1. Injection Molding (Thermoplastics)

General
Designation
Molding: Injection (thermoplastics)

The process
INJECTION MOLDING of thermoplastics is the equivalent of pressure die casting of metals. Molten polymer is injected under high pressure into a cold steel mold. The polymer solidifies under pressure and the molding is then ejected.

Various types of injection molding machines exist, but the most common in use today is the reciprocating screw machine (shown schematically). Capital and tooling costs are very high.

Production rate can be high particularly for small moldings. Multicavity molds are often used. The process is used almost exclusively for large volume production.

Prototype moldings can be made using cheaper single cavity molds of cheaper materials. Quality can be high but may be traded off against production rate. Process may also be used with thermosets and rubbers.

Some modifications are required - this is dealt with separately (see Injection Molding - thermosets).

Complex shapes are possible, though some features (e.g. undercuts, screw threads, inserts) may result in increased tooling costs.

STRETCH BLOW MOLDING (SBM) is an important variant of the extrusion and injection blow molding processes. It is most commonly used as injection stretch blow molding for the production of oriented PET drinks bottles.

In injection SBM a preform is injection molded (as for injection blow molding). This is then transferred hot to the blow mold where it is stretched longitudinally by plunger before being blow radially.

The biaxial stretching significantly improves the mechanical properties (strength and toughness) of the finished part. In extrusion SBM the cut parison is mechanically stretched longitudinally before being blown.

Capital and tooling costs are very high as is production rate. Hence process is used exclusively for high volume production.

Process schematic
Physical Attributes
Adjacent section ratio 1 - 2
Aspect ratio 1 - 250
Mass range 0.02205 - 55.12 lb
Minimum hole diameter 0.02362 in
Minimum corner radius 0.05906 in
Range of section thickness 0.01575 - 0.248 in
Roughness 7.874e-3 - 0.06299 mil
Quality factor (1-10) 1 - 6
Tolerance 3.937e-3 - 0.03937 in

Economic Attributes
Economic batch size (mass) 1.102e4 - 1.102e6 lb
Economic batch size (units) 1e4 - 1e6

Cost Modelling
Relative cost index (per unit) 18.16 - 113.3
Parameters: Material Cost = 4.309USD/lb, Component Mass = 2.205lb, Batch Size = 1000, Overhead Rate = 110USD/hr, Capital
Write-off Time = 5yrs, Load Factor = 0.5
Capital cost 3.77e4 - 8.483e5 USD
Lead time 4 - 6 week(s)
Material utilization fraction 0.6 - 0.9
Production rate (mass) 66.14 - 2205 lb/hr
Production rate (units) 60 - 3000 /hr
Tool life (mass) 1.102e4 - 1.102e6 lb
Tool life (units) 1e4 - 1e6
Tooling cost 3770 - 9.426e4 USD

Process Characteristics
Primary True
Secondary False
Tertiary False
Prototyping False
Discrete True
Continuous False

Supporting Information
Design guidelines
Complex shapes are possible. Thick sections or large changes in section are not recommended. Small reentrant angles are possible.

Technical notes
Most thermoplastics can be injection molded. Some high melting point polymers (e.g. PTFE) are not suitable. Thermoplastic based composites (short fiber and particulate filled) are also processed. Injection-molded parts are generally thin-walled.

Typical uses
Extremely varied. Housings, containers, covers, knobs, tool handles, plumbing fittings, lenses, etc.

The economics
Tooling cost range covers small, simple to large, complex molds. Production rate depends on complexity of component and number of mold cavities.

The environment
Thermoplastic sprues can be recycled. Extraction may be required for volatile fumes. Significant dust exposures may occur in the formulation of the resins. Thermostatic controller malfunctions can be extremely hazardous.

Shape
Circular prismatic True
Non-circular prismatic True
Solid 3-D True
Hollow 3-D True
2. Polymer Extrusion

General

Designation
Molding: Polymer Extrusion

The process
In POLYMER EXTRUSION, polymer in powder or granule/pellet form is processed by a rotating screw through a heating chamber and the resulting melt is forced through a shaped die orifice. The extrudate is cooled as it leaves the die. The extrudate is then 'drawn down' to a smaller cross-section. Variations of the process include film blowing, extrusion blow molding and filament forming. The process is used to coat wire, which can be achieved at very high speeds. Extrusion is also used as a preprocess to many of the molding processes such as injection molding. The process has the advantage of relatively low tooling costs, though capital costs are high and the output usually requires further processing, varying from simply cutting to size to remelting and injection molding. Die design is complicated by 'die swell', hence tolerances are not as tight as for the pressure molding processes.

Process schematic

Physical Attributes
Adjacent section ratio  1 - 1.5
Aspect ratio  1 - 1000
Mass range  22.05 - 2205 lb
Minimum corner radius  9.843e-3 in
Range of section thickness  4.921e-3 - 0.2461 in
Roughness  0.01969 - 0.06299 mil
Quality factor (1-10)  1 - 9
Tolerance  0.01969 - 0.03937 in

Economic Attributes
Economic batch size (length)  39.37 - 3.937e7 in
Economic batch size (mass)  440.9 - 1.102e5 lb
### Cost Modelling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative cost index (per unit)</td>
<td>49.53 - 1807</td>
</tr>
<tr>
<td>Parameters: Material Cost = 4.309USD/lb, Component Mass = 2.205lb, Batch Size = 1000, Component Length = 32.81ft, Overhead Rate = 110USD/hr, Capital Write-off Time = 5yrs, Load Factor = 0.5</td>
<td></td>
</tr>
<tr>
<td>Capital cost</td>
<td>9.426e4 - 7.54e5 USD</td>
</tr>
<tr>
<td>Lead time</td>
<td>2 - 4 week(s)</td>
</tr>
<tr>
<td>Material utilization fraction</td>
<td>0.9 - 0.99</td>
</tr>
<tr>
<td>Production rate (length)</td>
<td>0.03937 - 2.559 in/s</td>
</tr>
<tr>
<td>Production rate (mass)</td>
<td>11.02 - 440.9 lb/hr</td>
</tr>
<tr>
<td>Tool life (length)</td>
<td>3937 - 3.937e5 in</td>
</tr>
<tr>
<td>Tool life (mass)</td>
<td>2.205e4 - 2.205e6 lb</td>
</tr>
<tr>
<td>Tooling cost</td>
<td>942.6 - 4713 USD</td>
</tr>
</tbody>
</table>

### Process Characteristics

- Primary: True
- Secondary: False
- Tertiary: False
- Prototyping: False
- Discrete: False
- Continuous: True

### Supporting Information

**Design guidelines**

Limited to uniform prismatic shapes (constant cross-section). Fairly complex cross-sections are possible including hollow shapes.

**Technical notes**

Most polymers including particulate and short fiber filled thermoplastic composites. Most commonly used for thermoplastics but also used for thermosets, elastomers and foams with suitable modifications to the process.

**Typical uses**

Rods, channels, pipes, tubes, window frames, plastic coated wire, seals, edge guards, filaments, film (film blowing process), sheet stock, pellet stock (e.g. for IM).

**The economics**

Tooling cost range covers small, simple to large, complex dies.

**The environment**

Dust exposure in resin formulation. Thermostatic controller malfunctions can be extremely hazardous.

**Shape**

- Circular prismatic: True
- Non-circular prismatic: True
3. Thermoforming

General
Designation
Molding: Thermoforming

The process
THERMOFORMING involves the heating of a thermoplastic sheet to its softening point followed by forcing it against the contours of a mold and then cooling.
Various thermoforming processes are used including vacuum forming, pressure forming, plug-assisted forming and drape forming. All of the processes rely on a pressure differential to force the sheet against the mold. Female or male molds may be used.
The process is capable of handling a very large range of sizes from items such as disposable drinks cups to boat hulls. Similarly, the process is capable of a wide range of production capabilities from low to very high volume.
The process has the following advantages: low tooling costs (low pressures and one mold half only), low capital costs, high production rates (automated machinery), and, in addition, it can use predecorated sheet stock.
The process gives good physical properties and quality (thinning can occur at corners). The disadvantages include: raw material is more expensive (sheet rather than pellet), sheet trimming required, and sheet scrap cannot be recycled directly.
Also, the process can be labor intensive.

Process schematic

Physical Attributes
Adjacent section ratio  1 - 1.1
Aspect ratio  1 - 1000
Mass range  6.614e-3 - 22.05 lb
Minimum corner radius  3.937e-3 in
Range of section thickness  9.843e-3 - 0.2362 in
Roughness  0.01181 - 0.06299 mil
Quality factor (1-10)  1 - 4
Economic Attributes

Tolerance 0.01969 - 0.03937 in
Economic batch size (mass) 4.409 - 440.9 lb
Economic batch size (units) 10 - 1000

Cost Modelling

Relative cost index (per unit) 14.88 - 35.49
Parameters: Material Cost = 4.309USD/lb, Component Mass = 2.205lb, Batch Size = 1000, Overhead Rate = 110USD/hr, Capital Write-off Time = 5yrs, Load Factor = 0.5
Capital cost 9426 - 9.426e4 USD
Lead time 1 - 2 week(s)
Material utilization fraction 0.5 - 0.9
Production rate (mass) 22.05 - 2205 lb/hr
Production rate (units) 6 - 1e4 /hr
Tool life (mass) 4409 - 4.409e5 lb
Tool life (units) 1e4 - 1e6
Tooling cost 94.26 - 1885 USD

Process Characteristics

Primary True
Secondary False
Tertiary False
Prototyping False
Discrete True
Continuous False

Supporting Information

Design guidelines
Shape capability limited to simple shapes of constant cross-section. Undercuts are possible but increase tooling costs considerably. Holes and openings are not possible without additional processes. Fiber reinforcement may further limit formability.

Technical notes
The process is used with thermoplastics, foams and short fiber reinforced thermoplastics. ABS, PA, PC, PS, PP, PVC, polysulfones, PBT and PET are particularly suited. Some limitation on fiber content. High melt viscosity is best
Maximum depth-to-width ratios vary from 0.5 to 2 depending on method of forming.

Typical uses
Trays, signs, packaging, refrigerator liners, aerospace components e.g. large secondary structure air frame parts - helicopter fairings and cowlings, boat hulls, bath tubs, drinks cups, etc.

The economics
Tooling cost range covers small, simple to large, complex molds.

Shape
Dished sheet True
4. Extrusion Blow Molding

General

Designation
Molding: Extrusion Blow Molding

The process
In EXTRUSION BLOW MOLDING, a tube (or parison) is extruded and clamped in a split mold. Air is then injected under pressure inside the parison, blowing the polymer against the mold walls where it cools and freezes.

The mold is opened and the part ejected. Surplus material at both ends of the part is then removed. The process uses thermoplastics of high melt viscosity and high molecular weight. It is most widely used with PE (especially HDPE), PP and PVC.

Other thermoplastics are also used. The process is capable of producing irregular shaped containers and blown handles. Mold cost is lower than for injection blow molding.

It is generally most competitive for larger containers (capacity > 0.5 L) and high batch sizes.

Process schematic

Physical Attributes

Adjacent section ratio  1 - 2
Aspect ratio  1 - 800
Mass range  0.5512 - 6.614 lb
Minimum corner radius  0.1181 in
Range of section thickness  0.01575 - 0.252 in
Roughness  7.874e-3 - 0.06299 mil
Quality factor (1-10)  1 - 8
Tolerance  9.843e-3 - 0.03937 in

Economic Attributes

Economic batch size (mass)  1.102e4 - 1.102e6 lb
Economic batch size (units)  1e4 - 1e6

Cost Modelling

Relative cost index (per unit)  18.46 - 31.91

Parameters: Material Cost = 4.309USD/lb, Component Mass = 2.205lb, Batch Size = 1000, Overhead Rate = 110USD/hr, Capital Write-off Time = 5yrs, Load Factor = 0.5

Capital cost  5655 - 5.655e4 USD
Lead time  4 - 6 week(s)
Material utilization fraction  0.5 - 0.8
Production rate (mass)  22.05 - 440.9 lb/hr
Production rate (units)  10 - 250 /hr
Tool life (mass)  1.102e4 - 1.102e6 lb
Tool life (units)  1e4 - 1e6
Tooling cost  1885 - 5655 USD

**Process Characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>True</th>
<th>False</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>True</td>
<td>False</td>
</tr>
<tr>
<td>Secondary</td>
<td>False</td>
<td>True</td>
</tr>
<tr>
<td>Tertiary</td>
<td>False</td>
<td>True</td>
</tr>
<tr>
<td>Prototyping</td>
<td>False</td>
<td>True</td>
</tr>
<tr>
<td>Discrete</td>
<td>True</td>
<td>False</td>
</tr>
<tr>
<td>Continuous</td>
<td>True</td>
<td>False</td>
</tr>
</tbody>
</table>

**Supporting Information**

**Design guidelines**

Used for thin-walled hollow or tubular articles with small openings (e.g. bottles). Irregular shapes are possible.

**Technical notes**

Thermoplastics commonly used include: HDPE, LDPE, PP, ABS and uPVC. Limited level of reinforcement possible for composite materials (i.e. particulate and short fibers). The wall thickness should be as uniform as possible to ensure more rapid molding cycles and to avoid distortion.

**Typical uses**

Primarily bottles and containers - from small bottles to large (10000L) oil storage tanks. Useful for larger containers and irregular shapes e.g. detergent bottles, drums, tanks, toys (balls, baseball bats, etc.).

**The economics**

Tooling cost range covers small, simple to large, complex molds.

**The environment**

Waste material is recyclable.

**Shape**

Hollow 3-D  True

---

### 5. Injection Blow Molding

**General**

**Designation**

Molding: Injection Blow Molding

**The process**

In INJECTION BLOW MOLDING, a hollow preform is injection-molded over a mandrel which provides the hollow shape. The mandrel transfers the hot preform to the blow molding die and also functions as the blow nozzle.

Air is injected under pressure through the mandrel blowing the polymer radially against the mold walls where it cools and freezes. The mold is opened and the part ejected. The process produces no waste material.

Injection blow molding offers better control over finished part weight and wall thickness (than extrusion blow molding) and is capable of high tolerances in the unblown, injection-molded neck area, hence is it useful for screw closures, etc.

Handles may be molded in (solid only). The process is most competitive for production of small bottle sizes (< 360mL), for rigid thermoplastics (e.g. PS, PC, PET, etc.), and for wide mouth containers.

Tooling costs are much higher than for extrusion blow molding, hence process is only used for volume production.

Stretch Blow Molding is an important variant. It is most commonly used for the production of oriented PET drinks bottles.

**Process schematic**

**Physical Attributes**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>1 - 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjacent section ratio</td>
<td></td>
</tr>
</tbody>
</table>
Aspect ratio        1    -   400
Mass range         2.205e-3 - 0.5512 lb
Minimum corner radius 0.1181 in
Range of section thickness 0.01575 - 0.1181 in
Roughness          7.874e-3 - 0.06299 mil
Quality factor (1-10) 1 - 8
Tolerance          9.843e-3 - 0.03937 in

**Economic Attributes**

Economic batch size (mass)     4409 - 4.409e5 lb
Economic batch size (units)    1e5 - 1e7

**Cost Modelling**

Relative cost index (per unit)  16.3 - 29.64
Parameters: Material Cost = 4.309USD/lb, Component Mass = 2.205lb, Batch Size = 1000, Overhead Rate = 110USD/hr, Capital Write-off Time = 5yrs, Load Factor = 0.5
Capital cost      5655 - 5.655e4 USD
Lead time         4 - 6 week(s)
Material utilization fraction 0.9 - 0.99
Production rate (mass) 4.409 - 11.02 lb/hr
Production rate (units) 100 - 2500 /hr
Tool life (mass)    4.409e4 - 4.409e6 lb
Tool life (units)   1e5 - 1e7
Tooling cost       5655 - 1.885e4 USD

**Process Characteristics**

Primary            True
Secondary          False
Tertiary           False
Prototyping        False
Discrete           True
Continuous         False

**Supporting Information**

**Design guidelines**
Used for thin-walled hollow or tubular articles with small openings (e.g. bottles). Suitable for fairly regular shapes.

**Technical notes**
Thermoplastics commonly used include PET, PC, HDPE, LDPE, PP, ABS and uPVC. Limited level of reinforcement possible for composite materials (i.e. particulate and short fibers)
The wall thickness should be as uniform as possible to ensure more rapid molding cycles and to avoid distortion.

**Typical uses**
Primarily bottles and containers - largely small bottles (< 0.5L), wide mouth containers, and simple shapes.

**The economics**
Tooling cost range covers small, simple to large, complex molds.

**The environment**
Waste material is recyclable. Significant dust exposures may occur in the formulation of the resins. Thermostatic controller malfunctions can be extremely hazardous.

**Shape**
Hollow 3-D True