Outline

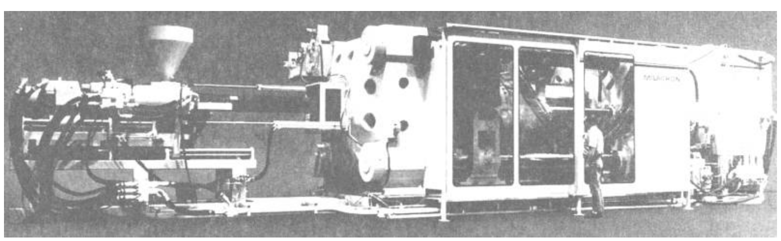
- *Injection molding*
- *Injection molding of thermosets*
- *Shrinkage*
- *Polymer foam*
- *Compression molding*
- *Transfer molding*

Injection Molding

- Polymer is heated to a highly plastic state and forced to flow under high pressure into a mold cavity where it solidifies; molded part is then removed from cavity
- Produces discrete components almost always to net shape
- Typical cycle time ~10 to 30 sec., but cycles of one minute or more are not uncommon
- Mold may contain multiple cavities, so multiple moldings are produced each cycle
- Complex and intricate shapes are possible
- Shape limitations:
  - *Capability to fabricate a mold whose cavity is the same as part*
  - *Shape must allow for part removal from mold*
- Part size from ~ 50 g up to ~ 25 kg, e.g., automobile bumpers
- Injection molding is economical only for large production quantities due to high cost of mold

Polymers for Injection Molding

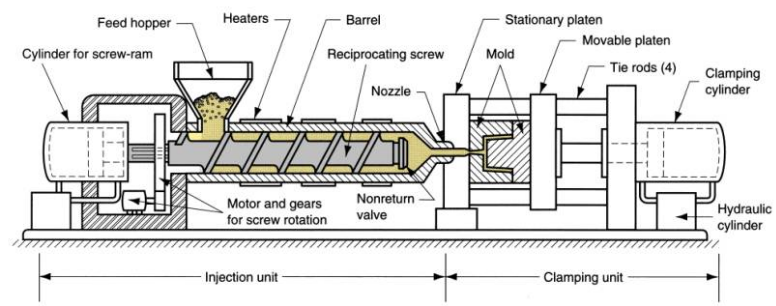
- Injection molding is the most widely used molding process for *thermoplastics*
- Some *thermosets* and *elastomers* are injection molded
  - Modifications in equipment and operating parameters must be made to avoid premature cross-linking of these materials



Two principal components:

- *Injection unit* – melts and delivers polymer melt, operates much like an extruder
- *Clamping unit* – opens and closes mold each injection cycle

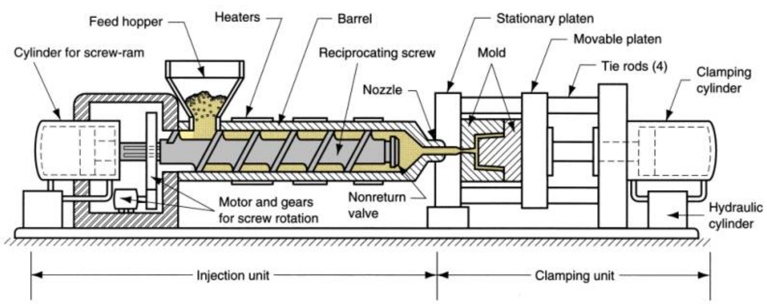
Injection Unit of Molding Machine



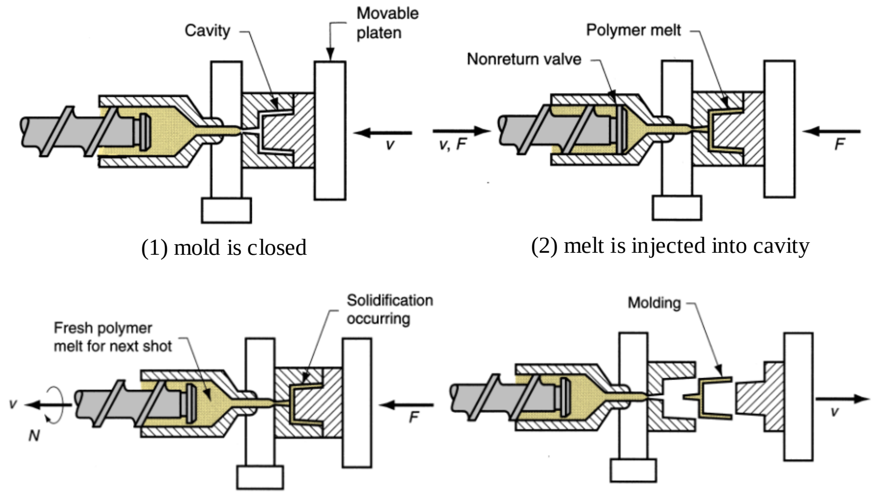
- Consists of *barrel* fed from one end by a hopper containing supply of plastic pellets
- Inside the barrel is a *screw* which has two functions:
  1. Rotates for mixing and heating the polymer
  2. Acts as a ram to inject molten plastic into mold
  - *Non-return valve near tip of screw prevents melt flowing backward along screw threads*
  - *Later in molding cycle ram retracts to its former position*

Clamping Unit of Molding Machine

- Functions:
  1. Holds two halves of mold in proper alignment with each other
  2. Keeps mold closed during injection by applying a clamping force sufficient to resist injection force
  3. Opens and closes the mold at the appropriate times in molding cycle



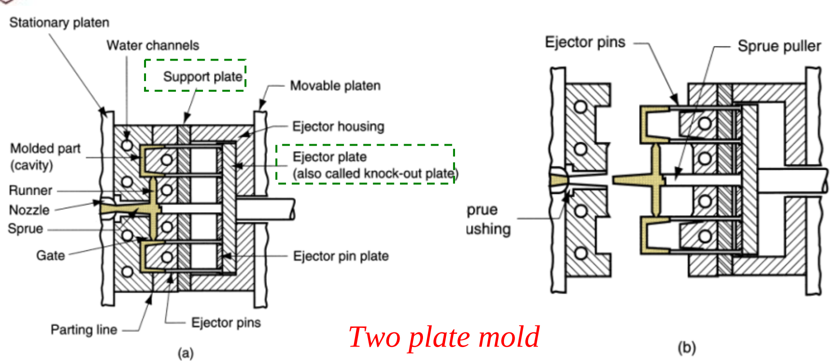
Typical molding cycle



(1) mold is closed (2) melt is injected into cavity

(3) screw is retracted (4) mold opens and part is ejected

The Mold



Two plate mold

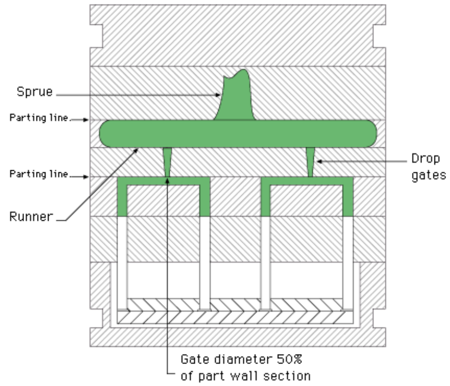
- The special tool in injection molding
- Custom-designed and fabricated for the part to be produced
- When production run is finished, the mold is replaced with a new mold for the next part
- Various types of mold for injection molding:
  – Two-plate mold - Three-plate mold - Hot-runner mold

Two-Plate Mold Features

- *Cavity* – has geometry of part but slightly oversized to allow for shrinkage
  – Created by machining of the mating surfaces of two mold halves
- *Distribution channel* through which polymer melt flows from nozzle into mold cavity
  - Sprue - *leads from nozzle into mold*
  - Runners - *lead from sprue to cavity (or cavities)*
  - Gates - *constrict flow of plastic into cavity*
- *Ejection system* – function is to eject molded part from cavity at end of molding cycle
  – *Ejector pins* built into moving half of mold
- *Cooling system* - consists of external pump connected to passageways in mold, through which water is circulated to remove heat from hot plastic
- *Air vents* – to permit evacuation of air from cavity

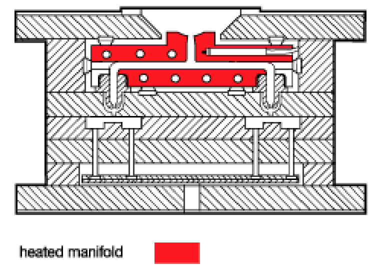
Three-Plate Mold

- Uses three plates **to separate parts from sprue and runner when mold opens**
- Advantages over two-plate mold:
  - Allows automatic operation of molding machine
    - *As mold opens, runner and parts disconnect & drop by gravity into two containers under mold*
  - Flow of molten plastic is through a gate at the base of part rather than side, allowing more even distribution of plastic melt into sides of cup



Hot-Runner Mold

- Eliminates solidification of sprue and runner by locating heaters around the corresponding runner channels
- While plastic in mold cavity solidifies, material in sprue and runner channels remains molten, ready to be injected into cavity in next cycle
  - *This saves material that otherwise would be scrap*



Shrinkage

- Reduction in linear size during cooling to room temperature
- Polymers have high thermal expansion coefficients, so significant shrinkage occurs during cooling in mold
- Typical shrinkage values for selected polymers:

Plastic	Shrinkage, mm/mm (in/in)
Nylon-6,6	0.020
Polyethylene	0.025
Polystyrene	0.004
PVC	0.005

Compensation for Shrinkage

- Dimensions of mold cavity must be larger than part dimensions:

$$D_c = D_p + D_p S + D_p S^2$$

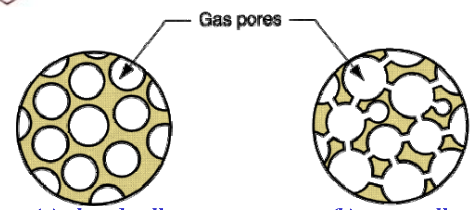
where D_c = dimension of cavity; D_p = molded part dimension, and S = shrinkage value

- *Third term on right hand side corrects for shrinkage in the shrinkage*

Shrinkage Factors

- *Fillers* in the plastic tend to reduce shrinkage
- *Injection pressure* – as pressure is increased, forcing more material into mold cavity, shrinkage is reduced
- *Compaction time* - similar effect - forces more material into cavity during shrinkage
- *Molding temperature* - higher temperatures lower polymer melt viscosity, allowing more material to be packed into mold and reducing shrinkage

Polymer Foam



(a) closed cell *(b) open cell*

- Low density
- High strength per unit weight
- Good thermal insulation
- Good energy absorbing qualities

- A polymer-and-gas mixture that gives the material a porous or cellular structure
- Most common polymer foams: polystyrene (Styrofoam), polyurethane
- Other polymers: natural rubber ("foamed rubber") and polyvinylchloride (PVC)

Classification of Polymer Foams:

- *Elastomeric* - matrix polymer is a rubber, capable of large elastic deformation
- *Flexible* - matrix is a highly plasticized polymer such as soft PVC
- *Rigid* - polymer is a stiff thermoplastic such as polystyrene or a thermoset such as a phenolic
- Depending on **chemical formulation** and **degree of cross-linking**, polyurethanes can range over all three categories

Extrusion of Polystyrene Foams

- Polystyrene is a thermoplastic polymer
- A physical or chemical blowing agent is fed into polymer melt near die end of extruder barrel; thus, extrudate consists of expanded polymer
- Products: large sheets and boards that are subsequently cut to size for heat insulation panels and sections

Molding Processes for Polystyrene Foams

- *Expandable foam molding* - molding material usually consists of prefoamed polystyrene beads
- Prefoamed beads are fed into mold cavity where they are further expanded and fused together to form molded product
- Products: *hot beverage cups* of polystyrene foam are produced in this way

Thermoplastic Foam Injection Molding

- Molding of thermoplastic parts that possess dense outer skin surrounding lightweight foam center
- Part has high stiffness-to-weight ratio suited to structural applications
- Produced either by *introducing a gas into molten plastic* in injection unit or by *mixing a gas-producing ingredient* with starting pellets
- During injection, a small amount of melt is forced into mold cavity, where it expands to fill cavity
- Foam in contact with cold mold surface collapses to form dense skin, while core retains cellular structure

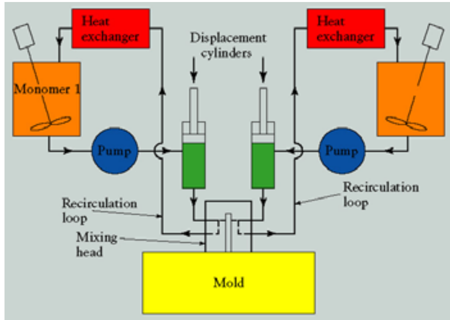
Injection Molding of Thermosets

- Equipment and operating procedure must be modified to avoid premature cross-linking of TS polymer
  - *Reciprocating-screw injection unit with shorter barrel length*
- Temperatures in barrel are relatively low

- Melt is injected into a heated mold, where cross-linking occurs to harden plastic
- Mold is then opened and part is removed
- Curing is the most time-consuming step in the cycle

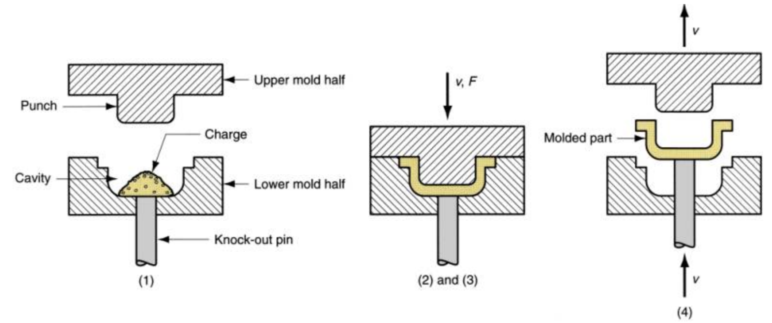
Reaction Injection Molding

Two highly reactive liquid ingredients **are mixed and immediately injected** into a mold cavity where chemical reactions leading to solidification occur



- RIM was developed with polyurethane to produce large automotive parts such as bumpers and fenders
  - *RIM polyurethane parts possess a foam internal structure surrounded by a dense outer skin*
- Other materials used in RIM: epoxies, and urea-formaldehyde

Compression Molding



- An old and widely used molding process for thermosetting plastics
- Applications also include rubber tires and polymer matrix composite parts
- Molding compound available in several forms: powders or pellets, liquid, or preform
- Amount of *charge* must be precisely controlled to obtain repeatable consistency in the molded product

Molds for Compression Molding

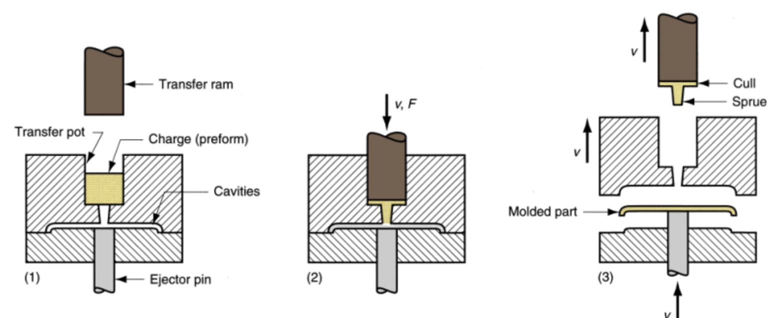
- Simpler than injection molds
- **No sprue** and **runner** system in a compression mold
- Process itself generally limited to simpler part geometries due to lower flow capabilities of TS materials
- Mold must be heated, usually by electric resistance, steam, or hot oil circulation

Materials and Products in Compression Molding

- Materials: phenolics, melamine, urea-formaldehyde, epoxies, urethanes, and elastomers
- Typical TS moldings: electric plugs, sockets, and housings; pot handles, and dinnerware plates

Transfer Molding

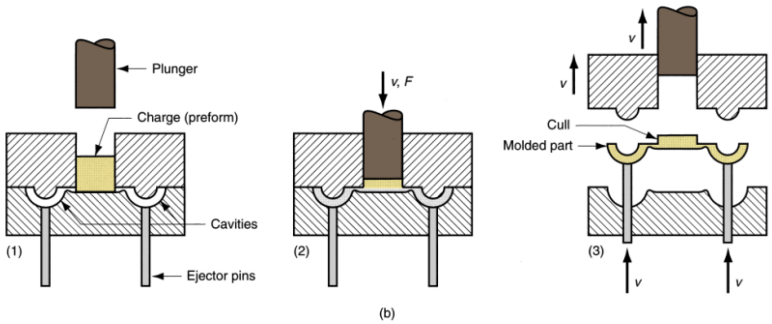
- TS charge is loaded into a chamber immediately ahead of mold cavity, where it is heated; pressure is then applied to force soft polymer to flow into heated mold where it cures
- Two variants:
  - *Pot transfer molding* - charge is injected from a "pot" through a vertical sprue channel into cavity



Pot transfer molding

Transfer Molding

– *Plunger transfer molding* – plunger injects charge from a heated well through channels into cavity



Plunger transfer molding

Compression and Transfer Molding Compared

- In both processes, scrap is produced each cycle as leftover material, called the *cull*
- The TS scrap cannot be recycled
- Transfer molding is capable of molding more intricate part shapes than compression molding but not as intricate as injection molding
- Transfer molding lends itself to molding with inserts, in which a metal or ceramic insert is placed into cavity prior to injection, and the plastic bonds to insert during molding

Next time:

Blow Molding and Thermoforming