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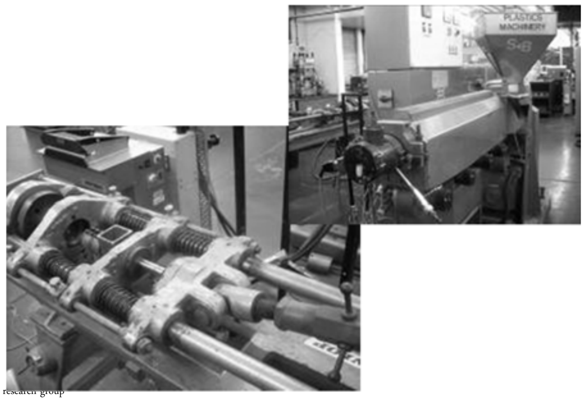
Moulding processes
MTT655 Polymer Processing

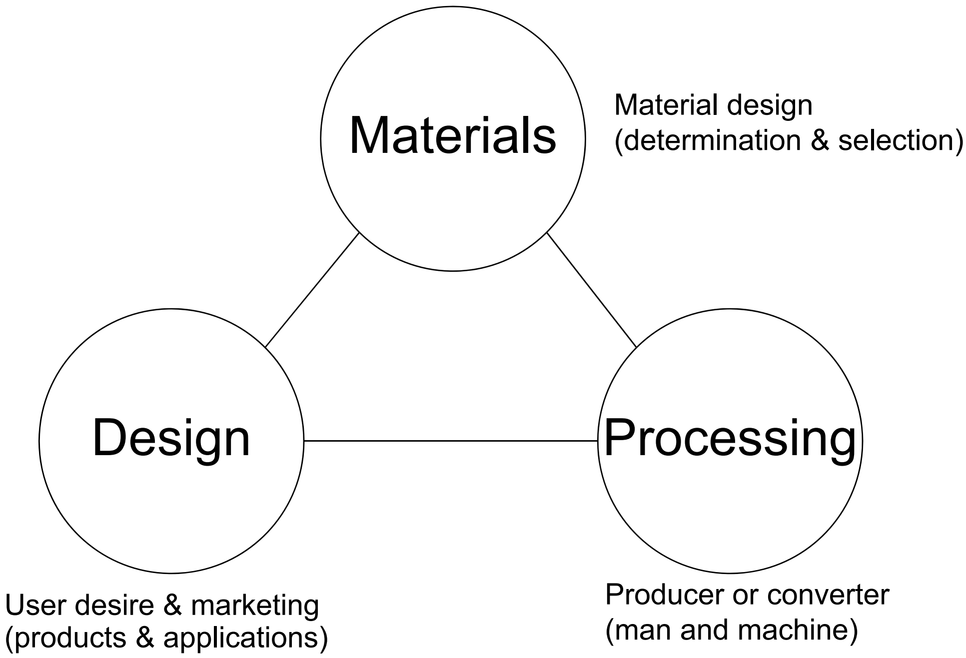
Apisit Kositchaiyong

Polymer processing

- **Shaping process**
  - **Mould**
    - Injection
      - Injection moulding
      - Injection blow moulding
      - Reaction injection moulding
    - Compression moulding
    - Transfer moulding
    - Thermoforming
    - Rotational moulding
    - *..and so on..*
  - **Die**
    - Extrusion
      - Sheet
      - Film
      - Lamination
    - Extrusion blow moulding
    - Calendering process
    - Pipe/tube extrusion
    - *..and so on..*
- **Mixing process**
  - **Melt mixing**
    - Screw extruding
    - Two roll mill
    - Barbendering
    - *..and so on..*
  - **Dry mixing**
    - Stirrer or blading
    - Rock & roll (drum mixer)
    - *..and so on..*



Material processing loop



(Structure-Property-Design-Processing)

Polymer products & applications

Polymer PROcessing and Flow (P-PROF) research group
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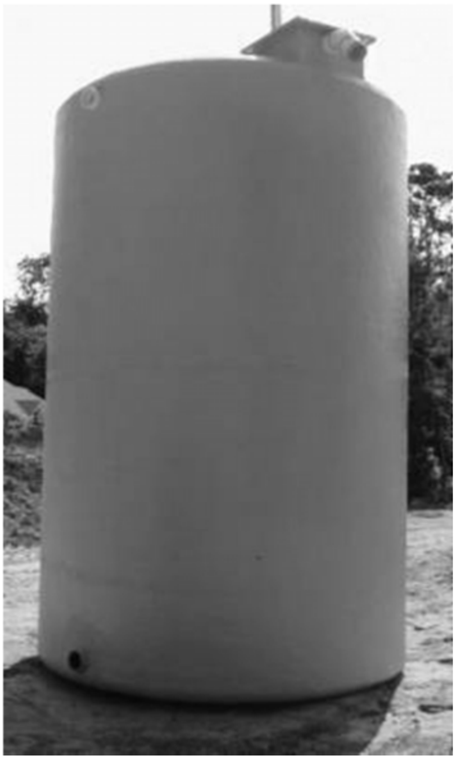
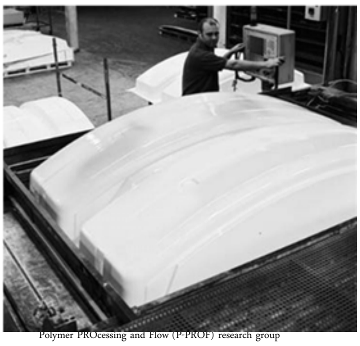
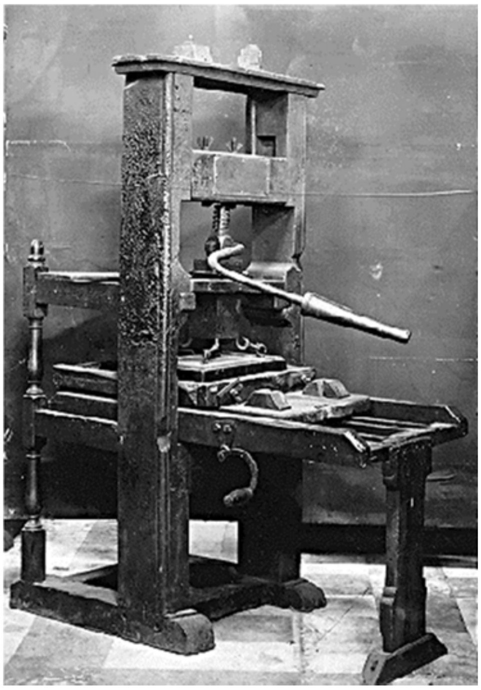
Polymer products & applications





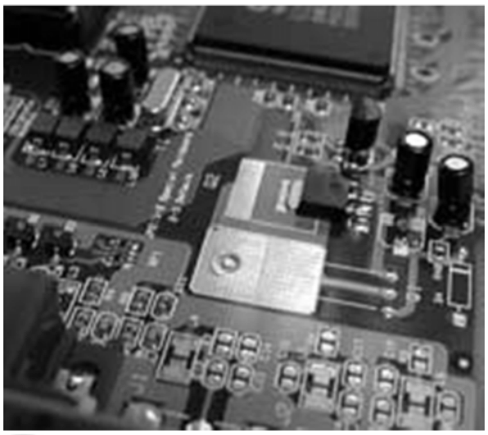
Compression moulding process

The compression moulding is the oldest mass production process for polymer products. The process is used mainly with thermosets and rubbers. In the case of thermosets the feed materials are often made into preforms to ease loading and heated prior to moulding in order to reduce cycle times.

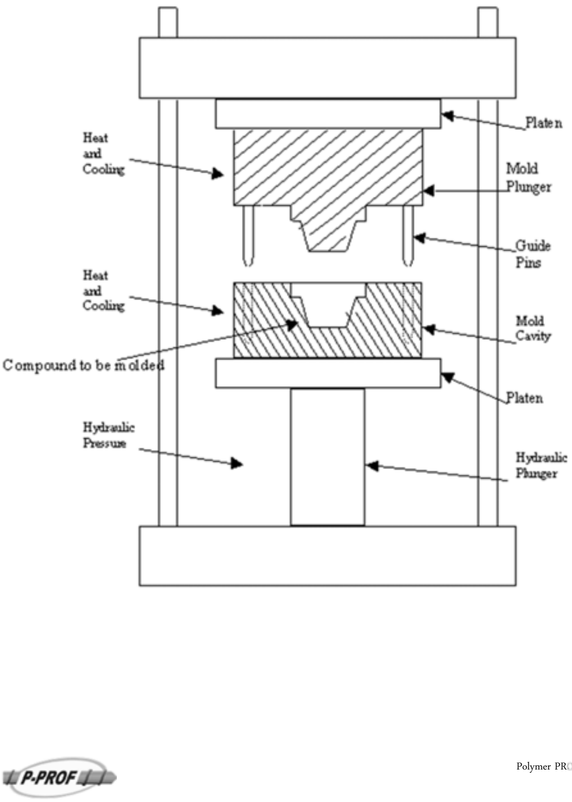




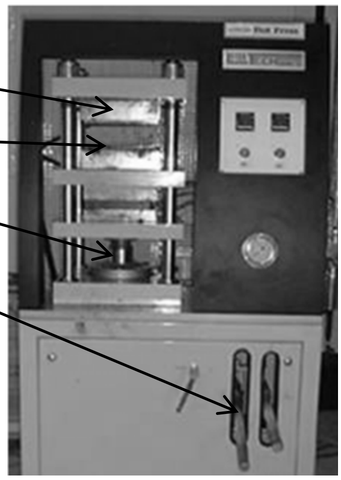




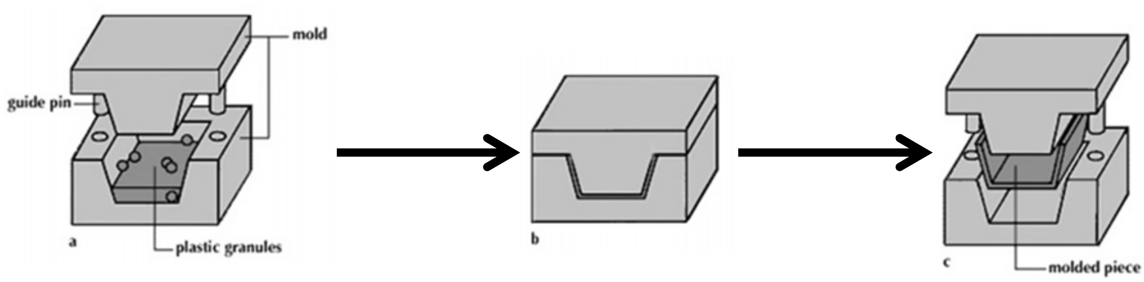

Compression moulding machine



i) Platen heater
ii) Mould
iii) Ram
iv) Hydraulic pressure



Production cycle



Step 1 : The moulding materials is loaded into the female section of the mould.

Step 2 : The mould is slowly closed over the last 20 mm (15-30 seconds) to prevent air entrapment.

- *Opening mould again to allow the air escape completely.*
- *Closing mould again to complete the moulding cycle.*

Step 3 : The mould is opened after complete curing process. And then ejecting the moulding.

http://www.molders.com/compression_molding.html (18June08)

Classification of compression moulding process

Operating method	Physical mould design
I. Hand mould II. Semi-automatic III. Automatic	I. Positive mould II. Semi positive mould III. Flash mould IV. Sub-cavity gang mould V. Split-wedge and split-cavity moulds

Operating method

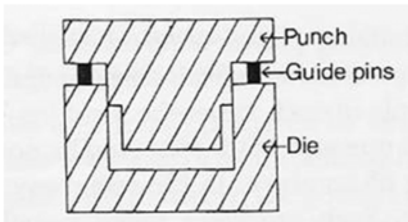
I. **Hand mould** : This type of mould is loaded with polymer outside the press. All these operations are *done manually*.

II. **Semi-automatic** : This type of mould is permanently fastened in the press, but *the loading and unloading operations are carried out manually*.

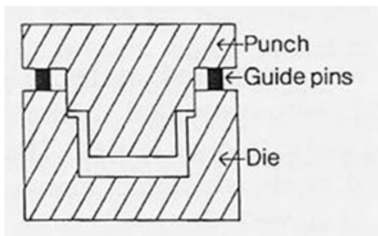
III. **Automatic** : The same as type (II), but *the loading and unloading operations are carried out automatically*.

Physical mould design

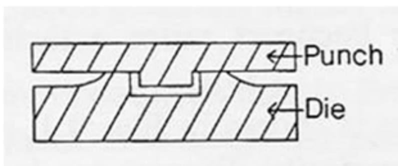
Positive Mould :	This type of mould is designed such that all the material charged into the tool as a result of the small clearance (typically 0.08 mm) between the male and female parts of the mould. The charge weight of the material needs to accurately weighed out. The excess materials that protruded out of the mould is in the vertical direction.
Semi Positive Mould :	This type of mould is a combination of flash and positive moulds and that the flash is separated from the material. The mould is designed such that the positive section of the tool is only engaged over a limited range of the movement of the tool, typically the last 2 mm of closing stroke.
Flash Mould :	This type of mould is dependent on the cavity being overcharged with material in order to ensure the complete filling of the cavity when the mould is closed. The excess material escapes at the arting line of the tool, which is aligned perpendicular to the clamping force, to form flash.



I. Positive Molds



II. Semi Positive Molds



III. Flash Molds

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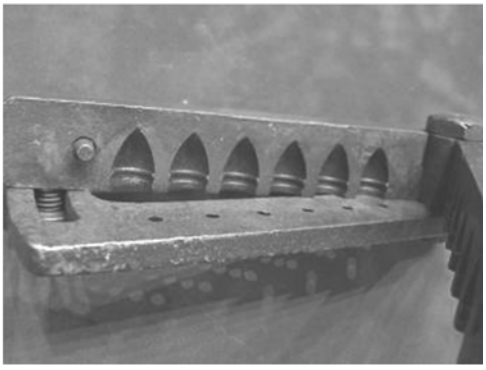
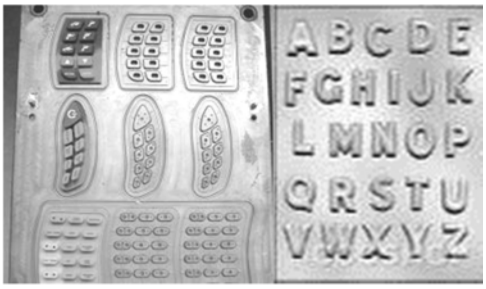
Physical mould design (cont.)

Sub-cavity gang moulds :	These types of mould have a chamber into which several separate smaller moulds are placed. The charge of material is distributed between the individual cavities by the action of the press closing the mould. Density variations can arise in the components produced due to the poor flow of the moulding powder around the cavity.
Split-wedge and split-cavity moulds :	These types of moulds allow the production of components with undercuts and projections (e.g. lettering)





Principle of Compression moulding

Compression presses are usually described in term of the following:

(i) The clamping force

(ii) The number of daylight (Apertures into which a mould will fill)

Melted Polymer

(iii) Upstroke or Down stroke. This defines manner in which the press opens.

Comparison of closure forces	
Process	**Closure force (tonnes)**
RRIM (Reinforced reaction)	50
SMC compression moulding	800
CIM in polypropylene	2500
CIM in polycarbonate	3500

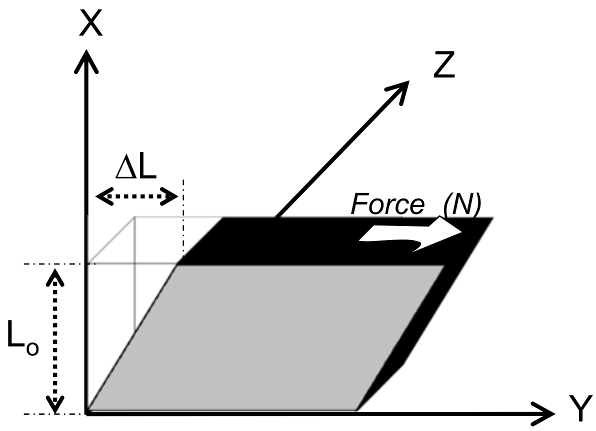
http://www.custompartnet.com/calculator/clamp-force

Typical shear rate in processing

- Compression molding - 1-10 s^{-1}
- Calendering - 10-10^2 s^{-1}
- Extrusion - 10^2 -10^3 s^{-1} and above generally
- Injection molding - 10^3 -10^4 s^{-1} out of Newtonian range




Basic polymer rheology



Shear stress (N/m²)

$$\tau = \frac{F}{A};\left(\frac{N}{m^2}\right)$$

Shear strain (m/m)

$$\gamma = \frac{\Delta L}{L_o};\left(\frac{m}{m}\right)$$

Strain rate (s^{-1})

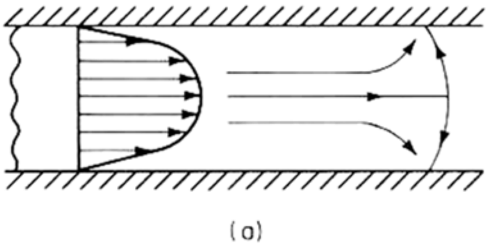
$$\gamma = \frac{\Delta L / s}{L_o} = \frac{V}{L_o};\left(s^{-1}\right)$$

Viscosity (Pa·s)

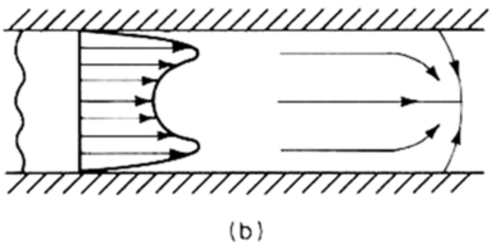
$$\eta = \frac{\tau}{\dot{\gamma}};\left(\frac{N/m^2}{s^{-1}}\right)$$

Velocity profiles during compression molding

Intermediate between the ***Hele-Shaw (shear flow)*** and ***lubricated squeezing flows (plug flow)***

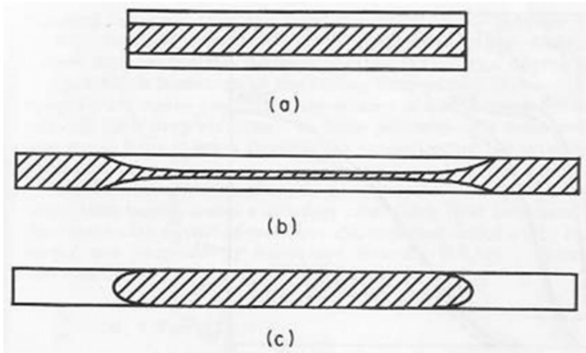


Generalized Hele-Shaw flow



Reverse fountain flow

Effect of transverse velocity profile on filling pattern ;



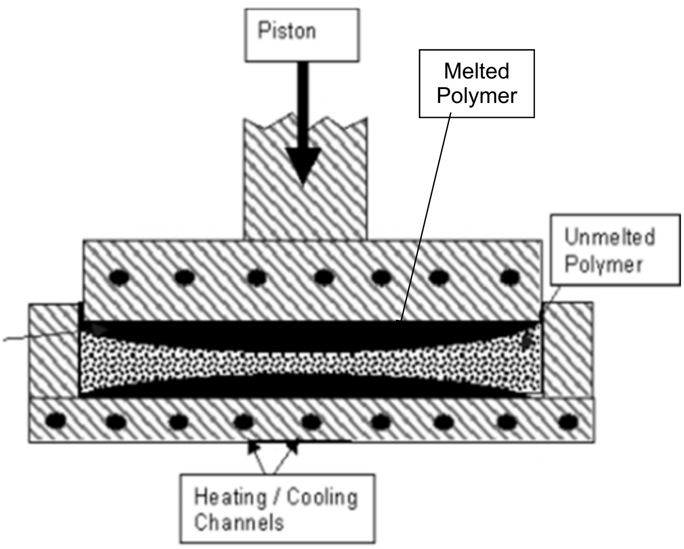
Cured part

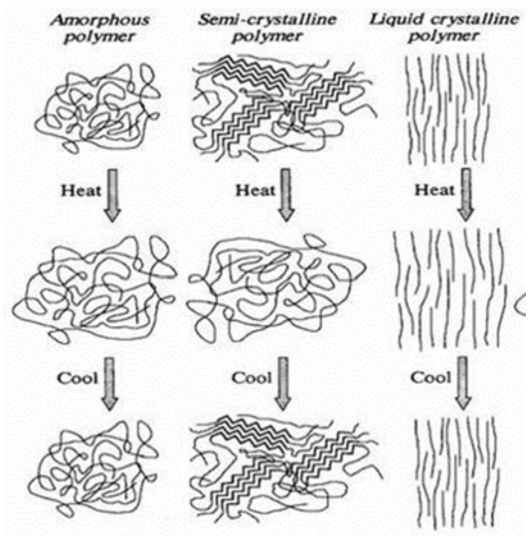
Uncured part

(a) Transverse section of initial charge
(b) Final part when filled with Hele-Shaw velocity profile
(c) Final part when filled with reverse fountain velocity profiles

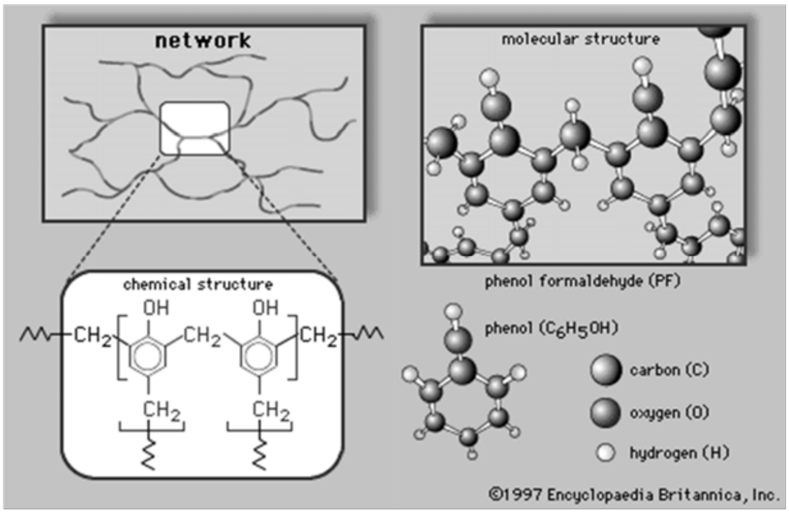
Ref. Avraam I. Isayev, 1987, Injection and Compression Molding Fundamentals, pp. 510

Melt mechanism in thermoplastic materials





Crosslink-reaction in thermosetting plastics

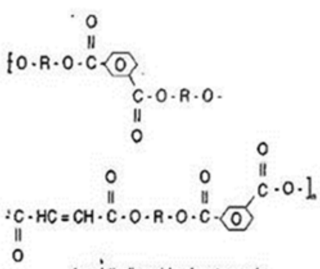


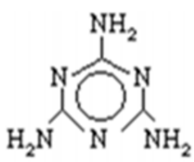
High moulding pressures are often required;

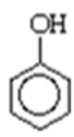
- to ***force*** the material to flow into the shape of the cavity
- to ***stop*** the formation of porous products as with some type of moulding powder, water is a by-product of the polymerization process.

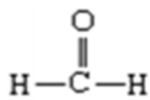
Typical thermosetting plastic : P and T used for compression moulding

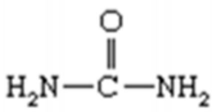
Material	Temperature (^oC)	Pressure (MPa)
Unsaturated polyester	110 - 170	1.4 – 6.9
Melamine / Formaldehyde	145 - 165	30 – 60
Phenol / Formaldehyde	155 - 170	15 – 60
Urea / Formaldehyde	125 - 160	15 – 30
NR (Conventional vulcanization)	150 - 160	15 - 20

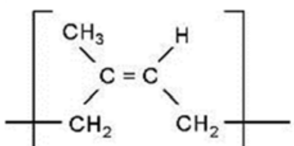

Isophthalic acid polyester resin


melamine


phenol

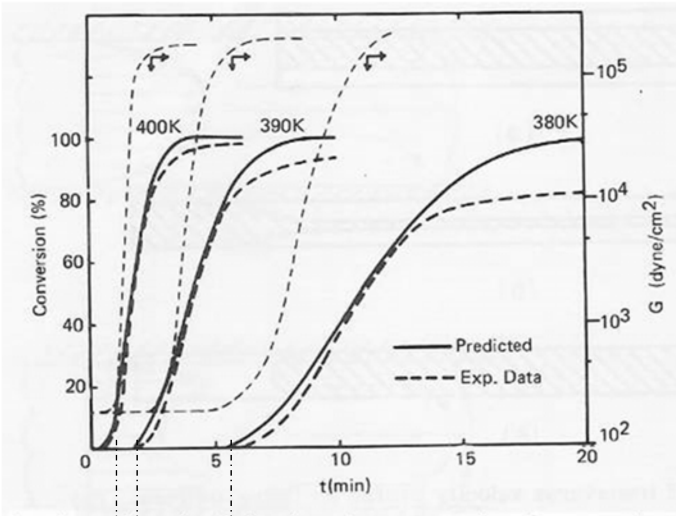

formaldehyde


urea


NR

Dwell time and curing temperature of thermosetting plastic

- In compression moulding process, ***Dwell time*** is an initial period where no appreciable curing takes places, additionally it can be adjusted by varying inhibitor concentration.
- Complete curing does not occur at low temperatures because the developing network structure has a glass-transition temperature (T_g) which increases as the reaction proceeds.



Isothermal curing behavior of unsaturated polyester resin

- At the starting point (dwell time), curing then begin slowly, after that it is accelerated and proceeded most rapidly around the halfway point, finally, slows down and levels off when incompletely cured.

Ref. Avraam I. Isayev, 1987, Injection and Compression Molding Fundamentals, pp. 512

Pros and Cons

- No sprues and runners, wastage is minimized. (2-5%, but irrecoverability)
- Internal stresses are minimized. Thin walled articles are easy to manufacture and also easy to make large articles and fairly intricacy.
- There are fewer knit lines and less fiber-length degradation than injection molding. And also a little shearing (low orientation which are not disturbed or oriented during process) force to cause track, the mechanical and electrical are retained.
- The mould maintenance is low (little erosion due to low shear force) and the presses (capital and tooling costs) are relatively cheap.

- Wastage of energy and heating the mould during each cycle
- Poor product consistency and difficulty in controlling flashing
- The mould has to be designed such that all the corners of the mould will fill.
- It is difficult to mould with inserts.
- There may be porous in moulded article due to gassing of volatile matter during condensation reaction.

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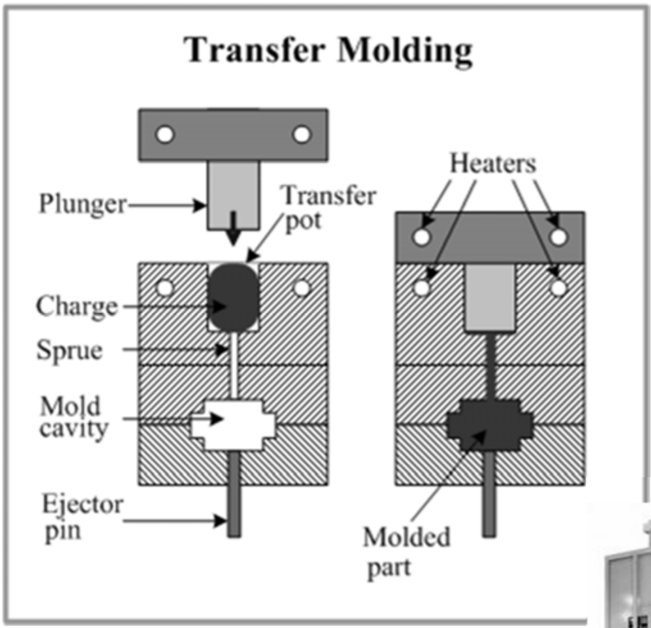
Transfer moulding



Transfer moulding is similar to compression moulding but employs a piston/cylinder device. The material is placed above the closed, heated mould and is forced downward through the gate and into the mould cavities. The mould is held closed while the material cures. This process results in **transfer moulded** parts being cleaner and more consistent than compression moulded parts.

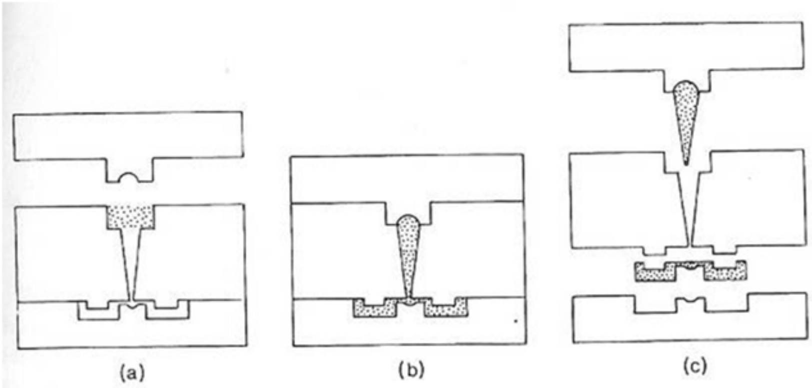
Summery of Transfer Molding

Transfer molding is similar to compression molding in that a carefully calculated, pre-measured amount of uncured molding compound is used for the molding process. The difference is, instead of loading the polymer into an open mold, the plastic material is pre-heated and loaded into a holding champer called the pot. The material is then forced/transferred into the pre-heated mold cavity by a hydraulic plunger through a channel called sprue. The mold remains closed until the material inside is cured.

Transfer molded parts inherently have less flash (excess material that runs along the parting line of the mold) than their compression molded counterparts because the mold remains closed when the plastic enters the mold cavity. However, transfer molding still produces more waste material than compression molding because of the sprue, the air holes and the overflow grooves that are often needed to allow air to escape and material to overflow.

One of the key advantages of transfer molding over compression molding is that different inserts, such as metal prongs, semiconductor chips, dry composite fibers, ceramics, etc., can be placed/positioned in the mold cavity before the polymer is injected/drawn into the cavity. This ability makes transform molding the leading manufacturing process for integrated circuit packaging and electronic components with molded terminals, pins, studs, connectors, and so on.

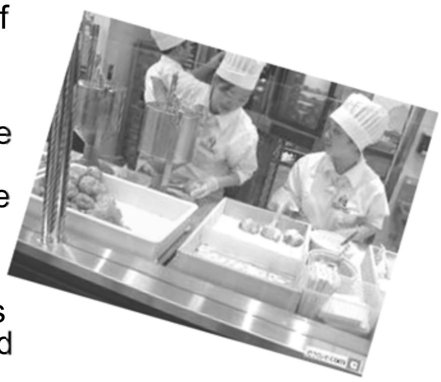
Molding cycle of a plunger-type transfer mold



(a) 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".

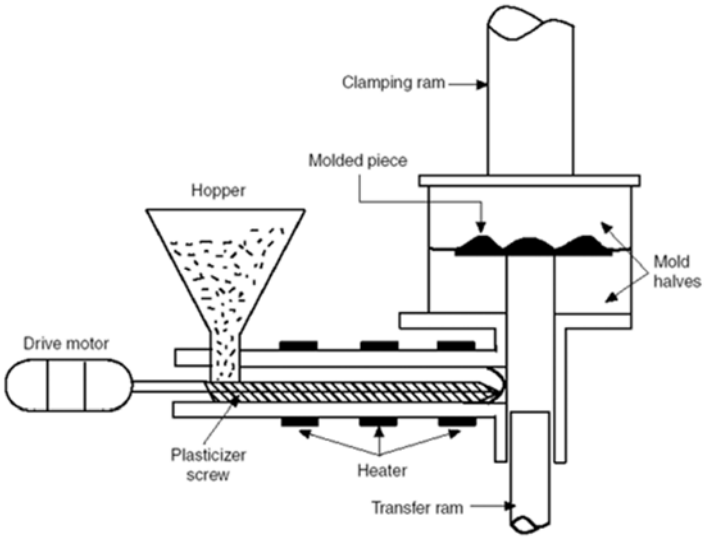
(b) The mold is closed up and under hydraulic pressure the rubber is forced through the small hole (the "gate") into the cavity. The mold is held closed while the rubber cures.

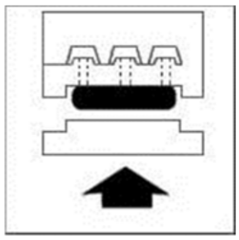
(c) The plunger is raised up and the "transfer pad" material may be removed and thrown away. Mold is opened and the part can be removed. The flash and the gate may need to be trimmed.



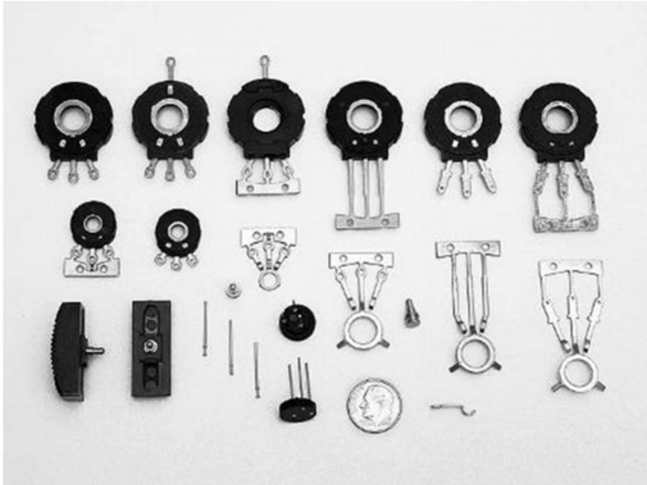
www.leechind.com (13July08)

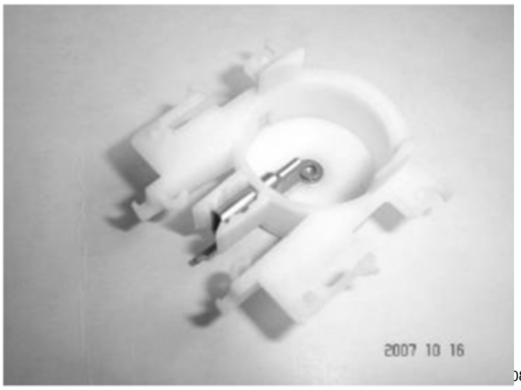
Molding cycle of a pot-type transfer mold.





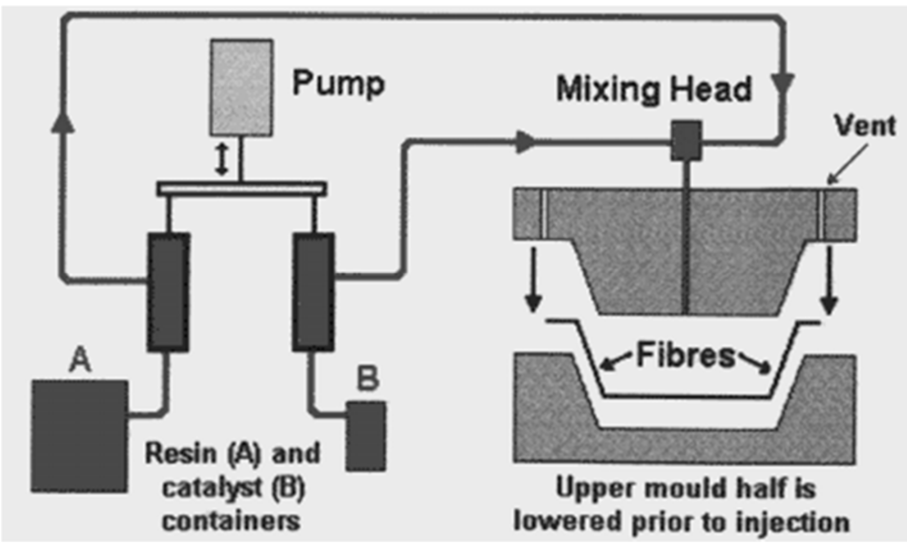
(a) Molding compound is placed in the transfer pot.
(b) Forced under pressure when hot through an orifice and into a closed mold.
(c) When the mold opens, the sprue remains with the cull in the pot, and the molded part is lifted out of the cavity by ejector pins.





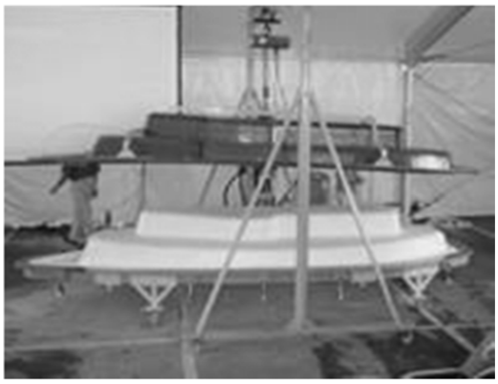
08)

Although transfer molding can also be used for thermoplastics, the majority of the materials used in this process are still thermosets, Some common ones are:



Examples of thermosetting materials and products from Transfer moulding process :

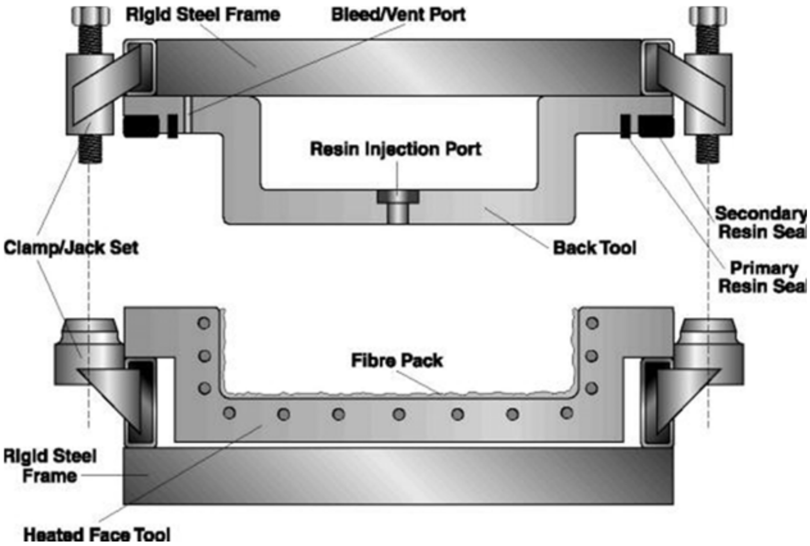
- Epoxy
- Polyurethane
- Polyester (Unsaturated)
- Phenol-formaldehyde Plastic (PF, Phenolic)
- Silicone rubber (SI)



The moulding powders are often preheated prior to moulding to reduce cycle times. The pot temperature is usually slightly lower than the mould temperature. Typical moulding pressures and temperatures are given in Table below.

Material	Temperature (^{o}C)	Pressure (MPa)
Unsaturated polyester	110 - 170	5 – 15
Melamine / Formaldehyde	145 - 165	75 – 150
Phenol / Formaldehyde	155 - 170	60 – 150
Urea / Formaldehyde	125 - 160	60 – 150

In the composite industry, fiber-reinforced composites are often manufactured by a processed called Resin Transform Molding (RTM). Layers of textile preforms (long fibers woven or knitted in patterns) are pre-arranged in the mold. The resin is then injected to impregnate the performs. Valcuum is often used to avoid air bubbles and help draw the resin into the cavity. In addition, the resin used has to be relatively low in viscosity.



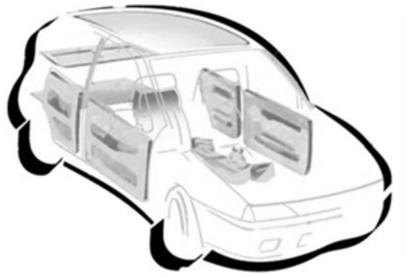
Advantages	Disadvantages
• Consistency of products • A number of small parts could be made easily and controllable • A good choice to make inserted thermosetting products • Reduction the risk of damage or movement of thin or delicate mould parts or inserts • Productive cycle time is shorter than that of compression moulding • Fast setup time and lower setup costs than injection molding	• Wastes more material than compression molding (scraps of thermosets are not re-useable) • Production speed lower than injection molding (Longer cycle time) • Maintenance cost will be possessed due to wearing occurred • Tooling is more complicating as compared with compression moulding, as a result being more in expensiveness

Thermoforming process

Film and sheet process

Thickness → < 0.25 mm → film

Thickness → > 0.25 - 10 mm → she



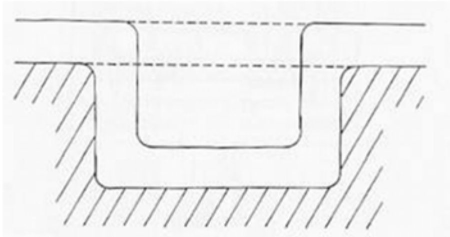
What is thermoforming process??

- The basic principle of the thermoforming process bears some similarity to ***metal stamping techniques***.
- But thermoforming has far fewer limitations in;
  - Stretching
  - Depth-of-draw ratio
  - Material distributions

???

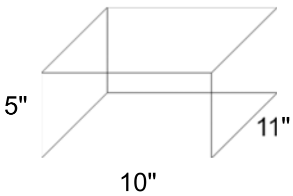
Draw ratio

Draw Ratio = the Surface Area of the part / Footprint of the part



Ideal deformation pattern.
(Ref. D.H. Morton-Jones, *Polymer Processing*, 1989.)

Example :



Assume a part size of 10" x 11" x 5" deep.
Surface Area = 2(10" x 5") + 2(11" x 5") + (10" x 11")
= 300"
Footprint = 10" x 11" = 110"
Draw Ratio = 2.73

If the desired ending wall thickness is 0.100" use the draw ratio value as follows (Assuming perfect material distribution.):
2.7 x 0.100" = 0.273" starting gauge.

Principle of Thermoforming

- The process carry out by bringing down the temperature of the polymer sheet, usually thermoplastics, to a point where the polymer sheet is softened and then forming it into or around a mould, The shaping process being then achieved by cooling.
- The sheet is normally produced form sheet extrusion with a wide range of thickness from 0.25 mm to 10 mm.
- In the case of multi layer product, the sheet are produced from the variants of extrusion including co-extrusion, lamination and coating process.
- Example products such as; venting egg, egg cases, bath tubs, packaging trays, swimming pools, boat hulls, blisters packs refrigerator main liners and inner and sinks.

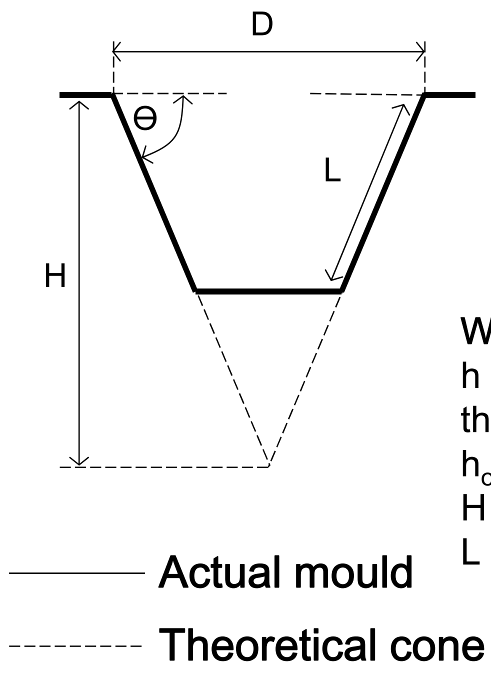
Estimation of wall thickness distribution

In practice, in order to minimize the stress and some other problem in thermoforming, an understanding of the phenomena and the causes of these problems in the process is required. One of the simplest method is to analysis the thickness distribution of the product, this being based on the fact that the more stretching elongation, the less the thickness and the more likely the stresses set up.

Products from thermoforming can be categories into two broad groups, these including *thin-walled* and *thick-walled* products. *Thin-walled* ones are usually obtained by mould having *multiple-cavities* whereas *the other* are produced by a mould with *one cavity*.

Thin-walled products are then likely to give higher level of the stresses due to larger extendibility of the products or greater reduction in sheet thickness.

Thermoforming analysis

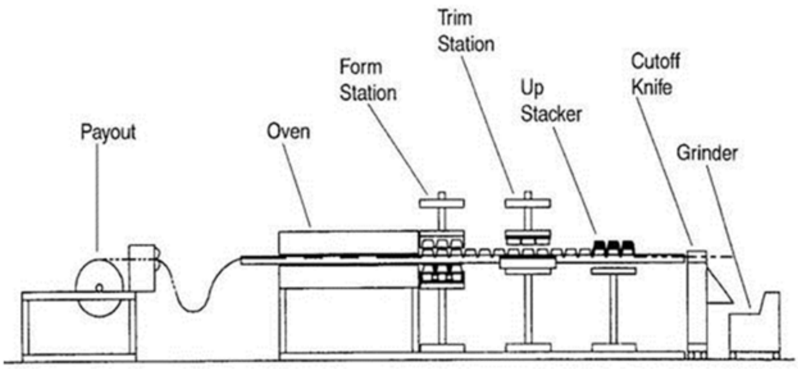


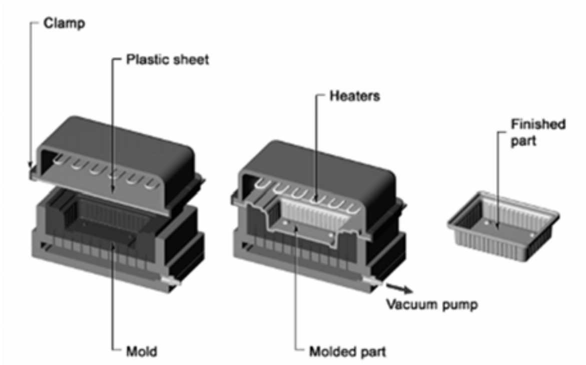
$$\frac{h}{h_0} = \left[\frac{1+\cos\theta}{2}\right]\left[\frac{H-L}{H}\right]^{\sec\theta - 1}$$

Where
h is the final thickness of the thermoformed product.
h_o is the initial thickness of the sheet.
H is the thickness of the forming.
L is a distance down its side.

The basic components of the thermoforming process:

- Thermoplastic sheet
- Clamping mechanism
- Heating systems
- Molds
- Forming force
- Trim apparatus

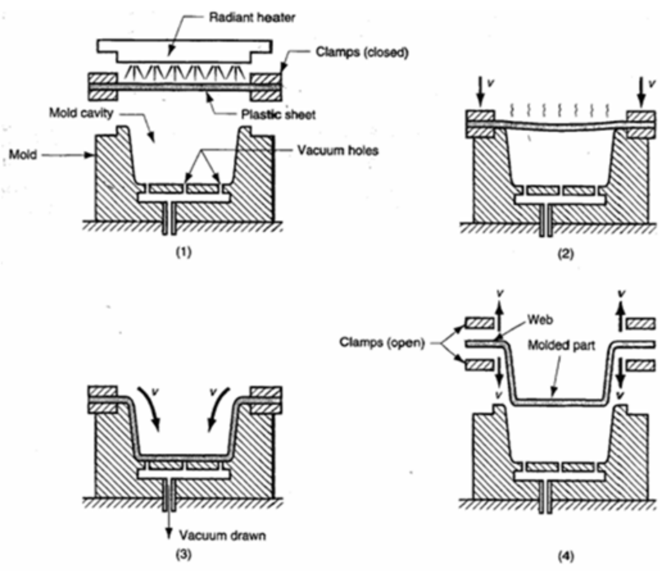




Production cycle

The production cycle of process mainly required ;

- Loading and/or unloading stations (with clamping unit)
- Oven station (with radiation heaters)
- Forming station (with a vacuum unit)



Thermoplastic sheets

Thermoplastic sheet resins which make by calendering or casting or extruding process and typical thermoplastic sheets used in thermoforming are;

Some examples of materials in vacuum forming. (**Ref.** D.H. Morton-Jones, *Polymer Processing*, 1989.)		
Material	*Application*	*Comments*
ABS / S-HIPS	Refrigerator	Ease of forming, oil/fat resistance
Matt ABS/high heat ABS	Motor trade, Dashboard area	Non-reflective, good heat distortion
PP / filled PP	Motor trade parcel shelves	Cost effective, rigid
PP UV stable / PP copolymer	Out door applications – garage forecourts	UV stabilizing, expensive – top layer only
Three layer, with scrap in center	Various	Cost effective

Clamping mechanisms

I. **Clamp-frame mechanisms**

Usually, one frame is made stationary while the thermoplastic sheet is clamped between the two frames. The clamping action the two frames are closed (with the sheet in between) together and capture the precut sheet on all four sides. The stronger gripping, permitting no slip or movement of the sheet, may be used the implements such as riveted pin.

II. **Transport-chain mechanisms**

In the case of a continuous manner, transport-chain system performs the duties of a clamp frame. The roll stock material is unwound and carried through a partial or complete thermoforming program by this transport chain.

Heating systems

☞ Gas as heat power source

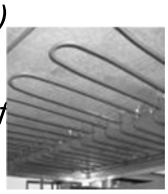
Inexpensive compared with the cost of electric power but being difficult to precising temperature control and possible to generate exhaust and carbon monoxide.

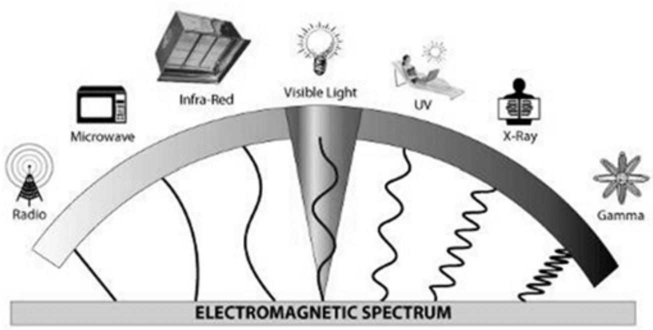
☞ Electrical power source

It is the most widely used heating energy source although it is more costly. Because the availability of electric power and its unlimited controllability, together with the multitudes of instrumentation and heating element types, make the electrical heating technique the most versatile and adaptable system for thermoforming.

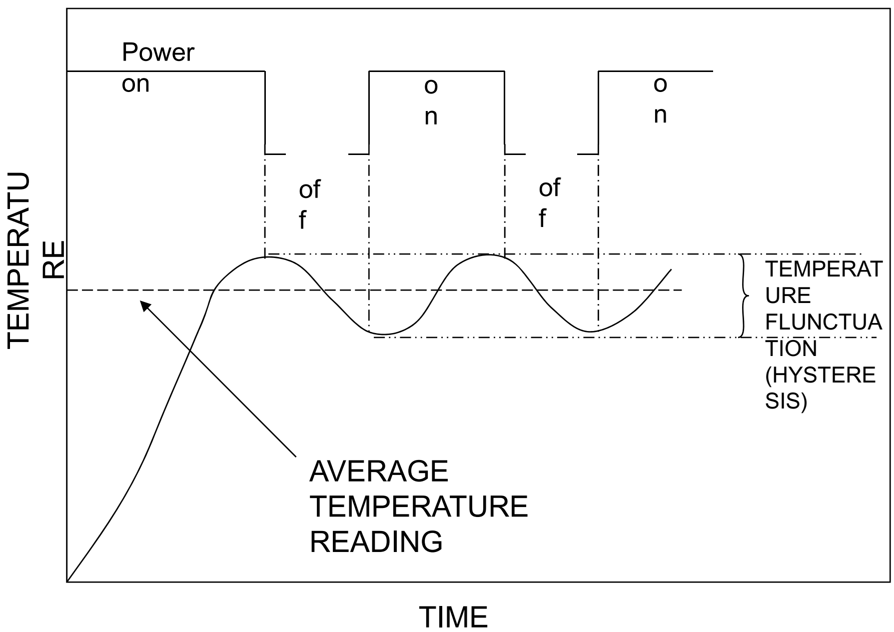
There are three basics heating method used in the thermoforming process:

- **Gas-fired convection ovens**
  (burning air and blown)
- **Contact heating**
  (contact on heated surf
- **Radiant heating**
  (IR-light-spectrum wavelength)





Wave function of electrical heating control

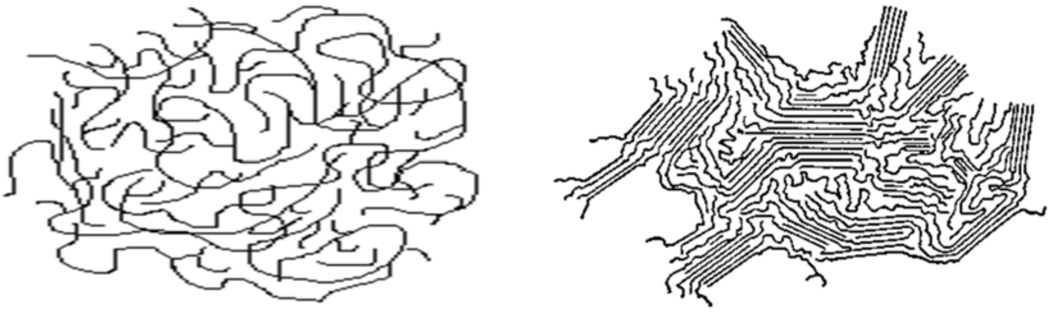


Redrawn from, Practical Thermoforming: principles and applications, John Florian, 1987

Degree of temperature used for thermoplastic thermoforming process

The heating time and temperature used for softening the sheet are vary important for vacuum forming technique.

- *10-15^{o}C* below the glass-transition temperature for **amorphous polymer**.
- *5-10^{o}C* below the melting temperature for **semi-crystalline polymer**.



(a) (b)

Amorphous (a) and semi-crystalline (b) structure of polymer

Classification of thermoforming process

Thermoforming process can be classified as follow;

☞ *Production line*

These can be determined as follow; (i) One stage thermoforming (ii) Two stage thermoforming and (iii) Rotary thermoforming.

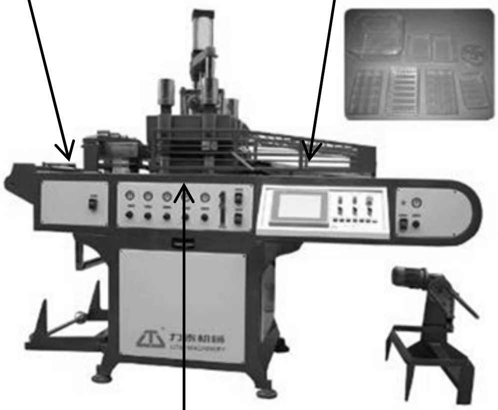
☞ *Mould types & forming forces*

There are a variety of methods in the thermoforming process that have been developed in order to achieve the most satisfactory product. These including: (i) Vacuum forming, (ii) Pressure forming, (iii) Air-blown forming, (iv) Vacuum-assist drape forming, (v) Plug-assist vacuum forming and (vi) Combined forming. Each forming method may be composed variant of mould such as *male mould*, *female mould* and also *match mould* (combining between male and female mould).

(i) One-*stage thermoforming*

Loading station

Forming and Cooling station

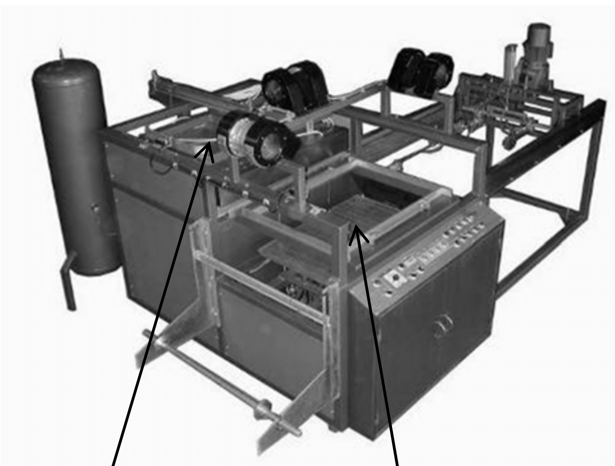


Heating station

One-stage thermoforming : This involves using one mould at a time. The production line is shown in the figure (on the left of this slide). The sheet is loaded and clamped at the loading station and then moved to be heated at the oven station before vacuum-drawing and cooling it at the forming station. The product is finally moved back to be unclamped and ejected at the loading station.

http://www.made-in-china.com/showroom/litaimachine/product-detailbVnJNcElsxMD/China-Fully-Automatic-Plastic-Thermoforming-Machine-TQA-520-580-.html, 25 Aug 2008

(ii) *Two-stage thermoforming*



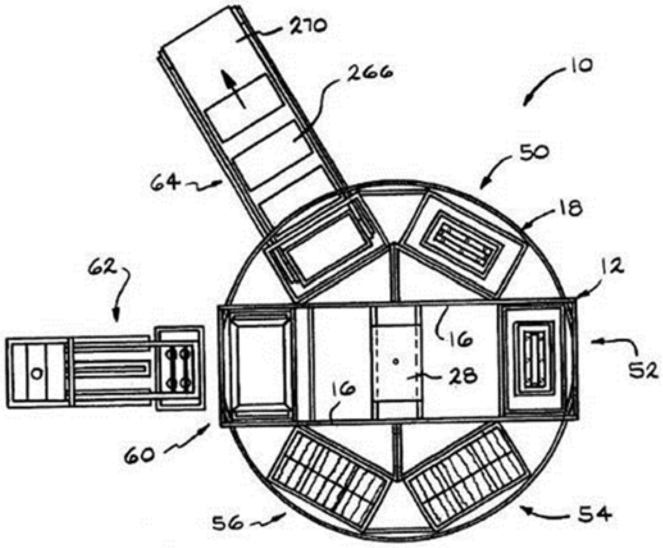
Two-stage thermoforming : This involves using two mould at a time. The production line is as the figure on your left: This is a combined line of two one-stage production lines. As one mould is vacuumed at the forming station another mould is placed in the oven to heat up. These two moulds have their own loading station

Mould No. 2 : In process of forming and cooling the product.

Mould No. 1 : In process of heating a sheet.

http://www.thaitechno.net/search.php?pageNum_rs_product=0&q=%20vacuum&totalRows_rs_product=135, 25 Aug 08

(iii) *Rotary thermoforming*



Six station rotary thermoforming

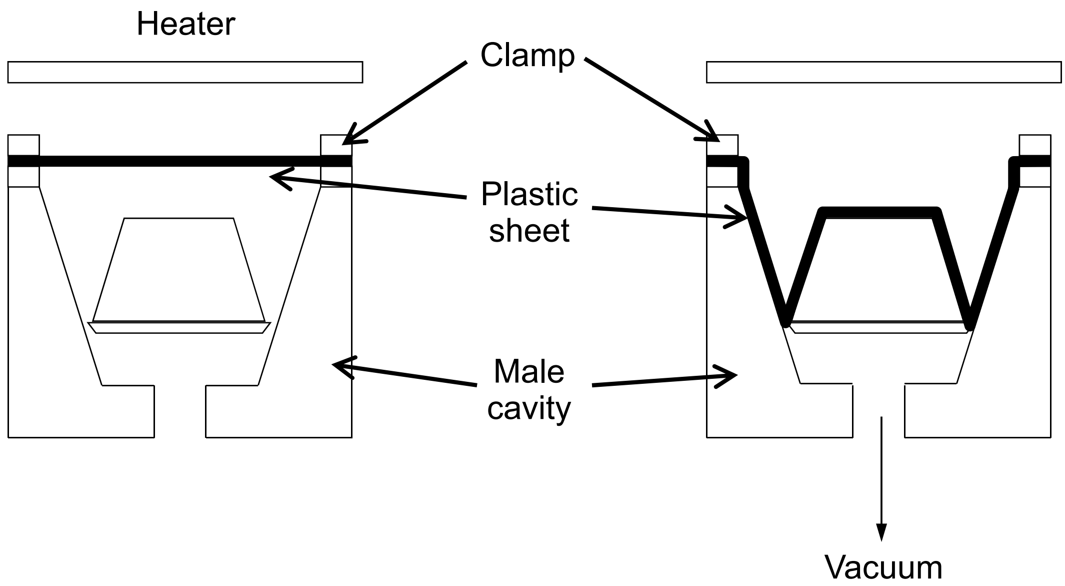
Rotary thermoforming : This involves using several moulds at the same time. The production line is rather similar to the single-stage, but it is set in the rotation way.

http://www.freepatentsonline.com/6705853.html, 25 Aug 2008

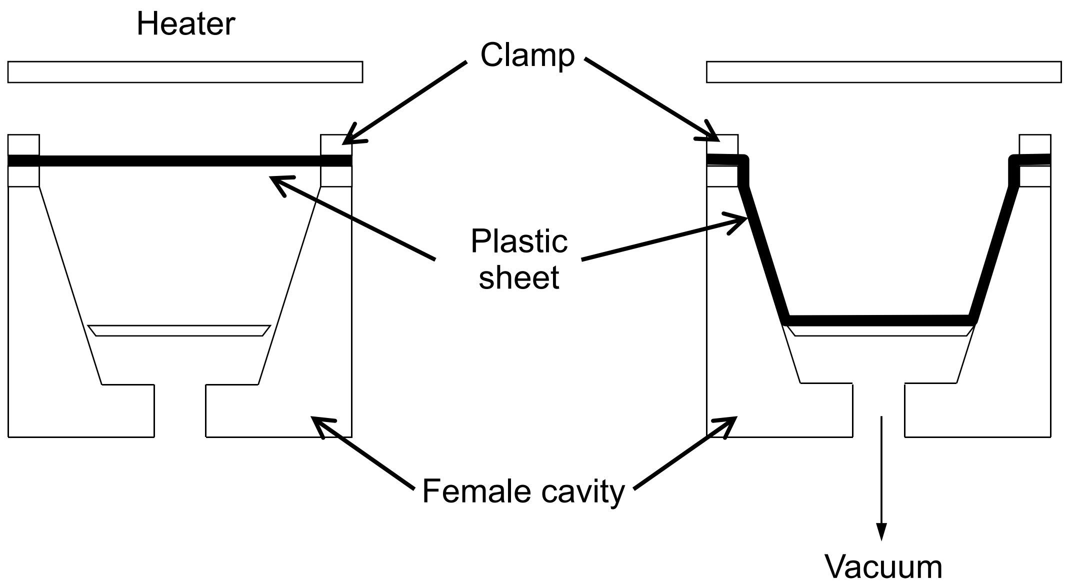
(i) Vacuum forming :The method involves clamping the sheet on the frame in the loading station, then softening it by the use of infrared radiant heaters in the oven. At the forming station, a vacuum is drawn between the mould and the sheet. The atmospheric pressure (1 atm) above the sheet will force the sheet to make a contact with the mould where it is cooled and shaped before unclamped and ejected at the loading station. The vent use to draw a vacuum is designed based on the time for the evacuation and the flow characteristics of the materials (such as viscosity and melt strength). This method has two principle variants regarding the design of the mould, these including

- Male mould type
- Female mould type

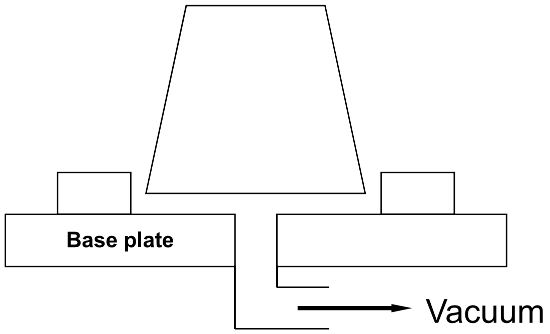
Male vacuum forming

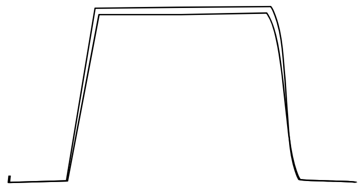


Female vacuum forming

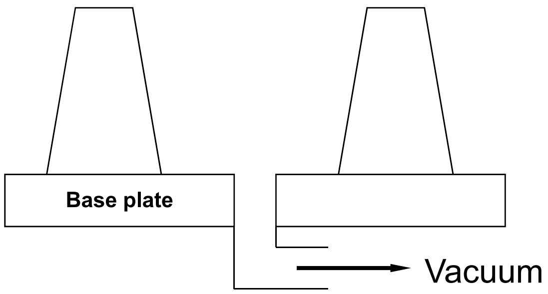


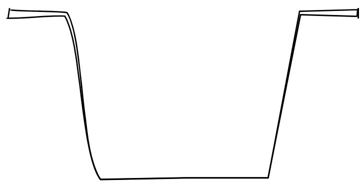
Male and female moulded part





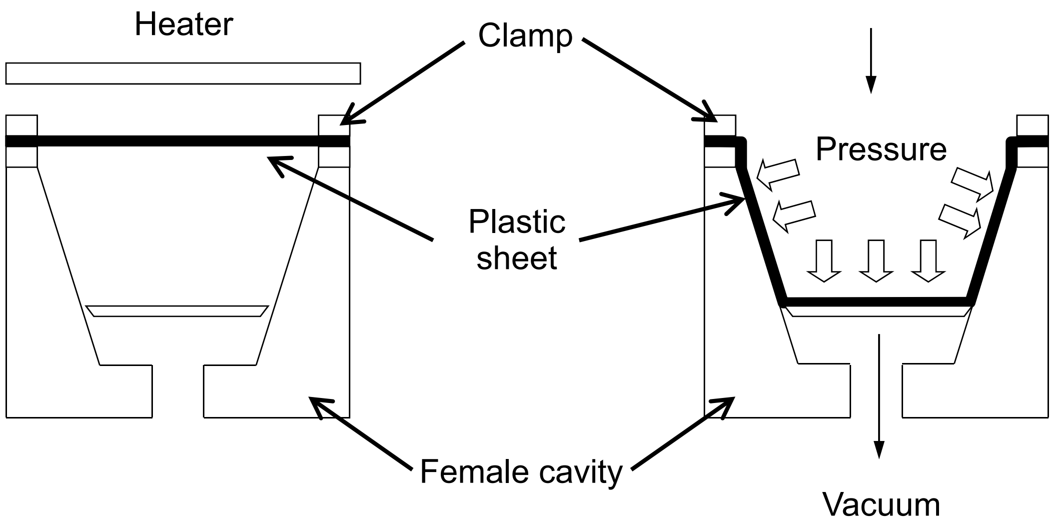
Formed part by male mo



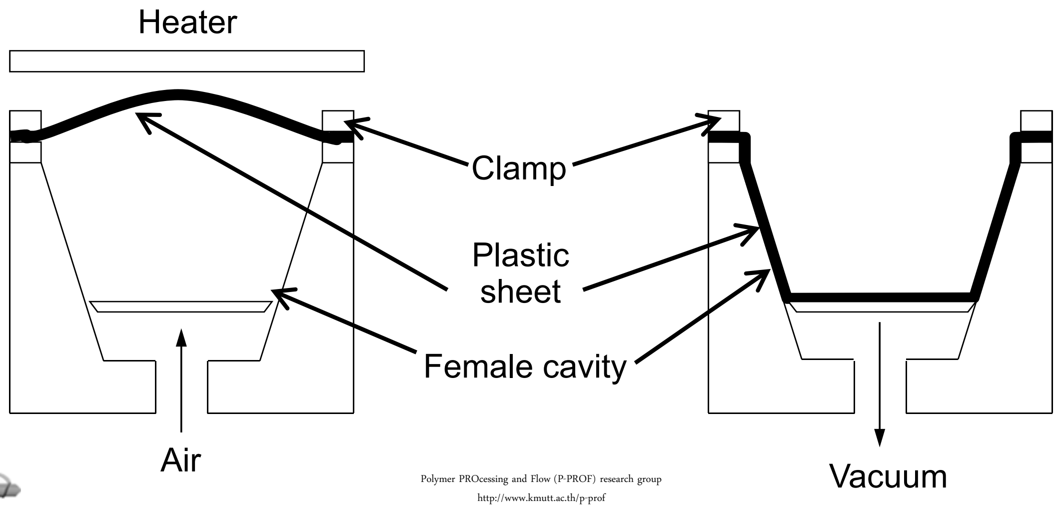


Formed part by female m

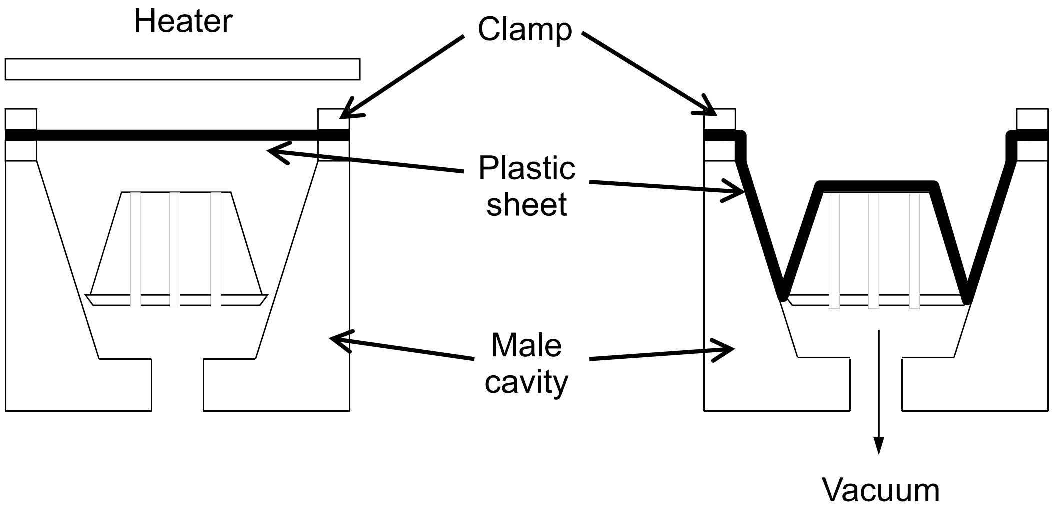
(ii) Pressure forming : The production line of this method is the same as the vacuum forming process with the addition of heated air with a positive pressure around 3-4 atm which is applied, at the forming station, above the sheet to force it into the mould. Since higher pressure is involved, this method is therefore used when manufacturing a thicker sheet. In addition, it is more preferred for female mould used regarding uniformity of the pressure applied across the sheet surface and thickness distribution.



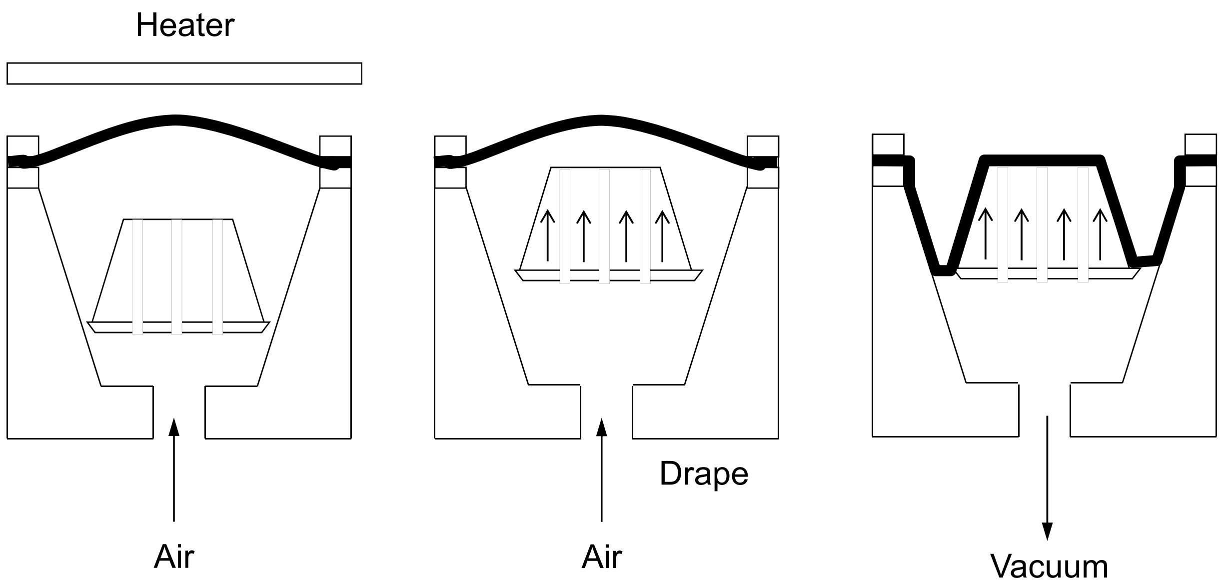
(iii) Air-blown forming : One of the problems which vacuum and pressure forming usually face is draw-down or sagging of the sheet during heating stage. They can result in premature cooling and this may lead to a rupture of the sheet before being vacuum-drawn due to the large difference in viscosity of the material. In order to overcome this problem the air-blown forming is required, the heated air being supplied at the oven station. The processing line and procedure are still the same as those described before with the exception that heated air is supplied under the sheet to support the weight of the sheet, this also giving more effective heating of the sheet.



(iv) Vacuum assist drape forming : In order to improve the thickness distribution some mechanical aids are required. Some mechanical aids are required such as drapes. The drapes enable more surface area for drawing a vacuum and this eases flows of the materials, and thus improved thickness distributions across the product area. In simple male vacuum forming, the larger thickness area are at the base and the rim of the product. By draping the process, the thickness at the base is reduced.

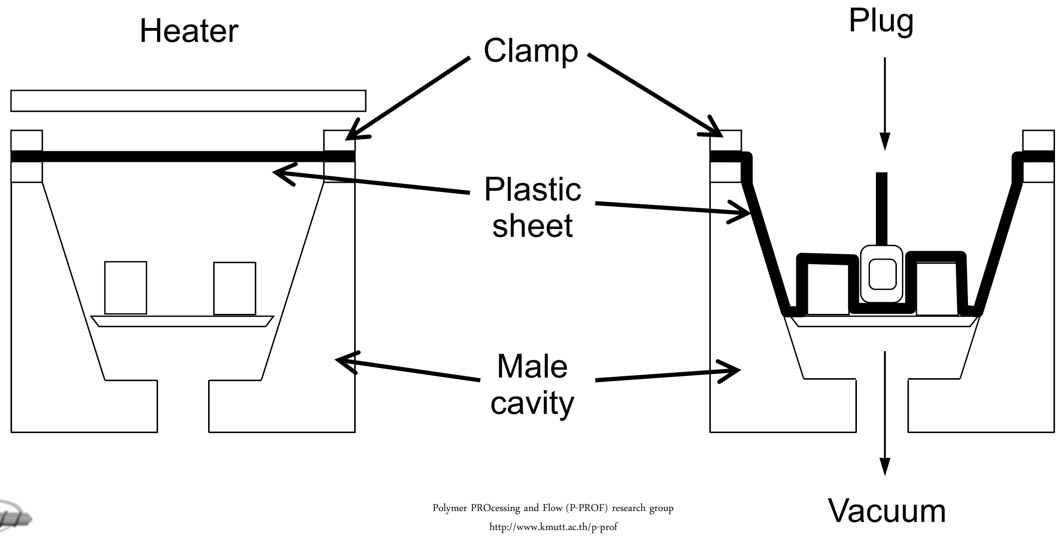


Air slip assisted drape moulding

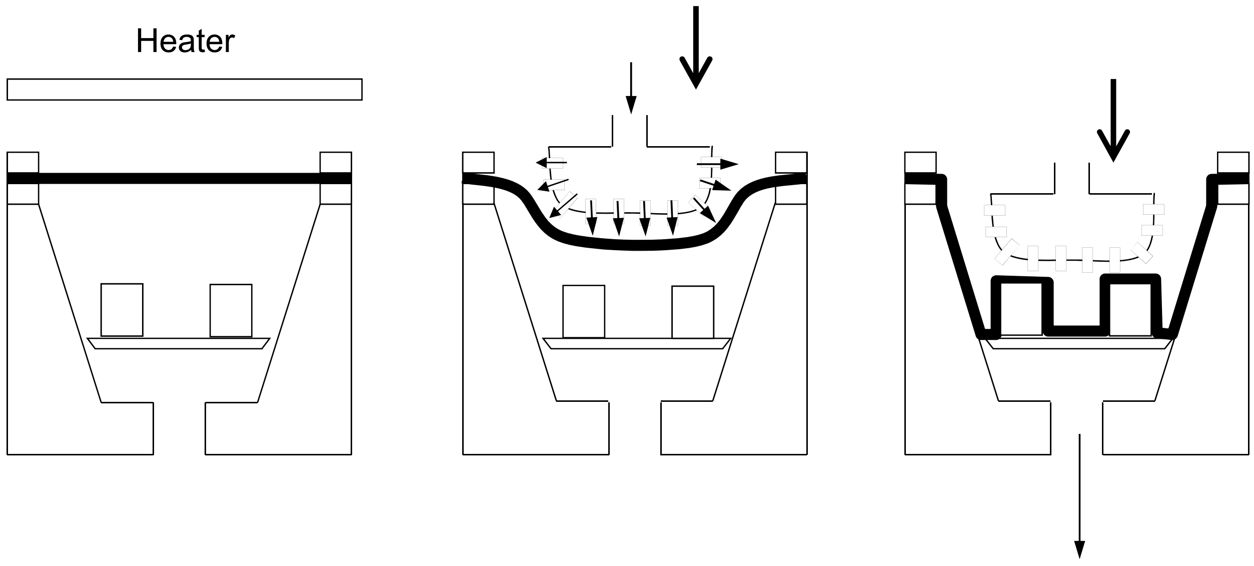


(Ref. D.H. Morton-Jones, *Polymer Processing*, 1989.)

(v) Plug-assist vacuum forming :This method is also developed from the simple vacuum forming. The purposes of this method is very similar to those in the pressure forming, including very thick product required and improved thickness distributions. The two advantages of the plug-assist over the pressure forming are to allow a very deep drawn product to be manufactured, due to the higher force or pressure given (approximately 10 atm or higher) and to prevent non-uniform cooling of the sheet as it usually occurs in the pressure forming.



Air-cushioned plug assistance



(Ref. D.H. Morton-Jones, *Polymer Processing*, 1989.)

(vi) Combined forming :These methods are mainly combinations of the above methods depending on manufacturing purposes, these including:

- (i) Vacuum forming + (iii) air blown vacuum forming
- (ii) Pressure forming + (iii) air blown vacuum forming
- (iv) Vacuum-assist drape forming + (iii) air blown vacuum forming
- (iv) Vacuum-assist drape forming + (v) plug-assist vacuum forming
- (v) Plug-assist vacuum forming + (iii) air blown vacuum forming

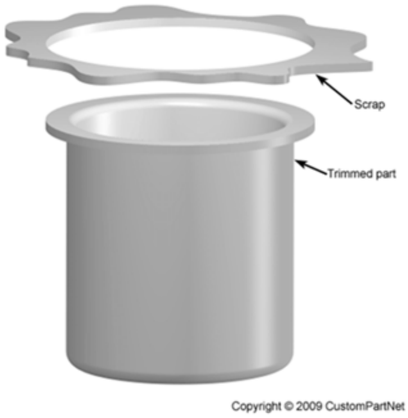
www.made-in-china.com (20July09)

www.plastics-technology.com (20July

Trimming process

Trimming process is a finishing process of thermoforming production cycle. This is importance key for cost reduction and competitiveness. The apparatus can be instanced such as;

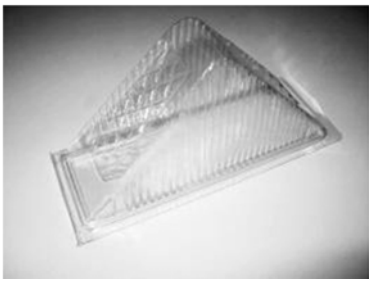
- Hand-held knives
- Electrical power tools
- Automated cutting tools
- Steel-rule dies
- Forged knife trim tools
- Matching punch and die sets



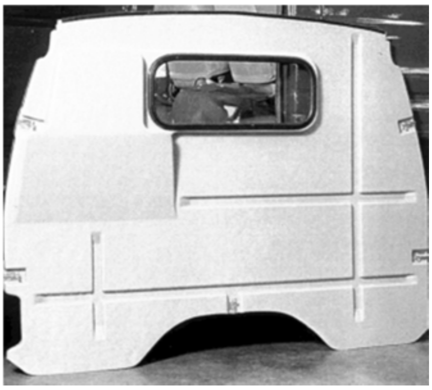
Example of Products made by thermoforming

1) Packaging industry
2) Fast-food (Take-out-food) industry
3) Retail food industry
4) Transportation industry
5) Sign manufacturers
6) Appliance industry
7) Institutional food service industry
8) Medical industry
9) Nursery (Horticulture) industry
10) Recreation industry
11) Housing and construction industry
12) Luggage industry
13) Photographic equipment industry
14) Food processors
15) Assembling production lines
16) Funeral industry

Ref. John Florian, 1987, Practical Thermoforming: principles and applications







Some examples of Troubleshooting in thermoforming process:

Problem	Loss of detail in forming
Causes	1. Underheated thermoplastic sheet condition. 2. Drop in the forming force level. 3. Plugged up vent holes or channels.
Remedy	1. Increase heater temperature or extent resident time in the oven. 2. Check the reason for the loss of vacuum or pressure forces. 3. Clean and reactivate plugged-up vent holes or channels.

Problem	Hole, slit, or rupture in the sheet
Causes	1. Faulty sheet supply (pinholes made into the sheet). 2. Underheated sheet rupturing under the forming force.
Remedy	1. Check sheet supply ;if pinholes appear repeatedly, reject. 2. Increase the heating of the sheet and decrease the level of forming force.

Ref. John Florian, 1987, Practical Thermoforming: principles and applications

Problem	Excessive thinning of the plastic after forming
Causes	1. Overheated thermoplastic sheet. 2. Using the simplest thermoforming techniques without plug assist. 3. Attempting deeper forming ratios than the process technique will allow. 4. Insufficient sheet thickness
Remedy	1. Check and adjust thermoplastic sheet temperature. 2. Upgrade the thermoforming method to use plug-assisted forming. 3. Use a warm plug assist and mould lip.

Problem	Formed plastic article sticking to the mould
Causes	The mould temperature is too hot.
Remedy	Apply means of cooling to the mould (metal moulds should be substituted for wood or synthetic mould materials) by installing a cooling jacket to the back side of the mould; increase the flow of coolant if more cooling is requried.

Ref. John Florian, 1987, Practical Thermoforming: principles and applications

Problem	Stripping difficulties
Causes	1. Using a male. Instead of a female, configuration. 2. Not enough side wall taper angle. 3. Use of undercuts or reversed draft angle.
Remedy	1. Convert male mould to female mould confriguration. 2. Make an oversized drawing with shrinkage measurement incorporated. Determine from the drawing if shrinkage can neutralizing the size of the undercut or reversed draft angle. 3. Apply mechanical strippers to the mould, such as spring, pneumatically or hydraulically activated stripper bars, or complete plates.

Problem	Overly detailed forming, such as mould roughness and vent-hole marking transferred from the mould to the formed articles
Causes	Overheated thermoplastic sheet introduced into forming together with excess pressure force.
Remedy	Reduce the heating levels of the sheet as well as the pressure of the forming force.

Ref. John Florian, 1987, Practical Thermoforming: principles and applications

Problem	Hot spots on the sheet
Causes	1. Heating element or control problem. 2. Possible drafty condition in the plant.
Remedy	1. Replace damaged or poor-quality heater elements and controllers 2. Apply screen shielding where hot spots occur. 3. Provide absolute draft protection.

Problem	"Fisheyes" on the formed article
Causes	Spotting or "fisheyes" will develop on a formed article where the heating of the sheet is interrupted either by poor surface contact with the heater (if a contact heater is being used) or foreign material is present on the surface of the sheet which absorbs the heat (e.g. water droplets on the sheet surface).
Remedy	Check the heating of the sheet and remove any obstacles (wipe or dry the surface).

Ref. John Florian, 1987, Practical Thermoforming: principles and applications

Problem	Excessive sheet sagging
Causes	1. Using unoriented thermoplastic sheet made by a method other than extrusion. 2. Using large thermoplastic sheets that cannot support their own weight under heating 3. Any overly heated sheet will develop a sag.
Remedy	1. Controlling the heating and the sheet's resident time in the ovens are the most common methods used to control sagging. 2. Occasionally, use of an expanding clamp frame or pin-chain rails can tighten the developing sag. 3. The elimination of the sheet sag is constant work, requiring heat adjustment and readjustment throughout the process.

Problem	Uneven wall thickness in formed articles
Causes	1. Improper heating of the thermoplastic sheet. 2. Poor prestretching of the sheet
Remedy	1. Check heating conditions. 2. Reevaluate forming method.

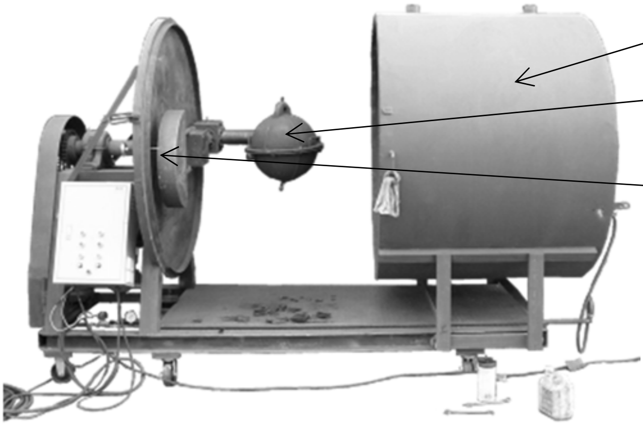
Ref. John Florian, 1987, Practical Thermoforming: principles and applications

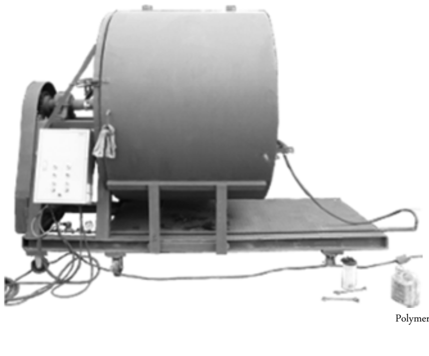
Problem	Weight differences among formed parts
Causes	1. Incorrect sheet gauge or variation in gauge. 2. Poor material distribution between cavities (robbing material from each other).
Remedy	1. Check the gauge thickness. 2. Add preclamping mechanisms to capture material, either around the entrie mould or at the individual cavitiess.

Problem	Wrinkling or webbing in a formed article
Causes	1. Access sheet material (larger than the mould surface) due to overstretched sheet material prior to forming. 2. Webbing can develop between male mould configurations if they are too close together.
Remedy	1. Limit the prestretching of the sheet. Usually reduced air pressure or prestretching time can eliminate the wrinkles. 2. Allow more space between male configurations (more than a 1:1 draw ratio) 3. Use matched mould or mechanical pushers to force the material to form

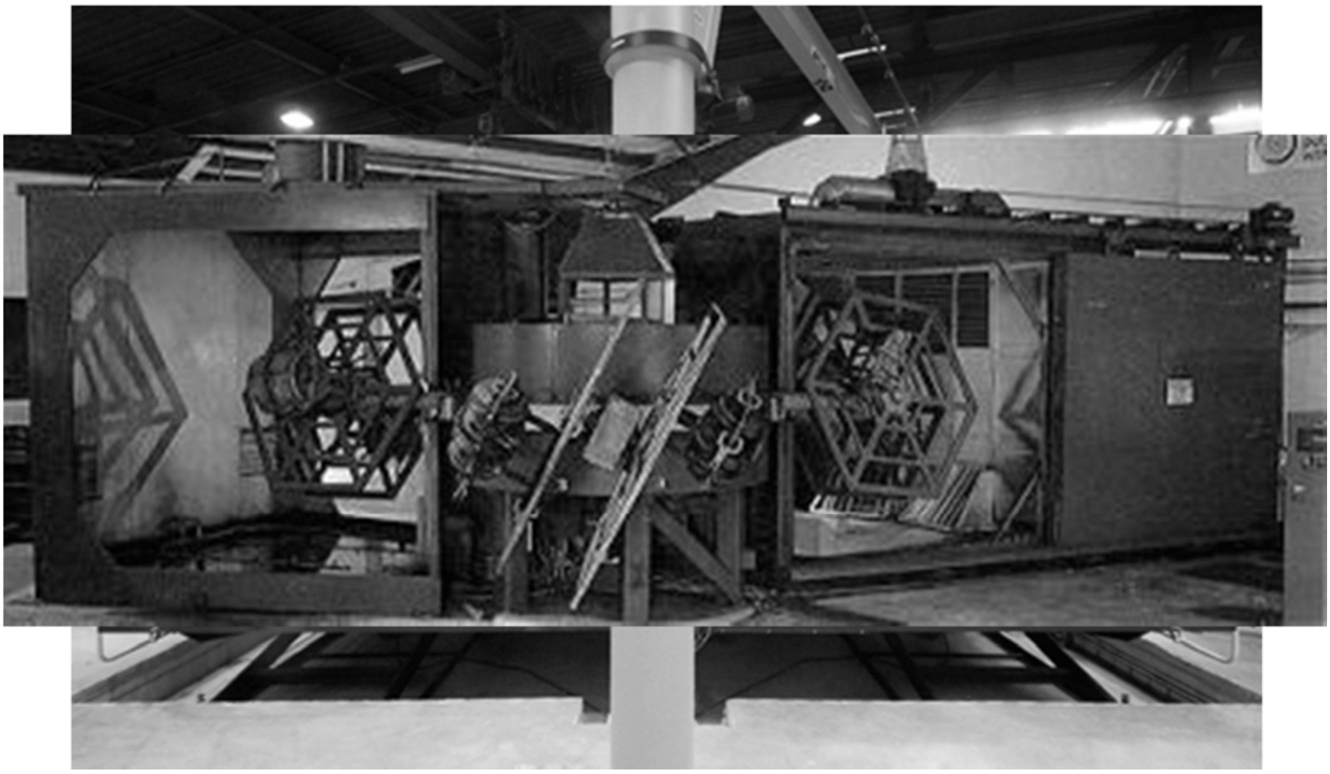
Ref. John Florian, 1987, Practical Thermoforming: principles and applications

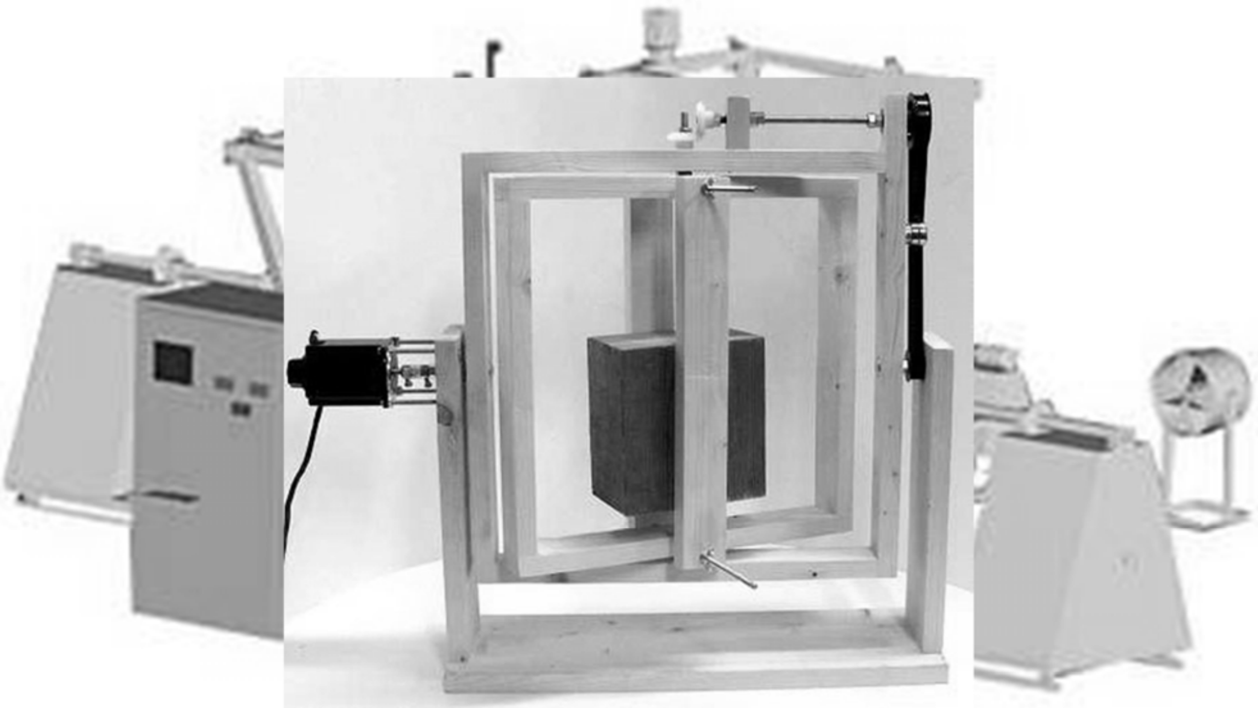
Rotational moulding process





Synonym : Rotomoulding, Rotocasting





Polymer PROcessing and Flow (P-PROF) research group
http://www.kmutt.ac.th/p-prof

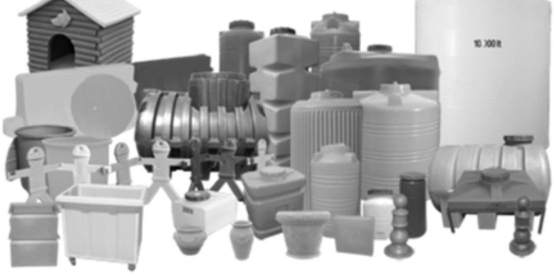
Some examples of rotational moulding articles

Process definition

Rotational moulding is a high-temperature, low-pressure, open-moulding plastic-forming process that uses heat and biaxial rotation to produce hollow, one piece parts.

The rotational moulding is an alternative method of making a hollow product which can also be manufactured by other processes such as extrusion and injection blow moulding.

The rotational moulding is also suitable for making larger and excessively thicker products (from 3 mm to 10 mm) where other processes have difficulties manufacturing them such as complex shapes, non-uniform thickness, orientation residual stress.



Ref.
ณรงค์ฤทธิ์ สมบัติสมภพ, “เอกสารประกอบคำสอนวิชา MT640 Polymer Processing”
Beall, Glenn L., 1998, “Rotational molding : design, materials, tooling and processing”

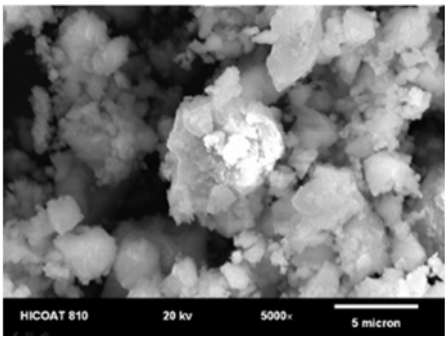
Process-Related Material Requirements

- Rotational moulding is a ***materials-dependent process***.
- This process differs from other thermoplastic processes in that both the plastic material and the mould must be ***heated and cooled during each moulding cycle***.
- There are ***no forces*** on plastic material to push or pull it into contact with the cavity.
- Moulding is actually achieved by the powdered or liquid plastic material ***adhering*** to, or ***sintering*** onto, the cavity.
- For the absenting of pressure in the process, the individual particles of material must be capable of ***flowing together*** to produce a homogeneous, solid wall.
- Complex-shaped and multifunctional industrial parts with fine surface details require a ***melt index of five or greater***.

Forming ability of PE articles filled by Calcium carbonate and fly ash

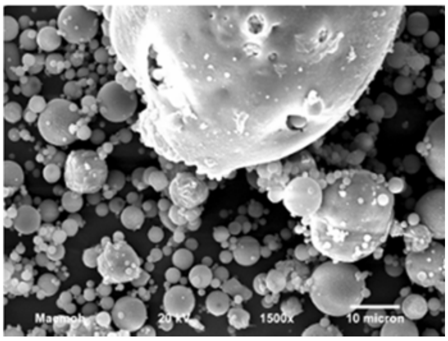
PE + 10% Calcite

PE + 10% Fly Ash



Calcium carbonate particles

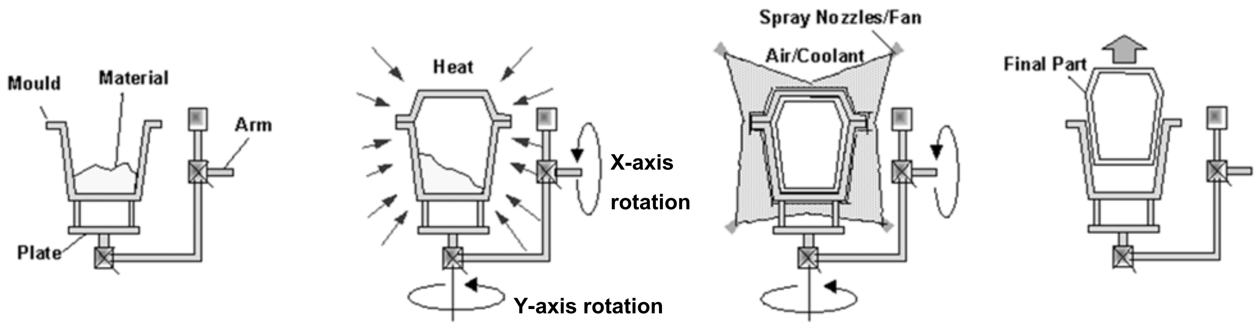
อ้างอิงจาก
ณรงค์ฤทธิ์ สมบัติสมภพ และคณะ (2549) รายงานวิจัยฉบับสมบูรณ์ “โครงการผลิตภัณฑ์ถังบรรจุน้ำทิ้งที่ขึ้นรูปด้วยกระบวนการแม่พิมพ์หมุนเหวี่ยงเพื่อการลดต้นทุนฯ”



Fly ash particles

Processing cycle

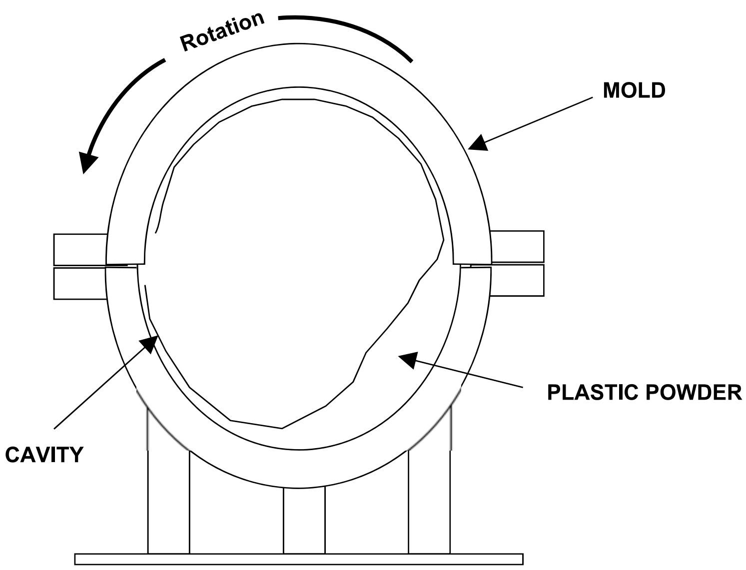
The Four Principal Stages of Rotational Moulding



(a). Charging the Mould *(b). Heating the Mould* *(c). Cooling* *(d). Demoulding*

The mould itself can also rotate biaxially, the mould rotating two axes (x and y axes) at right angle to each other. The rotation speed of two axes are different, the speed parallel to the y axis being usually four times that perpendicular to the y axis. The speed varies (but typically 20-25 rpm) depending on many factors such as flow characteristics of the material, heating time and temperature and thickness of the moulding required.

Ref.
ณรงค์ฤทธิ์ สมบัติสมภพ, "เอกสารประกอบคำสอนวิชา MT640 Polymer Processing"
http://www.me.qub.ac.uk/research/rotomould/

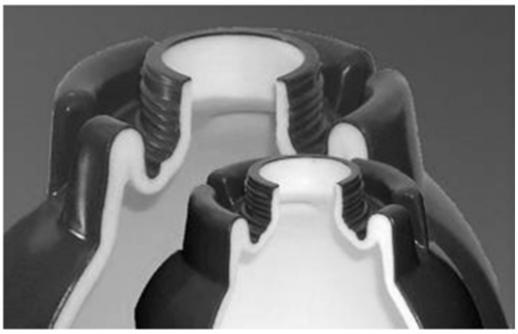


During the rotational moulding process the mould rotates while the plastic material remains in the bottom of the cavity. The plastic adheres to the hot cavity as it passes through the material.

Redrawn from "Rotational molding : design, materials, tooling and processing", Beall, Glenn L., 1998.

Multi layer products

Co-rotational moulding can be achieved in two slightly different ways. ***Firstly***, the mould is coated by outer layer and then is stopped for a manual provision of the inner layer (or inner layer) the process is then repeated. ***Secondary***, an internal feedstock is given inside the mould to supply the inner layer (or inner layers) after the outer one is completed.



The main difficulties of the co-rotational moulding are

- Compatibility of the polymers used.
- Polymer viscosity.
- Moulding temperatures.
- Degree of thermal contractions

Some of materials were used in rotational moulding process

- **High-Density Polyethylene (HDPE)** : HDPE in the powder form suitable for the rotational moulding process was marketed in **1961** by U.S. Industrial Chemical (now Equistar Chemicals). in the past this suitable PE were achieved by pulverized PE into the fine powder.
- **Polycarbonate (PC)** : PC was the first rotationally mouldable material that combined transparency resistance, impact strength, and good stiffness. It was discovered in **1957**, but it took until **1968** before the first transparent lighting globes were rotationally moulded by Formed Plastics, Inc.
- **Cross-linked PE (XLPE)** : In **1970** ,XLPE ,obtained form Phillips Chemical Co., were used to producing gasoline tank. Because they improved the material's chemical stress crack resistance, stiffness, and low temperature impact strength.
- **Glass fibre reforced PE and nylon** : The both were introduced in the late **1970**s. But the anticipated markets did not materialize and these materials were withdrawn. Later in **1978** a mouldable grade of Nylon 6 was marketed. Some example of Nylon 6 products such as fuel tanks, high temperature heating ducts for transportation industry.
- **Linear Low-Density Polyethylene (LLDPE)** : The **1980**s were great decade for rotational moulding industry because LLDPE which be introduced by Du Pont, can be easy-to-process that provided a combination of properties that revaled XLPE for heat, chemical, and low-temperature impact resistance. LLDPE were quickly accepted and grew to be the most common rotationally moulded material.
- **Polypropylene (PP)** : Rototron Corp. started selling rotational moulding grades of PP in **1975**, but this material was handicapped by its low impact strength.
- **Others** : Polyvinyl chloride (PVC), Acrylonitrile butadiene styrene (ABS), Acetal, Acrylic, Cellulosics, Epoxy, Fluorocarbons, Ionomer, Phenolic, Polybutadiene, Polyester, Polystyrene (PS), Polyurethane (PU), Silicone.

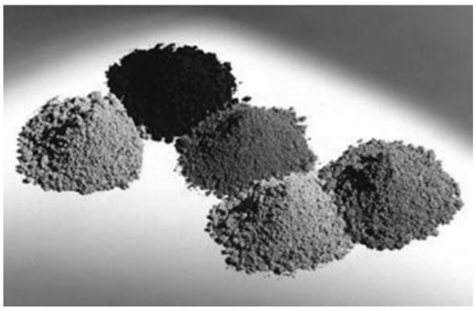
The maximum allowable wall thickness is dictated by cycle time and the material's ability to withstand high temperatures without degradation. Recommended wall thickness for commonly rotationally moulded materials were presented as table bellow:

Plastic material	Ideal		Possible	
	Min. mm	Max. mm	Min. mm	Max. mm
PE	1.50	12.70	0.50	50.80
PP	1.50	6.40	0.75	10.16
PVC	1.50	10.16	0.25	25.40
Nylon	2.50	20.32	1.50	31.75
PC	2.00	10.16	1.50	12.70

* ***Ref***. Beall, Glenn L., 1998, "Rotational molding : design, materials, tooling and processing"

Special plastic and additives

Special plastics	Additives	
Reinforced plastics	Pigments and dyes	Antioxidants/heat stabilizers
Filled plastics	Foaming agent	Ultraviolet light stabilizer
Multi-wall parts	Toughening agent	Flame retardants
Foamed part	Flow enhancers	Cross-linked additives
	Internal lubricants	Antistatic additives



Product quality and applications

The other advantages of the rotational moulding over other process are as follows:

a) The machine and the mould are relatively inexpensive.

b) The process design and modification are simple.

c) The rotational-moulded products are free-stresses due to the fact that the process involves comparatively low pressure and slow cooling rate especially for thick-walled products.

d) The process gives more uniform thickness and better thickness distribution due to biaxial rotation.

e) No orientation and weld line in the product are present in the products due to the fact that there is no uniaxial flows and the process involves low pressure.

f) There is a little scrap.

g) Process modifications can easily be done. For example, changes in thickness of products are achieved by changing the weight of the polymer powder and/or rotation speed.

h) Ribs can be inserted for increasing the strength of the products.

Limitations of rotational moulding process

These include:

a) The cycle times are too long becacue the cooling and heating are taking place in the same mould.

b) Small and thin-walled components are difficult to mould.

c) Melt temperature during rotation are difficult to control.

d) Air bobbles may be present.

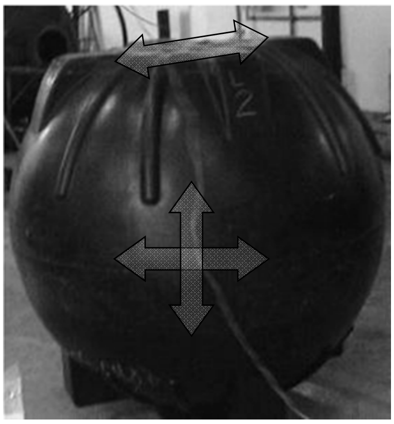
e) There are various densities in a product and this may lead to warpage.

f) It is likely to have warpage if there are any metal insertion due to difference in thermal contraction between polymer and metal. This effect becomes even more complex when many types of metals are involved.

Compare rotational moulding process to ***<u>competitive process</u>***

	Thermoform.	**Blow moulding**	**Rotational moulding**
Thickness	0.25 - 10 mm.	0.4 – 1.5 mm	0.5 – 50 mm
Process	Stretching process, shear and elongation	Stretching process , shear and elongation	No stretching, Low shear and pressure
Multilayer	Lamination or co-extruded sheet	Difficult and expensive	Easy and do not need adjust the process
Thickness uniformity	Less uniform	Less uniform	More uniform
Mould running	May be negligible releasing agent	May be negligible releasing agent	May need to using mould release
Thickness adjusting	Depend on sheet gauge	Depend on preform or parison gauge	Weight of feedstock

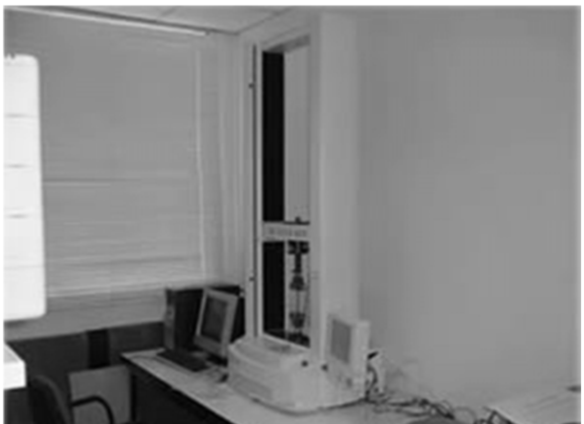
Some of mechanical tests for tank article form rotational moulding products



Test specimen (form BS 2782 Method 320 A)

Test directions

- Horizontal
- Vertical
- Bottom



Universal testing machine

Polymer PROcessing and Flow (P-PROF) research group
http://www.kmutt.ac.th/p-prof

Pros and Cons

Contents	Compress	Transfer	Thermoform	Rotational
Raw materials	1) Thermosetting 2) Thermoplastic	1) Thermosetting 2) Thermoplastic	Thermoplastics	1) Thermoplastic 2) Thermosetting
Material status	Mat, Sheet, Dough, Granule, Powder	Dough, Granule, Powder	Sheet	Powder, Liquid
Orientation	Low	Medium to High	High	Low
Heater	Hot oil, Electrical heater	Hot oil, Electrical heat	Infrared, Radiation	Gas burner, Heater oven
Tool cost	Low	More than as comparing there	Medium to High	Low
Maintenance cost	Low	Medium to high	Low	Medium to high
Residue stress	Low	Low	High	Low
Shear rate in processing	1-10 s^{-1}	N/A	N/A	zero
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