:

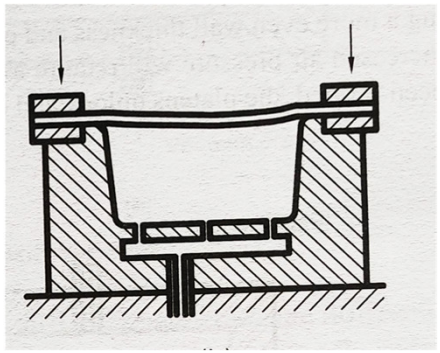
- Most thermoplastics can be processed
- Tooling cost are low; tooling material is machined aluminium and even wood
- Relatively simple process

① Vacuum Thermoforming

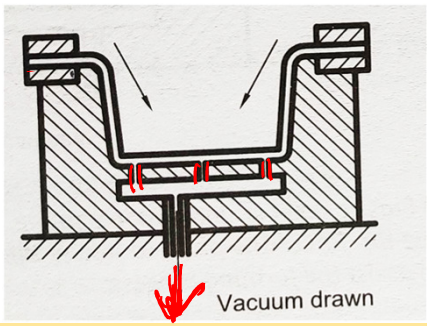
- Thermoplastic sheets can be formed into 3D shapes by application of **heat and vacuum**
- During the process, the plastic sheet is heated, then attached over the mould and then drawn by vacuum
- Integrated water cooling system brings down the temperature
- Once the **curing temperature** reached, the **air flows** back to the mould and separates the new part from the mould



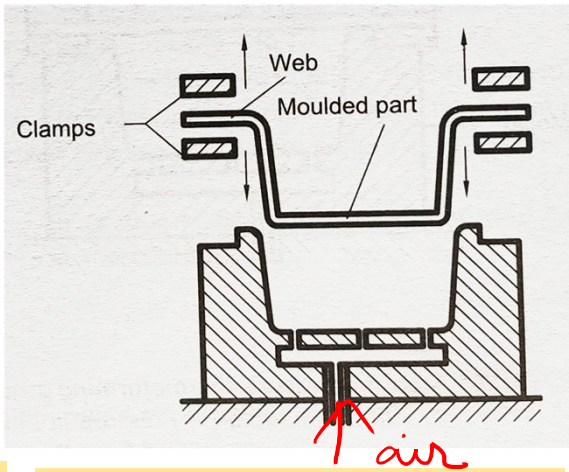
Step 1: Plastic sheet is clamped and heated



Step 2: Heated sheet is attached to the mould



Step 3: Vacuum applied to draw the sheet to conform the shape of the mould

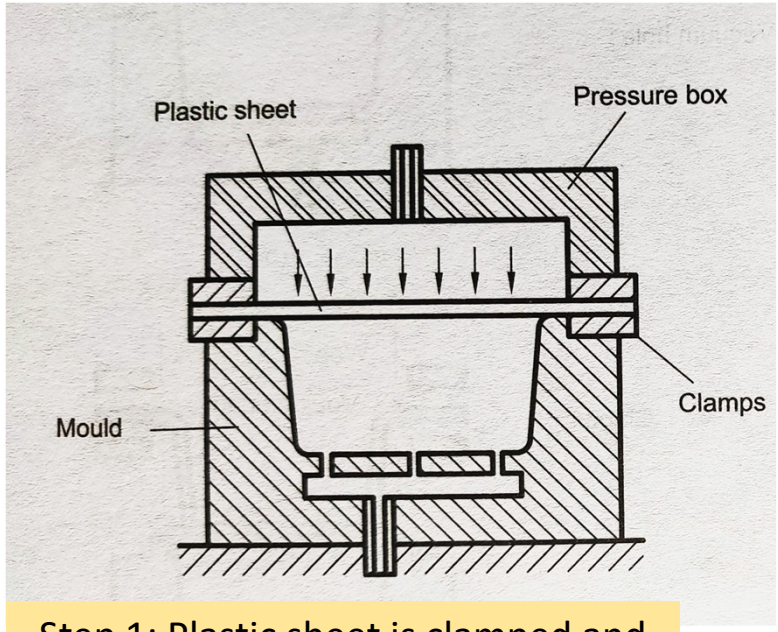


Step 4: Moulded part is released

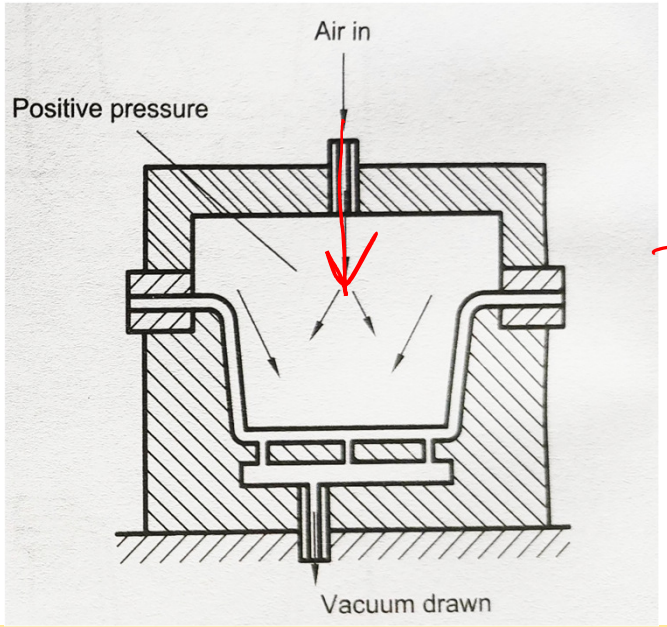
[Courtesy: Manufacturing Technology-I, P N Rao]

② Pressure Thermoforming

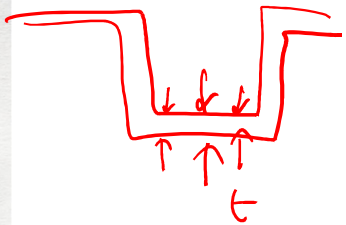
- It utilizes **both pressure and vacuum**, hence better than vacuum thermoforming
- Compressed air pressure reduces cycle time and temperature requirement
- Improves distribution of material and more even wall thickness (t)
- Can create parts with greater details, textured surfaces, undercuts and sharp corners (compared to vacuum thermoforming)



Step 1: Plastic sheet is clamped and attached to the mould and heated



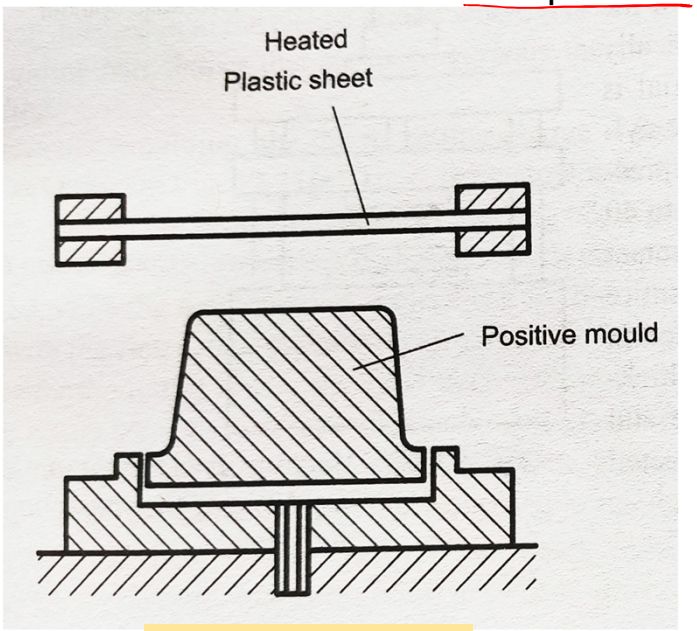
Step 2: Pressure applied from top of the sheet to conform the mould shape (vacuum assists the process)



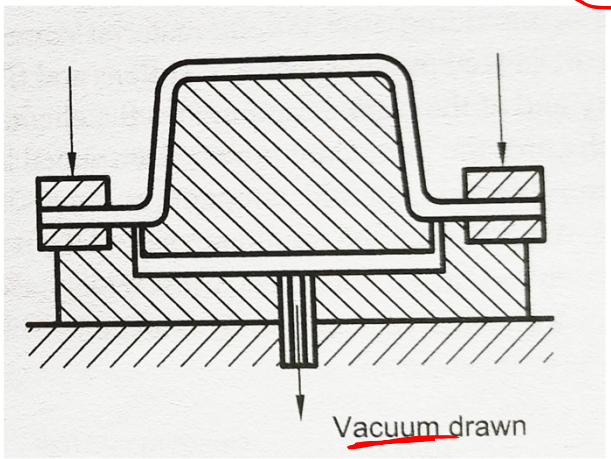
[Courtesy: Manufacturing Technology-I, P N Rao]

3 Drape Thermoforming

- Vacuum and pressure thermoforming use negative moulds but this technique uses **positive moulds**
- In negative moulds, the exterior surfaces will only have the exact details and forcing the material to follow the contours is more difficult
- In this process, the sheet is clamped, **heated** and **mechanically stretched**
- A pressure differential is applied to form the sheet over a positive mould
- Positive moulds are easier to build and cheaper but they can be easily damaged
- Drape forming can **also** be used **only with gravitational force**
- It is somewhat similar to deep drawing process of sheet metal



Step 1



Step 2

[Courtesy: Manufacturing Technology-I, P N Rao]

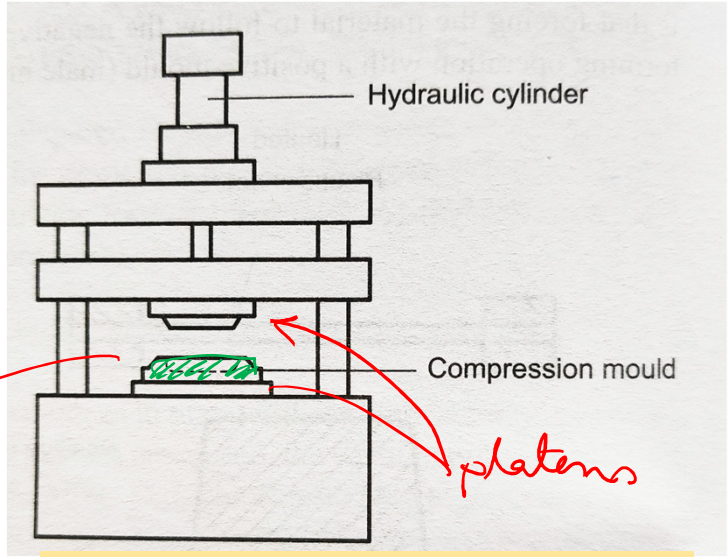
Processing of Thermosetting Plastics

- Thermosetting plastics cannot be remelted once polymerisation occurs
- Hence, **resin** compounds of thermosetting materials required to be formed before polymerisation
- Thus, mould used should provide the conditions for **polymerisation within the moulding machine**
- Generally, temperature and pressure are the variables permitted to vary during the polymerisation
- **Compression moulding** and **transfer moulding** are two manufacturing processes widely used for thermosetting plastics

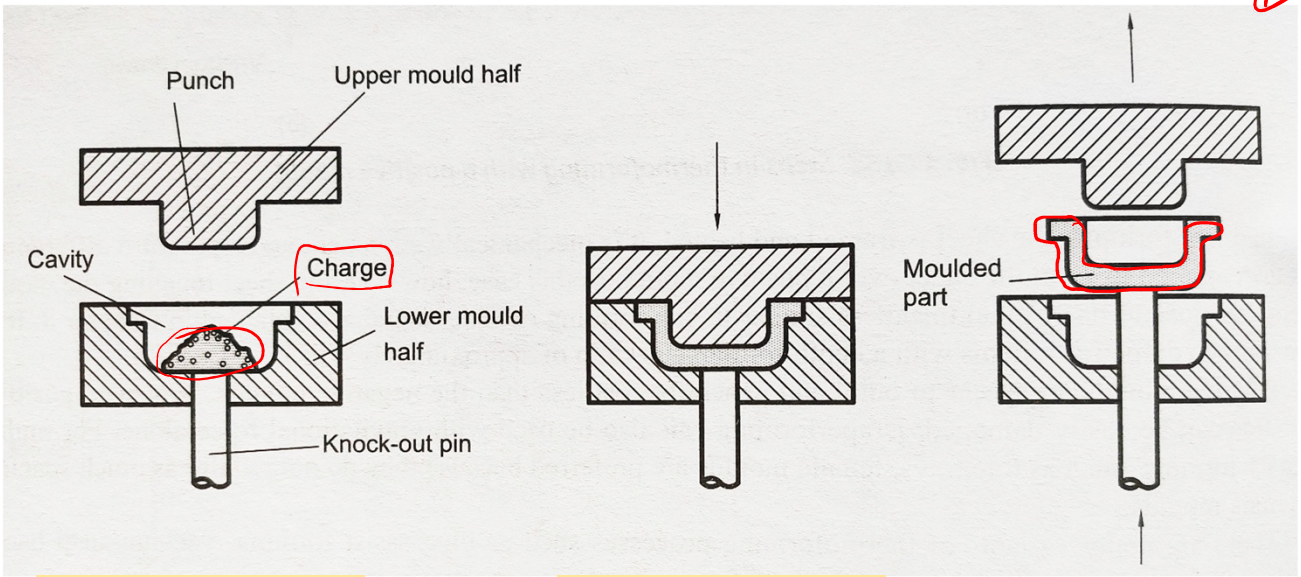
Curing: a chemical process that hardens the polymer material by cross-linking polymer chains. Although it is basically referred in the case of thermosetting polymers, the term is used for any solid polymer produced from liquid solution.

Compression Moulding

- Oldest plastic processing technique
- Compression **mould** is made of **two halves** connected to the **platens** of the press
- As the material touches the electrically heated mould surface, it softens and fills the entire cavity
- At the same time, **chemical reaction** starts and **cures** the part
- After curing, the mould opens and the produced part is ejected
- Most widely compression-moulded plastic is bakelite



Compression moulding machine



Step 1 | Step 2 | Step 3

Charge: preheated moulding material

(thermosetting plastic)

[Courtesy: Manufacturing Technology-I, P N Rao]

Compression Moulding

Advantages of compression moulding:

- Simple and relatively low tool cost
- Most of the material is moulded with little waste
- High stability and dimensional accuracy
- Required moulding pressure is low; hence, large parts can be manufactured with smaller presses
- Good for large parts
- Shrinkage is minimized

Limitations of compression moulding:

- The depth (h) of produced part is limited
- Mould design is tougher for complex geometry mould design
- The amount of the charge is strictly controlled

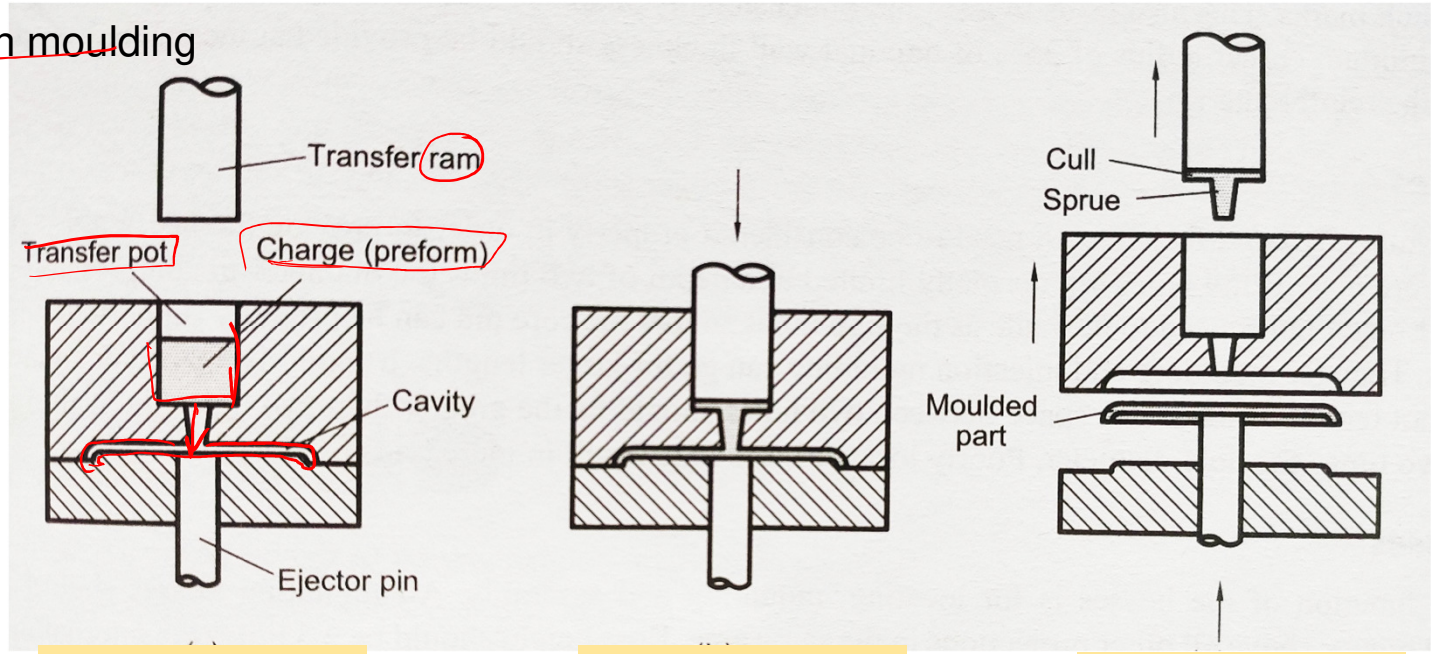
[Courtesy: Manufacturing Technology-I, P N Rao]

Transfer Moulding

- Similar to compression moulding but developed to **avoid limitations of compression moulding**
- In transfer moulding, the thermosetting charge is **heated** and **compressed** in a **separate chamber** and then injected into the closed mould to cool and solidify
- **Advantages**
- Transfer moulding can create parts more intricate than compression moulding but not as intricate as injection moulding
- Curing time is less than compression moulding
- Time taken for injection is less as the mould is closed before injection

Disadvantages

- Sprue and cull (left-over with ram) cannot be recycled
- Higher moulding pressure required compared to compression moulding



[Courtesy: Manufacturing Technology-I, P N Rao]

Thank you